JOINT U.S.-ROMANIAN SEMINAR ON EARTHQUAKES AND ENERGY

SPONSORED BY THE NATIONAL SCIENCE FOUNDATION (U.S.) AND THE NATIONAL COUNCIL FOR SCIENCE AND TECHNOLOGY (ROMANIA)

BUCHAREST 2-9 SEPTEMBER 1985

VOLUME 3: ENERGY

ORGANIZING GROUPS:
ARCC
UCLA
INCERC

EDITORS:
SAMUEL ARONI
ROMULUS CONSTANTINESCU

Joint U.S.-Romanian Seminar on Earthquakes
and Energy. Bucharest, 2-9 September, 1985.

Volume 1: Introduction and Summary
Volume 2: Earthquakes
Volume 3: Energy

Architectural Research Centers Consortium, Inc.

1. Seminar, Earthquakes, Energy, U.S.-Romania
I. Aroni, Samuel, II. Constantinescu, Romulus

Library of Congress Catalog Number: 87-70464

This report was prepared with the support of the National Science Foundation, Division of International Programs, Grant No. INT 85-03889, and the Romanian National Council for Science and Technology (CNST), under the U.S.-Romanian Cooperative Science Program. Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the National Science Foundation, or the Romanian National Council for Science and Technology.

Published by the Architectural Research Centers Consortium, Inc.
1735 New York Ave., N.W.
Washington, D.C. 20006

Reproduced in Romania, 1987

i.c.

VOLUME 3: TABLE OF CONTENTS

INTRODUCTION

The Joint U.S.-Romanian Seminar on Earthquakes and Energy was held September 2-9,1985, at the Romanian Building Research Institute (INCERC) in Bucharest. The seminar was supported by the National Science Foundation (NSF) Division of International Programs (Grant No. INT 85-03889) and the Romanian National Council for Science and Technology (CNST), under the U.S.-Romanian Cooperative Science Program. During that week over seventy researchers from Romania and the United States met in intense and vivid discussions about topics of building research, with the focus on earthquakes and energy conservation. The seminar provided an opportunity for exchanging scientific research information, and encouraging the establishment and planning of future joint research cooperation.

The groundwork for the seminar began in the spring of 1984, when the Architectural Research Centers Consortium (ARCC) was searching for ways to further international cooperation. ARCC is an organization of over forty academic institutional members devoted to supporting and encouraging research in the fields of architecture and building. The membership of ARCC includes leading university-based research centers and has a broad geographical distribution within the United States. ARCC has also conducted seminars with other overseas researchers, including those in Sweden and the United Kingdom. The initiative for this seminar was taken by Professor Samuel Aroni of UCLA. With the encouragement and help of NSF, he traveled to Romania in September 1984 and met with Dr.Eng. Romulus Constantinescu of INCERC, the Romanian Building Research Institute. INCERC is a large and impressive research organization in Bucharest under the direction of the Central Institute for Research, Design, and Guidance in Civil Engineering (ICCPDC), established in 1950 and consisting of four sections and six laboratories. Earthquake research and energy conservation are prominent in its activities, representing two of its four sections. During the September 1984 visit, an agreement was reached to organize a seminar, to be held at INCERC in Bucharest as a first step of collaboration between Romanian and American institutions and researchers in areas of mutual interest. The two subjects selected were earthquake issues and energy conservation. In addition to their intrinsic importance, the decision to focus on both of them stemmed from the belief in the advantage of synergism. There is some interaction between them, and having two subjects for the seminar enhanced the possibilities of finding areas of future collaboration, and encouraged cross-fertilization of research ideas.

We are well aware of the earthquake dangers facing the Pacific coastline of the United States, as well as many other locations within the national boundaries. Significant research has been conducted and much more is needed. Among the important topics of recent research interest have been the problems of old buildings, their repair, strengthening and reconstruction, issues of vulnerability and risk of both buildings and lifelines, non-structural elements, performance of emergency facilities during earthquakes, issues of human behavior and injuries, and planning for earthquake preparedness and disaster mitigation. Romania is also located in a seismic region and suffered greatly from the earthquake of March 4, 1977, in which some 1,600 persons were killed, over 11,000 were injured, 33,000 buildings collapsed or were severely damaged, industrial facilities were seriously damaged, and damage totaled over $2 billion. There is much to be learned from this major earthquake, which has been studied in great detail by Romanian researchers and is the subject of a recent comprehensive Romanian book. The third most important event in the modern seismic history of Romania was the recent earthquake near Tulcea in the eastern part of the country, on November 13, 1981. The epicenter was near settlements which have developed rapidly in recent years, and the behavior of modern high-rise construction as well as the non-structural damage are of particular interest. The Romanian earthquakes are of special international importance because of the proximity of a large number of prefabricated industrialized buildings. This is probably the first time that such newer buildings have been subjected to major earthquakes on such a large scale, and their seismic behavior is of great interest. Serious seismic research in Romania has gone on for a long time at their Building Research Institute (INCERC), both in Bucharest and at the Jassy branch of the ICCPDC, where some of the earliest earthquake testing facilities, including shaking tables, were developed.

During the last ten years, energy conservation in buildings has been the subject of research interest in the United States. The use of solar energy, active and passive systems, utilization for hot water and space heating, and the upgrading of existing buildings have all been topics of both field work and research activity in both countries. Romania has also put an emphasis on energy conservation at a larger urban scale. Romanian solar installations during the last five years have included some 600 projects for hot water or space heating and some 14,000 apartments. The solar hot-water installation in Baneasa (Bucharest), consisting of 2239 apartments, is the largest in Europe and possibly in the world. Industrial applications include an interesting ice manufacturing plant using solar energy, and large projects for heat recovery from industry for storage and use by some 20,000 apartments for both hot water and space heating. A two-story experimental solar house, which includes four apartments, has been erected at INCERC for comparative research of active and passive systems for both space heating and hot water.

The seminar consisted of an opening session, followed by four working sessions, with the participants divided into two groups discussing earthquakes and energy respectively. The presentations and discussions on the subject of earthquakes covered the spectrum of seismic vulnerability and behavior of buildings, urban systems and critical facilities, as well as human behavior and injuries during earthquakes. Those dealing with energy conservation, included solar passive and active systems, retrofitting, daylight applications, total building performance, and problems of energy conservation at an urban scale. Each of the four working sessions, concentrating on a specific group of related topics, consisted of one or two presentations of American papers, a summary of the relevant Romanian papers presented by a rapporteur, and an open discussion. The seminar was enriched by field visits to a large scale solar installation and to the Jassy Seismic Testing Station and laboratory. The final day, devoted to research needs and areas of future cooperation, proved to be very fruitful and productive.

Romanian participants included engineers, architects, planners, and sociologists from INCERC and over a dozen other institutes, centers, laboratories, and universities throughout Romania. They prepared sixty-one papers, thirty-seven on the subject of earthquakes and twenty-four on energy topics. The American team consisted of nine academics, from seven different universities, each with a paper on earthquakes (four papers) or on energy (five). A bilingual program and abstracts of all the papers was prepared by INCERC and distributed at the seminar. The seminar was co-chaired by Dr. Constantinescu and Professor Aroni.

We would like to thank all those who in various ways contributed to the seminar and made it possible, including all the seminar participants. Mr. George Matache of CNST, and Eng. Valeriu Cristescu, the General Director of ICCPDC and INCERC, provided significant help and guidance. Eng. Emil Sever Georgescu of INCERC was of invaluable help in the seminar organization. The excellent work of a number of staff, and scientific translators at INCERC is gratefully acknowledged. Our gratitude is expressed to Dr. Gerson Sher, Ms. Bonnie H. Thompson, and Ms. Deborah L. Wince of the NSF Division of International Programs and to Dr.William Anderson and Mr. Gifford Albright of the NSF Directorate of Engineering for their support and assistance. In the United States , the seminar participants were selected with the help of an Advisory Committee consisting of Professor David S. Haviland (Dean, School of Architecture, Rensselaer Polytechnic Institute), Dr. Frederick Kringold

(Associate Dean for Research and Extension, College of Architecture and Urban Studies, Virginia Polytechnic Institute and State University, and President of ARC), and Professor Samuel Aroni.

The work of the joint seminar is presented in three volumes. Volume 1 contains an introduction and summary of all papers, sessions and discussions. Significant contributions were made in the writing of this volume by Professor Daniel Abrams, Professor Volker Hartkopf, Professor Henry Lagorio, Dr. Horea Sandi, Professor Robert Shibley, and Eng. Teodor Teretean. Volume 2 contains the forty-one papers on the subject of earthquakes, and volume 3 the twenty-nine papers on topics of energy. The editorial help of Mr. William Fulton, in the United States, is much appreciated. The reproduction of these volumes was performed at INCERC.

The American participants express sincere thanks and gratitude to the Romanian hosts for their outstanding hospitality, both scientifically and socially. Finally, we hope that this publication will prove to be useful and will further contribute to the achievements of the goals of the seminar.

Professor Samuel Aroni, Ph.D.
Graduate School Of Architecture and Urban Planning, UCLA

Dr. Eng. Romulus Constantinescu
Deputy Scientific Director
Romanian Building Research Institute, INCERC

I. SESSION I THE THEMES OF ENERGY PAPERS.
BUILDING PERFORMANCE.

I.1 TRANSDISCIPLINARY BUILDING DIAGNOSTICS AND THE CONCEPT OF TOTAL BUILDING PERFORMANCE

Peter Mill[1]
Volker Hartkopf
Vivian Loftness

ABSTRACT

This paper introduces the concept of total building performance and the building diagnostic tools for measuring and assessing this performance. Integrated with the present building delivery process, these tools offer new quality assurance procedures for providing suitable, reliable, and sustainable conditions for occupancy comfort (defined in physiological, psychological, sociological, and economic terms). The paper establishes the importance of understanding component to component interfaces within the occupied building, in contrast to studying discrete materials, components and assemblies. Above all, however, the paper attempts to stress the importance of transdisciplinary knowledge - empirical and deductive - for ensuring total building performance.

[1] P. Mill, Director Architectural and Building Sciences, Public Works Canada; V. Hartkopf, V. Loftness, Carnegie-Mellon University, Pittsburgh, PA 15213

ISSUES & PROBLEMS:

INTRODUCTION

In recent years, the international emphasis on resource management - specifically energy and economic resources - has put a new stress on the building industry, in excess of the traditional building demands of health, safety, and welfare. This sudden elevation of a single building requirement has in turn triggered a series of measurable building failures. In some cases, design for energy conservation has led to intermittent high velocity air supply systems, with serious consequences to acoustic comfort. A demand for air tightness has raised questions of air quality and building inadequacies regarding human health. A major increase in enclosure insulation has led to unexpected levels of condensation and eventual enclosure degradation. It is not the recent focus on energy conservation or other resource management efforts that is at fault for these building failures, however, but the lack of transdisciplinary understanding of the impact one building performance criteria has on the other performance criteria and the multiple performance aspects of the issues and problems that face building owners, managers and occupants today.

Sample Building Issues and Problems

The issues and problems that face the building community today vary from building wide (macro-scale) conditions, to building subsystem conditions, to workplace (mini-scale) conditions. With each new field evaluation completed, it is becoming increasingly clear that most if not all of these issues have multiple performance aspects, demanding a multiple performance evaluation procedure. For example, energy efficiency was originally seen as a disciplinary, single performance issue that could be tested independent of other performance variables. The air quality, thermal quality, visual quality and even building integrity failures that resulted from modification for energy efficiency, however, have highlighted the multiple performance nature of energy evaluations. For this reason, we have begun to focus on energy effectiveness, the energy efficient delivery of thermal, visual, functional/spatial, and air quality, as well as building integrity.

Four building wide issues of special prominence today, also have multiple performance aspects: the sick building syndrome; the widespread introduction of information technology; white collar productivity; and worker satisfaction. Although less universal in nature, several major building issues are brought up again and again by clients: rapid degradation of roof or facade assemblies; excessive maintenance requirements; and the image that the building presents to the public. Although these issues were originally ascribed to building integrity/material science evaluations alone, the problems may stem from, or greatly affect, such performance qualities as thermal comfort, functional/spatial comfort and air quality.

Naturally, such client concerns as compliance with code or compliance with the project brief will be multi-disciplinary in nature, as will resource effectiveness and organizational fit. Figure 1 identifies some of the primary and secondary performance qualities contributing to each of these current building issues.

At another scale, building owners and managers will often run a check on major building subsystems such as the HVAC, vertical transportation, security, or firesafety systems. Although one can always check these systems against their ideal state, the multiple performance implications of these systems are of greatest significance. For example, vertical transportation not only affects the spatial quality of the building (easy access, wayfinding), but has consequences for acoustic quality (minimizing disruption) and air quality (minimizing pollution generation and migration). These consequences make it imperative that field evaluation of the condition of systems also be multi-disciplinary in nature.

Even the local complaints that building managers have to deal with on a day to day basis are often manifestations of multiple performance problems. Complaints of bad air may represent thermal, air quality, or spatial problems. Complaints of freezing temperatures may represent a thermal and a building integrity problem, with potentially far greater consequences than individual dissatisfaction. Certainly decisions made to locally retrofit a space in response to complaints must be evaluated for the implications in other performance areas.

The multiple-performance aspect of the issues and problems facing building owners, managers, and occupants today does not imply that building evaluation must be extraordinarily time consuming or complex. It does imply, however, that the building must be approached from a basis of 'total building performance', with recommendations made accordingly.

EXAMPLE ISSUES AND PROBLEMS FACING THE BUILDING COMMUNITY

	generic performance qualities affected					
• BUILDING WIDE - MESO-ENVIRONMENTS	FUNCT./ SPATIAL	THERMAL	AIR QUALITY	ACOUSTIC	VISUAL	BLDG. INTEG.
Energy Effectiveness						
Sick Building Syndrome						
Automation Impact						
Worker Productivity						
Worker Satisfaction						
Spatial Effectiveness						
Flexibility/Use Change						
Overcrowdedness/ Population						
Image - Public Interface						
Building Degradation:						
roof						
facade						
Excessive Maintainance						
Compliance: with code						
with project brief						
Environmental Control (decision)						
Resource Effectiveness						
Organizational Fit						
• SUBSYSTEM CONDITION						
Firesafety						
Telecommunications						
PLEC						
Security						
Transportation						
HVAC						
Sanitary						
Access/Egress						
MINI-ENVIRONMENTAL CONDITIONS						
Complaints:						
Thermal Discomfort						
Noise/ Disruption						
Air Quality, Sickness						
Glare, Eye Problems						
Aches, Ergonomic Discomfort						
Inadequate Furnishings						
~~Windowless~~ Office VIEW, DAYLIGHT						

TOTAL BUILDING PERFORMANCE

It is critical to begin with a complete definition of the building performance mandates to be assiduously met by building policy makers, programmers, architects, engineers, contractors, owners, and managers. For the sake of discussion, this definition can be divided into two areas. First, there has been a fundamental mandate over the centuries for building enclosure integrity - protection of the buildings visual, mechanical, and physical properties(1) from environmental degradation through moisture, temperature, air movement, radiation, chemical and biological attack, and environmental disasters (such as fire, flood, earthquake). Established by concerns for health, safety, welfare, resource management (energy, money) and image, the requirements for building integrity are set by the limits of "acceptable" degradation (of the visual, mechanical, and physical properties) ranging from slight decay, to debilitation in the ability to provide weather tightness or environmental conditioning for the function, to total devastation or destruction. Second, there are a series of mandates relating to interior occupancy requirements (Human, animal, plant, artifact, machine) and the elemental parameters of safety and comfort (5 senses) - thermal quality, acoustic quality, visual quality, air quality, and spatial quality - dependent on physiological, psychological, sociological and economic values.

Total Building Performance[2], therefore, is the simultaneous provision of functional/spatial quality, thermal quality, air quality, acoustic quality and visual quality within the integrated setting of the occupied building, and the provision of building integrity for the integrated 'system' over time. The programming, design, construction and operation of buildings for total building performance is intended to ensure the immediate suitability of the integrated setting for the building occupancies and functions (all performance qualities), as well as the long term reliability (maintainability) and flexibility, over the life established by the client.

To deal with the complexity of issues facing building owners today, and to cut across disciplinary boundaries in the delivery of satisfactory building environments, it is necessary to put forward a discrete list of performance qualities of equal weight and primary concern for the building industry. The following outline has been developed to introduce the subset indices of the six performance qualities indentified:

---

[2] also known as 'whole building performance' and 'overall building performance' in the research community (CIB, ASTM, ISO)

TABLE 1: SIX BUILDING PERFORMANCE MANDATES

I. FUNCTIONAL/SPATIAL QUALITY
based on knowledge of the building occupancies, occupancy functions and organizational structures
   A. Individual Space Layout Quality
      useable space, furnishings, layout efficiency access, anthropometrics, ergonomics, image, flexibility/growth occupancy controls
   B. Aggregated Space Layout Quality
      proximities, access, compartmentalization, useable space, layout efficiency, image, amenities, flexibility/growth
   C. Building Siting Layout Quality
      access, public interface/image, indoor-outdoor relationships, outdoor space layout, flexibility/growth
   D. Quality of Conveniences and Services
      sanitary, firesafety, security, transportation, electrical, telephone, information technology, flexibility/growth

II THERMAL QUALITY
   A. Air Temperature
   B. Radiant Temperature
   C. Humidity
   D. Air Speed
   E. Occupancy Factors and Controls

III. AIR QUALITY
   A. Fresh Air
   B. Fresh Air Supply, distribution
   C. Mass Pollution[2]: gases, vapors, micro-organisms, fumes, smokes; dust
   D. Energy Pollution: ionizing radiation; microwaves; radio waves; light waves; infrared
   E. Occupancy Factors and Controls

IV. ACOUSTIC COMFORT
   A. Sound Source - Sound Pressure Levels and Frequency
   B. Sound Source - Background Noise
   C. Sound Path - Noise Isolation (air and structure borne)
   D. Sound Path - Sound Distribution
      absorption, reflection, uniformity, reverberation
   E. Occupancy Factors and Controls

V. VISUAL COMFORT
   A. Ambient Light Levels - artificial and daylight
   B. Task Light Levels - artificial and daylight
   C. Contrast and Brightness Ratios
   D. Color Rendition
   E. View, visual information
   F. Occupancy Factors and Controls

IV. BUILDING INTEGRITY
based on knowledge of loads, moisture conditions, temperature, air movement, radiation conditions, biological attack, fire, manmade and natural disasters
   A. Quality of Mechanical/Structural Properties
      compression, tension, shear, abuse
   B. Quality of Physical/Chemical Properties
      watertightness, airtightness, transmission, reflection, absorption of heat, light and sound energy, firesafety
   C. Visible Properties
      color, texture, finish, form, durability, maintainability

Quality Thresholds: The Limits of Acceptability

Each building performance mandate has a "comfort zone", establishing the limits of acceptability for the type of occupancy concerned. These limits, often translated into standards and codes, budgets and guidelines, are established by the physiological, psychological, sociological, and economic[3] requirements of the occupancy. The limits must be established for the range of building or space functions and the range of occupancy types and factors (age, metabolic rate, clothing, health).

LIMITS OF ACCEPTABILITY FOR BUILDING PERFORMANCE

	PHYSIO-LOGICAL	PSYCHO-LOGICAL	SOCIO-LOGICAL	ECONOMIC
SPATIAL PERFORMANCE				
ACOUSTIC PERFORMANCE				
THERMAL PERFORMANCE				
AIR QUALITY				
VISUAL PERFORMANCE				
BUILDING INTEGRITY				

In regards to human occupancy, **physiological requirements** aim to ensure the physical health and safety of the building occupants, sheltering basic bodily functions - sight, hearing, breathing, feeling, movement, etc. - from wear or destruction over time, against such conditions as fire, building collapse, poisonous fumes, high and low temperatures, poor light. **Psychological requirements** aim to support individual mental health through appropriate provisions for privacy, interaction, clarity, status, change, etc. **Sociological requirements** (also referred to as socio-cultural requirements) aim to support the well-being of the community within which the individuals act, relating the needs of the individuals to those of the collective. Finally, **economic requirements** aim to allocate resources in the most efficient manner in the overall goal to serve user needs, within the wider social context.

The interdependencies of these four limits of acceptability might be best illustrated through an acoustic performance example Guidelines, codes and standards have been developed to protect the human against excessive noise. To mitigate physiological hearing damage, both noise intensity and duration are considered. To mitigate psychological discomfort, noise frequency (even beyond the known hearing threshold) is evaluated, to eliminate the distraction of low frequency rumbles and high frequency hisses. To mitigate sociological hearing discomfort, consideration is given to speech articulation, to help ensure privacy in offices or between apartments. Finally, the availability of resources (financial, technical, energy) superimposes another layer of requirements, establishing limits or feasibility alongside the limits of acceptability. Decisions, however, must be tempered with the full understanding of resources over time, evaluating allocations necessary for initial outlay, operating costs, maintenance costs, eventual replacement or conversion costs, and associated personnel costs.

Performance quality thresholds are building specific limits of acceptability, or comfort zones, for each performance quality mandate, given the improved understanding of the individuals' physiological, psychological and sociological limits. At least five quality thresholds can be determined for the evaluation of a buildings' functional/spatial, thermal, air, acoustic and visual qualities as well as building integrity over time:

1. Codes and Standards
2. Guidelines
3. Project Brief
4. Standard Practice
5. Research Developments

It is often assumed that each threshold is more stringent than the one before, such as the successively tighter thermal comfort zones taken from the local codes, general government guidelines, and the specific project brief for a health facility. Recent research results, however, begin to promote 'comfort zones' for long term occupancy settings that cross over the boundaries of codes, guidelines, even standard practice - for short periods of time (combined with occupancy control) - to offer change or relief from overly static situations. Building function and occupancy types often dictate the performance thresholds necessary for the tasks to be performed. Theatres demand heightened levels of acoustic performance;

Nursing homes require excellent thermal performance and air quality; Monuments require outstanding building integrity - against visual degradation (e.g. appearance), mechanical degradation (e.g. structural integrity), and physical degradation (e.g. weather-tightness). As illustrated, the performance priorities of various building types or functions can be generally established, however, this does not obviate the building designer or evaluator(s) from meeting all performance qualities capably, or from establishing the priorities of the particular client, regardless of building function.

Performance Priorities for Various Building Types

	Spatial	Acoustic	Thermal	Air Qual	Visual	Integrity
Small Office	✓		✓			
Large Office	✓	✓	✓	✓	✓	
Multi Family	✓	✓				✓
Single Family	✓		✓			✓
Stores					✓	
Shopping Centers	✓		✓	✓	✓	
Hotel Motel	✓	✓	✓			✓
Elementary Schools	✓	✓	✓	✓	✓	✓
Secondary Schools	✓	✓	✓	✓	✓	✓
Warehouses						
Assembly		✓		✓	✓	
Clinics	✓			✓	✓	
Nursing Homes	✓		✓	✓	✓	✓
Hospitals	✓		✓	✓	✓	✓

Units of Evaluation: The Element of Time

The performance concept establishes that the primary goals of buildings are to serve user needs in the broadest sense: occupancy needs (human, animal, plant, artifact) as well as the needs of the surrounding community[4]. The thresholds, or limits of acceptability, are defined by the individual's and the community's physiological, psychological, sociological, and economic needs, requiring a sophisticated understanding of the complex term "comfort". Instead of prescriptive specifications for component selection, this concept emphasizes the specification of the desired performance of the whole system (building and community), and the resulting demands on component parts.

When evaluating such a system of building and community, performance can be stated, and alternatives compared, in terms of suitability, reliability, and flexibility[5]. **Suitability** is a measure of the degree to which a building and its component parts serve user needs in the present and near future. **Reliability** is expressed as the probability that the service will continue to perform as intended throughout the life of the facility, given appropriate maintenance and use. **Flexibility**, including adaptability, is a measure of the systems' ability to accomodate changing functions and

UNITS OF EVALUATION FOR BUILDING PERFORMANCE

	SUITABILITY	RELIABILITY	FLEXIBILITY
STRUCTURE			
ENCLOSURE			
INTERIOR			
SERVICING SYSTEMS			

UNITS OF EVALUATION BASED ON INTENT OF THE BUILDING

	TEMPORARY	SHORT LIFE	LONG LIFE	PERMANENT
SUITABILITY	✓	✓	✓	✓
RELIABILITY		✓ SHORT TERM	✓ LONG TERM	✓ LONG TERM
FLEXIBILITY			✓	✓

Interrelationships of Building Performance Mandates

Performance requirements in each of the six categories cannot be understood in isolation from the other. First of all, they are related in a complex manner through their physiological, psychological, sociological and economic values. For instance the concept of privacy has acoustic, spatial, visual and olfactory (air quality) dimensions.

Second, in trying to fulfill the requirements of one performance mandate, side effects are created which impinge upon the fulfillment of another. The need for acceptable air quality, for example, may lead to a ventilation rate which will affect both thermal and acoustic comfort.

Third, performance requirements are related to each other through the multiple effects of building component choice. The selection of a ceiling light fixture has implications in terms of heat as well as light, noise as well as radiation. Although the building component may provide adequate performance in one dimension, it may fail in other areas, due to specification, context or maintenance.

To deliver a project that is acceptable in all the performance areas, therefore, conflicts must be resolved between performance mandates and limits, and priorities must be set, based on the building or space function. Then, total building performance evaluation techniques are needed to consider these complex interrelationships in the conception, design, specification, installation, and use of components and assemblies within buildings - techniques which are the focus of building evaluation.

Components and Component Interfaces for Total Building Performance

The materials, components, and assemblies synergistically designed to create buildings, then, must also be synergistically designed to fulfill the basic performance mandates for building integrity, thermal quality, acoustic quality, lighting quality, spatial quality, and air quality. For the sake of discussion, building materials and components can be grouped into four assembly categories: load bearing structure, exterior enclosure, interior enclosure, and servicing.

1) Examples of **load bearing structural** assemblies include suspension structures, with tension cables and compression masts as components, as well as frame structures with vertical columns, horizontal beams and diaphragms as components.

2) The **exterior enclosure** assembly incorporates roof, exposed exterior walls and floors, below grade exterior walls and floors, and connective components such as parapets. Then, within the broad component classification of exterior wall, exist secondary components such as windows, and tertiary components such as mullions, eventually arriving at aluminum as a material.

3) **Interior enclosure** is composed of: fixed spatial components such as walls, ceilings, floors; and furnishings such as chairs, desks, movable partitions.

4) **Servicing** assemblies include mechanical (HVAC), electrical (lights, power), vertical transport (elevators, stairs, escalators), sanitary (plumbing), firesafety, and telecommunications equipment.

One component may be serving a dual function: e.g. load bearing structure acting as exterior enclosure and/or interior definition; servicing assemblies acting as interior definition or exterior enclosure[4]. In fact, the richer building designs capitalize on this multiple function as a design approach. What is critical to the concept of total building performance, however, is the understanding that these four assembly categories are often only designed to their respective component performance requirements, resulting in the inability of two assemblies (component to component interfaces) to sustain all six performance mandates. For example, a roof membrane carefully designed to roofing component performance specifications may itself be watertight, but the elevator shaft, designed to other component specifications may penetrate the membrane without adequate detailing to guarantee the air, vapor, or water seal under differential expansion and contraction. Traditionally, the performance of individual components is measured and predicted in isolation from other components, often in the laboratory. Today, this is slowly giving way to integrated performance measurements and assessments. The suitability, reliability, and flexibility of components **and their interfaces** in providing for the basic performance requirements of the occupancy, is best evaluated under conditions of that occupancy. It is the dynamic environment created by the managers and users of buildings which provides the realistic basis for appraisal.

Gaps Between Professional Design Disciplines

In traditional design processes there has often been a clear delineation of responsibility and accountability for selecting structural, enclosure, servicing, and interior system components. This division of responsibility often leaves one primary decisionmaker for each major set of components, suggesting a minimum conflict for the building delivery, with clear role definitions.

BUILDING SUB-SYSTEMS

CONSULTING PROFESSION	STRUCTURAL	ENCLOSURE	SERVICING MECHANICAL	INTERIOR
ARCHITECTURAL	○	●	○	○
MECHANICAL			●	
ELECTRICAL			●	
LIGHTING		○	○	○
ACOUSTICAL				○
STRUCTURAL	●			
INTERIOR PLANNER				●
ENERGY CONSULTANT		○	○	

● PRIMARY RESPONSIBILITY
○ SECONDARY RESPONSIBILITY

The problem with this division of responsibility and decisionmaking power is that the ultimate provision of functional/spatial, thermal, air quality, acoustic, and visual performance, as well as building integrity, is entirely dependent on the effective integration of all building subsystems in the occupied building.

Listing the design professions or disciplines involved in subsystem design and integration, and assigning traditional performance responsibilities, another set of gaps become apparent.

PERFORMANCE QUALITIES

		SPATIAL	THERMAL	AIR QUALITY	ACOUSTIC	VISUAL	BUILDING INTEGRITY
DESIGN PROFESSIONS/DISCIPLINES	ARCHITECTURAL	●			○	○	●
	MECHANICAL		●	●			
	ELECTRICAL	●				○	
	LIGHTING	○				●	
	ACOUSTICAL				●		
	STRUCTURAL	○					●
	INTERIOR PLANNER	●			○	○	●
	ENERGY CONSULTANT		●	○		●	
OTHER BUILDING DECISION MAKERS	OWNER/ FINANCER	●					●
	CONTRACTOR			○			●
	MANAGER OPERATOR		●	●		○	●
	OCCUPANT	○				○	

● PRIMARY RESPONSIBILITY ○ SECONDARY RESPONSIBILITY

For instance, only one decisionmaker, the acoustical engineer, takes primary responsibility and accountability for acoustics in buildings, and then traditionally only in special purpose buildings or spaces, where communication with speech or music is essential. Sometimes other design decisionmakers will take partial responsibility (without full accountability), but these players are often not well versed in the fundamentals of acoustics. This may in part, explain the poor acoustic performance of open office areas, many restaurants, athletic facilities, and even classrooms.

Air quality and visual (lighting) performance also have few advocate decisionmakers in the design process. Responsibility for good air quality in buildings is assumed to be taken by the mechanical engineer and later to the building manager/operator. However, this accountability is assigned without control over the realm of design decisions which affect air quality, such as: selection of materials; space layout affecting air distribution; processes and equipment to be housed; or the detailing and construction of vertical shafts and plenums that affect pollution migration.

If it were not for the development of a new design profession or discipline - the energy consultant - visual (lighting) performance would have only one player in the design process - the electrical/lighting consultant. Again, many integration decisions critical to lighting performance, such as height and depth of spaces, window size and control systems, and surface colors, would not be relinquished to team decisionmaking except in buildings where seeing/display is critical, such as museums.

Although many energy consultants have not become advocates for air quality, they have altered to some extent the design process, by strengthening team decisionmaking processes with regards to structure, enclosure, interior and mechanical system integration, originally for the provision of thermal comfort. As a result of this new design consultant or expertise, decisions about structural system type, and integration with enclosure; enclosure materials and detailing; and interior layouts and furnishings - have been added to the traditional 'thermal comfort' discussions of the isolated mechanical system design.

Both spatial performance and building integrity have the greatest chance of success, given the number of decisionmakers taking responsibility. The design and financing of materials and details for building integrity often go through a collective and iterative decisionmaking process to ensure performance suitability, reliability, and as programmed, flexibility.

Gaps in the Building Delivery Process: The Concept of Stress Factors

The second division of responsiblity which leads to potential building performance problems exists between the stages of the Building Delivery Process. Public Works Canada has instituted a well defined Project Delivery System (PDS) outlining deliverables and criteria for 10 stages in building production: 1) Identification of Needs and Opportunities; 2) Option Analysis and Selection; 3) Project Definition; 4) Design; 5) Working Documents; 6) Contracting; 7) Construction; 8) Commissioning; 9) Occupancy; 10) Evaluation.

A major concern is the lack of 'teeth' (testable thresholds of acceptable quality) in each stage of the project delivery system towards ensuring total building performance.

Performance failures can result from decisions made at any step in the delivery process, decisions that reduce the alternatives for each succeeding step, such that the final product has less chance for success. The concept might be titled **'stress factors'**, or the introduction of a decision in any stage of the project delivery system that significantly narrows the range of decisions possible in successive stages towards the delivery of functional/spatial, thermal, air, acoustic, and visual quality and building integrity.

A client may dictate at the outset that a large portion of the resources should be allocated to decisions that "show" such as facades and lobbies, resulting in tremendous restraints on roof and foundation budgets. The feasibility study and program may dictate that skylit spaces are of critical importance. In preliminary design, the architect may put forward an expression in which flat roofs are an important component, with skylights dotted across the expanse. The specifier in working drawings may produce a detail that requires precision construction, without assurance of the matching investment in quality materials; while the contractor has been asked to fast-track, with the client's emphasis, again, that the work that 'shows' must be impeccable. Finally, the building manager is conscientiously 'putting out fires' while preventative maintenance of drainage channels and flashing valleys on the roof are left to less hectic times. The result? A massive roof leak. No one decisionmaker is at fault, though law suits are intended to prove the contrary. The performance failure is a result of stress factors that began at the conception of the project, making it increasingly difficult for the succeeding decisionmaker to ensure performance. The solution may be a level of comprehension of building science and building performance, that spans the entire building delivery process, and a commitment to relieving (or at least acknowledge) stress factors at each stage of decisionmaking.

The Concept of Transdisciplinarity:

Transdisciplinarity is the development of decisionmaking procedures for the elimination of gaps between professional design disciplines and gaps in the project delivery system in the delivery of total building performance (functional/spatial, thermal, air, acoustic, visual qualities and building integrity). Transdisciplinary procedures include: total building performance design standards, matched with field measurement and assessment techniques for compliance at each stage in the project delivery system; team decisionmaking, with advocacy, iterative and matrixed decisionmaking methods for building system integration and the reduction of stress factors; and 'post-occupancy' evaluation to narrow the gap between occupancy physiological, psychological, and sociological needs today, and design directives.

The transdisciplinary process would be based on establishing a full design team, at the time of conception, capable of making collaborative, informed decisions. The full design team would include experts in each performance quality area, and experts in critical stages of the project delivery system (programming, design, working drawing/specification, construction, occupancy), with emphasis on those performance areas most important to the functions and occupancies of the project. During the early design stages, each team member would enunciate and champion the building performance criteria for which they are responsible, such that all team members can successfully participate, and such that performance stress factors are understood in the siting, massing, organization or spaces, enclosure and opening design, and the integration of system decisions in design stage. For collective decisionmaking, an advocacy process would be based on verbal negotiations and requires the interested and vocal participation of each team member. An iterative process would be based on written (including drawing annotations) round-robin negotiations. A matrixed process would be more deliberate, conducted in a series of meetings, first chaired by the performance quality experts, then by project delivery experts (programming, design, working drawing/specifications, construction, occupancy), then by design disciplines (architects, engineers, consultants).

Ultimate design decisionmaking can be hierarchical (based on lines of accountability) or shared (with multiple accountability) reflectign the complexity of integrating building structural, enclosure, interior and servicing systems for the delivery of total building performance. The team would highlight the most critical performance qualities required in the building, establish thresholds or limits of acceptability, and select appropriate field testing procedures for each stage of the project delivery system.

Finally, transdisciplinary methods would be used in the post occupancy evaluation of buildings, incorporating functional/spatial, thermal, air, acoustic, and visual quality experts as well as building integrity experts, resulting in recommendations for change in a specific building, the entire building stock, or the project delivery system.

BUILDING DIAGNOSTICS

Definition

Building Diagnostics is the measurement and assessment of a building's ability to provide functional/spatial quality, thermal quality, air quality, acoustic quality and visual quality for its occupancy, as well as to provide building integrity versus degradation.

The measurements and assessments must be completed in a **transdisciplinary** manner for each of the six performance areas, in **relation** to established quality thresholds **or limits** of acceptability, for **the** specific occupancy and function. Building diagnostics can establish, at various stages during the project delivery system, the **suitability** of a building and its component parts to serve occupant needs in the present, the **reliability** that the service will continue to be suitable throughout the life of the building (dependent on the appropriateness of the maintenance and operation practices), and the **flexibility** or adaptability of the building and its component parts to provide long term suitability given changing occupancies and functions.

Illustration

To begin with, the building diagnostician must establish the relevant performance requirements, and their limits of acceptability, before measuring a specific material, component or assembly. When measuring the performance of light fixtures, for example, the visual comfort mandate and the client's limits of acceptability (or standards) must be established, as well as related acoustic, thermal comfort, and radiant/health standards. Then as outlined in the IES standards(7), a comprehensive in-place testing procedure is necessary to establish the suitability, reliability, and flexibility of the lighting fixture within the occupied setting.

To establish the **suitability** of the lighting assembly in providing the accepted range of foot candles on the task surface, without jeopardizing other comfort requirements, the fixtures must be **measured within** the overall assembly of ceiling, floor, wall, furniture, partitions and occupants - at various times of the day. Lighting suitability is as dependent on the position and color of partitions, the position and color of furniture, and the fixtures interference with acoustic comfort or thermal comfort, as it is dependent on the manufacturers labelled foot candle levels.

To establish the **reliability** of the lighting assembly in providing visual comfort **over time**, requires **measurement and comparison** of the long term quality of the ballasts and starters, the tubes and bulbs, the lenses and reflectors, etc. Acrylic lenses provide suitable light transmission at installation, but are not necessarily reliable, since they often yellow when exposed to light. Establishing reliability also depends on the measurement and assessment of the maintenance effort that can be reasonably expected, including cleaning schedules, replacement schedules, etc.

To establish the ability of the lighting assembly to sustain visual comfort over time, given changing occupancy, function and use, **flexibility measurement** must identify the **range** of conditions under which the system will maintain suitability, or the investments necessary for adaptation. This measure anticipates new office planning in which functions may change from drafting to lounge areas, increased density and major partitioning may divide light fixtures, or dark painted walls may reduce reflectivities. Flexibility and adaptability, then, is a measure of the level of effort and resources necessary to sustain suitability over changes in occupancy, function, or use.

Diagnostic Measurement - Equipment and Procedures

Increasing expectations and demands for building enclosure integrity and occupancy 'comfort' has spurred an unprecedented growth in instrumentation and measurement techniques for buildings. Parallel and interwoven advances in the behavioral and social sciences[8], combined with the expansion of scientific engineering and medical testing[9], has greatly enhanced our understanding of the way in which buildings affect occupant physiological, psychological, sociological, and economic requirements. As a result, ABS has been able to capture and develop a range of diagnostic measurement tools - equipment and procedures - capable of determining the suitability, reliability, and flexibility of building components and component interfaces, towards providing total building performance. The following five levels are defined in an attempt to capture the various forms of diagnostic measurement approaches used at ABS today:

TABLE 2: Levels of Diagnostic Measurement

1. Plan/Archive Analysis
   a. Plans, Specifications, Photographs
   b. Building Budgets, Implementation History
   c. Occupancy/Management Records

2. Expert Walkthrough Analysis
   a. Ear: listening
   b. Eye: seeing
   c. Nose: smelling
   d. Hand, Body: touching, feeling
   e. Mouth: tasting

3. Occupancy and Use Analysis
   a. Questionnaire
   b. Interview
   c. Behavioural Mapping, Physical Traces

4. Simple Istrumentation Analysis

5. Complex Instrumentation Analysis

Each level of diagnostic measurement involves the use of different tools and procedures to go with those tools. Depending on which performance qualities are being tested, at which building scale, each level of measurement may also vary according to: cost, level of expertise needed, repeatability, depth of evaluation achieved, and assurance or reliability of results.

ABS is also trying to determine whether (and when) there are clear relationships between these five levels of measurement, such as: one clearly depending on another; one clearly revealing the scale of the problem or the percent of building coverage needed; one giving identical results as another, with high percentage frequency; and one allowing quantifiable enhancement of another.

Regardless, each level of diagnostic measurement will feed into records, independently or combinations of various levels and various performance qualities. Checklists, counts, annotated plans, photos or videos, plots (curves, histograms), and tables may be carried away from a field evaluation as records of diagnostic measurements.

Diagnostic Assessment - Procedures and Equipment

While diagnostic measurement implies the collection of relevant data and the equipment, expertise and methods necessary for this collection, diagnostic assessment refers to the generation of recommendations from this data, and the equipment (e.g. computers), expertise (e.g. algorithms) and methods necessary for the interpretation. Indeed, the weakest links in evaluating total building performance today are the procedures for diagnostic assessment. Over the past four years, ABS has been amassing and developing diagnostic assessment procedures, eventually to be independent of the measurement procedures. Seven levels of diagnostic assessment have been identified to date:

TABLE 3: Levels of Diagnostic Assessment

1. Expert/Informed Judgement
2. Pattern Recognition
3. Simple Algorithms
4. Statistical Assessment
5. Complex Algorithms
6. Expert Systems
7. Mock-up Sensory Assessment

An expert/informed judgement requires an individual well versed in a particular science area, such as an acoustician who can immediately recognize the curved walls as the cause of an echo. Assessment by pattern recognition is being developed for such complex instrumentations techniques as thermography, where the video records are compared to existing patterns to see if the problem is one already recognized and rectified in another building evaluation. Simple algorithms include such things as scales, such as CO_2 limit for occupied spaces, and curves, such as NC curves setting acoustic limits. Statistical assessment include such packages as SASS, presently utilized by ABS(where large measurement data bases are under consideration. Assessment through complex algorithms include such integrated scales as the psychrometric chart which incorporates temperature, humidity, air speed and radiant indices into the thermal comfort assessment. Expert systems may be the assessment procedure of the future, incorporating expert judgements, pattern recognition, and algorithms from innumerable building evaluations over time, into large knowledge bases for decisionmaking. Finally, mock-up sensory assessments incorporate a cyclical process of measurement, individual or collective assessment and modification, followed by measurement, until the ideal state is achieved.

Each of these levels of assessment have different cost and time and confidence implications for the completion of building evaluations and recommendations. Each of the procedures are independent of the **equipment** used for diagnostic assessment, equipment ranging from hand calculations and plots, to simple graphic plotters, to calculators and micro-computers, to large scale computers. The simplest of scales or algorithms can be read into the most complex equipment.

A diagnostic assessment (and recommendation for action) can only be made based on the comparative performance of the measurements to quality thresholds or limits of acceptabiity. On most projects, ABS tries to determine the following thresholds in each performance area, as applicable to the field evaluation: 1) codes and standards; 2) guidelines; 3) project brief requirements; 4) norms or state of the art thresholds; and 5) research results. However, the thresholds established today have serious shortcomings in their ability to deal fully (in a transdisciplinary manner) with all performance variables. To begin with, the algorithms that form the basis of the assessment procedure often avoid the full set of performance indices and the performance to performance conflicts. Despite the comprehensiveness reflected in ASHREA's Thermal Comfort Standard[10](55-81), thermal comfort (as controlled by thermostats) is often assessed in the field by building operators and users given air temperature measurement alone, with no call for radiant temperature conditions, air movement, clothing, or metabolic rate. Even when all thermal comfort factors are accounted for, action is often recommended despite the implications it will have on other performance mandates, such as air quality or acoustic comfort. Before transdisciplinary actions can be effectively recommended from diagnostic measurement, stronger assessment algorithms must be developed, fully defining the six performance mandates, their limits of acceptability (guidelines, codes and standards), and their relationships to each other. With the computer available as an assesent tool, we now have the capability of storing broad measurement data bases, assimilating assessment algorithms for several performance mandates, and finally daagnosing for **total building performance**.

Written recommendations are the final product of the diagnostic measurement and assessment procedures. At the outset, the project manager and client must ascertain the type or types of recommendations desired, based on the level of confidence needed, and the associated cost and time implications:

1. Specific Building Retrofit
2. Organizational/Use Change
3. Maintenance and Operation Change
4. Generic Retrofit (widespread application)
5. Project Delivery System Change
6. Codes and Standards Change
7. Data Base Development
8. Recommendation for Furthur Testing

Project Management: Menu Packaging

With this 'menu' eastablished, the challenge of cost-effective performance evaluation of occupied buildings lies in the packaging of appropriate measurement techniques and records, with assessment techniques and types of recommendations, given the client's problem, or issue, and resource limits.

The field project manager must also ensure the methods for transdisciplinarity in each stage of the field evaluation project: identifying the multiple performance implications of the issue; identifying the component to component interfaces that must be addressed, and the mix of disciplinary experts that must be present; organizing the menu package to reflect the performance priorities through resource allocation and stages in the field strategy; ensuring transdisciplinary communication in the field; and finally processing the field findings and recommendations through an advocacy, iterative, or matrixed procedure ensuring total building performance. In all cases, the strategic packaging of the levels of measurement and assessment to address a particular issue or problem, must incorporate (to one level or another) the full set of performance criteria for building occupancies - functional/spatial quality, thermal quality, air quality, visual quality, acoustic quality, and building integrity.

CONCLUSION

Introducing Building Diagnostics into the Project Delivery System

Building diagnostics (measurement and assessment) has the potential of rapidly becoming a major tool in building appraisal, to evaluate suitability, to anticipate long term performance and the resources necessary to sustain this performance, and to assess risk. Upon reviewing the various types of measurement equipment and procedures available it sould be clear that this ability to appraise performance and risk will be available to most of the building decisionmakers, throughout the building delivery process.

In the early stages of opportunity/need identification and option analysis, diagnostics can be used to test the existing facility and alternative facilities against that need. In the design of new museums for example, transdisciplinary expert walkthroughs of existing museums can integrate the evaluation of visual quality, functional/spatial quality, thermal and air quality, as well as building integrity critical to early concept development.

In the programming and design stages, performance specifications would be developed 'with teeth' or tests to ensure the building's quality after preliminary design, after design development, after final design, and after working drawings. Energy budgets for example can be without irrevocably waiting for final working drawings.

Before contractors are selected, their qualifications for delivering a building that performs (in all quality areas) can be coarsely tested at their completed buildings. During construction, regular performance testing should be completed for comparison with the project brief. After a suggested one-year handoff between contractor and building manager (through system balancing and commissioning), the building should again be tested for its total building performance, given the new occupancies and functions.

A series of staged, mini-test packages can be introduced during the maintenance and operation of a building to anticipate performance problems and failures and establish preventative maintenance procedures.

Finally, there is the evaluation stage with which building diagnostics is traditionally tied. At this stage in the project delivery system, field measurement and assessment can lead to any of the eight levels of recommendations previously described. One of the most significant contributions will be the measurement and assessment of the total building performance of a full range of existing building types, for feedback into the project delivery system. Evaluating the suitability, reliability, and flexibility of a building, in meeting its function(s) over time, will enable the building community to anticipate and prevent failure, as well as improve the overall performance of buildings for their specific occupancies.

In pursuit of accomplishing this feedback, there is a serious need for knowledge development and packaging, including: refining the thresholds or limits of acceptability for performance, given varying occupancy types and functions; defining the interrelationships (and conflicts) between different performance mandates; discovering the critical component interfaces affecting each performance mandate; developing the menu of 'diagnostic' measurement tests for evaluating transdisciplinary as well as unidisciplinary performance; developing the menu of 'diagnostic' assessment tests; and establishing education and training programs aimed directly at each major decisionmaking group in the building delivery process.

REFERENCES

In noted cases, concepts and terminology have been drawn from:

(1) Fix, W. and Rubben, A. "A New Approach for Calculating Time Dependent Effects in Polymer Building Materials," **Proceedings Performance Concept in Building, Third ASTM/CIB/RILEM Symposium**, (Lisbon, Portugal), 1982

(2) Woods, J.E., "Do Buildings Make You Sick?," **Proceedings Third Canadian Buildings Congress Achievements and Challenges in Building 1982**; National Research Council no. 21158

(3) Blanchere, G., "The Notion of Performance in Building: Building Requirements and "What are the Natures of Performance and Evaluation for the Three Levels: Building, Component, Materials?," **Proceedings Performance Concept in Buildings 1972**; National Bureau of Standards NBS 361

(4) **CIB Report Publication 64** "Working with the Performance Approach in Building," January 1982, pp. 10, 5, 17, 20

(5) Lemer, A.C. and Moavenzadey, F., "Performance of Systems of Constructed Facilities," **Proceedings - Performance Concept in Buildings 1972**; National Bureau of Standards NBS 361

(6) "The Project Delivery System" of Public Works Canada, Stages 1 to 10, (Public Works Canada), 1978

(7) ANSI/IES RP1 1982 "Practice for Office Lighting," IES Lighting Handbook, 1981 ed. J. Kaufman Illuminating Engineering Society (New York), 1981

(8) Mill, P.A.D., "Thermography - a New Building Science Tool," Report Series no. 29 (Public Works Canada), 1979

(9) ANSI/ASHRAE Standard 55-1981 "Thermal Environmental Conditions for Human Occupancy," (Atlanta), ba. 1981

II. SESSION II RESEARCH NEEDS. BUILDING STANDARDS, STRATEGIES AND CONSERVATION.

II.1 ENERGY EFFICIENCY IN BUILDINGS: RESEARCH NEEDS FOR THE NEXT DECADE

Walter M. Kroner
Professor and Director
Center for Architectural Research
Rensselaer Polytechnic Institute
Troy, NY, USA

ABSTRACT

The focus of this paper is on the identification of research needs for energy efficient buildings in the United States of America. Near-term and long-term research needs are presented which could lead towards improved levels of energy-efficiences in buildings and suggest new concepts for energy conscious architecture. Near-term research needs are based on the assumption that codes, policies, construction and building-use will continue more or less as we know them now; the design and construction of buildings, as well as their placement within the existing fabric of communities, will essentially remain as they now are; lifestyles, separation of work and living environments, and building-use patterns are expected to continue more or less in their present formats.

The long-term research needs are based on architectural and engineering design concepts which give new meaning and definition to architecture and building technologies. Implicit within these design concepts are potentials for energy savings, and levels of energy efficiency, beyond those possible through conventional architectural solutions. Long-term research needs assume that we can modify our social institutions, laws, life-styles, and design-thinking. With these assumptions, and the proposed design concepts, we can initiate the suggested long-term research activities. If proven to have merit, these research activities may allow a planned transition to new forms of energy efficient buildings, communities, and behavior.

INTRODUCTION

"The future of the past is in the future
The future of the present is in the past
The future of the future is in the present"
(by John McHale, 1969)

Energy use in residential and commercial buildings in the United States totaled 26 QBtu on a primary basis in 1983, equal to 36% of total U.S. energy consumption.[1] Residential buildings accounted for almost 15 QBtu (21% of national energy use), while commercial buildings accounted for almost 11 QBtu (15% of national energy use).

Analysis of total U.S. energy use (including industrial and transportation uses as well as building uses) conducted at the Oak Ridge National Laboratory suggested that energy use in 1982 (71 QBtu) was almost 35 QBtu lower than it would have been had historical (pre-embargo) trends continued unchanged. Nearly half of the 35 QBtu reduction appears to be due to slower growth in GNP after 1973. It appears that the remaining 19 QBtu reduction was due to improved energy efficiency, with roughly 40% due to higher energy prices and the rest (13% or 4.5 QBtu) due to the effects of government and utility conservation programs, and other non-energy price factors (accelerated trends away from energy-intensive industries, non-price-induced technological advances, energy shortages, deregulation of energy-using industries, and increasing public awareness of the energy "crisis").

The opportunities for large additional increases in energy efficiency and, more important, in dollar savings for consumers, have been well documented. We have learned how to design and re-design new and existing residential and commercial buildings which use very little energy. To continue the progress of energy improvements in buildings we need to move in several directions:

1. What are some of the general research directions?

-- We need to work out remaining technical problems, from earlier energy conservation efforts, to more widespread adoption of past demonstrations of achievable efficiency (e.g., overcoming barriers of indoor air quality, the need for more accurate predictive models for energy use, application of new materials to building construction, and integrating building data bases and collection efforts).

-- We need to improve and apply our knowledge of behavior as it affects energy use (e.g., understanding the effects of occupants on energy use, or of how markets for appliances and home construction influence the selection of energy features).

----

1 Energy Review, DOE/EIA-0035, Energy Information Administration, U.S. Department of Energy

-- We need to work on sub-applications of technology which have been neglected in the past decade; these include multifamily housing and warm climate building design techniques.

-- We need to fully implement the many ideas and techniques which have been developed already. Effective implementation requires experimentation with program delivery options, greater use of program evaluation, and adequate mechanisms for information and technology transfer.

These efforts will enable substantial progress towards achieving greater energy efficiencies in buildings.

NEAR-TERM RESEARCH NEEDS

This part of the paper outlines near-term research needs for energy efficient buildings which extends the efforts of the last ten years. The research and development efforts can begin immediately, and will help to advance our current knowledge and practice of achieving energy efficiency. The objectives of the recommendations are to fill in gaps in knowledge and to round out the variety of situations where this knowledge can be put to use.

Several areas of work will enable us to more fully benefit from research conducted over the past decade. First, we need to look at buildings as a whole and to understand the interrelationships among existing building energy research. An integrating framework needs to be developed to consider building component research, the study of whole building systems, design and analysis of building environments for non-energy qualities such as air quality or work productivity, and the long-term effects of building design. This framework will allow a consolidation of the gains of the past decade.

Second, there are technical issues in building energy efficiency which require further refinements. There also are needs to increase the sub-applications of energy efficiency technologies already developed. These sub-applications may be for markets or target audiences previously overlooked. Examples include energy management control systems for residences (down-scaled from commercial building equipment) or retrofit measures for multifamily residences and mobile homes.

Third, research from other fields needs to be adapted for use in energy efficiency objectives. A considerable body of research in the social sciences exists to explain behavior, attitudes, and decision-making processes of individuals and organizations. This research needs to be more effectively translated and incorporated into knowledge of how government, utilities, or product manufacturers can more successfully influence energy purchase and use behavior.

Fourth, the results of the past decade of research must be put to good use. A significant body of research findings and experimental program outcomes, regarding energy efficiency in buildings, needs to be translated into relevant policy and program implications. These, in turn, need to be applied through the channels of building construction, appliance and equipment sales, and program intervention strategies. The effectiveness of these applications should be communicated back to researchers to ensure a feedback loop for future research.

The near-term research needs presented here focus on: whole building energy performance, building technologies, building control technologies, and building retrofit.

1. Research Needs Related to Whole Building Energy Performance (WBEP).

The term "whole building energy performance" (WBEP) is used to call attention to a particular way in which a building is defined for purposes of WBEP research. The focus is on the end-product of the building design and construction process -- the building itself; the forces which influence the design of the building as well as its use over time, and the total energy performance in terms of quality, efficiency and the resulting environmental qualities. Thus whole building energy performance is concerned with the interrelationships of individual elements and their collective impact on the quantity and quality of the building in use.

a. Specific WBEP research needs.

Near-term research needs related to WBEP are a series of issues questions, and needs for knowledge including:

-- How do quality control, siting, and interactions among individuals who design, construct, control, own, finance, and occupy buildings affect WBEB?

-- How does overall building form, thermal massing configuration, placement, orientation affect WBEP?

-- What are the differences between fundamental architectural design strategies such as: atriums, special enclosures, buffer spaces, and interior space configurations in relation to WBEP?

-- How do the various combinations of building materials, parts, components, mass, wall/roof designs and their operation affect WBEP?

-- How does the climate and context impact WBEP through individual building elements?

-- How do various thermal, luminous and fresh-air design strategies and technologies affect WBEP?

-- How do various types of sensor and control strategies affect WBEP?

-- How do various forms of integrating active and passive comfort technologies within a building affect WBEP?

-- How are the thermal, luminous, and fresh-air qualities affected by various levels of whole building energy efficiencies?

- -- We need to understand energy-efficiency and energy conservation strategies in relation to sensory qualities as they impact human beings and human productivity.
- -- How do building occupants, users, and O&M personnel impact WBEP?
- -- What are the differences between WBEP and various forms of building ownerships?
- -- How do various techniques used to seek sensory comfort by occupants impact WBEP?
- -- We need to develop tools to assist WBEP research in terms of whole building measurements.
- -- We need to develop standards as related to duration of measurements, types of data, format of data, and monitoring techniques.
- -- We need to develop short-term measurement techniques for whole buildings to predict long-term performance including what is to be measured, over what length of time, by whom, and how the data should be formatted for different data users.
- -- Research is needed to enable designers and builders to optimize wall/roof designs as climate and building orientation vary. We need to identify research needs in relation to passive and active solar systems as integral parts of HVAC systems.
- -- We need HVAC-related research on very low energy buildings in hot humid, and hot dry climates, as well as those in cold climates.
- -- We need field measurements on the output of the HVAC systems in passive solar buildings.
- -- We need research on heat-loss and gain in residential environments from people, appliances, equipment and other internal gains and losses, and the affect of occupancy.
- -- We need research to develop a standard and accurate method for measuring whole building energy performance as it is affected by heat loss to the ground under different climatic, soil, and design conditions.
- -- We need to develop evaluative (predictive) tools to assess or evaluate the numerous voluntary energy rating systems that are being used.
- -- We need to investigate indoor air quality, air movement and infiltration in relation to various energy efficient building designs.
- -- We need to determine and measure areas of thermal transfer within whole buildings.

2. Research Needs Related to Building Technologies.

Research is needed to refine the knowledge and application of technologies already developed to improve energy efficiency.

-- For existing buildings, we need to know how conservation measures actually perform in comparison to engineering calculations.

-- Special attention also is needed to new or modified retrofit techniques for multifamily housing and mobile homes, when single family conservation techniques cannot be directly duplicated.

-- Where the owners of existing buildings are looking for advice on the best ways to invest money in energy efficiency, it is important to have the results of research and experiments which identify the relative performance of alternative conservation measures.

-- Less research has been carried out on issues of use and operation of buildings than on the controls and equipment installed in buildings. More research is needed on the role of users and operators who interact with building and equipment monitoring and control systems. Important issues are how the operators use the control equipment, what forms of response are taken with monitoring equipment, and how information display features of the equipment can be best designed for informed use by the building operator.

-- The current monitoring and control technology developed for commercial and industrial building applications offers the possibility of modification for use in smaller commercial facilities and in residences. This research can take advantage of microprocessor and sensor technology developments. User issues such as interest in user-programmable controls and information feedback mechanisms need to be researched.

-- The development of such equipment as waste heat recovery systems, cogeneration, and thermal energy storage systems raises important issues of how this equipment can be integrated into buildings, what the relationships will be to power and thermal systems, and what kinds of control systems might be required to operate such buildings effectively.

-- Finally, there is still substantial room for improving the energy efficiency of residential and commercial appliances.

3. Research Needs Related to Building Control Technologies.

For commercial buildings, a key research need is to understand how building operators use and respond to building monitoring and control equipment, and whether information is presented in a way to facilitate the operators understanding of sources of energy system inefficiency. For residential energy consumers, modification of energy use will depend largely on receipt of specific, credible information on their energy use, options for better managing this use, and highly visible communication of feedback on energy use. Research must address consumer communication systems, feedback mechanisms, and the related opportunities for introduction of alternative utility rates and load management strategies. Assessments are needed of consumer response to real-time feedback and diagnostics information.

Greater application of such technology promises considerable improvement in energy efficiency. Outdoor temperature reset controls for residential hydronic heating systems can save 10-20% of heating energy. Micro-processor-based energy management systems and direct digital controls can save 10-15% of energy use. On a national basis, an estimated 60 gigawatts of electric peak demand could be displaced if microprocessor residential energy meters were installed in all 88 million U.S. households. Specific research needs include:

-- Should the controls be permanent or portable? Should their power source be through building power line carriers, hard-wired (AC or DC?), or phone-line carriers?

-- How susceptible to non- or under-performance are these technologies for such factors as:

  - construction/installation according to design specifications,
  - proper commissioning, testing, and verification of building control system performance, and
  - training of operating personnel or residents who must respond to or operate the control equipment?

-- What changes are needed in perfecting current technologies in response to knowledge gained on these factors?

-- Can low-cost sensors and control actuators be developed at reduced costs in order to ensure greater installation of the technology?

-- Under what conditions can mass production be undertaken? (e.g., must there be some guaranteed demand for control technologies, from utilities or large home builders?)

-- Will provision of greater energy use information to building operators lead to more efficient building energy operations?

-- What features of system information display, user interaction, and user response cues might facilitate effectiveness of the equipment?

4. Research Needs for Building Retrofit.

There has been considerable research and data collected on the savings potential and cost effectiveness of particular residential retrofit measures. Still, there are a number of outstanding issues related to building retrofits, both in the residential and commercial areas.

The retrofit research activities proposed here center around collecting actual performance data and trying to understand how various factors affect energy savings. Specific issues which need to be investigated include:

-- In the residential sector, there has been tremendous variation in retrofit savings and cost effectiveness between individual homes. Additional research is needed to better understand the causes of the variation between retrofits and to minimize these variations. Savings can be affected by a wide range of factors including the type of measure, the quality of installation, the characteristics of the building, and the behavior of the occupants.

-- A related issue is the generally poor agreement between savings predicted in an audit and actual savings after the retrofit is carried out. Additional research is needed on the ways to improve the accuracy of audit predictions.

-- Opportunities for retrofitting multi-family buildings and mobile homes have received little attention relative to retrofits for single family dwellings. Research needs to be carried out to determine the most promising retrofit measures for different building types and to understand the factors that caused a certain level of savings (or lack of savings). Also, research is needed on how to maximize the savings and cost effectiveness of multi-family and mobile home retrofits.

-- In the commercial sector, the available data primarily pertains to "whole building performance" following building retrofits. Research is needed to determine the cost, savings, and related factors for individual retrofit measures in different building types (e.g., lighting system retrofits in schools, boiler retrofits in hospitals, HVAC retrofits in high-rise office buildings).

-- Other important technical issues which still must be resolved for all building types include the degradation and the lifetime of retrofit measures and persistence of energy savings.

-- On the analytical side, conservation "supply curves" have been generated for retrofits of existing homes. By ordering conservation measures on the basis of cost effectiveness and showing energy savings, the curves can be very useful for planning and analyzing programs. Further research is needed to update these curves on the basis of actual performance results, and to generate curves for a wider set of housing types and climates. This requires data on the actual cost and savings of specific retrofit projects.

-- Determine the impact of various partitioning strategies and thermal zone concepts on building energy use.

-- Perform further applied research related to energy efficient buildings, including:

    - Advanced insulation materials and techniques.
    - Advanced refrigerant mixtures.
    - Innovative windows and window systems.
    - Effects of envelope systems(wall and roof assemblies, earth-contact surfaces, ceilings, etc.).

- Moisture transfer and condensation on envelope subsystems.

-- Conduct research to determine the steady state performance of building materials including concrete, wood gypsum, insulation, vapor retarders, plastics, glass, etc. with particular attention to characteristics relating indirectly to energy such as thermal storage capacity, absorbtivity, emittance, reflectivity.

-- Test and analyze the dynamic behavior of infiltration and methods of joints and joining techniques, and related research on natural and forced ventilation.

-- Research the relationship of building surface coating materials (e.g., paints, resins) to building energy performance.

-- Develop new materials such as dessicants and phase-change materials and evaluate for passive energy system applications.

-- Research improved performance of motors and low-cost motor-controllers used in building systems both for new equipment and retrofit or modification to existing equipment.

-- Assess best applications and sizing conditions for waste heat recovery systems in buildings. Do this separately for furnaces, refrigeration and air conditioning equipment, and systems integrated with boilers.

-- Develop ideas for integrating conventional and new HVAC components with various types of passive energy systems, including the development of controls and sensors which can serve both active and passive systems.

-- Assess improvements needed to expand applications for small scale cogeneration and other decentralized integrated energy efficiency technologies (thermal energy storage, fuel cells, etc.) with attention to reducing equipment size, materials, or weight.

-- Identify community-scale energy technology improvements which might substitute for individual building equipment; determine minimum building population densities.

-- Develop and test building diagnostic components including sensors, controls, energy flow control devices for various building scales and types.

-- Research new computer control technologies for entire "building management systems" including energy management.

-- Improve the reliability of facility or equipment energy management control technology (direct or computerized) to a level of precision required by the utility industry for load management purposes.

-- Develop lower-cost metering equipment for time-of-use or real-time energy metering.

-- Develop customer-programmable and controllable technology to exert customer choice in loads managed for the benefit of time-of-use or other utility-related economic reasons (interruptable rates, contract curtailment, etc.) Technologies include:

  - Programmable controls, Demand Subscription Service, thermal storage, etc..
  - Group load curtailment controls.
  - Developments in lower cost microprocessing and communications technologies.
  - "Smart Homes" or "Smart Meters".

-- Develop new and high-efficiency HVAC systems which include heat recovery and can be used at various scales (workstation, room, zone, building). Research use of manual vs. automated control systems.

-- Conduct research to address special issues of appliance energy efficiency:

  - Dehumidification capabilities of highly efficient air conditioning equipment.
  - Corrosion of heat exchangers in condensing furnaces and compressors of refrigeration system.

-- Develop more efficient residential appliances including:

  - Refrigerators and freezers.
  - Air conditioning equipment with dehumidification capacity.
  - Fuel-fired water heaters.
  - Fuel-fired heat pumps.
  - Advanced lighting technologies.
  - Integration of microprocessor controls into domestic appliances.

-- Develop speciality systems and components for retrofit application to residential and commercial buildings. Emphasis is required on HVAC equipment, insulation, glazings and window systems, envelope components, fresh air heat exchangers, and domestic hot water systems.

LONG TERM RESEARCH NEEDS

We are witnessing change all around us every day. Societal priorities such as international security, free market economic philosophies, and environmental waste management are shifting. Our priorities for: comfort, lifestyle preferences, and resource-use shift in response to: political, institutional and economic conditions. The consequences are changes in the quality of the environment around us. Technological developments introduce new products such as computers, and programmable controls on microwave ovens or videorecorders which change the way we think about and control our household and workplace activities. Institutions are changing their roles and the services they offer, as witnessed by the dramatic changes in telecommunications and banking.

As our community and personal worlds change, we can expect the ways we use energy will change also. Some change will be to meet new functions, some will be responsive to new technologies for carrying out current activities, and some changes will result in totally new concepts for the buildings we occupy. It is difficult to predict these changes, nevertheless, we need to antcipate these changes in order to identify future research needs.

This section of the paper suggests concepts, and related research which are part of a transition from buildings and institutions as we now know them, to a future which is not entirely visible from where we stand today. We cannot anticipate this future with great detail. The research and program ideas reflect possible first steps on new paths of energy use in buildings.

Three examples are provided, which begin to suggest long-term research and proof-of-concept assessment, for increasing the efficiency of our buildings and communities: beyond the state-of-the-art levels.

1. Research Related to Task-Oriented Comfort Systems

The current approach to providing thermal, luminous, and fresh-air comfort within buildings is to condition the entire building volume. The concept of TASK-ORIENTED COMFORT SYSTEMS (TOCS), however, suggests that we create a heterogenous thermal environment. A heterogenous thermal environment is one in which the general building volume is maintained at temperature and humidity levels required by building materials and content, while a second thermal environment is created, within the first, which provides the sensory comfort qualities for each task area individually. Since building energy consumption is primarily determined by the amount of energy needed to maintain human comfort the TOCS hypothesis is that heterogenous environments consume less energy, compared to our present environmental control technologies and their use.

Task-oriented comfort systems would provide an individual person with his/her thermal, luminous, and fresh-air needs. Such a system would be responsive to an individual's unique physiology, activity level, and state of health. The general building volume will be maintained at temperature, humidity, lighting, and fresh-air levels separate and distinct from task oriented systems. This idea is not new; localized and/or portable sources of heat, task lamps, hand-held fans, and portable bedwarmers, are historic examples. Today we have: electric blankets, battery operated garments, task-lighting, portable fans, small room air conditioners, humidifiers, and desk-top air purifiers. Life-support system networks,used in hospitals, allow connection of patient-oriented technologies for treatment and survival. On airplanes each seat has its own light and fresh air service system. For more extreme environments we have an astronaut's space-suit, diver clothing, fire-fighter protective garments, and speciality clothing for hazardous environments.

A task-oriented cooling system was developed and tested in a Kansas City factory in 1974. The system was able to maintain a satisfactory working environment (79 degree F) in the plant in the conditioned spaces even on days when the thermometer soared to temperatures as high as 104

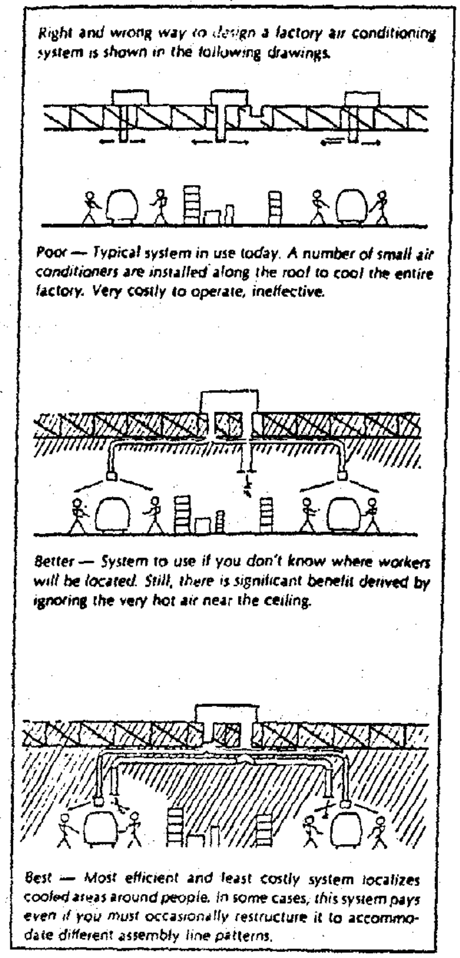


Figure 1: A TOCS for Cooling as as used in Kansas City (lower diagram was actually implemented)

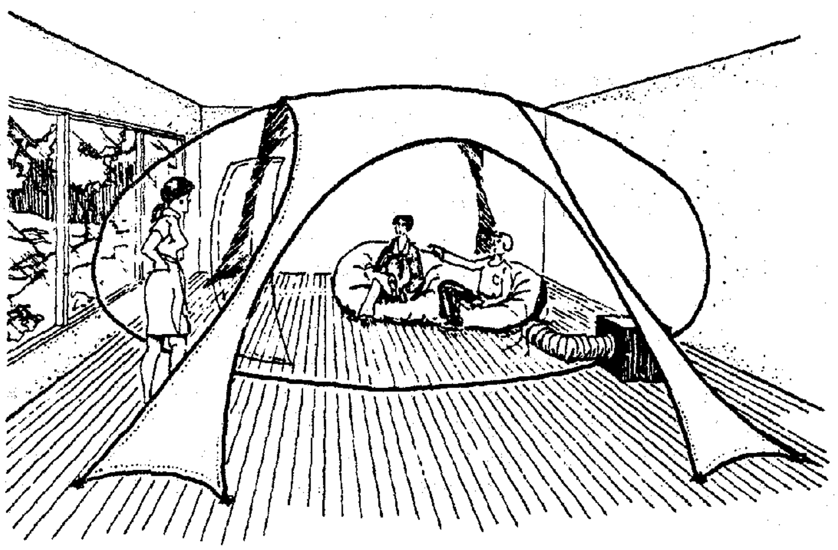


Figure 2: Transparent and Portable TOCS with its own thermal Environment.

and 106 degree F outside. The system also proved significantly less expensive to install and operate than its alternative (Figure 1).

The following types of task-oriented comfort designs are suggested as a beginning:

-- FLOOR OR CEILING PLUG-INS: This design strategy is a self-contained unit designed to provide thermal, humidity, lighting, and fresh-air quality levels. Such systems are envisioned to plug into a supply network within the building not unlike a telephone.

-- PORTABLE PLUG-INS: This type of unit is small in scale, highly portable, and capable of being moved about not unlike a floor lamp or file cabinet. It too would plug into a distribution network.

-- FURNITURE INTEGRATED SYSTEMS: a task-oriented comfort system may be an integral part of a work-station, desk or chair while its performance is controlled by the occupant. Free-standing partitions, beds, sofas, benches, and assembly lines would have built-in comfort capacity (Figure 2).

-- GARMENT INTEGRATED SYSTEMS: This type of people-oriented comfort system is an integral part of clothing, similar to special uniforms worn by some workers or athletes.

Building types such as: office buildings, manufacturing facilities, hotels/motels, residences, hospitals, restaurants, schools, and places of assembly where people are stationary for some beneficial amount of time are candidates for utilizing TOCS'.

a. Potential Impact due to TOCS.

Perhaps the most significant impacts of TOCS are worker productivity, improving the sensory qualities for building occupants, reducing occupant complaints related to work and living conditions, and of course energy savings.

The energy saving potentials are difficult to predict since actual TOCS performance and efficiency data does not exist. However, if we compare a standard ten story office building (100,000 square foot) located in New York City, operated in a conventional manner, to an identical building and occupancy, where the general building volume temperatures are allowed to float between 55 and 90 degree F; task lighting and TOCS are used and a general illumination level of 10 fc is maintained; energy consumption is reduced by 40%. Although this saving does not reflect the energy needed by the TOCS, a conservative estimate suggests that, with the use of TOCS, the energy demand of such an office building could be reduced by 10 to 20 percent.

The nature of building design and building subsystems would change significantly. Building volumes could be reduced as well as the high cost of mechanical systems.

Buildings themselves would be less costly in terms of initial construction costs due to improved net to gross volume ratios made possible by reductions in mechanical equipment, ducts, and interstitial spaces. Assuming that building occupants can now depreciate TOCS's, as they do furnishings, additional economic benefits are possible. New product and service markets are created supporting increased employment and the general economy.

Since buildings themselves do not have to provide total and complete comfort, lighter weight buildings, less expensive enclosures, and greater interior flexibility could offer new architectural design opportunities at improved material efficiencies.

The use of TOCS will also have an impact on: utilities, load management, and electrical demand? Institutions concerned with standards, product safety, health, and human welfare will need to explore their roles vis-a-vis TOCS prototypes.

b. Research Needed to Establish Proof-of-Concept or Feasibility.

TOCS Prototype Development needs to occur which explores both the feasibilty and energy savings potential of TOCS's. Such an effort needs to explore the impact of various TOCS on support systems and energy supply networks.

Technology Transfer investigations are critical since non-building industries already are involved in small individual-based technology developments. Industries which produce small-scale comfort technologies for airplanes, motorhomes, hospitals, trucks and trains, as well as speciality clothing manufacturers (for NASA, military, sports, and recreation) may have relevant information and products related to the development of TOCS.

Health and Comfort standards, as related to buildings with heterogenous thermal environments, need to be re-examined. Comfort standards need to be developed for the TOCS themselves. What happens when a person working "under" a TOCS leaves the work space and moves about in a building area which is maintained at different temperature levels? What are the appropriate temperature levels for the general building volume? What is the impact on a person's physiology if the person moves from TOCS through a different temperature zone? These questions require new research in the area of physiology.

Responsibilities for providing comfort within buildings need to be redefined. Should the building come equipped with TOCS? Does the employer provide and maintain TOCS? or, should the employee provide the TOCS? These are some of the design and legal questions which need to be researched.

Standards related to TOCS comfort designs, building quality levels, energy conservation codes, building energy efficiency standards, and new safety standards need to be developed. It is conceivable that building energy consumption standards may be based on occupancy and activity patterns as opposed to generic building type.

Impact on Building Systems, What will the impact be on building materials and equipment if we assume that building volumes are now maintained at different temperature and humidity levels then previously? If we assume that TOCS essentially represent sources of energy supply. how will this free energy be stored, and where, within a building?

Another area of important research is human factor analysis focusing on how people will react to the flexibility of TOCS and the inflexibility of non-TOCS building types.

2. Dynamic Buildings and Building Components

Current building forms are almost totally static objects. The few features which have been designed to respond to climate and human activities are: operable windows and skylights, doors, drapes, and venetian blinds, ivy growing on the wall, moveable partitions, and some forms of moveable walls.

The forces of nature and human needs create dynamic conditions for buildings. Natural forces (sun, wind, precipitation, light, moisture, odor, and sounds) are constantly changing - e.g. dynamic. Some of these forces are assets and/or liabilities, some forces are predictable, others are not. Similarly, human needs and conditions are also difficult to predict for any reasonable length of time. Our modern-day life styles, activity patterns, value shifts, building turn-over, occupancy changes, and building content shifts, suggest an increasing need for highly adaptive buildings. It is not uncommon to find that a building's interior is changed before its construction is completed. Many office spaces are completely gutted and reconfigured every 3-5 years. These dynamic phenomena are the principal determinants of energy consumption patterns within buildings.

It is hypothesized that buildings which are highly responsive to dynamic conditions will not only be light in weight, require less material resources, be more responsive to human environmental needs, they will also save significant amounts of energy through a procedure of programmed optimization.

Biological forms and structures exhibit a great deal of dynamic behaviour in response to need and climate. Color, texture, size, configuration, moisture content, and form change in response to nature. Animals migrate, change their appearance, and hibernate. People select and change their clothing depending on weather, mood, and activity. Human physiology has a dynamic response system (sweating, increased/decreased blood circulation near the skin, eyelids, and vibrating muscles).

Dynamic buildings and/or building components are built-forms which have the capacity to anticipate and respond to changes in nature and human occupancy. 2 It is important to recognize that dynamic buildings are not just instruments to gain improved energy efficiencies, they can also improve the qualitative aspects within the built-environment. A dynamic building is envisioned to produce a more harmonious and responsive

----

2 Sometimes the term "smart buildings" or "smart walls" is used to imply dynamic.

environment filled with delight, and enlightenment.

Dynamic buildings and building components are not a new idea. The Pittsburgh stadium (a domed building) can move an entire building facade out of the way and the Hooker Chemical building, in Buffalo, NY, has a double skin with moveable fins for lighting and insulation control which are adjustable according to what nature dictates.

There are many design concepts for dynamic buildings and building components at different building scales and applications. They can be organized into three types:

-- DYNAMIC INTERIORS, provide the ability to modify the spatial volume, its configuration, and degree of enclosure or openness. For example, dynamic elements would allow one to increase the floor to ceiling height in the summer and decrease it in the winter, or to change the location of interior spaces according to seasonal changes. Ceiling, floor and wall surfaces could have the ability to change color, absorption, reflectance, and emissivity in response to changes in light and thermal requirements. Interior surfaces could become "hot" or "cool" depending on sensory needs.

-- DYNAMIC BUILDING ENCLOSURES, could include roof and wall elements which have the ability to change their physical characteristics and properties. The enclosure could change color, absorption, conductivity, reflectivity, emissivity, light transmission, air movement through the envelope, and visibility, according to internal needs or exterior conditions. Dynamic devices would provide shading, light reflection, or track solar radiation for energy collection or optical lightwave transport. Linked to a weather forecasting system, the building could modify its exposure and sensitivity accordingly. Controls could use micro-processors for automatic adjustment, with manual overrides for greater occupant control.

-- DYNAMIC BUILDINGS, could change their overall form, orientation, configuration, or degree of exposure. A building could have spaces which extend outward from a fixed building core and are collapsed when not in use (Figure 3). Alternatively, modules of space can be added to or taken away from a basic building core as required. Old spaces are traded in, as "used rooms", while new rooms are plugged in. A dynamic building also might track external forces and react accordingly. A building could rotate and adjust its surface characteristics to avoid the wind, catch the sun, provide a particular view, or catch a cooling breeze (Figure 4 & 5). Similarly, the building could raise/lower itself in or out of the ground or water to control its degree of exposure.

According to preliminary studies, size and scale do not appear to be a problem for dynamic buildings. The ease and simplicity of designing and utilizing dynamic structure depends on whether we continue to build on land. Floating structures provide a simple way of having a building rotate, or submerge itself, and could also avail themselves of the thermal and energy potential from the surrounding water environment.

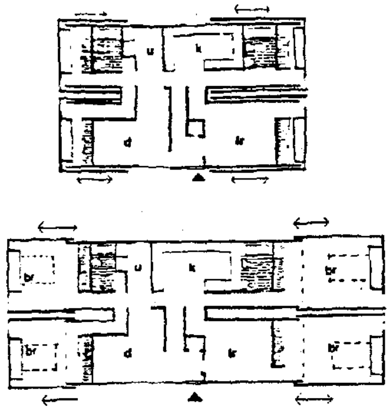


Figure 3: An Expanding and Contracting house. Beds fold up into wall and the entire room telescopes toward the core.

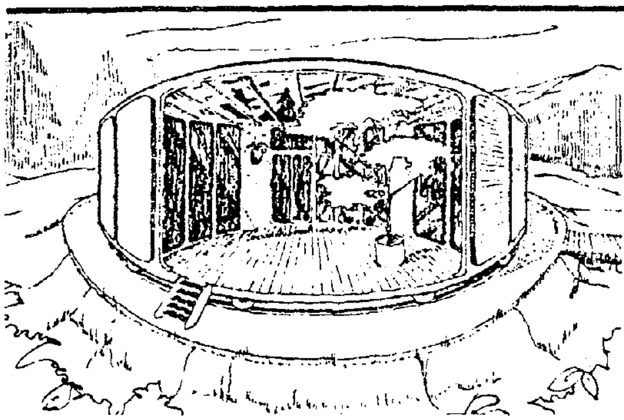


Figure 4: A Rotating Structure guided on tracks; with a variety of wall surfaces.

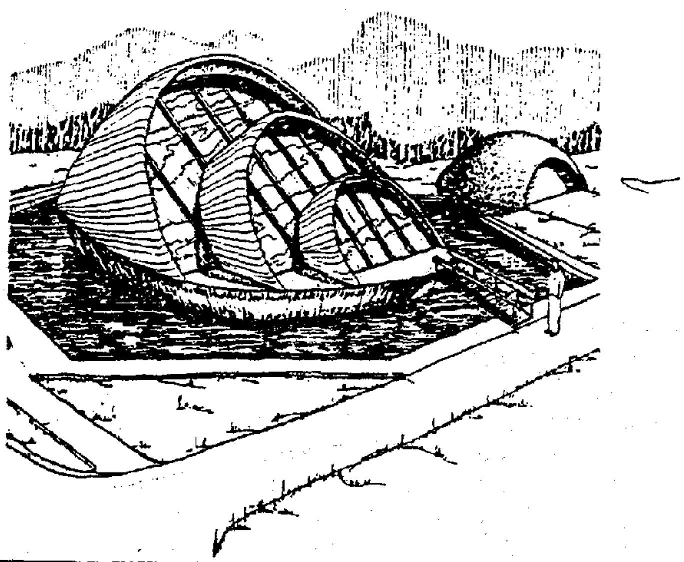


Figure 5: A Floating Structure, designed as a Passive Solar Residence.

Depending on the what type of comfort technology is used, it is conceivable that interstitial enclosures themselves could be transformed into occupied space if we used TOCS systems as previously described. The places and spaces created by the interstitial enclosure could become part of the public space or remain the private domain of the building owner.

-- INTERSTITIAL ENCLOSURES AD INFRASTRUCTURES. Interstices can also be envisioned as enclosing groups of buildings -- buildings within a "building". A large enclosure, designed to serve as protector and modulator of natural forces for all of the buildings within, would function as an infrastructure. In that sense it is similar to our streets, sidewalks, parks, sewer and water lines, and electric and communication distribution systems serving groups of buildings. Such interstices have the capacity to collect, store, and control flows of energy, air, and moisture for an entire community.

This concept would reduce the performance expectations and design requirements for the individual buildings within the enclosure. Buildings themselves, depending on their physical properties, could function as thermal storage devices. The buildings within the enclosure could now be light-weight structures with much more simplified construction detailing. Cities could be responsible for providing such interstitial enclosures as infrastructures, and the energy consumption of individual buildings would be reduced through the creation of tempered zones.

-- INTERSTITIAL ENCLOSURES AS A RETROFIT STRATEGY. Retrofitting building enclosures is a complex and expensive proposition, even if it is done for energy conservation alone. The large-scale interstice concept, however, offers some interesting possibilities. By designing structures and enclosures spanning between buildings, and covering streets, we can create a new retrofit strategy. Such a strategy would also change the nature of the existing public spaces. Streets become malls, outdoor spaces become semi-conditioned environments, tempered and conditioned by nature (without using non-renewable forms of energy) to extend their use in inclement weather. City street and ground maintenance is reduced, and the buildings themselves are thermal storage elements. Existing building renovation is simplified since keeping the rain and cold out is no longer an expensive proposition.

The interstitial enclosure concept, as described, is not limited to a particular building type. It is applicable to buildings, communities, neighborhoods, and cities. It is a concept potentially useful for new and existing buildings and communities.

c. Assessment of Energy and Non-Energy Impacts.

At the present time it is difficult to determine what the energy saving potential of interstices is. We know that interstitial enclosures for individual buildings can reduce their energy consumption anywhere from sixty to 90 percent in a cost-effective way. Large-scale interstices no doubt will save large amounts of energy but they need to be analyzed in terms of their cost effectiveness, and savings which accrue to the community in maintenance and repair. Cities, or portions of a city, could be envisioned as energy consumers and producers which would change the economic impact significantly.

d. Research Needed to Establish Proof-of-Concept or Feasibility.

-- The research and design effort would have to focus on investigating current large-scale spaces (atriums, long-span space frame structures, fabric structures, etc.) and their cost and energy data. Prototype designs would have to be developed to the point where their energy characteristics could be modeled. Economic analysis is required which can address the complex interplay between initial cost, life-cycle cost, and improved living/working qualities, productivity, and the inherent advantages of operating and maintaining a community.

-- In addition, research in innovative structural systems, light-weight materials, methods of handling fire-safety and pollution control are just a few of the related research areas. The research effort needs the participation of urban designers, economists, architects, engineers, social scientists, ecologists, and artist.

CONCLUSION

It is suggested that much remains to be done to realize additional energy savings and improvements in energy efficiency for buildings. As related to the near-term research needs, there will come a point where the research investment will produce diminishing results, in terms of energy, unless we are willing to re-think our approach to design, building, and the use of buildings. The long-term research needs, based on different concepts about buildings may allow us to realize energy savings far beyond what is now thought of as reachable. In addition, it is suggested that we can significantly improve the ways and means by which our built-environments are responsive to human needs, be it sensory comfort or economics. To realize these benefits it would be appropriate to begin the long-term research effort now, since a long lead time is indicated, but also to be prepared with alternatives if and when we need them.

II.2

Energy in Buildings:
Trends in New and Retrofit Non-Residential Strategies*

Robert G. Shibley
Professor and Chairman
Department of Architecture
School of Architecture and Environmental Design
State University of New York at Buffalo
Buffalo, New York 14214

INTRODUCTION

In 1982, the major financial press in the US, The Wall Street Journal and Business Week, as well as the popular professional press, Progressive Architecture, AIA Journal, Building Design and Construction, and Architectural Record, reported on the results of an analysis of the design and performance trends of award winning energy conscious (non-residential) buildings ("Design Performance Trends for Energy Efficient Commercial Buildings", 1982). The research team, composed of the author, an architect, an engineer, and an economist, was charged by the U.S. Department of Energy (DOE) to derive general trends in energy conscious design from an assessment of sixty-five exemplary building designs developed from 1971 and 1982. All the projects in the sample were judged to be state-of-the-art in energy consciousness by a peer review process. Fifteen of the buildings in the sample were under design after 1979. The remaining fifty were designed in an even distribition over the eight previous years. The building sample was drawn from the prestigious Owens Corning Fiberglas (OCF) Energy Conscious Design Awards Program (note 1).

---

*Portions of this Draft are extracted from an unpublished U.S. Department of Energy Report, "Design and Performance Trends in Energy Efficient Commercial Buildings", developed by Robert Shibley, Kim Hart, John Kurtz and David Hartman in 1983. Other portions are drawn from an article by Shibley in the unpublished proceedings of the Building Research Workshop, Reading, UK, August 1982.

Obviously DOE and the research team were pleased by the success story represented by the data and celebrated in the media. The examination of types of energy conscious design strategies employed, and their cost/performance, clearly showed that from 1971 to 1982 the professions designed new buildings which consumed about half of the energy of buildings constructed the previous decade, and that they did so without major added construction cost. It was as if to say, "the professions have arrived--they can now build new buildings which consume far less energy at minimal to no cost premiums."

In retrospect, the celebration may have been premature and perhaps dangerous. The research, and subsequent press reports, did not bring to the attention of the public and professionals the fact that the existing building stock accounts for well over half of the building inventory we will be living with in the year 2000. Much of it was built prior to 1972. The energy conscious retrofit was clearly not celebrated or even identified as worthy of celebration.

The strategies to employ in building retrofits have not been carefully researched, and approaches to such research are meager compared to the availibity of information regarding the easier problem of designing new buildings. Significant renovation projects were invited every year of the eleven year life of the awards competition, but only two of the sixty-five buildings given awards were retrofit projects. Both of these renovations were of historic structures. While some "ordinary" facilities, improved with "excellent" retrofit solutions to both energy and program requirements were submitted, they were not judged "significant" by the award committees.

Implicit in this history is a major challenge to both design professionals and researchers in the decade of the 1980s - the development of effective strategies for the energy and programatic retrofit of the existing building stock.

One could conclude that the trend analysis suggests that most of the so-called "interesting" work appears to be almost done. A closer examination, however shows that there is much more work to be done related to both new buildings and retrofits.

Before describing the nature of the challenge of the 1980s, it is important to review the successes of the last 15 years. There is an increasing number of cost effective design strategies available to designers. The introduction and gradual acceptance of these strategies have had clear implications for design, construction and operation performance. The strategies and their performance implications, have led design professionals and researchers alike to forecast design trends for the next decade along with trends in building performance and operation. These forcasts also include predictions about the modification of the design process.

SUMMARY: "DESIGN PERFORMANCE TRENDS FOR ENERGY EFFICIENT COMMERCIAL BUILDINGS"

The Department of Energy report used a sample of sixty-five projects -- all the buildings which had received awards from the Owens Corning Fibreglass Program for 1972-82. Over twenty building types were represented; sixty percent of the projects exceeded 100,000SF; and projects were evenly split between government and private sector ownership. There was a wide geographic distribution within the US.

In the early years of the OCF awards program (1972-75), engineering solutions with strong HVAC and conservation emphasis were well represented. From 1976 through 1978, active solar was very popular with the juries and there was much experimentation with a wider variety of strategies. Between 1978 and 1982 passive daylighting and cooling became much more popular and there was a clear emphasis in jury commentary about the quality of design integration.

The results of the report were organized around three general topics: (1) Trends in Energy Conscious Design; (2) Trends in Performance: Design, Construction and Operation; and (3) Speculation on Future Trends.

Trends in Energy Conscious Design

Trends in design were examined by assessing which design strategies were employed in the sample and by when they received awards.

1. "The most commonly used energy strategies involved modification of the building envelope and improving the HVAC system."

2. "Active Solar has been commonly used in this (OFC) building sample but shows a relative decline in recent years."

3. "Passive Solar, particularly the use of daylighting, has increased in popularity."

4. "A number of strategies were intermittently reported and indicated no definitive trends."

5. "Overall there appears to be some shift from mechanical system emphasis to more integrated, architectural solutions." (DOE, 1982)

A further observation is that the overall number of strategies employed in any given building tends to have increased in recent years. There are more stategies to draw from and, incrementally, more of them are being employed interdependently in integrated architectural solutions.

The categories of strategies used to analyze the projects included siting/berming, envelope, HVAC, lighting, controls, active solar, passive solar heat, natural cooling, daylighting, and central plant/process. Each strategy was further subdivided into tactics illustrated in figure 1.

Trends in Performance: Design, Construction and Operation

The trends reported in the analysis have performance implications related to the design process, construction costs and building operation. In general, design requires more specialized labor at an increased cost. Construction occurs with a modest (if any) cost premium, and operational "fine tuning" determines long term success and failure.

Design Performance was perhaps the most difficult to judge. It seems clear that both the amount of overall time and specialized labor time required to create an energy conscious design is greater than that which is required to do conventional architecture. Data were not available from the OCF sample to suggest this, but incremental design costs were reimbursed in another research effort called the DOE Passive Solar Commercial Building Program (see note 2). The data from that program offers support for this premise.

Architects of both the DOE Passive Solar Commercial Building Program and the OCF program winners suggest that increased attention to predesign and early schematic design activity will yield improved results in terms of potential energy savings. One implication of increased attention to predesign involves developing better predesign tools. Another is to give predesign activities more attention in professional schools and in continuing professional education programs. Such increased attention is offered through DOE curriculum packages in the US (ACSA, 1981) as well as through the American Institute of Architects, Design and Energy Program (AIA, 1981).

The construction analysis portion of the DOE report focused on new office buildings which are well represented in the OCF awards program and in the ongoing DOE experimental building programs. The analysis was based on data reported in the entry submissions, interviews with owners and managers of completed projects and comparisons with conventional existing buildings.

Categories of Energy Conservation and
Solar Energy Design Strategies

General Strategies	Specific Energy Features
. Siting/Berming	Orientation, siting, landscaping Berming, earth contact
. Envelope	Multiple glazing Extra insulation Infiltration control Shading, reflective glass
. HVAC	Heat recovery, air to air heat exchangers Heat pumps Variable air volume distribution Thermal storage
. Lighting	Task lighting High performance lighting
. Controls	All types including time clocks, enthalpy, energy management systems, facility automation systems
. Active Solar	Space heating and/or cooling Domestic water heating
. Passive Solar Heating	Direct gain (walls or floors) Trombe walls
. Natural Coolings	Natural ventilation Night flushing Evaporation, radiation or dehumidification
. Daylighting	Window strategies (extra glass, placement) Light shelves Clerestories, roof monitors, skylights Atriums, sunspaces
. Central Plants/Process	Multi-building utility plants, cogeneration, industrial process heat

figure 1

The building owners and managers contacted offered actual utility consumption records and initial (as built) costs. The comparisons with conventional existing buildings were based on data provided by the Building Owners and Managers Association International, for offices, and by the American Association of School Administrators, for schools. Both institutions reported data collected in recent membership surveys.

Office building projects analyzed show substantial improvements in new building energy use with site energy consumption approaching 30,000 BTU/SF/yr. Schools show similar improvement, with site energy consumption for recent winners predicted at 45,000 BTU/SF/yr. Most projects are reporting these improvements with a modest five percent to ten percent initial cost premium, and some report no cost premium at all.

Operating performance reported by early award winners suggested that in larger, commercial, structures there is a long period of trial-and-error fine tuning required to get the building to maximum performance. In each of two cases examined in depth, the annual energy consumption (normalized for changing loads) showed ten to twenty percent reduction in consumption in each of their first four years of operation.

Future Trends

What has been derived from the real experience to date, in particular from the OCF analysis, led the DOE research team to speculate on what will happen next - on where the next ten years might lead. This speculation is reduced below in terms of the trends in design, trends in building performance and operation and changes in the design process (note 3).

Trends in design, based on real building exerience to date, suggest we can expect:

1. the institutionalization of proven conservation techniques. The tight, well-insulated envelope, high efficiency HVAC, low wattage lighting, and energy management control systems that received awards from 1971 to 1975, are now becoming commonplace.

2. increased sensitivity to climate and solar geometry. Daylighting is a feature in most recent award winners, although it is not a common component of current architectural practice. Solar heat gain control strategies and the selective use of passive solar space heating and natural cooling are also on the rise.

3. increased sophistication in HVAC and lighting integration. Heat recovery/thermal storage systems and cogeneration will become more common.

The context within which these trends evolve and their impact on overall building design should not be a surprise, but should rather be part of the proactive decision to accept or resist such evolving methods of practice. That proactive decision should be informed by research.

Trends in building performance and operation, again rooted in the OCF and DOE experiences, suggest we can expect to see:

1. a greater use of new building energy performance specifications, allowing more design freedom while providing owners with predictable energy costs.

2. an increased emphasis on achieving energy efficiency at little or no extra construction cost -- but likely at higher architectural and engineering design costs.

3. an increased utilization of energy service and utility company shared saving plans which will help defray extra capital costs and will strengthen motivation to maintain energy efficient operations.

Finally, changes in the design process, which we could infer from the real building experience to date, indicate:

1. there may be stronger owner involvement early in design development, establishing energy efficiency as a key objective.

2. there may be greater pressure on the architectural/engineering professions to do more analysis of multiple design options. There do not appear to be cookbook solutions, and there are significant opportunities for both long term performance and initial cost improvement.

3. there will be an increasing use of computerized models to project energy use and evaluate financial impacts.

THE CHALLENGE OF THE '80's

It is clear from this review that much has been accomplished in energy conscious design for new construction yet there is still much to do. The potential for improved efficiency and better quality is greater than ever due to the evolution of computer applications and due especially to computer aided design systems which are enabling the reorganization of the process by which places are made, managed and maintained. What we have to know as individuals is changing dramatically with the introduction of smart communications lines which network data, experts and images simultaneously. Where CAD was once the province of only large firms--the smart line and other forms of networking and service delivery will soon market to very small firms. This may lead to a "cottage industry" autonomy with a large intellectual and skill base. What one knows many can know. What one is able to do many will be able to do.

Commensurate with the potential for still greater improvements in both new and retrofit construction is the need for such improvements. Ian McHarg has suggested that "man is a planetary disease." Since 1800, the average life span of individuals has tripled. There are more and more people in the world with higher expectations. In 1800 the world had a total population of 1 billion people. By 1935 there were 2 billion people; by 1975 we had 4 billion people, by 2000 we project 6 billion people, and by 2025 over 8 billion people will inhabit the planet. A large segment of this growth is concentrated on urban areas. Deli will grow from 11 to 30 million people by the year 2025. Jakarta will move from 8 to 30 million. Mexico City will continue to grow from 18 to 30 million. It is clear that this "disease" requires energy to grow.

4% of the world's population now consumes 40% of its resources. As expectations for a better standard of living rise, world energy resources will not be able to keep up without significant new initiatives on all fronts.

These short range population projections accompanied by higher and higher expectations of a good standard of living all suggest the real energy crisis has not yet occurred.

The need for continued emphasis on energy conservation in both new and retrofit construction , is not immediately obvious and is certainly not as glamourous as the earlier preliminary work. The past decade of international attention and accomplishment have led some to perceive there is little else of significance to be done.

The current situation in US based energy research related to buildings can be likened to the situation in physics at the turn of the 19th century. John Trowbridge, Chairman of the Physics Department at the Massachusetts Institute of Technology at that time was advising his students to get out of physics because "there is little else of use to study." He saw physics as confirming, with increasing levels of accuracy, the dominate theories in the field. He did not see such confirmation as delightful work. Radical advances in Physics have proven his advice, at best, poorly timed. The residual effects of continued study in physics have led to all manner of new insight into the nature of the universe.

Like the physicists of the late 1800s and early 1900s, those interested in energy conservation are not done. To begin, we need a clearer understanding of the outside forces which help put measurements in the context of all that is part of building. We also need to be more accurate in assessing these forces. Regarding commercial buildings and retrofit technology in particular, the search for knowledge on the significant variables in the field of all variables continues.

1. What is the nature of the populations to be served by new and retrofit buildings? How will changes in information technology, communications, political economies and the nature of work itself influence the fundamental relationship between people and the places they inhabit? With ever more rapid changes will come greater and greater demands on the ability of the building stock to accommodate.

2. How will the improved understanding of energy consumption in buildings, and especially in retrofit buildings, further enable the building stock to adjust to new demands placed on it by new technology and a changing pattern of work?

3. How will the introduction of new communications technology, integrated with low cost computer aided design technology, influence the structure of the design professions? The nature of the professions is changing rapidly and such changes will clearly influence design performance.

CONCLUSION

Energy in buildings, particularly in existing buildings, will remain a significant topic of research. We need knowledge in the design and planning professions to accomodate the projected demand for energy in the world. It will remain a topic of concern because of the central position of energy in the affairs of the world -- energy is a metaphorical conduit which links interconnects all things. Finally, the tiopic of energy in buildings will remain on the agenda of the research community because it represents a specific and significant acknowledgement that every act of building is a public act with broad public consequences.

NOTES

1. An initial analysis of the Owens-Corning Fiberglass Design Awards Program was performed by the author and a team of architects and engineers from the Booz-Allen & Hamilton, Inc. in Washington D.C. This analysis was presented to DOE in a report entitled "Design and Performance Trends for Energy Efficient Buildings" in March 1982. Key individuals other than the author who participated in the analysis were from Booz-Allen & Hamilton and included John Kurtz, Kimball Hart and David Hartman, project manager. Eric Hjerberg, Mark Moskovitz, and Kirk Renaud assisted in data gathering and analysis. Portions of this paper are pulled directly from this unpublished DOE report. The author was a member of the OCF jury in 1981 and was chairman of the 1982 jury.

2. The DOE Passive and Hybrid Experimental Buildings Program was part of a larger program designed to advance passive solar design and illustrate its relevance to non-residential structures. The author was the director of that program in Washington in 1980-82. During that time, Ted Kurkowski was the Senior Program manager for the experimental buildings program assisted by a large support team including Harry Gordon and Bill Fisher from the Burt, Hill, Kosar, Rittleman, Associates Washington Office, as well as Kim Hart and William Whiddon, then of Booz-Allen & Hamilton, Inc.

3. These projections were developed by the author and Davi Hartman of Booz-Allen & Hamilton, Inc. for presentation to the Building Owners & Managers Association International Annual Convention in Washington, D.C. on June 23, 1982.

BIBLIOGRAPHY

American Institue of Architects (AIA) (1981). Energy in Design: Techniques, AIA, Washington, D.C.

Association of Collegiate Schools of Architecture (ACSA) (1981). Passive Solar Curriculum, ACSA, Washington, D.C.

U.S. Department of Energy (U.S. DOE) (1982). Design and Performance Trends for Energy Efficient Commercial Buildings, U.S. DOE, Washington, D.C. (unpublished report with Booz-Allen & Hamilton, Inc., Washington, D.C.

II.3 ENERGY EFFICIENCY OF FLOWS INVOLVED IN THE ERECTION AND SERVICE OF BUILDINGS

Gheorghe Polizu x)

The last decades have been characterized by the evolution of design concepts. They are now focused on building service and aesthetics, and in particular on the efficiency of a building's service, rather than stability resistance, and durability, as was previously the case.

In addition, the performance and service of each individual building can be important. In this category, we can list construction time, materials, and equipment, as well as some construction solutions, which can cut down on maintenance and repair through durability or create some special environment such as the "white rooms" used in the electronics industry.

At present, building performance has much in common all over the world. The reason is because of a progressive process in highly inertial and, at the same time, traditional system.

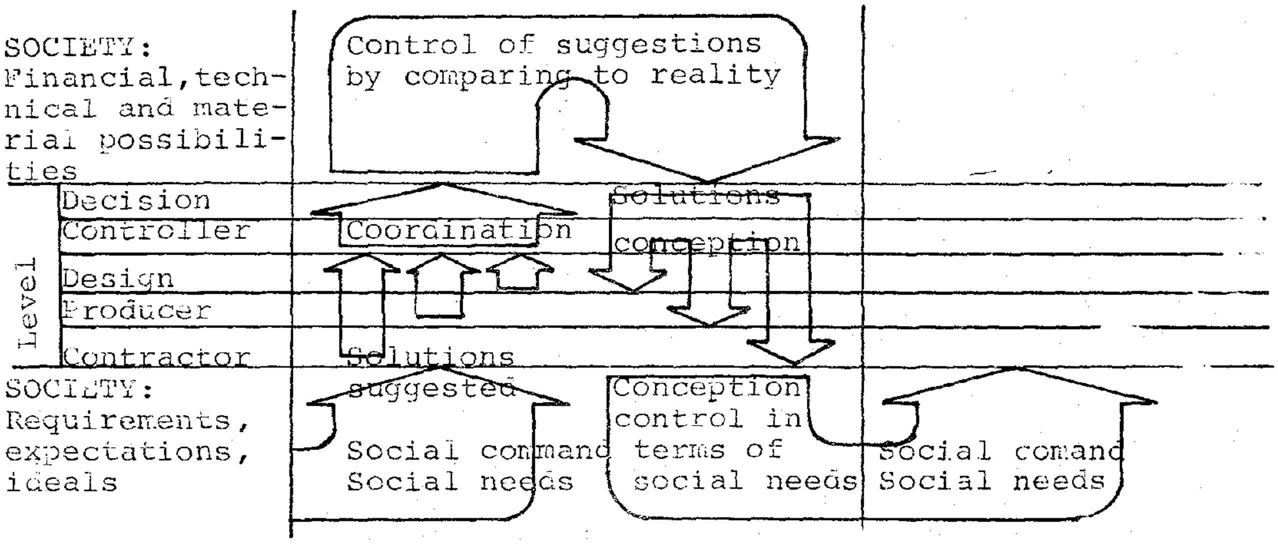


FIGURE 1.

x) Dr.Arch. Director - The Central Institute for Research, Design and Guidance in Building - ICCPDC, Bucharest, Romania

The way in which we build arises from the conception of solving the social necessities occurring at one time, and it is determined to a certain degree by the scientific, technical and material possibilities of the period, as is presented in fig.1. The decisive element acting on the system is INFORMATION, involved at different levels, both in the assembly of resources and in the quantification of the product, as far as performance is concerned.

The way in which we build; what materials, elements, and equipment we produce; what suitable technologies we use are all based on different decisions involving known information and the way in which one decision affects another. The synergistic effect is not easily achieved because of the complexity and the interdisciplinary nature of construction activity. The distortions intrinsic in the system and its information can lead to contradictory decisions, counterproductive to the general aim and objectives of the construction.

The second main element, connected with the information system, is the GENERAL VISION, INTEGRITY OF INFORMATION. In the final analysis, society is not interested in obtaining incomplete information about the efficiently of any one of the parts of the system, but in improving the building concept, performance, and its service as a whole. A general evaluation and survey cannot be useful unless the aim of the building is considered. This aim is related to the specific features of geography, namely climate ; to the fundamental objectives; to the stage of development; to the evolution of the physical basis; and to the requirements of the project, for each of the building objectives. All these must be continuously and dialectically consistent with a basis for comparison, which is also changing and relates to the possibilities of generally reaching the objectives.

The dynamic optimization of all the factors involved in the building activity implies considering that the aim of this activity is solving the social requirements efficiently, that is,performing the necessary building with a minimum social effort and achieving its service for the needed period of years.

We consider that this intervention is not useless, notwithstanding the fact that in many cases the social requirements and the the aims of the building activity are still confused with optimizing the stage of construction and its particular details (activities of builder, manufacturer, amounts of materials). For example, cheap building is sometimes emphasized, taking into account initial costs and initial consumption of resources, including energy, without knowing the implications in time of this initial economy. This initial saving can be rapidly eroded, mainly from the point of view of energy. In the same way, in other situations, the manufacturers of some materials or building units emphasize the economic consumption of resources, without considering the long-term repercussions, during the lifetime of the construction. Unfortunately, in many cases, the final result is different from the expected one. In this way, society loses, even if initially the results, considered in a limited manner, are seen to be remarkable.

Some additional explanations are necessary as introductions to this paper.

The first point is that any building has its own lifetime, which includes the service period, recycling and modernization, and finishes with demolition and recycling in nature. Within all these periods, the building involves consumption of resources, governed by design, except in some specific cases. It must be emphasized that, generally, we cannot assume an interdependence between the initial building resources and those necessary during the lifetime of the project. Reduced consumption of resources during the lifetime does necessarily mean increased resources for construction, but only a judicious concern based on overall optimization.

The second point is that the design concept - systems and utilized resources - cannot be the same irrespective of the construction problem. An exhibition pavilion will be built differently from a dwelling or a building used in the electronics industry.

The third point is that, as with other economic activities that have mass requirements, permanent construction programs of a mass-produced nature demand standardization and modular coordination of the physical component elements, equipment, tools, and devices during some stage of the building activity development.

Finally, the requirements of each project, the specific conditions of the site, or the geographical location can and must influence affect the design concept and the construction solution.

So in the case of large sites placed in the industrialized countries, it is more than likely that industrialized constructive solutions are used. These solutions use serial products of large gauge, which justify the utilization of special equipment for transport and on sites. In the case of small sites in the same conditions, the industrialization is limited to the utilization of light prefabs, of cast-in-place concrete industrializing processes, etc, avoiding the constructive solutions which would require use of expensive equipment.

So we cannot speak in principle about a series of modalities with the same technological age which has to be in accordance with the concrete construction programs permanently.

This implies that prior to the actual performing of a building there should exist materials, elements and equipment production with which the respective building will be performed. In fact,this is the case, and according to the evolution in the general technological program the endowment specific to building industry increases.

In general, the consumption of resources and manpower in a particular situation is reduced as the level of technology increases. But resources and manpower are also necessary during the lifetime of the building, which has to be considered from the beginning of erection to its final demise. In order to exemplify this aspect, Table 1 pressents the necessary manpower for the erection, maintenance, and repairs of a dwelling, using different building systems. But, related to this problem, it must be underlined that as manpower is reduced, the system flexibility is also reduced because of serial production limits.

The manpower consumption for the erection and service of a dwelling realized with different structural systems

TABLE 1

Percentage

Structural system	Consumption in factories of technological equipment	Consumption for the dwelling erection			Consumption during the service of the dwelling
		Consumption in the materials factory	Consumption on the site	TOTAL	
0	1	2	3	4	5
Masonry bearing walls with monolith floor slabs	2.8-4.2	10.2-14.3	81.5-89.0	100.0	25.0-35.0
Monolithical reinforced concrete frames with masonry infill	3.5-4.7	12.4-15.7	68.8-72.8	84.7-93.2	25.0-35.0
Entirely precast	4.2-4.7	22.8-25.6	46.7-52.5	73.7-82.8	15.0-18.0

0	1	2	3	4	5
Assembled light weight autoclaved concrete elements	3.8-4.2	17.8-20.0	37.3-41.8	58.5-66.0	18.0-39.0
Reinforced concrete box units	5.6-6.4	32.3-33.3	14.5-16.3	52.4-56.0	18.0-30.0
Plastic box units on steel scke-leton	2.8-3.2	15.5-17.4	9.7-10.8	28.0-31.4	. . . . .
Open pre-fabrication with light-weight par-tition walls	4.4-4.9	24.5-27.5	15.2-17.1	44.1-49.5	. . . . .

Considering the flows used for building erection and service we must mention from the very beginning that, at present the spe-cialists, concerns have been limited only to erection.

At present, the service flows and the way in which the erec-tion activity influences in time the building behaviour a e not systematically taken into account.

Concerning the erection flows due to the conditions speci-fic to different countries, to the volumes of workings, to the dif ferent programs and to the building technologies specifications,we can find at present an infinity of realization flows. As we can-not approach all these ones we are to discuss only three of them, more specifically.

The first is the SIMPLE FLOW characterized by the fact that the building acquires shape on site by special manual and handi-craft placing of some products (materials and elements) which are industrially manufactured, mainly in building material industry , or in-situ erected on site. So, the erected building, in the course of its operation period will go through different service cycles during which it will be modified, adapted and modernized(especial-ly the industrial buildings but also other categories). Some ma-terials and equipments will be replaced by others, using the same technological flow or others (see Fig.2)
EVOLUATED SIMPLE FLOW presented in Fig.3.

This flow is to a very large extent similar to the simple-flow which was completed with a new element generated by the de-

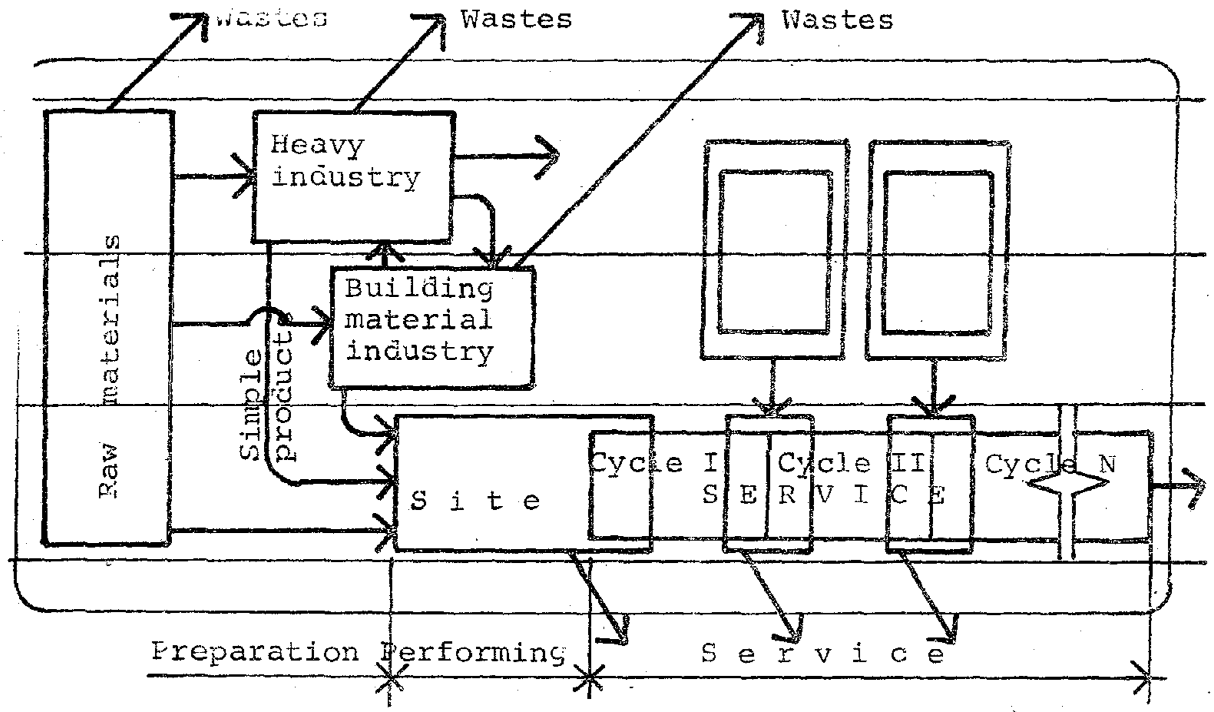


FIGURE 2

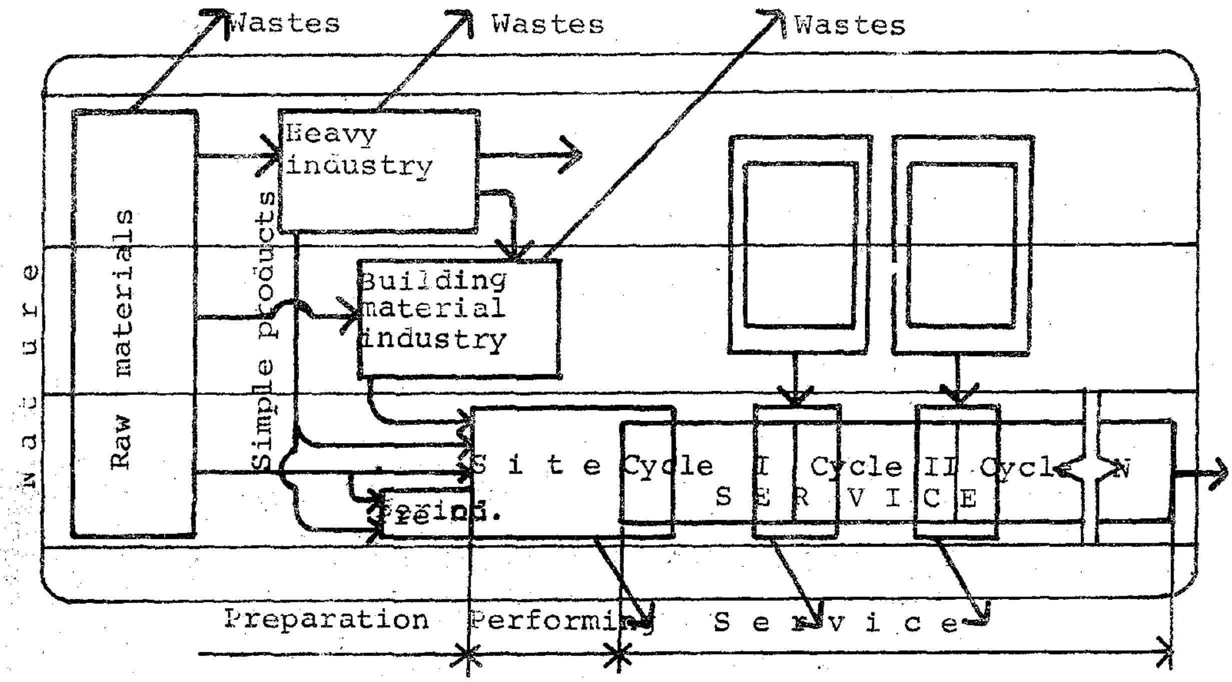


FIGURE 3

velopment process: a specialized unit for work preindustrialization resulting from the constructor's initiative with a view to simplify site work. Within this unit--production base--reinforcements are cut and bent, casing panels and small precast units are performed, etc. In the framework of this flow, site activity is mainly manual, but the use on site of non-specialized equipmentor plants may be considered as well.

At the other end of the flows evolution,one can mention INTEGRATED FLOWS WHICH ARE EXTENSIVELY used in developed countries today mainly in the case of important construction programs.A building "grows" progressively on site by mounting-special mechanical, dry modulated subsystems (typified) produced outside the site, in specialized industrial units, and involving specific materials and technologies. The site becomes therefore a mounting section and the building period is considerably reduced as compared to the period required in case of the simple flow. The possibilities of modifying on site the industrial products are reduced and the system may be characterized as scarcely flexible. The scheme of this flow is presented in Fig.4.

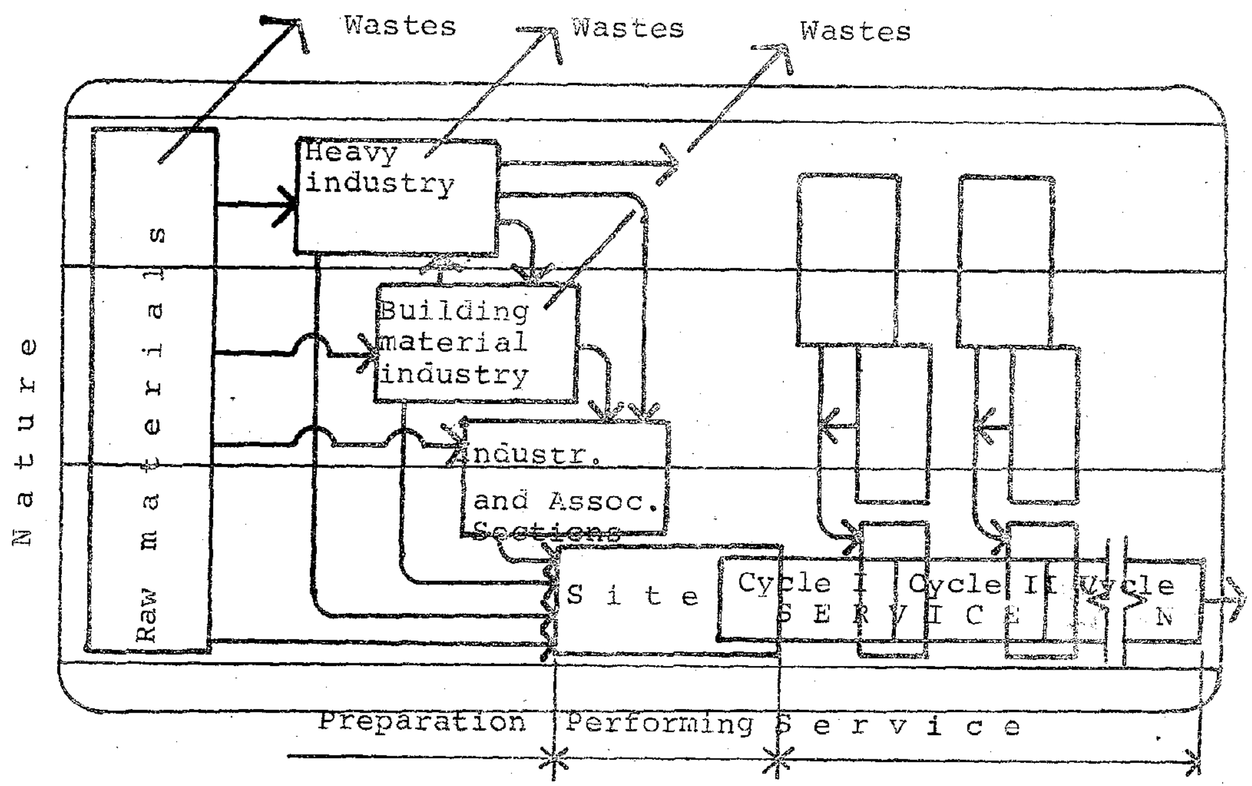


FIGURE 4

We may conclude that the evolution from the simple to the integrated flow is obvious. Unfortunately the latter is not proper to all cases, as a certain organizational structure and a specific material base are required. Table 1 presents an illustration -- referring to hand labor. Annex I generally introduces the conditions to be observed in heavy industry, building material industry and by the general contractor when using one of the flows previously described.

As concerns the potential of the flows, Fig.5 presents the structure of average energy consumption in dwelling and production buildings if they are placed in warm, temperate, or cold zones.

Annex 2 presents certain details on the contribution of the building units and parts to the overall energy consumption.

A few ideas are worth mentioning as compared to Fig.5 and Annex 2.

-- Firstly the importance of the energy quantity required for space heating in the cold season in case of buildings placed in temperate and cold zones; may we further mention that the specification in Annex 2 referring to the energy transfer involves only the perimeter areas separating the heated space from the outside and first of all the glazed zones.

All this generates the necessity of developing the production of such units and their proper use in perimeter closings; the advantages to be obtained will be used in ensuring inside the comfort and consequently the fuel requirement will be reduced thanks to the building's thermal inertia.

-- A further remark which is valid for buildings placed in cold and warm zones is that the energy consumption specific to the materials and hand labor required in maintenance, repair, and modernization activities performed during the service of the building or construction roughly estimated for two generations (60 years).

This consumption is comparable to the one initially required in the building process and may be reduced by using durable materials requiring few remarks of finishings and anticorrosive protection.

-- The third element to be discussed is the site energy consumption which is mainly formed of labor -- energy consumption -- important in the case of the simple flow and from the energy consumption of machines and equipments used on site -- in the case of the integrated flows.

On the whole, the overall energy consumption (labor+equipment) is considerably reduced in the case of the integrated flows compared to simple ones, where equipment needs are smaller.

STRUCTURE OF ENERGY REQUIREMENT IN BUILDING PERFORMING AND SERVICE

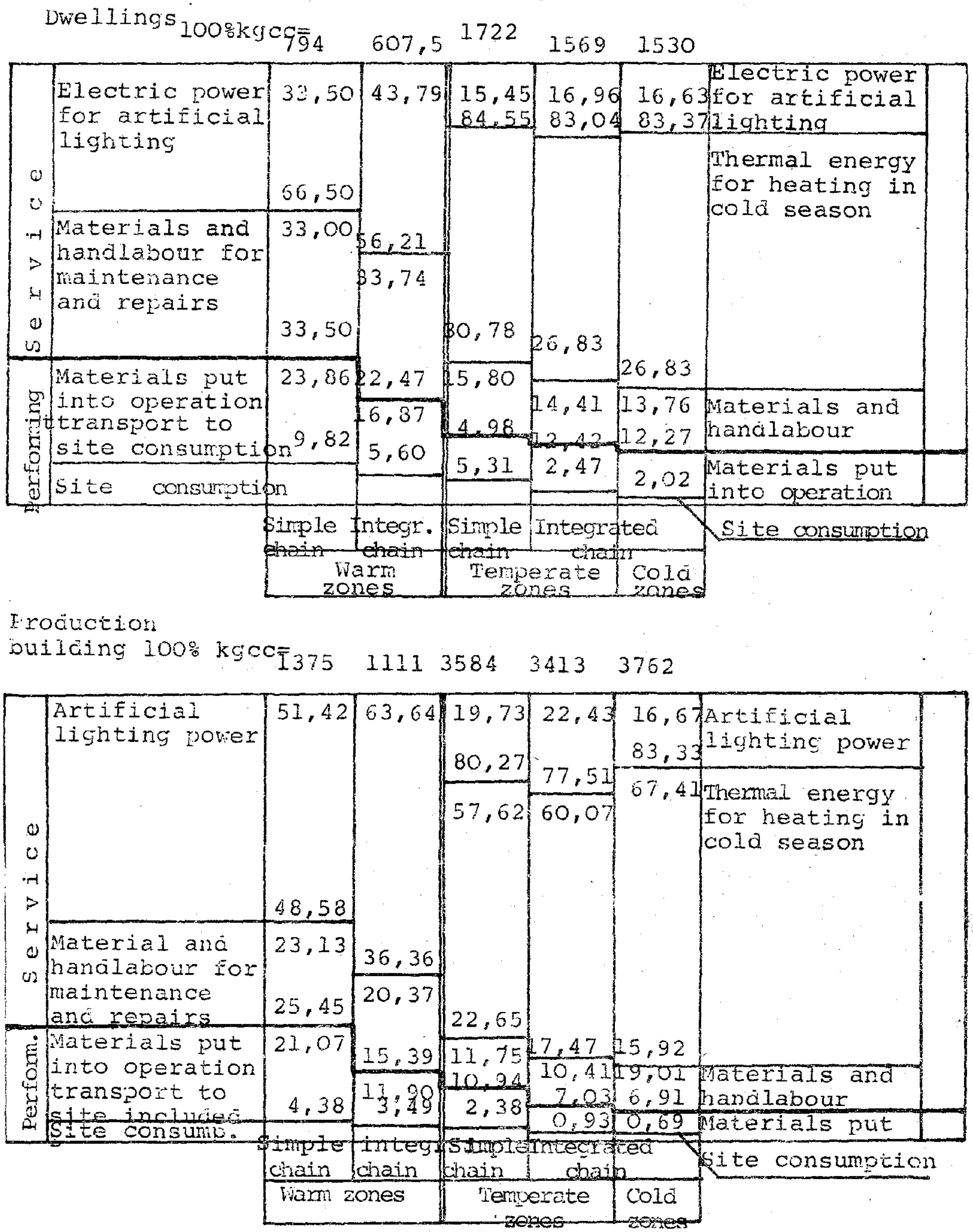


FIGURE 5

In order to have a clearer view of the manual labor effect on site, i.e. to analyse the opportunity and efficiency of manual labor utilization that "is not an energy consumer", and in order to estimate certain conclusions in connection with the developing of layout systems that do not imply the use of mechanical means for site operations, a study concerning "energy cost" of manal labour was worked out. The synthetic result of this study is presented in Fig.6.

At the basis of the study is the idea that society covers the expenses for labor payment and for its daily revitalization, meaning its food and the food of persons supported by the working people (this being in fact the energy consumed for providing "physical strength" of labor), as well as the energy required for artificial lighting, for heating, for public and private transportation, for clothing, etc. Thus, the energy consumption varies from country to country, depending on the geographic area (determining if heating is required or not), the number of family members, and the endowment degree (the existence of public transportation, electrical installations, etc).

It can be concluded that in order to obtain a potential contribution of 0.10 - 0.16 H.P. (0.34 - 0.45 kgcc) representing the amount of work given by the worker, the society consumes up to 1./06 kgcc/h (Canada), 1.39 kgcc/h in Romania, and 1.51 kgcc/h building materials becomes a luxury and a nonsense on a certain development step of the society, being justified only for the developing countries and only as long as the necessary industrial substructure is missing.

The study emphasizes once more the care that should be given to the approach of problems concerning labor and mechines and equipments for building, i.e., the fact that machines and equipments spur labor that, as society progresses technically and technologically, must be turned to good account. In other words, labor is not interesting for "the mechanic capacity" it represents but for its capacity of moving and driving more and more specialized machines and equipments that agree energetically with the real need of capacity required to handle materials, elements and subassemblies on site. Thus the design and manufacturing of light building elements supplied in a ready-to-be-used form, made so that they might be quickly and securely mounted by dry methods, becomes fruitful.

Another element that energetically affects building erection flows and that, from the goes with the ways of action analysed in this chapter, is made the weight of the buildings and hauling distances.

The fact that, at present, a buildings represents about $1t/m^2$ developed built area (Dba) and an industrial building comes close to this value, must be given thought in a world with limited energy

ENERGETIC EQUIVALENT OF HANDLABOUR

A) Energetic structure of site consumption handlabour

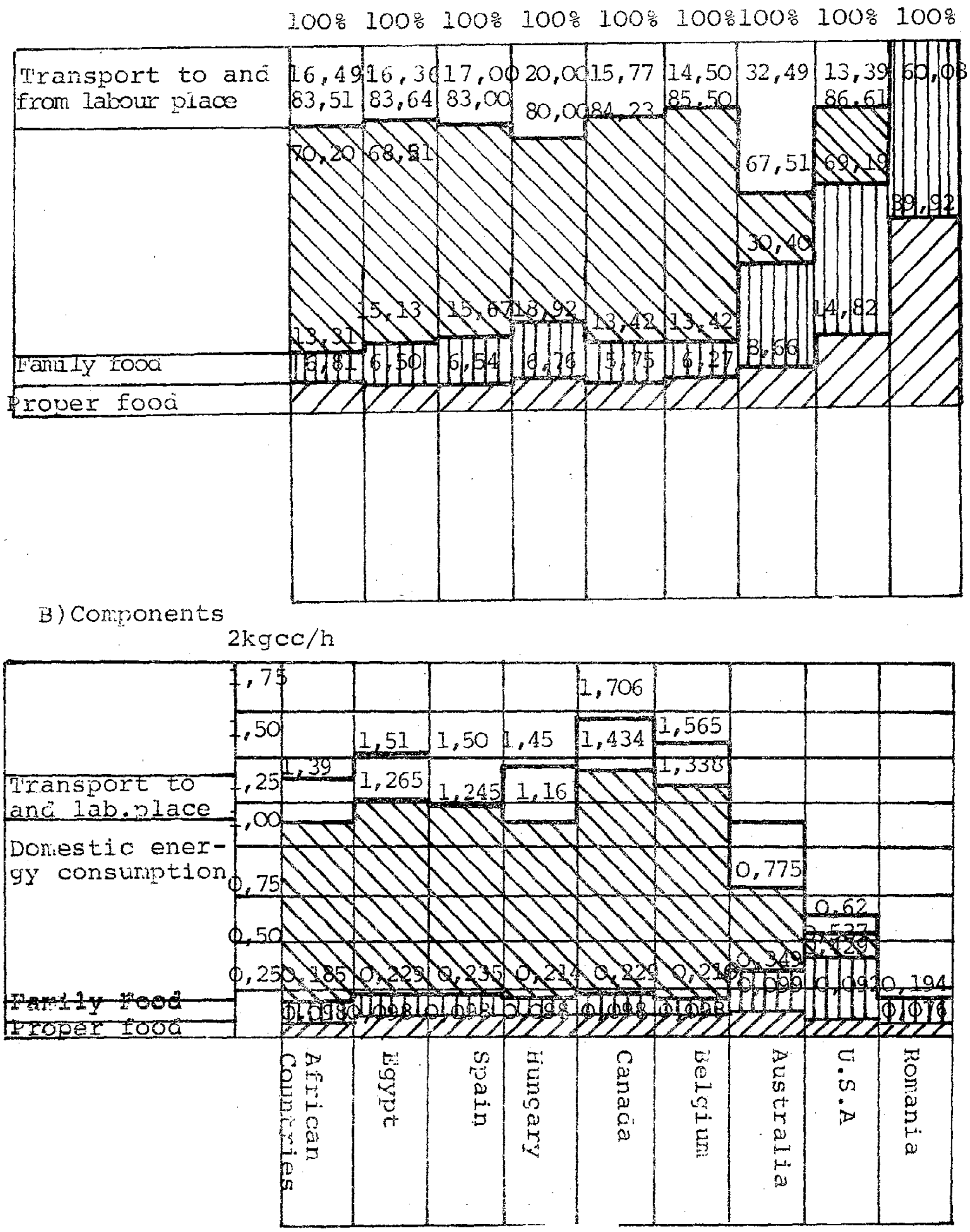


FIGURE 6

resources. The problem rose and was solved in other industrial branches: MINIATURIZATION !

In our opinion, what follows concerning miniaturization, in the building field, must be represented by the new generation of light building elements that are to be produced by the industry in charge and that can solve the problem of the whole building. It must be mentioned that, at present, it is possible-for instance - to erect industrial constructions in steel or prestressed concrete with the structures not higher than 70-80 kg/m^2 for bays of 12 x 18 m and that exists elements for walls and thermally insulated roofs at a level of Ro = 2 m^2 °C/W weighing less than 20 kg/m^2. Nevertheless, even at these buildings, the about 15-20cm thick concrete floor represents 375 - 480 kg/m^2, counteracting in a way the effort made to reduce the weight of the structure. Thus the development of research programs is abviously needed, in order to improve certain elements that can be mass produced as to meet the requirements imposed by a heavy floor with 1/4 of their weight.

Finally we wish our approach to plead for a reanalyis of all mounting activities and for on-site placing of materials and elements. Thus, if the most productive method is the dry, mechanical mounting of elements specially designed for quick mounting, this becomes the most efficient method from the energy point of view. Let us examine the other types of activities (monolithization mounting, mounting by welding, monolith casting in varions technologies, etc.). The stage of monolith building using blocks or elements (made of ceramics or other materials) with current sizes is finally reached. It must also be added that the erection of walls using ceramic ware blocks in order to provide the thermal protection required by the norms and regulations existing in all the countries located in temperate or cold zones would result in considerable thickness (50 cm or more) and the erection of a 25-30 cm-thick wall and its covering on the exterior side with materials adequately protected against bad weather would further move masonry away from the advantageous zone. Furthermore, such thickness will determine an increase of transportation volumes and consequently energy, as well as an increase of the structure, all these affecting possibilities of efficient turning to good account, from the energy point of view of labor on site.

It is necessary to notice the fact that, in general, precasting on site must be strictly limited to light or very heavy elements, being not recommended for the usual ones as long as the working methods and materials are the same, as in the case of their monolith casting, while the on-site prefabrication of micro production elements or additional ones prove to be due -- to required preparations disadvantageous.

In order to avoid such situations action must be taken, starting with the very design, that must agree with all the interests, i.e. of the beneficiary as well as of the building material and element manufacturer without leaving aside the consumer, thus designing a building ready to provide high efficiency under service conditions; to be functional, sensibly structured, easy to build using mass production elements; and dimensioned according to the technology it covers. The designed solutions must come from an optimizing action that aims at reducing the implications that the erection and service of a building are likely to transmit outside the system. Only by adopting this line of action and by understading deeply all these problems shall we be able to face the judgment of the future.

CONCLUSIONS

Bearing in mind the partial and subjective character of this communication, we consider that the problem of the overall energy efficiencies of the flows involved in the erection and service of buildings are important for all the factors linked to these processes, thus justifying the proposition of approaching these aspects value as a measure for the technical level of the building activity and the performance of the erected building.

The future substantial improvement of energy efficiency imposes special tasks concerning research and design activities for the equipment, element, and material manufacturers; for the builder (concerning working technologies on site, skilled workers formation); and also for the beneficiaries of the buildings, who must have the know-how of providing the adequate service conditions of the building, according to the level of the designed parameters.

The main directions to be taken and the priorities in approaching and solving the various problems must be permanently guided towards obtaining a positive synergetic effect, based on a unitary and critical conception and the obvious criteria of dynamic optimization.

Therefore, we must act in such a way that the necessary premises are created for the general improvement of the efficiency concerning design, erection and service of buildings.

II.4 AN ENERGY CONSERVATION APROACH TO ARCHITECTURAL SOLUTIONS AND ASPECTS

Nicolae Leonăchescu x)

The architectural design of a building is usually done on the basis of functional considerations as well as aesthetic and urban integration criteria. The changes of the volumes and the harmony of the facades are achieved by means of materials and location while the aestetic limits are imposed by economics location while the aesthetic limits are imposed by economics.

In the middle of the energy crisis, architectural solutions must be conservative from the energy point of view.

The architectural design of a building must be seen as serving primarily a new criterion or a compulsory parameter, that is, energy conservation.

Conservative solutions, from the energy point of view, are those that imply a reduction to the utmost of the dissipated thermal flow on the outside ("heat losses") during the cold season of the year, keeping, at the same time, a comfortable temperature inside the building with minimum service expenses.

The building must be regarded as an energy system and the "ideal" one is that where the energy consumption for heating is practically null. It seems that such an objective is still far from being achieved but the erection of buildings having minimum energy consumption is possible and solutions appear firstly in the architectural design.

The building, viewed as an energy system, interacts with the surrounding environment, providing the energy and substance flow. Any substance flow (air, water vapors) that passes through a building implies ipso facto a convective transfer of energy.

1. ENERGY INTERACTIONS WITH THE EXTERIOR AIR

1.1. The prism as an architectural solution for the shape of the building is widely used,though, the prism with horizontal rectangular or square section is not conservative from the energetic

---

x) Prof.Dr.Eng. - The Civil Engineering Institute, Bucharest, Romania

point of view. Considering the dominant wind direction, convention coefficients have different values a function of the shape as the thermal and dynamic limit stratum is subject to wind whirls raised round the building. Heat transfers by convection increase as follows: function of dominant wind direction:

1. Horizontal circular section buildings;
2. Square section buildings subject to normal direction wind on a side;
3. As in 2 above but subject to corner direction wind;
4. Hexagonal section buildings subject to corner direction wind;
5. As in 4 above but subject to normal direction wind on a side;
6. Elliptical section buildings with velocity vector of dominant wind parallel to the long axis of the ellipse;
7. As in 6 above, but parallel to the short one;
8. Rectangular section buildings subject to normal direction wind on the long axis of the rectangle.

This growth order of convection coefficients resulted from water tests run on prisms of the above mentioned type section. The rate between these convection coefficients at the first and last shape (rectangle/circle) is 3740 : 967 = 3.867. This order is obviously kept for air too.

Thus, regarding energy, priority is given to buildings with cylindrical section in plane, then to those with square section, and finally to the less recommended rectangular ones. The above mentioned rate -- 3.867 -- is not to be neglected. These conclusions do not consider the economic aspect of the erection technologies for cylindrical buildings, which may be more expensive than the prismatic ones.

The shape of the building also influences the air flow penetrating through it. If the overall pressure difference acting on the opposite sides of a building subjected to dominant wind action in winter, is increased the air flow to which the building is permeable is also increased. In such a case, the connected thermal flux is increased too. Therefore the shape of the building is important from this point of view too. The above mentioned order may be regarded as an orientative suggestion even for the way in which is increased the air flow penetrating through a building be it cylindrical or prismatical. The prismatic shape is at a loss in terms of energy even from this point of view.

1.2. <u>LOCATION IN URBAN CONTEXT</u>

The general, urbanistic conception can be viewed either as an advantage or not in the line of energy conservation. Thus, corridor arrangement of buildings increases "heat losses". In order to reduce the thermal flow dissipated in the surrounding environ ment, intermediate curtains of trees were adapted, the land was used energetically (protecting relief forms), the buildings werw placed in alveoli, the residential buildings were alternating with social and cultural ones, etc.

1.3. THE INNER STRUCTURE OF THE BUILDING.

The rooms meant for living require stricter conditions of thermal comfort as compared to the common corridors or annexes. Thus, placing as many thermal resistances as possible within the way of the thermal flow dissipated on the outside, the flow is diminished, conserving at the same time the internal energy.

Therefore, the corridors must follow the contour of the residential buildings. The existence of the interior stairs is an energy luxury.

The bedrooms must be placed in the weight center of the section, where energy is conserved. In the end, it is obvious that the solution is to be given function of other parameters such as natural light, thermal flow, etc.

1.4. FACADE DETAILS

1.4.1. Cantilever balconies present disadvantages as compared to loggias. The reinforced concrete plate of a cantilever balcony intensifies heat transfer through the contact surface of the plate with the facade. The dissipated thermal flow is increased by 10 - 20% due to base effect with lateral cooling (identical to fins of air cooled engines). When the length of the cantilever is above 1 m it has no significant thermal effect. The increase in absolute value of thermal flow is although unessential. At a reinforced concrete cantilever plate with a 1000 x 100 mm section the flow may increase in specific conditions from 10.08 to 12.015 W.

Balcony-closing during winter has a much more conservative effect from the energetic point of view.

The heat transfer overall coefficient is 2.034 $W/(m^2.k)$ for an exterior wall in red brick. If the balcony is closed with a 2 mm window, the same coefficient is reduced to 1,343 $W/(m^2.k)$, meaning a 34% reduction of outside dissipated thermal flow (1.343 : 2.034= 0.66) on the whole closed surface, not to mention the reduction of the air flow penetrating the structure.

Even temporary closing with cloth curtains conserve energy during winter.

1.4.2. Intensive glass covering of facades increases "heat loss" proportionally to the surface. Temporary window use is obviously compulsory, as each layer of air no more than 1 cm thick is a perfect thermal insulator. Thus, glass coverings, although they meet aesthetic requirements, must be reduced to limits imposed by natural lighting of interiors.

1.4.3. Exterior windows with steel joinery are disadvantageous in terms of energy because heat transfer through metal is intensified on the basis of a thermal bridge effect. Besides, air permeability of steel joinery windows is greater than that of a wooden one.

Energy priority of double or triple glass windows is out of question. Advantageous in terms of energy are blinds, shutters,and curtains that decrease transfer through radiation of energetic flow. In winter, a transparent plastic sheet placed between two glass layers decreases dissipated thermal flow.

Often, window joints to masonry are deficient and air permeability on the frame contour of the respective window increases. This results in the increase of "heat losses" through that particular zone and in condensation on the interior side of the wall around the window, being in a literary way accepted as "a crown of carelessness". Space-sealing between masonry and exterior window or door case is, in terms of energy, advantageous. Thus, exterior masonry thickening around windows becomes an energetic requirement, being at the same time the solution to deficient joining.

1.4.4. Materials used for exterior structures must have high thermal insulating properties. Material choice is to be made according to minimum value of thermal conduction coefficients as well as permeability even to vapours.

2. ENERGY INTERACTIONS WITH RAINFALL WATER

2.1. Wet materials present higher thermal conduction coefficients than dry ones. Wet brick has, for instance λ = 1,05 W / (m.k.) while in dry condition its λ= 0.35 W/(m.k.) this is, three times smaller.

Dry cork has λ= 0.07 W/(m.k.); for wet cork λ= 0.14W/(m.k.) and for frozen cork λ = 0.35 W/(m.k.). These values clearly show the necessity of protecting building materials against water action because their thermal insulating properties diminish with the increase of their humidity.

2.2. A cornice roof is advantageous in terms of energy compared to a terrace, because it keeps the water away from the building.

2.3. Continuous sidewalks (in concrete slab), as wide as possible, surrounding the building help to the removal of rainfall water from the building in the vicinity of the foundation, where heat transfer is intensified.

2.4. Masonry arches above windows have a double energy function: diminish air vapor permeability of exterior walls down the window and the exterior wall thus the wooden joinery is better protected and has a longer life.

2.5. The blinds also protect wooden joinery from rainfall water, reducing at the same time radiation phenomena.

2.6. Downpipes and deficient water installations have a negative energetic role. They must be kept in good functioning condition all the time.

3. ENERGY INTERACTIONS WITH THE SOIL

The study of the energy interactions between a building and the soil was largely presented in a previous paper (1). The main conclusions of the study follow:

3.1. Burying depth of a structure determines its "heat losses". The deeper it is buried the smaller are "heat losses", because the dry soil layer acts as thermal insulation. At certain depths, structures no longer need internal heating sources.

3.2. Underground water increases thermal flow dissipated from the building to it and to the exterior air. The deeper the underground water, the more thermal flow decreases. The most disadvantageous situation from the energetic point of view is the one in which underground water comes in contact with the building (partially or totally buried). In such cases building materials are subject to degradation in time and aboveground structures are also affected by the capillarity phenomenon that finally generates dampness and disadvantageous energetic effects.

3.3. Thermal insulation of building elements that come in contact with soil must have an uneven thickness.

A solid thermal insulation of floors and vertical walls that come in contact with the soil must be done in the thermal turbulence zone where temperature gradient is maximum.

3.4. Drains executed in the soil, on the perimeter of the building zone, have a positive role when it comes to conserving the energy of the respective building. They keep rainfall water away from the building and as a function of their depth, they can lower the upper level of the under round water.

Soil dryness around and under this water has a conservative energetic effect, thus requiring that such measures should be taken.

3.5. Local or neighboring (slope, drains, trenches collapsing) transfer heat intensity from the building to the environment. Thus differentiated thermal insulation is required around these parts.

These conclusions are valid even when the direction of the thermal flow is reversed, as in the case of refrigerating chambers.

Technical and architectural implications of the energetic interaction between a building and the visible or invisible solar radiation are the object of an ever-increasing number of specialists. Energetic conservative solutions lead to a socalled "solar architecture" and to layers capable to absorb incident radiation all over the year.

Leaving aside the type of energetic interaction, it is high time that architectural solutions recognize the paramount importance requirement of energy conservation.

In this respect, traditional solutions prove to be sources of inspiration not to be ignored.

BIBLIOGRAPHY

1. Leonăchescu N. - Heat transfer buildings-soil.

II.5 NOISE ABSORPTION AND THERMAL INSULATION

C. Peştişanu x)
L. Popescu xx)

The materials used at present for the sound absorbing insulation, to control the noise in Bucharest subway stations of ventilation are: mineral wool as plates in the perforate sheet zincate steel boxes or blockwork of the sound absorbing autoclaved cellular concrete (GBN 35) with core in waste of mineral wool.

The sound - absorption coefficients, , for the mineral wool and for the autoclaved cellular concrete blocks (GBN 35) prove these materials are much less efficient in the domain of the low frecquencies. Besides, the consum of included conventional energy (in kilogram conventional fuel upon square metres, kgcf/m^2), in the case of mineral wool or/ and the amount of manual labor in the case of blockwork decrease considerably the technical - economical efficiency of these materials.

In order to decrease the consumption of the conventional included energy we propose the utilization of the prefabricated plates in porous, foamed ceramics of clay containing carbon residues, dimensions 300 x 600 x 80 mm and aproximately 10 kg/piece weight. The plates are fastened by means of ceramic accessories, profiles with double T section, on the noise's room wall or/and ceiling.

The ceramic plates may be used, also as a floating slabs in the structure of the floor acoustic insulation.

By using the porous foamed ceramic prefabricated plates, especially when they are manufactured of clay containing carbon residues it is possible 25% - 85% reduction of the conventional included energy. The cost of those new insulations is 40% - 50% less then that of the previous solutions.

The porous foamed ceramic plates may be also used without restriction as thermal insulation material in the roof plate structures or in the prefabricated panels for the external walls.

Noise absorbing treatments directly applied at the source of the noise are one of the most efficient solution for the insulation

x) University Professor, Dr.Eng. The Civil Engineering Institute Bucharest, Romania
xx) University Lecturer, Dr.Eng. The Civil Engineering Institute Bucharest, Romania

of the noisy rooms. In most cases, the utilization is made of some energy-intensive materials (for instance: mineral wool) or of some technology for execution with a high degree of manual labor at the building-sites and a small productivity (for instance: the autoclaved cellular concrete bricklaying having included a core of mineral wool) followed in this case by a reduced economical efficiency. The noise absorbing materials utilized at present for the noisy rooms (for instance: Bucharest subway stations of ventilation) are the plates of mineral wool set in perforated steel boxes, or the noise absorbing autoclaved cellular concrete blocks (dimensions 200 x 300 x 600 mm) with a core of mineral wool.

The mineral wool is considered one of the most efficient material from the noise absorption point of view: the coefficient of noise reduction, for the 5 cm or 10 cm thick plates, will be 0.65 or 0.75, calculated as an arithmetical mean of the values of the sound-absorption coefficients , variable with the frequency (Fig. 1). These high coefficients are due to the great porosity, about 0.8. From the examination of the variation of the sound-absorption coefficients it may be noticed that the efficiency of the 5 cm thick mineral wool plates is very sensible at low-frequency noises. In order to obtain for comparable values with the aritmetical mean, for the domain between 125 and 1000 Hz., it is necessary to increase the thickness of the plates from 5 cm to 10 cm, an increase followed by direct consequences for the economic index, especially for the specific consumption of conventional included energy. From that point of view the mineral wool is one of the energy-intensive material with 142 kgcf/m^3 consumption, that is 7,1 kgcf/m^2 for 5 cm thickness of the plates, without the consumption of energy for the perforated steel boxes which ensure their application on the surface of walls and the ceillings of the noisy rooms.

The noise absorbing blocks of autoclaved cellular concrete (GBN 35) with a core of mineral wool plates are characterized by the value 0,62 of the coefficient of noise reduction. That is a net value to the value of the 5 cm thick mineral wool plates. But the bloocks include an important amount of energy, approximately 16,9 kgcf/m^2, resulted from the included energy, 74 kgcf/m^3 in the GBN 35 blocks, and respectively 2,1 kgcf/m^2 in the 1,5 cm thick mineral wool layer. The treatment realized by means of the noise absorbing autoclaved cellular concrete blocks have a sensible reduced efficiency for the absorption of the noises with a high frequency (1000 Hz), or for the entire scale of frequencies in case of a high relative humidity of the air in the rooms (due to this system having closed pores).

We have to take into account the previous technico-economical considerations as well as the specific conditions of utilization in noisy industrial rooms (humidity and relative high speeds of the air currents, etc.), which limit or reduce the domain of a reasonable utilization of the noise-absorbing mineral wool treatment or of the blocks; these solutions may be replaced with some new ones, more

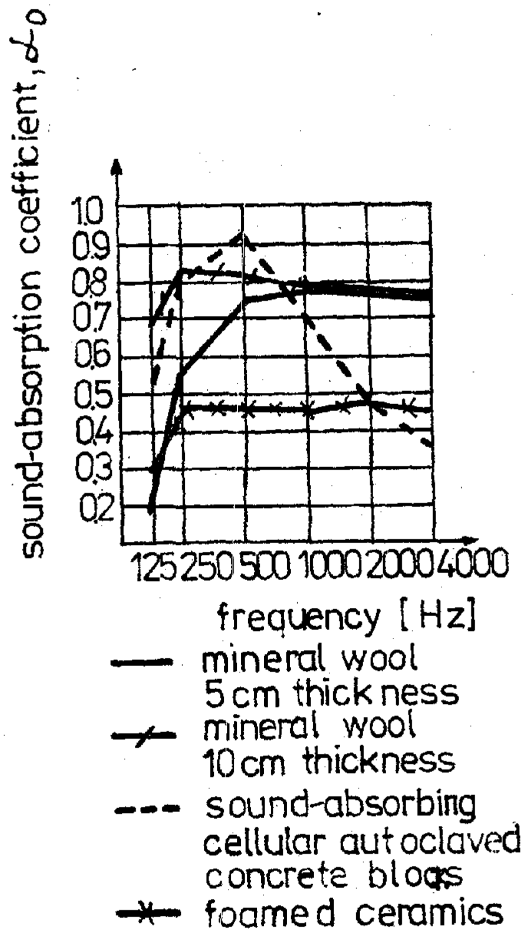


Fig.1

efficient from the point of view of needed energy consumption and manpower during construction, as well as with a greater longevity, having the same noise absorption efficiency. The porous materials used to absorb the noise are constituted of a rigid skeleton with pores to create narrow canals of different forms with the object allowing of the passage of air. The acoustical incident waves, upon a such porous material, determine oacillations of the air contained in the pores; due to the air viscosity, these oscillations are accompanied by friction and kinetic-energy of the air, which oscillates and is partially transformed into thermal enėrgy. The transformation of energy also takes place due to the reversible process linked to the thermal conductivity of the air and of the skeleton. At the same time, when the skeleton itself begins to oscilate, supplementary thermal energy is released due to the inner friction in the material. The studied materials, in view of replacing the present solutions used in noise absorbing treatments for the noisy industrial rooms; are obtained by the reevaluation of some industrial waste material: waste of sponge glass bounded with phenolitic rigid foam, waste rubler bound with latex, foamed ceramic obtained from clay having carbon residues (coal-sterile) respectively the foamed concrete. Out of these materials the foamed ceramics may be singled out for its advantageous characteristics in acustical absorption, thermal insulation, and a small included energy consumption (Table 1, Fig. 1).

The sound-absorption coefficients α_c have been determined upon cylindrical test tubes with 28 mm or 97 mm in diameter and 50 or 100 mm height, using the Kundt's tube method. From Figure 1 it may be noticed that the foamed ceramics are characterized by an approximate constant value of the α_0 coefficient, equal to 0,48 for the noises with greater than 250 Hz frequencies and the coefficient of noise reduction (α = 0,4) is next to this value.

In the domain of low-frequencies (f $\leq$ 125 Hz) α_0'= 0,3, a value near that of the mineral wool plates (α_0 = 0,5). The favorable characteristics for the noise absorption of the ceramic material are dues to its well structure with open pores, which ensure both the disapperance of the acoustical energy and the rapid elimination

Insulating material	Density kg/m^3	Thermal conductivity $kcal/mh^\circ C$	Coefficient of noise reduction α o	Conventional included energy, $kgcf/m^2$
Mineral wool 5 cm thickness	100	0,04	0,65	7,1
Mineral wool 10 cm thickness	100	0,04	0,t5	14,2
Noise absorbing autoclaved cellular concrete blokcs	800	0,200	0,62	16,9
Foamed ceramics in ordinary clay	800	0,20	0,40	5,3
Foamed ceramics in clay containing carbon residues	800	0,20	0,40	2,7

of the excessive humidity which may penetrate it.

With regard to the included energy consumption, the foamed ceramics is an advantageous solution, even if for its manufacturing the ordinary clay is used; the efficiency is sensibly increasing when the carbon residues are used as raw material, because, in this case, important savings may be obtained during the combustion. The advantages, for the utilization of the porous ceramics ar noise-absorbing material in form of prefabricated plates (Figure 2), come from the simplification of the operations, the reduction of the manual labor, and the elimination of the humid operations on the building-sites. The protection of the ceramic noise absorbing plates exposed to strong currents of air in the stations of ventilation or high humidity may be realized with a simple film which does not affect the porosity of the material. The protection must stay open, being endowed with deep canals, preferably communicating among them. The capacity of noiseabsorption is greatest when the dimensions of the pores are great enough so that the acoustical reflected energy becomes as small as possible, respectively the impedance of the material has to be nearer to the resistance of the air and, at the same time, the dimensions of the pores must be small enough so that to ensure the vanishing of energy through frictions.

For a certain frequency of the noise, at a normal incidence

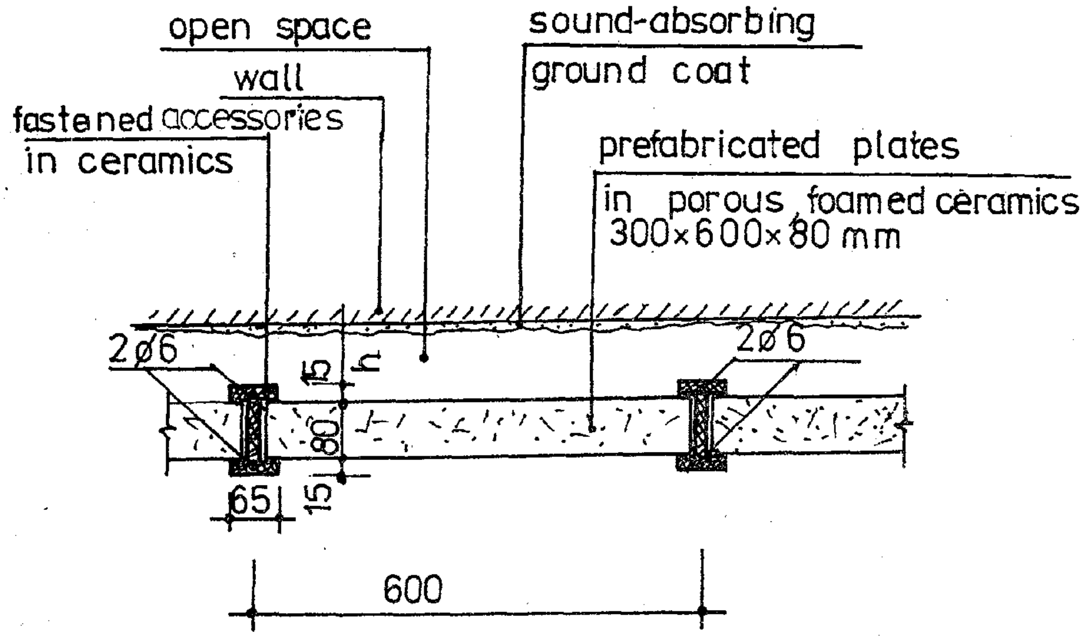


Fig.2

the expression of the sound-absorption coefficient depends on the section and the number of pores per unit surface, so that:

$$\alpha'_o = \frac{4M_1}{2M_1^2 + 2M_1 + 1} \qquad (1)$$

where

$M_1 = M/n\ a^2$;

M_2 = the coefficient of proportionality;

πa^2 = the surface of a section in a pore;

n = the number of pores per unit surface.

From the relation (1) it may be concluded that the α'_c values are passing through a maximum equal to 0,83 for $M_1 = \frac{1}{\sqrt{2}}$. The maximum value of α'_c in the name for all the porous materials. The corresponding frequency for the maximum results from the relation:

$$f = k\ \frac{1}{\mathcal{X} \rho} \cdot \frac{1}{n^2(\pi a^2)^2} \qquad (2)$$

in which k is a factor of proportionality;

$\mathcal{X}$ is a structural factor, undimensional, which considers the influence of the geometrical structure of the pores, with the values included between 1 ... 5;

ρ the density of the material.

In order to obtain an acoustical absorption as near as possible to the maximum for the low-frequency, according to (2), a value is necessary to be as great as that of the product $n^2(\pi a^2)^2$.

Consequently, we need the increase in the number of pores per unit surface, under conditions of maintaining the diameter of the pores small enough for easy and fast thermal transfer of the contact of air with the walls of the canals. It may be seen that for a material with certain characteristics, the sound-absorption coefficient increases with the frequency; generally, its values being small at the low frequencies and relatively large as the sound-absorption coefficient is obtained with a greater thickness of the noise absorbing material. For the usual thicknesses, at high-frequencies, the sound-absorption coefficient is sensible independent on the thickness of the porous layer. In order to obtain high noise absorptions for all the frequencies, it is necessary to use a sufficiently great thickness and thepromotion of inclined resistances. The application of a thin film, aimed at the protection of the material, may be favorable for noise, absorption and obtaining an assembly of resistances in series. This solution must be attentively examined and the implementation has to be based upon previous acoustical measurements, because it may lead to an unfavorable modification of the treatment. The acoustical absorption calculation obtained by the utilization of the foamed ceramics plates in the noisy industrial rooms imposes the determination of the diffused coefficient of the noise reduction, with the aid of the measurements carried on in the reverberation-room, using a 10 m^2 absorbing surface or, simplor, with the help of kundt's tube method, taking into account the relation between the specific impedance of the noise-absorbing element and the coefficient of noise reduction and a normal incidence.

The acoustical absorption of a material is influenced by its setting against the wall; the acoustical absorption of the porous layer directly laid on the reflecting surface of a wall becomes smaller at the low-frequencies. If between the porous sheet and the reflecting surface of the wall a layer of air is maintained, the acoustical absorption of the ensemble changes in a favorable manner for the low-frequencies (see Figure 2). In case of a normal incidence of the acoustical waves on a reflecting rigid surface, the incident waves, together with those reflected, from a system of stationary waves to which the next peak of the speed is located at the reflecting surface. The maximum absorption is obtained when this peak is inscribed in the thickness of the porous layer

$$L = \frac{\lambda}{4} - \frac{c}{4f_i} \qquad (3)$$

where c is the speed of the sound in the air;

f_i - the frequency for which we have to set a maximum absorption.

In this way a rational noise-absorbing solution must be composed from a treatment with an air-layer at the back. Such a solution is applicable only in the condition of the utilization of a porous material heavy enough to neglect the impact of its oscillations upon the ensemble. The foamed ceramic plates, as well as those of foamed-concrete, meet this condition.

The absorption characteristic of the sound-absorbing treatment of ceramic plates may be improved if these have longitudinal printed striations upon the surfaces of plates. Presented in Figures 3 and 4 are experimental application, upon a small surface (about 10 m^2), in order to watch the behavior "in situ", of the noise-absorbing treatment realized in plates of foamed ceramics, respectively foamed concrete, at one of the Bucharest subway station of ventilation.

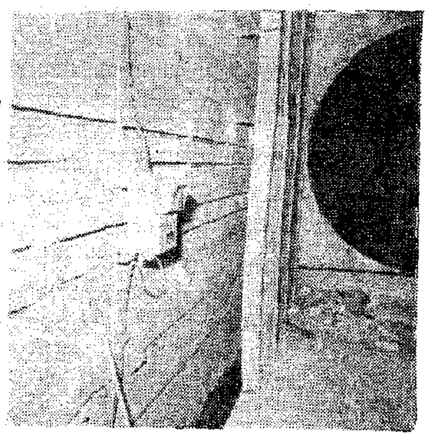


Fig.3

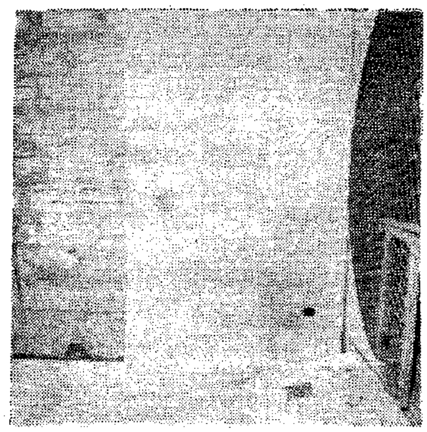


Fig.4

In these figures may be also noticed the noise-absorbing brick laying used at present for the insulation of these rooms, a bricklaying realized of blocks with a core mineral wool. The implementation of the treatment with an air-layer at the back, besides previously indicated advantages, removes the risk of humidity in the porous material due to the infiltration of water from the earth through the walls of the underground located rooms.

BIBLIOGRAPHY

(1) Handbook of noise and vibration control, 4th edition, Trade Technical Press LTD, Morden, Surrey, England, 1979 ;

(2) Stabilirea consumului de energie înglobată în materialele de construcţii şi instalaţii produse de MEFMC, Indicativ C 1878, vol. 1 CMC;

(3) PESTISANU C., POPESCU L., Reconsiderarea soluţiilor de izolare împotriva zgomotelor produse în centralele de ventilaţie ale metroului Bucureşti. Contract nr.191/1982 Institutul de

Construcţii Bucureşti, 1983;

(4) PESTISANU C., POPESCU L., Soluţii noi de insonorizare a încăperilor industriale zgomotoase, I.Placaje fonoabsorbante realizate prin valorificarea unor deşeuri industriale, Buletinul Stiinţific al Institutului de Construcţii Bucureşti, nr. 2/1984, pg. 3-12.

II.6 THE SHARE OF LIGHTING IN BUILDING ENERGY SYSTEMS

Cornel Bianchi x)
Gabriel Chiriţă xx)

1. LIGHTING - A COMPONENT OF BUILDINGS ENERGY SYSTEM

Electric lighting represents one of the energy consumers, a component of a building's functional equipment, which ensures a physical and intellectual production normal activity in industrial and non-industrial precincts.

Generally, the shape of the building construction materials influence directly energy consumption in building by their insulated characteristics and the size of the windows.

An external wall provided with a large number of window-panes is apparently an ideal solution from the point of view of day light contribution and energy savings in illumination, but utterly inadequate from the point of view of lighting quality and heating.

Thus, on the one hand, taking into account the light microclimate, too large a number of windows panes will cause very high illuminance levels in proximity to the windows during daytime, decreasing considerably as we advance to the other end of the room, and bringing about intolerable luminance contrasts that ought to be balanced by artificial (electric) lighting of the dark side of the room (of a high level and implying therefore considerable energy consumption), obviously an uneconomical and unacceptable solution in the present energy conjuncture.

Also, the luminance contrasts generated by the unequal distribution of solar light incident at the window-pane are improper for normal human productive activity.

On the other hand, from the thermal point of view, too large a window-pane surface will result in considerable heat losses during winter, hence excessive energy consumption, and during summer too much heat coming from outdoors, which causes disconfort ought to be balanced by additional energy consumption required in conditional air preparation.

---

x) Dr.eng. The Civil Engineering Institute, Bucharest-Romania

xx) Eng. The Civil Engineering Institute, Bucharest-Romania

The previous studies /1/ have demonstrated that from the technical and economical point of view the adequate solution is the following one: up to 20% of the whole external wall surface is represented by window-panes, a satisfactory visual contact with the natural environment being thus ensured.

Vertical position of the window-panes is recommended, the worker's sight angle to the exterior being thus favorable both from the psychological and from the daylight points of view (the natural light source --the sun-- has an apparently vertical movement being in sight for a quite long time).

Life, physical or intellectual work, amusement or relaxation can't be separated from a light-comfortable microclimate;its general view can be seen in Figure 1, in which quantitative and qualitative conditions components required by visual comfort are schematically represented.

One of the important components, for both the comfort and the energy consumption in the illuminance level obtained at the working table from the light sources of the illuminating system.

The essment of illuminance level has been extensively dealt with in the researches of developed countries (U.S.A., Netherland, West Germany, Great Britain, The Soviet Union, France).

It can be specified that there are three determining criteria in assessing illuminance levels (visual target, visual performance, and visual satisfaction), and in accordance with them the research has assessed:

-- A minimal level corresponding to acceptable visual perception of human traits, and coinciding with an 150-200 l x to h = 1,5 m horizontal lighting;

-- An optimal level corresponding to the effective visual target and which for instance, in intellectual work rooms may reach 1.000 - 1,500 lx.

However, in no nation has standard optimal levels been assimilated, service levels the optimal value, determined by economic reasons and using in most cases the additional local lighting, were adopted.

We must point out that on the other hand work productivity depends directly on the illuminance level value, and visual fatigue, wastes number, and work accidents increase when illuminance level decreases.

In analyzing these aspects the present paper has approached the problem of the existence or non-existence of acceptsble solutions for economical illumination system, in qualitatively and quantitatively acceptable conditions, meant to ensure normal human activity.

Theoretical and experimental studies of illuminating time from Electrotechnic Chair of Faculty of Installation aim at finding methods of reducing the electro-energetical consumption, having permanently in wind the overall energy system of the consumer building, the interrelationships between functional, productive and constructive behaviour.

Thus, three research methods have been performed:

-- Implementation of light pressure sodium lamps of high efficiency in building illuminating;

-- Implementation of integrated natural and effective lighting;

-- Implementation of reduced lighting systems in dwellings.

2. RESEARCH ON THE IMPLEMENTATION OF HIGH PRESSURE SODIUM LAMPS (HPS) IN BUILDINGS PRECINTS

Introduction of high efficiency lamps as illuminating systems, in our case HPS source, represents even at first sight an alluring solution by the spectacular economical effects that can be achieved.

It is worth mentioning the simple way of implementation in the case of existing installations provided with high pressure mercury lamps (HPM). HPM may be directly replaced by HPS without modifying the existing installation.

The aim of the research was to answer with clarity and a certainty question that generated many contradictory opinions:May HPS be used in interior lighting of certain industrial areas? If the answer is "yes", what is the domain of use and what are the limitations ?

The experiment took place in the Visual Research Laboratory of the Faculty of Installations (Fig,2) provided with a multivalent lighting system with many light sources different in their nature (HPS, HPM, tubular fluorescent lamps, incandescent filament lamps) shielded by a luminous ceiling of the grill type. Each system is driven separately by hand control from the control board which may be seen in the Figure 2, and the adjustment of the illuminance level per source type is performed by a tension manual controller. The large window pane surface on the outside wall(see Fig.3) allowed of the extension of the study to include electric lighting systems combined with daylighting.

A laboratory experiment program was aimed at the study of the interrelationship of man-color light source according to the functional diagram in Figure 4. Thus starting from the comparisons between lighting sources different in color (HPD, HPM, tubular fluorescent), visual tests on subjects (80 persons) for short and normal terms of time were performed in quantitatively and qualitatively normalized conditions with permanent control of the illuminance level.

The tests and their final interpretation revealed the possibility of using HPS lamps in interior lighting, the luminous microclimate obtained being worm, "sunny" and stimulating for work as well as acceptable from the point of view of the combined nated use of daylight and electric lighting. However, the system cannot be used rendering of dim colors is required.

The economic consequence of HPS lamp implementation is the significant saving obtained by the buildings energy system: 40-60% as compared to HPM lamps and 20-40% as compared to tubular fluorescent lamps.

3. RESEARCH ON THE IMPLEMENTATION OF INTEGRATED SYSTEMS OF DAYLIGHTING AND ELECTRIC LIGHTING

The problem of daylighting and electric lighting integration in dwellings is generaly more acute during the transition period (in the morning and in the evening) when the daylight dwindles as well as all day long when in large interiors additional electric highting is requied due to the quick dimming of daylight away from windows.

The study of integrated systems comprises two main directions:

-- Qualitative, concerning the effects of the directionality of the lighting, luminance distribution in the visual field, and the aspect of rendering and adjusting the environmental colors;

-- Quantitative, concerning the constant maintenance in time and in space of the overal medium illuminance (daylight + electric lighting).

We will discuss further, this latter direction, which indues energetic aspect of the interaction between daylight and electric light.

According to our own laboratory researches (6,7) and conforming to specialized literature on the subject (8) important electric power savings are generally obtained by the constant maintenance of total lighting (Fig.5) during the above mentioned intervals by gradually switching or dimming the electric lighting in concordance with daylight variations.

The theoretical grounding of the paper (6) led to the classification of automatic adjusting methods of luminous flux from two points of view:

According to the zoning degree of working surfaces (the non zoned surface, having one single zone z = 1, and surface with 2 zones, having z < 1);

-- According to the power variation degree during the transition intervals (jump variation - s and progressive - p).

The following flux-adjusting methods are obtained out of the combination of the two criteria already mentioned: (s, 1) , (s, z), (p, 1), (p, z).

For the non-zoned areas (s, 1), where the total lighting is achieved by simultaneous switching, two automatic adjusting methods which may produce certain saving come on:

-- the zoning and the starting of the lighting at nominal tension on successive zones (s,z) is advisable for percincts where the daylight is distributed according to a steep curve;

-- the simultaneous switching of the lighting system starting from a minimal tension and progressively increasing it to from a minimal tension and progressively increasing it to the nominal value (p, 1) is advisable for percincts where the daylight is distributed according to a plate curve.

A method very similar to the automatic adjusting method (s, z) already described may effect certain savings by turning to progressive automatic switching (s,z) on large areas where the manual switching is used for different parts of the system (p,1). The decision in this case should be taken after savings calculus.

The researches performed show that the automatic flux adjustment in integrated light systems is an efficient method for electric power savings if it implemented in large sized precincts (industrial halls) where the electric power is vised above $15W/m^2$. Hence it follows that the industrial hall minimum surface should be $1,000\ m^2$.

According to these conditions for 1 kW installed power an annual energy saving of about 160 kW/kW, an can be obtained.

4. RESEARCH ON THE IMPLEMENTATION OF REDUCED LIGHTING SYSTEMS FOR DWELLINGS

Even if electric energy in dwellings represents only 7 - 8% of the total energy used, out of which one-half is devoted to lighting and the other half to appliances, its reduction is of importance, since its use is irregular in time, and results in a heavy load during the evening hours, especially in autumn and winter.

Based on long-term experiments in 2 - 4 room flats, reduced lighting systems are acceptable for domestic activities in dwellings, as well as economical.

Residential lighting systems tested were:

-- The reduced lighting system for circulation, aiming to permit the circulation in annexes without using the normal lighting system at a low illuminance level (2-3 lx) with a visual sighting;

-- Reduced general lighting systems for living rooms aiming to achieve a low ambiance light (under 10 lx) that allow a cosy and functional ambiance.

The working areas in rooms (desks, tables) will receive additional auxilliary lights using pleasent and functional luminaires.

The experiments performed during 3 years on a flat equipphed with the above mentioned systems, with measurements made before and after the use of these systems showed an yearly energy saving for lighting of 40%. Figure 6 represents a load of overall consumption (lighting and home ustensiles)for the tested flat (continuous before the use, discontinuous line after).

The tests of convenience on 30 persons studied the already mentioned aspects of visual satisfaction and fatigue, obtaining over 70% good results, and reinforced the possibility of generalization of reduced lighting as a sure and efficient method of energy saving in residential lighting.

Thus, it seems obvious that the necessity of systematic handling of building energy consumption and its functional aspect is essential for normal life and activity process.

The energy savings in lighting must be considered only under the mentioned systematic overall for minimal conveniences within the quantitative and qualitative parameters of interior microclimate lighting.

BIBLIOGRAPHY

1. De Boer, J.B., Fischer,D. - Interior lighting. Philips Technical Library, The Netherland, 1978.
2. Bianchi,C. ş.a. - Proiectarea instalaţiilor de ilu minat electric. Editura Tehnică, 1981.
3. Bianchi,C., Moroldo,D. - Experimental Studies on Opportunities for Power Consumption Economics in the House. LIGHTING, -84, Varna, Bulgaria.
4. Koedom,M. - L'avenir de la famille lamps. LUX 107/1980.
5. Ionesco,S.-Economie d'energie dans l'éclairage industriel. La technique moderne, 1-2/1981.
6. Centea,O., Chiriţă,G. ş.a. - Reducerea cheltuielilor de exploatare la instalaţiile de iluminat artificial prin reglarea automată a fluxului luminos, I.C.B., 1971.
7. Centea,O., Chiriţă,G. ş.a. - Economisirea energiei electrice prin reglarea automată a fluxului luminos în perioadele de trecere de la zi la noapte şi de la noapte la zi, ENERGETICA' 81, Cluj-Napoca, 1984.
8. Bianchi,F. - Regolazione automatica della iluminazione artificiale a razionalizzazione dei consumi energetici, LUCE,1/1979.

II.7 ENERGY SAVING BY THERMAL PROTECTION OF THE EXTERIOR ELEMENTS OF BUILDINGS

Constantin Bogos[x]

Buildings are subject to the action of climatic factors in the area in which they are located. One of these factors is temperature, manifested either as temperature of the exterior air or as temperature due to the solar radiations. In the conditions of the temperate continental climate in Romania, exterior temperature permanently varies; so does inner temperature of buildings, which varies as a consequence of exterior temperature variation, excepting the case when the rooms are heated or climatized at a constant temperature. The humudity of the exterior and interior air also varies continually. Therefore a permanent change of heat and mass occurs between the interior and exterior of a building, a fact that imposes the necessity to realize a thermal protection able to render them suitable to the normal conditions of hygiene and thermal comfort, as well as to render them able to be exploited in cold seasons with a minimum energy consumption.

Present and future tendencies in the development of building construction for cold and temperate climate countries are the following :

- reduction of dead-load in the exterior elements (walls, terrace-roofs, etc.) by using some materials with a reduced apparent density and increased thermal efficiency, aiming at reducing the thickness of the elements;
- adoption of some multilayer composition of these elements;
- use of some materials having a high degree of tightness to water and water vapor, alongside materials of great permeability.

These new solutions have a different hygrothermal behavior than the classical ones. As a consequence, these new solutions required new research in order to establish the main hygrothermal characteristics of exterior elements of buildings (outer walls, terrace-roofs, joineries, etc).

The estimation - by analysis - of heat exchange that occurs between the exterior and interior of a building implies great difficulties and may not carried out but on the basis of some simplifying hypotheses that are seldom implementable.

---

x Dr.Eng. - I.C.C.P.D.C., Branch of Jassy - Romania

Consequently, experimental research regarding the hygrothermal behavior of exterior elements of buildings is imposed by:

- research on full-scale elements in specialized Research Stations;
- research on buildings already in service.

For testing and research of hygrothermal behavior of full-scale exterior elements, a Station for testing was erected in 1972 in Jassy - Romania, belonging to I.C.C.P.D.C. - Jassy Branch.

The Station building is composed of a 3-level single body (Fig.1).

The testing room (Fig.2) is 10 x 5,5 m in plane and 3.5 m high, having two areas separated by the element to be tested. In the warm area, the conditions of interior climate (temperature, humidity) are simulated while the cool area the conditions of exterior climate are simulated, The simulation of climate conditions is automatically performed both in permanent and variable regime by means of a cold-producing and air-conditionning equipment. Thus, any variations of air temperature are obtained from $-25^{o}C$ to $+70^{o}C$ as well as the variations of its relative humidity from 30% up to 100%.

The structural dimensions of the testing room allow research on full-scale elements: walls, wall-joinings of walls and floors, joinery elements and parts of terrace-roofs.

A new Station is under construction with maximum dimensions of the testing room 18 x 12 x 7m.

In permanent thermal regime, the following main characteristics of the exterior element are determined:

- the field of temperatures on the two surfaces of the specimen in order to establish the realization of the conditions of thermal comfort;
- the overall coefficient of thermal transfer (resistance to thermal transfer respectively) necessary for dimensioning the equipment of central heating;
- the risk of vapour condensations of the interior surface of the element.

These determinations allow establishment of actual heat loss in cold season and, consequently, optimization of exterior elements in order to reduce energy consumption of buildings during their service life.

In variable regime the following main characteristics are determined:

- the variation of temperature field of the two surfaces of the specimen as well as into its interior;
- the variation of the thermal flow that passes through the specimen;

- the damping coefficient of the amplitude of exterior temperature oscillations on the interior surface of the specimen;

- the phase-difference of thermal oscillations;

- the determination of overall deformations due to the action of the temperature variation in winter and summer conditions.

Having in view the large amount of experimental data to be considered and processed in variable regime an original system named INAD - 1000 - of automatic numerical logging of experimental data for measuring points is employed.

The experimental data logging is performed on punched paper tape and the data processing is done by a digital computer by means of some adequate computation programs, obtaining thus the main thermal characteristics of the specimen in the case of variable regime.

The temperature measurements are performed either by means of transducers mounted on surfaces of the tested specimen, or by means of a mobile transducer. As temperature transducers, some copper-constantan thermocouples or thermistors are employed. The measurement accuracy of temperatures is of $0.1^{o}C$.

The thermal flow measurements in permanent regime are made by means of the auxiliary wall method (with thermal flowmeter) or by means of the guarded hot box. The measurement accuracy of the thermal flow is of + 5 %.

Outside the Station, some specially fitted out testing stands have been installed permitting to establish the joinery behavior (windows, doors, etc.) under static and dynamic action of wind and rain.

In order to determine the thermal conductivity, an original apparatus named Thermocond equiped with a processor is used. The accuracy in observing the measurement regime is of $10^{-6\,o}C$ and the thermal flow is measured with 1% accuracy.

Since 1972 up to now 152 different solutions regarding the closing elements have been studied (exterior walls, terrace-roofs, joineries, etc) /1.2.3/.

The tested solutions have been either prototypes (when the optimizing of the hygrothermal protection was intended), or pre - cast panels or joineries produced in a large series in factories (when the production quality has been controlled and, its impro - vement was aimed at. In all the cases, the main objectives were: the obtaining of energy economy in building service, the impro - vement of hygrothermal comfort, the removal of the possibility of vapor condensation on the interior surface of the element, the increase of building durability. The results of this research has been evaluated by the customers: Central or Local Institutes for

Design, Prefab Panel Plants or Joinery Factories.

Within the framework of the research carried out we present two examples of prefab panels with inadequate thermal behavior:

- a prefab panel for residential buildings made of ceramic bodies and important reinforced concrete thermal bridges having their resistance to the mean weighted thermal transfer of a low value: $R_o = 0.62\ m^2\ {}^oC/W$ and with low temperatures on the interior surface which shows a thermal discomfort and a condensed vapor occurrence, pointed out by the dark areas in the Fig.4 which are the condensed-vapor areas for the relative normal humidity values of the interior air (60%) and for 20^oC interior air temperature and -15^oC temperature of the exterior air.

- a prefab panel for residential buildings in three layers with 8.4 cm thick polystyren insulation having its mean weighted resistance to the thermal transfer much diminished because of its 14.1% of the concrete thermal bridges (R_o=0.71 $m^2\ {}^oC/W$ and the possibility of condensed vapor occurrence on the inner surface in normal conditions of interior microclimat (which is pointed out in Fig.5 where a temperature variation on the interior surface is presented as well as the resistance to the thermal transfer in an horizontal cross-section located in the middle of the panel).

These examples have shown that, for obtaining important economies of energy in buildings service, one must operate in the direction of reducing the influence of the thermal bridges or even of their total elimination.

Consequently, IPCT Bucureşti /4/ has designed the following improved solutions from the thermal behavior view point(Fig.6):

- the P_1' exterior bearing panel in three layers having its thermoinsulation of 8 cm thick mineral wadding-plates G 100. The panel has concrete ribs (thermal bridges)only around the window gaps;

- the P_1 exterior bearing panel in three layers having its thermoinsulation of 8 cm thick mineral wadding plates G 100 and tying between the concrete layers by means of corrosion rezistant cramps (without ribs).

The resistance values of the thermal transfer of P_1' panel is R_o = 1,19 m^2K/W and the of P_1 is R_o = 1.56 m^2K/W.

The P_1' izotherms are presented in Fig.7 and the P_1 ones in Fig.8 in order to compare them from the thermal view point too.

When analyzing the values of the thermal transfer resistances of the two panels and of their temperature fields an indisputable superiority of the prefab panel without thermal bridges P1 emerges as against the one with minimal thermal bridges (4.1%), both as regards the energy economy in service and the thermal comfort realisation.

if one takes as reference the previous solution used for residential buildings with thermoinsulations of cellular autoclaved 15 cm thick of GBN-T type, the following economic efficiency for the panel without ribs results, calculated for one million square meter exterior elements for residential buildings:

- the total investment cost is reduced with 37 million lei;
- the necessary fuel consumption (energy) for heating is reduced with 8400 ton c.c.yearly;
- the steel and cast iron consumption in plants is redured with 3300 tons;
- the enclosed energy is reduced with 3200 ton c.c.

In conclusion, we also mention that the research regarding the thermal protection has also permitted generalizations with a theoretical-fundamental character regarding the hygrothermal behavior of the structural exterior elements. This research is further carried on, and its final result will lead to a more elaborated and through knowledge of the manner in which the heat and mass transfer are taking place, with important implications regarding energy saving in the existing industrial and residential building stock and in those to be built in the future.

BIBLIOGRAPHY

1. Bogos Constantin - Insulation properties of joints of precast reinforced concrete elements - volume II-Symposium RILEM-CEB-CIB-Athens, 1978, Greece.

2. Bogos Constantin - Einfluss der thermischen Brucken auf die Kondenswasserabildung an den Innenflachen von Aussen-Wanden-Bauingenieur, nr.7/1978,Berlin.

3. Bogos Constantin - New aspects regarding the heat transmission in designing the thermal protection for dwelling buildings - Romanian-English Symposium, 1980, Bristol, England.

4. Drimer M. Decusară - Design IPCT Bucureşti nr.9515/1984 - Study - New solutions for outside elements for dwelling buildings.

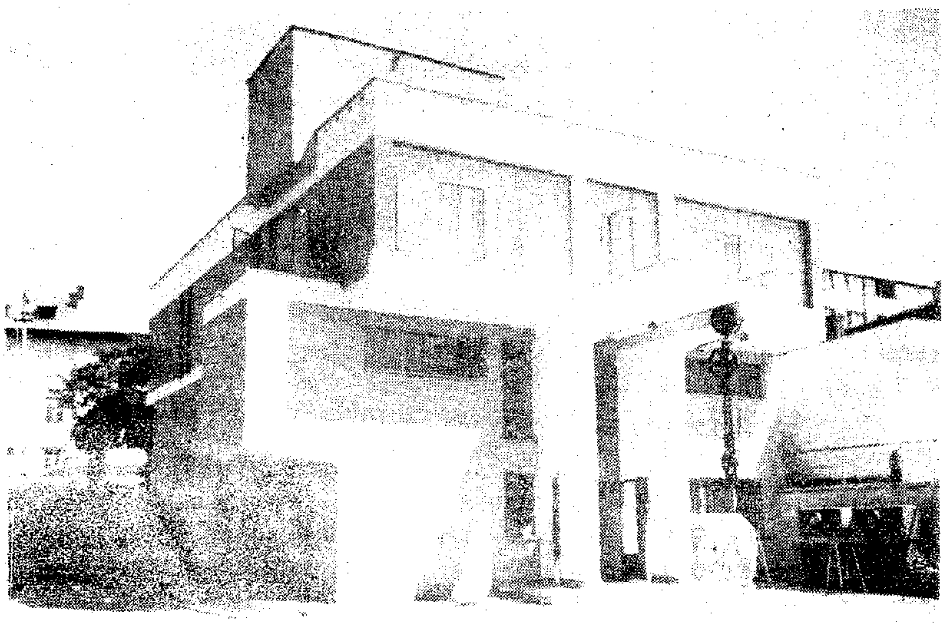


Fig.1-Hygrothermal Research Station for Constructions. I.C.C.P.D.C.-Jassy Branch-Romania. South facade.

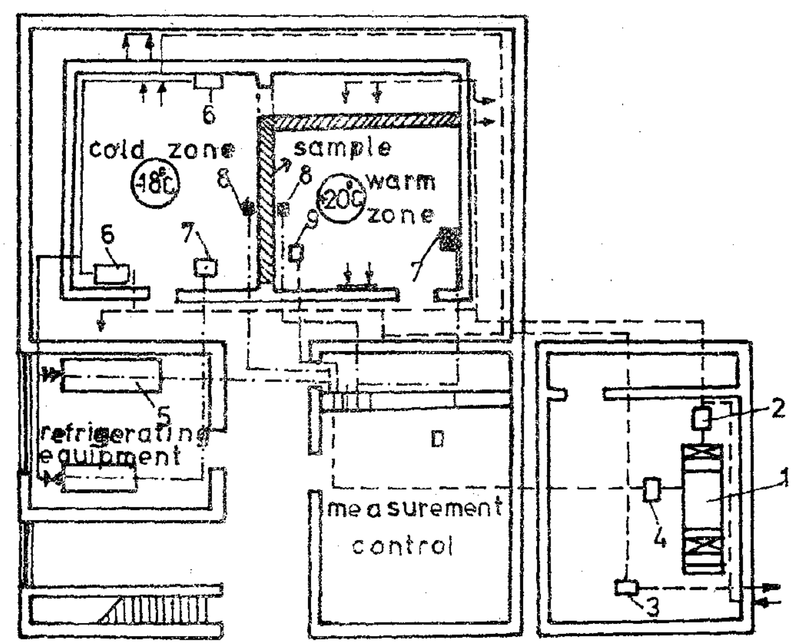


Fig.2-Hygrothermal Research Station for Constructions. I.C.C.P.D.C. Jassy Branch Romania. Technological lay-out.

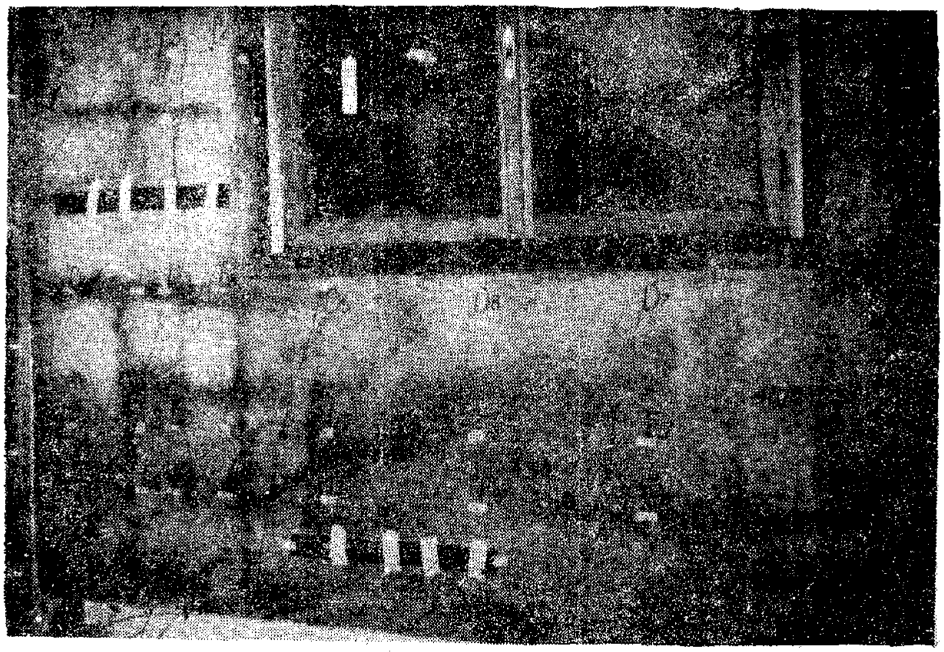


FIG. 3. Precast panel with ceramic bodies. Occurence of condensed-vapour the interior face.

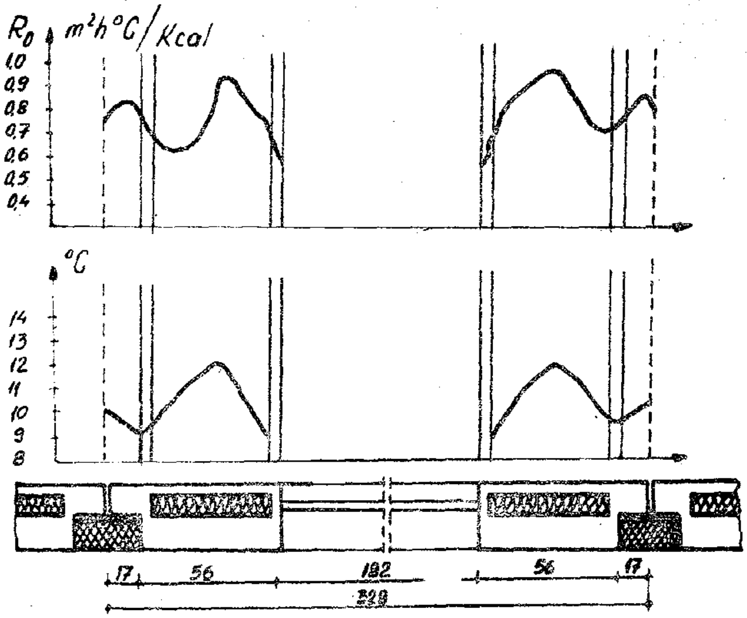


FIG. 4. Precast panel in three layers with polystyren thermoinsulation and thermal bridges of reinforced concrete.

Hygrothermal simultaneous testing of two exterior walls and of part of a terrace (for residential buildings)

FIG. 5

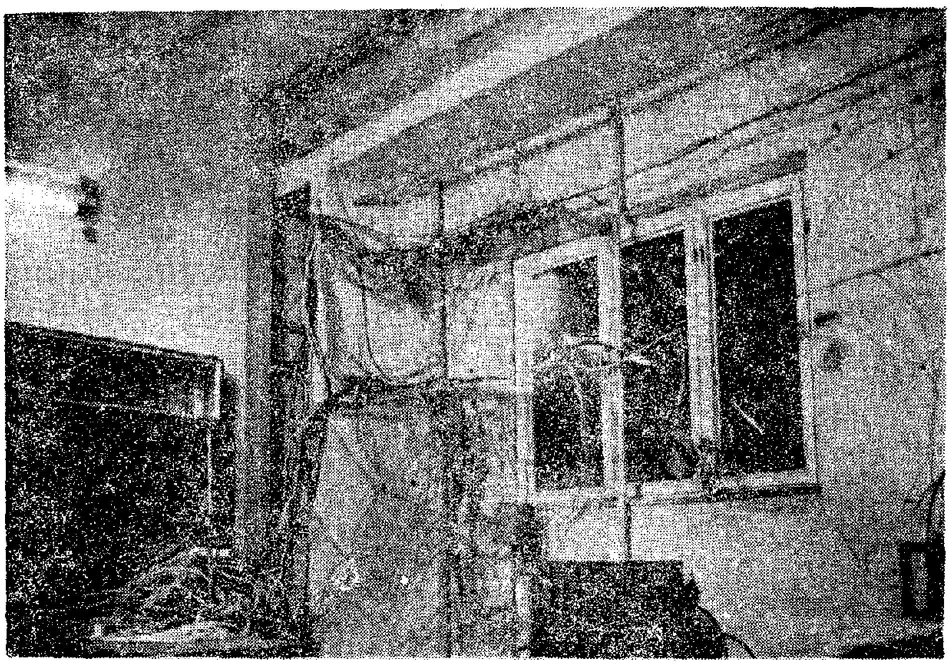


Fig. 6 Precast panel in three layers with 8 cm thick mineral wadding insulation

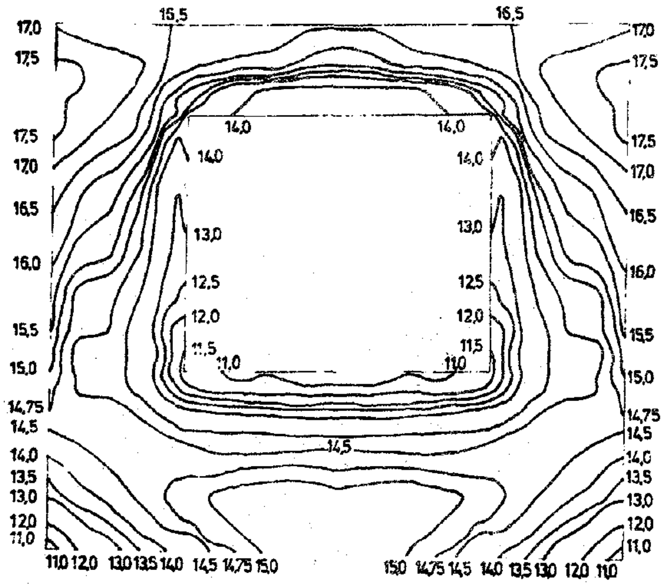


FIG.7. Isothermes of the inferior surface of a precast panel type P'1(with concrete ribs around the window gaps.)

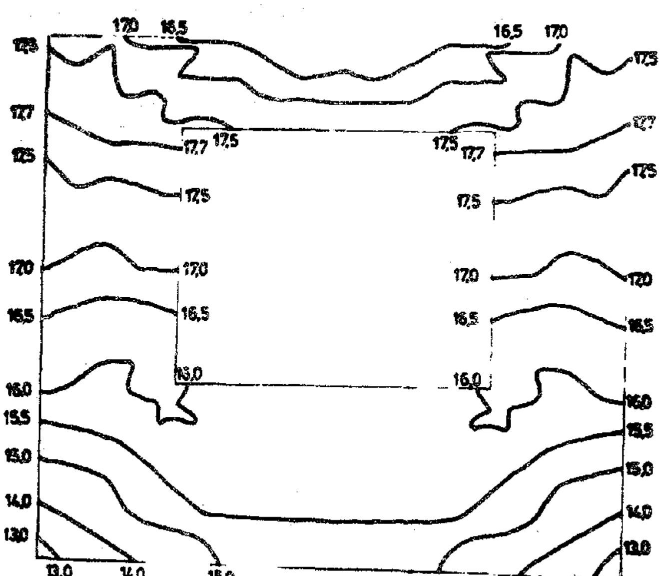


FIG. 8 - Isotherms of the interior surface of a precast panel type P1 (without concrete ribs).

II.8 ENERGY SAVING WITH LIGHTWEIGHT GRANULITE CONCRETE

Decebal Anastasescu[x]
Ion Ionescu[xx]
Ioan Koreck[xxx]

ABSTRACT

The structural, thermal and economic advantages of lightweight concrete with aggregates of expanded clay (granulite), and increasing difficulties in providing gravel aggregates (almost completely lacking in the Timişoara area), led to the design and construction, in 1974, of the first Romanian multistory structures with honeycomb shear walls and, subsequently to the introduction of various other structural types (low-rise, four - story buildings of large-size panels, ten-story buildings with cellular shear walls and central cores, etc.), using granulite manufactured at Lugoj.

The paper particularly underlines the energy-saving properties of lightweight granulite concrete structures,considerable savings having been achieved by the recuperation of the thermal energy consumed during the preparation of granulite in comparatively short periods of time (four to six years if the total structure is manufactured from this very efficient material, and less than two years, respectively, if the use of this material is restricted to the external panels of the structure). The paper also shows that important amounts of thermal energy (conventional fuels) can be saved in service due to the high degree of thermal insulation of external lightweight concrete panels, as compared to panels manufactured from an ordinary, denser, concrete grade.

A number of variants of prefabricated external panels from lightweight granulite concrete (one , two, and three-layer solutions) have been studied by specialists from IPROTIM and TAGCMT, and have shown better thermal insulating characteristics. Conclusions resulting from an extensive use of this material are formulated from the point of view of thermal and energetic efficiency.

---

x Dr.eng. - Design Institute of Timişoara (IPROTIM), Romania

xx Dr.eng. - Research and Design Institute for Building Materials (ICPMC) Bucharest, Romania

xxx Eng. - General Buildings and Installations Trust of the Timiş County (TAGCMT), Romania

One way of reducing the cost of a structure is to reduce the weight of its structure. Lightweight concrete, and particularly a grade that contains artificial aggregates based on expanded clay (granulite), has proved highly efficient in this respect. This is due to its physical, mechanical and thermal characteristics (reduced apparent density, high deformability, high energy absorbtion, and reduced conductivity, respectively)/1/, /2/, /3/, /4/, /8/, /10/. These characteristics lead to:

a) - a reduction in the weight of the structure and thus, implicitely, in the concrete and reinforcement areas, both in the under ground structure and the superstructure.

b) - a favourable behavior under earthquakes and shocks, and

c) - an increased thermal comfort in the building.

Material (steel, cement) and fuel consumptions, labor, transportation, and buildings costs are all reduced in this way.

The obvious advantages of this material and the increasing difficulty of providing the required gravel supplies for use as aggregates caused the manufacture of the first Romanian lightweight concrete shear walls at Timişoara in 1974, using granulite (class A3a) fabricated in Lugoj (a town not far from Timişoara). These lightweight concrete shear walls were used for high-rise apartment houses (basement + groundfloor + 10 stories), jointly designed by a group of specialists from ICPMC - Bucharest, IPROTIM -Timişoara and TCT - Timişoara /3/, /4/, /5/, /6/.

Between the years 1975 and 1984, over 18.200 apartments in residential buildings were built by TCM of lightweight granulite concrete. Out of these, 15.000 apartments were in low-rise, large-panel buildings (basement + groundfloor + 4 floors), and the rest were social and public buildings, such as three-to-nine story hotels, nursery-schools, students'hostels, etc., or in ten-story buildings with either slipformed honeycomb structures or precast elements /3/, /4/, /5/, /6/, /7/, /8/, /9/, /10/, and shear walls cast in plane steel forms.

The good thermal-insulating properties of granulite concrete were used from the very beginning on Timişoara building sites.

Thus, in 200 apartments of two ten-story buildings in the Timişoara "Circumvalaţiunii" district, self-bearing facade panels were made of B 150 granulite concrete in one-layer, 27 cm- deep structure /5/ (Fig.1). The same 27-cm-deep panel type was used in ten-story buildings (apartment houses) with precast peripheral frames and central cores (Fig.2), and for the "Timişoara" hotel, which, like the others has a framed structure of dense concrete/4/.

The same one-layer solution was applied to the 30-cm-deep external walls of ten-story buildings with slipformed lightweight-concrete honeycomb structures /3/ (Fig.3). This one-layer structure replaced the previous three-layer sandwich structure with its autoclaved cellular-concrete insulation, eliminating heat losses (inherent to the sandwich solution) from the earliest design stage. Labor saving of 10% were achieved with this new type of structure by avoiding the rather complicated placing of the thermal insulation material which, like the structure, had often been deteriorated in the process. The beneficial behavior of these panels for many years of service (in which no condensation has been found to occur) /11/, /12/ has proved that designers were right to promote the one-layer solutions described above. In addition to the advantages already described, this new building material is quite economical in terms of the total fuel consumption.

Although the manufacture of granulite makes the manufacture of lightweight granulite concrete more energy-consuming than the manufacture of a normal concrete with gravel aggregate, the total amount of energy-saving will, in the long run, prove to be much greater with granulite concrete. Due to the improved thermal insulation of granulite-concrete closing elements, the excess in energy consumption during manufacture will soon have be paid off, and any further energy savings will be sheer profit /8/, /13/.

In order to better assess the behavior of external panels manufactures in different solutions, IPROTIM specialists have worked out a standard design /14/ for four-story apartment buildings. The superstructures of these buildings consist of large-size panels of lightweight granulite concrete of class 3Aa(Fig.4) manufactured at Lugoj. Two types of panels were used:

a) - one-layer panels (type I) made of BG 200 granulite concrete 32-cm-deep, and

b) - sandwich panels made of BG 250 granulite concrete, with three layers consisting of structural granulite concrete(12 cm), mineral wool (8,5 cm) and a 6,5 cm protecting coat of granulite concrete respectively.

Monolithizations works were designed in granulite concrete of the BG 300 grade.

A comparison between the consumption indices obtained with granulite concrete and indices obtained with corresponding normal-concrete solutions shows that important savings can be acheived with the former indices (Table 1).

Values in parentheses indicate consumption for the BG 150 and the BG 200, concrete classes, respectively.

Fuel savings achieved under in-service conditions for a group of 20 apartments amount to 9.6 tcf (tons of conventional fuel) year with the first variant (type I), and to 15.6 tcf/year with second (type II). Thus, the original excess fuel consumption ing fabrication was completely paid off after 6 years (first

Table 1

External panel structure	Savings in consumption indices in case of: Reinforcing steel kg/m²Adc	%	Cement kg/m²Adc	%	Labor used during erection hours/m² Adc	%
Type I panels (one-layer solution	2,5	13,0	-7.0(3.0)^{x}	1,8	0.6	3.0
Type II panels (sandwich solution	2.0	10.5	-5.0(2.5)^{x}	3.0	0.5	2.5

variant) and four years (second variant) respectively. Compared with similar, normal-concrete buildings, net fuel savings after 6 and 4 years, respectively, amounted to 0.5 to o.78 tcf per apartment and year. Finally, with the second variant, the following savings were achieved on site per 1,000 apartments;

reinforcing steel: 130t
fuel : 500 tcf/year
investments : 2.000.000 lei

Good results were also obtained when lightweight granulite concrete was used for the structures of ten-story buildings (with basements). Such structures consists of sheat walls cast in situ in plane metal forms in a cellular system, precast floor slabs 18 cm deep, and columns cast in situ for the longitudinal facade.

According to the data provided by the standard design of IPROTIM/15/, the aavings achieved per 1,000 apartments as compared to normal concrete structures are:

reinforcing steel : 60t
fuel : 400 tcf/year
investments : 1,400,000 lei

In order to make granulite concrete even more efficient in point of energy consumption, it was attempted on the reduction of time required for recuperating the fuel excess consumption during granulite manufacturing.

The use of lightweight granulite concrete was therefore restricted to facade panels, which are the principal thermo-insulating members in a building structure. A number of constructive variants were studied in order to further improve the thermal insulating properties of these panels. The variants under consideration ranged from the one-layer solution described above to two-, three- and multi-layer solutions in which granulite concrete was combined with various materials with good thermal insulating properties. In designing these panels an account was taken of the positive results obtained by ICCPDC-Cluj-Napoca in the use of granulite concrete with improved thermal-insulating properties due to additions of slag (fly-ashes) from thermal power stations and foaming agents. Thus, after experimenting with the two-layer solution (15 cm autoclaved cellular concrete and 12 cm lightweight granulite concrete of the BG 200 grade), three-layer (Fig.5 b,c) and multi-layer solutions (Fig.5d) were used, combining granulite concrete with slag and a foaming agent. Table 2 indicated results (separately computed for each variant) regarding R_o (thermal resistance) and T_r (time of recuperation, in years, of the excess thermal energy consumed during granulite manufacture) of the lightweight concrete used. T_r values were obtained by comparing with a normal concrete solution recently adopted in a standard design of IPROTIM, T 770-84.

Table 2

Variants	$R_o \frac{m^2\,Ch}{kcal}$	T_r (years)
V_1 (Three-layer solution)	1.7	1.9
V_2 (Three-layer solution)	1.8	2.0
V_3 (Multi-layer solution)	2.1	1.8

It can be seen that the degree of thermal insulation of the lightweight concrete panels is significantly better than in the three - layer, normal-concrete solution($R_o \simeq 1.0$),and that the excess thermal energy consumed during the manufacture of granulite BG 200 was recuperated in a shorter period of time(less than two years), after which net savings of fuel were achieved during service.

CONCLUSIONS

To reduce the fuel consumption required for assuring high thermal comfort in residential buildings, the thermal protection of peripheral panels in buildings has to be improved. This can be achieved by:

a) replacing normal concrete in the composition of sandwich panels by lightweight granulite concrete;

b) combining lightweight granulite concrete with other materials with good thermal insulating properties (mineral wool, autoclaved cellular concrete and others) in multi-layer panels (which have proved to be better than one- or two-layer solutions);

c) reducing the weight of lightweight granulite concrete during the concrete processing by incorporating additives like ash from thermal power stations, foaming agents etc., and by improving the technology of granulite manufacture, respectively.

REFERENCES

1. Ionescu I., : Utilizarea betoanelor uşoare în construcţii (The Use of Light-Weight Concrete in Constructions), ODCAS, Bucureşti, 1969

2. Negoiţă A., Pop I., Mihai I., Dumitraş M., Strat L., Negoiţă I. Unele aspecte privind folosirea betonului uşor de rezistenţă în structuri amplasate în zone seismice (Some Aspects Concerning the Use of the Light-Weight Concrete for Structures Located in Seismic Areas), Sem.CEE ONU, Bucureşti, 1974

3. Anastasescu D., Ionescu I., Koreck I.: Structuri multietajate din beton uşor cu granulit realizate prin glisare în oraşul Timişoara (Multistoried Structures of Slipformed Light-Weight Granulite Concrete in Timişoara), A VII-a Conferinţă de betoane, Iaşi, octombrie, 1975.

4. Cristescu V., Ionescu I., Moldovan I., Anastasescu D., Ciulea Gh., Koreck I. : Clădiri de locuit şi social-culturale din beton uşor cu granulit realizate în judeţul Timiş (Light-Weight Granulite Concrete Buildings for Housing or Social and Cultural Activities in the Timiş Area), Revista Construcţii nr.8/1978.

5. Gheorghe, I., Rădulescu E., Marinov R., Ciomocoş T., Heinermann M. : Panouri mari pentru construcţiile P+10E din beton uşor cu granulit (Large Panels for Ten-Story Buildings Made of Light-Weight Granulite Concrete), Revista Materiale de Construcţii nr.2, 1975.

6. Ionescu I., Anastasescu D., Koreck I.: Quelques aspectes des recherches et des réalisations roumaines dans le domaine du béton léger de resistance, Rev.Ciments, bétons, platres chaux, nr.4/1978, Franţa.

7. Ionescu I., Anastasescu D., Koreck I.; Réalisation d'habitations en élélements préfabriqués de béton léger et en béton léger transportable en Roumanie, Rev.Ciments, bétons, platres chaux, nr.4/1979, Franţa.

8. Anastasescu D., Anwender W., Ionescu D.,: Clădiri de locuit S+P+4E din panouri mari prefabricate din beton uşor cu agregate de granulit (Four-Story Residential Buildings Made of Precast Light-Weight Concrete with Granulite Aggregates), Revista Materiale de Construcţii nr.1/1978.

9. Koreck I., Milişiu S. : Tehnologia utilizării betonului uşor cu granulit la realizarea construcţiilor social- - culturale (Light-Weight Granulite Concrete Technology for Buildings with Social and Cultiral Aim), Revista Materiale de Construcţii nr.1/1978.

10. Ionescu I., Anastasescu D., Koreck I: Realizarea clădirilor de locuit şi hoteliere cu prefabricate din beton uşor şi beton uşor transportat (Apartment Blocks and Hotels Built of Precast Lightweight Granulite Concrete and Easily Transported Concrete, Revista Materiale de Construcţii nr.3/1977.

11. Anastasescu D., Ionescu I., Koreck I.: Comportarea in situ a clădirilor civile realizate din beton uşor cu granulit(In Situ Behavior of Lightweight Granulité Concrete Buildings), Schimbul de experienţă "Comportarea in situ a construcţiilor", Ediţia a III-a, Călimăneşti, 1978.

12. Ionescu I., Anastasescu D., Koreck I.: Urmărirea comportării în timp a unor clădiri de locuit şi social-culturale realizate din beton uşor cu granulit (Observation of Long-Term Behavior of Lightweight Granulite Concrete Buildings for Housing and Social or Cultural Activities), Schimbul de experienţă "Comportarea in situ a construcţiilor", ediţia a IV-a, Tulcea, 1982.

13. Lupan M. : Folosirea betonului uşor cu granulit în construcţii şi economia de combustibil (The Use of Light-Weight Granulite Concrete in Civil Engineering with View to Fuel Saving), Revista Construcţii nr.8/1974.

14. IPROTIM, ICPMC, TCMT : Clădiri de locuit P+4E din elemente prefabricate cu beton de granulit clasa A3a - proiect tip experimental 19373/1975 (Four-Story Residential Buildings Made of Precast Elements from Light-Weight A3a-class Granulite Concrete - Experimental Standard-Type Design-19373/1975)

15. IPROTIM, ICPMC, IPT: Clădiri de locuit P+10E din beton uşor cu granulit clasa A3a - proiect tip experimental/1976 (Ten-Story Residential Buildings Made of Light-Weight Concrete with A3a Granulite - Experimental Standard-Type Design/1976.

16. Varna E. : Imbunătăţirea caracteristicilor termo-tehnice ale betoanelor uşoare (Improvements of the thermal characteristics of Light-Weight Concrete), Buletin Informativ ICCPDC,Filiala Cluj-Napoca, 1979-1982.

17. Toma M., Varna E. : Panouri exterioare monostrat din beton uşor cu granulit sau ACEn cu granulozitate discontinuă şi adaos de cenuşă de termocentrală (One-layer External Panels of Light-Weight Concrete with Granulite of ACEN with Discontinuous Granules and Thermal Power Station Ash Additions), Revista Construcţii nr.10/1979.

18. Cotuna I., Varna E. : Realizarea panourilor exterioare pentru clădiri de locuit în structură monostrat (External One-Layer Panels for Residential Buildings), Schimb de experienţă a laboratoarelor de construcţii, Constanţa, sept.1983.

19. IPROTIM - TAGCMT : Studiu privind panourile exterioare monostrat cu cenuşă şi spumant (A Study of Eyternal One-Layer Panels Containing Thermal Power Station Ash and Foaming Agents), Proiect IPROTIM nr.27.121/001-83.

Fig.1

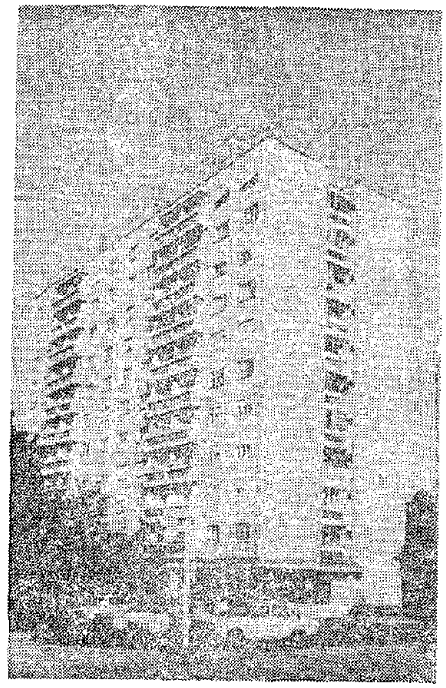


Fig.2

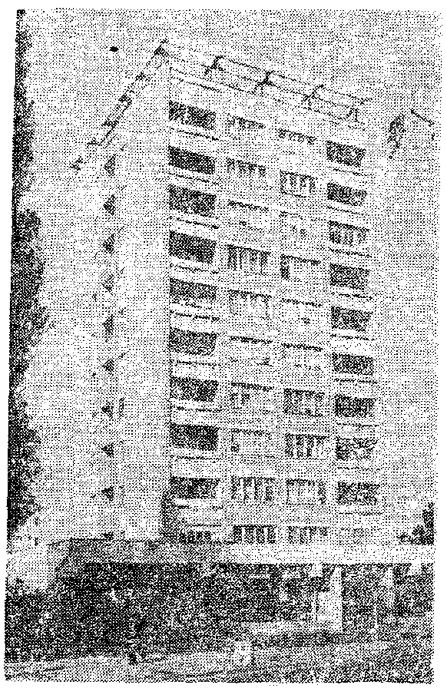


Fig.3

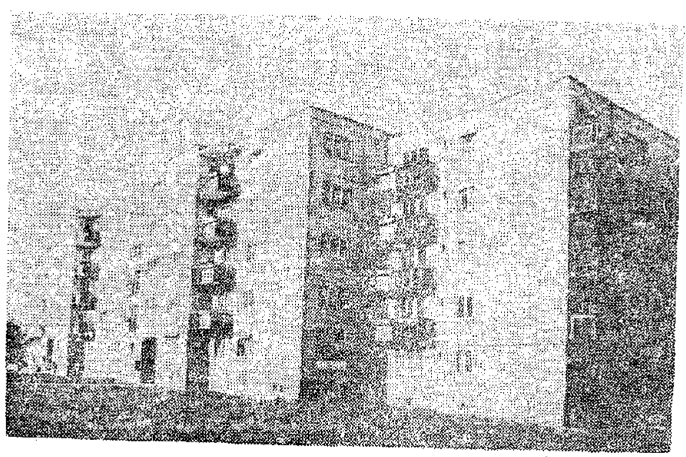
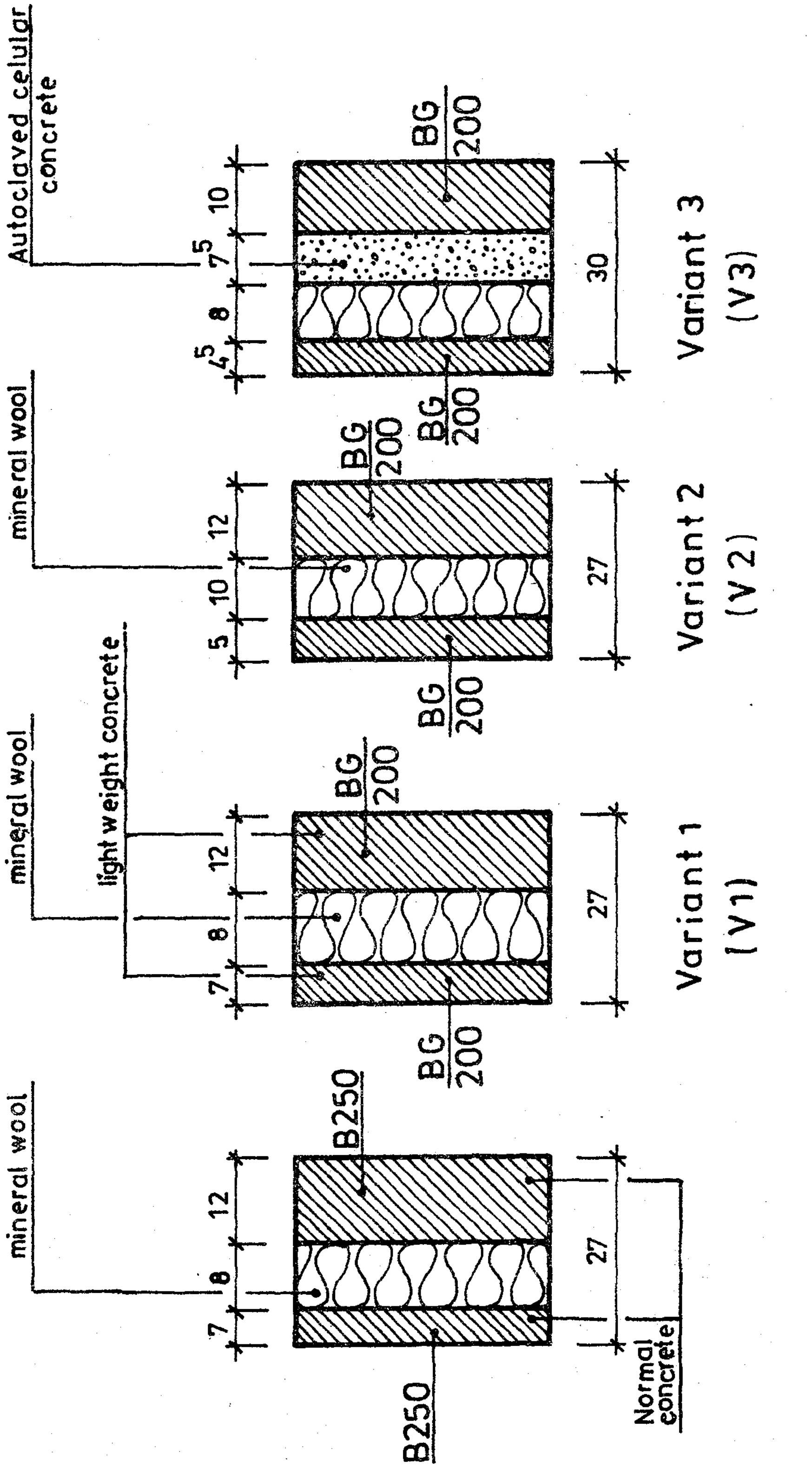


Fig.4



mineral wool
B250
B250
Normal concrete
7
8
12
27
mineral wool
light weight concrete
BG/200
BG/200
7
8
12
27
Variant 1 (V1)
mineral wool
BG/200
BG/200
5
10
12
27
Variant 2 (V2)
Autoclaved celular concrete
BG/200
BG/200
4,5
8
7,5
10
30
Variant 3 (V3)

Fig.5

III. SESSIONS III and IV SOLAR ENERGY IN BUILDINGS.
DAYLIGHTING.
ENERGY STORAGE.

III.1 PASSIVE SOLAR HEATING SYSTEMS

Baruch Givoni *

ABSTRACT

Various passive solar heating systems are discussed. The main design factors affecting their performance, their relative advantages and the main problems associated with them are analyzsed.

The solar passive systems discussed in the paper are :

--- Direct Gain

--- Collecting Storage Walls

--- Convective Loops

--- Sun Spaces

The state of the art in passive solar heating of buildings is reviewed. Issues which require more research are discussed:

--- The quantitative role of heat storage capacity in Direct Gain systems.

--- Interaction between the Thermal Storage Wall thickness and overall heat capacity of the heated space in Trombe Wall system.

--- Type and properties of the walls separating sunspaces from the main space.

--- Summer overheating by passive solar heating systems.

--- Mathematical design tools for passive soalr heating systems.

Results of recent personal research of the author are presented.

* Professor, Graduate School of Architecture and Urban Planning, UCLA, Los Angeles, California

In direct gain buildings the inhabited spaces are heated by the sun, admitted through conventional windows, skylights, etc. The building fabric itself acts as the necessary thermal storage to store excess solar energy during the sunny hours and release it back during the night.

The main factors affecting the performance of "direct gain" buildings are:

(i) location of solar glazing
(ii) sizing of solar windows
(iii) choice of glazing type
(iv) thermal quality of the building as a whole
(v) the amount and design details of the mass available for thermal storage
(vi) thermal coupling between "solar" and "non-solar" rooms
(vii) control options applicable to direct gain systems

1. Location of Solar Glazing for Direct Gain Heating

The major advantage of Direct Gain systems in building design is that significant amounts of solar energy may be collected through the elements which would be found in the building in any case, namely windows. This makes Direct Gain demonstrable the most cost-effective of all solar heating systems. From the viewpoint of energy collection, this is also the most efficient system, as energy is collected at the lowest possible temperature, namely at the comfort level.

There are a number of basic differences between windows and skylignts in their implications for building design. While with south-facing windows incoming energy is concentrated in southern rooms, or even in the southern parts of larger spaces, with skylights solar energy may introduced directly at desired points in the building. Furthermore, more efficient use of the building mass for energy storage is possible by utilizing internal partitions and even norhtern exterior walls (where they are sufficiently insulated externally). However, the use of the roof for solar admission is applicable only to single story buildings or to the upper story of multi-storied ones.

2. Sizing of the Solar Window

It is often tempting to make the area of southward facing windows as large as the building design allows, in order to maximize the penetrating solar energy during the heating season. However, such incoming solar radiation may raise the indoor temperature, which may rapidly exceed comfort conditions, even in winter. The magnitude of such temperature rise depends on the balance between incoming solar radiation, the amount stored for later use, and heat loss from the building. The maximum size of solar glazing should be related to the expected temperature rise on clear days.

There are two other negative effects of unnecessarily large glazing areas. First, glazing is usually the weakest point in the thermal quality of the building envelope, causing excessive heat loss at night. Second, the penalty of summer overheating in regions with hot summers from large areas of glazing may well be greater than the winter benefits.

There is no single, simple computation method for arriving at the desired window size, taking into account all the various factors involved, but from experience with occupied residential buildings employing Direct Gain, the following "rule of thumb" gives guidance for the initial design.

---- In a region of hot summers "solar" windows should be sbout 10 - 15% of the total heated floor area. They may reach 35% in the "solar rooms" where they are located, as long as problems of glare, overheating, fading, etc., are solved.

---- In cold regions larger solar glazing area (e.g. 30% of the heated area be appropriate, provided that high thermal resistance glazing is used (e.g. double glazing), together with the provision of effective night insulation.

Calculations based on energy criteria alone may tend to show cost benefits in "solar saving" increases for glazing areas up to about 50% and more of the floor area, especially in poorly insulated buildings. But the excessive solar energy may then cause thermal discomfort on clear days, and overheating in summer. It will also aggravate all the functional problems assiciated with this system.

3. Choice of Glazing Type

Many different kinds of glazing are available. The properties of the glazing, which determine its performance as a solar collector, are:

(i) average solar transmittence over the heating season;

(ii) the effective U value for conductive heat loss. If night insulation is applied then different U values will be effective during the daytime and at night.

It should be noted that not all of the net balance is useful in reducing auxiliary heating. With increasing indoor temperatures, heat loss through the building fabric is greater. If the temperature exceeds the maximum for comfort, excess heat may need to be "vented out". Consequently the actual "solar saving" is usually less than the net solar energy gain.

Note that the above discussion of energy balance highlights a common inherent inconsistency in some energy conservation standards. Southern glazing contributes to the "G" (or BLC) coefficient, even though in reality it may save energy when exposed to sufficient solar radiation and when sufficient thermal mass is available to store the energy for night-time use.

4. Thermal Mass and Heat Storage Capacity in "Direct Gain" Building

Thermal mass "stores" energy from sunlit hours for use at other times, and also serves to dampen excessive temperature "swings". Heat needs to be stored from the daytime to be given off during the night, thus the building mass should provide an effective "diurnal heat capacity". From the point of view of the daily cycle, only limited thicknesses of storage elements are useful, and this may determine the manner in which mass is incorporated in the building design.

The heat capacity of a material is a function of its specific heat, and of its mass. Since the specific heat of almost all masonry materials: concrete, brick, stone, adobe, etc., is similar (about 0.24 whr/kg.°C), the nominal heat capacity is essentially proportional to the total volume and the density of the material.

However, because we are also interested in the rate at which heat is absorbed and given up, the effectiveness of various materials to serve as thermal storage is not the same, but varies with the thermal conductivity mathematical model for calculating the "effective" diurnal heat capacity is presented in reference 6.

Generally, the amount of heat capacity should be related to the amount of the penetrating solar radiation on clear days. In given locations this means that the minimum amount of heat storage should be related to the size of the solar glazing. However, for a given size of the glazing the performance of the building will improve with the increase in the amount of heat capacity.

As a minimum, an effective diurnal heat capacity of about 150 whr/°C (per m^2 of glazing) should be considered. When the heat sotage is provided by concrete it means about 0.7 tons of concrete, or about $0.3m^3$, (with density of 2200 kg/m^3) for each m^2 of solar glazing. In a 24-hour cycle, only a thickness of up to about 10 cm will be fully effective, so that the minimum area of a storage element made of concrete should be at least 3 times the area of the glazing. If the thickness of the storage elements is greater, the area of concrete which will be required for effective sotrage will not decrease proportionately, due to the lower storage potential of the deeper layers.

Other masonry materials, with lower thermal conductivity, will require even larger minimum area (and thinner layers) for effctive thermal storage. On the other hand, in most cases a diurnal heat capacity beyond 500 (whr/°C-m^2) would not add greatly to the performance of the building.

5. Thermal Quality of the Building

When assessing the cost-benefit of direct gain provisions in a building. the criterion should be the usable energy delivered by the system. Thus "solar saving" is a better measure than the "solar saving fraction" (SSF), since it allows us to calculate the monetary value of the performance of the passive solar system and to compare it directly to the cost of the system.

In fact, it turns out that the economics of the solar system are better for buldings with higher heat loss coefficients' since such buildings need more heating in the first palce, the penetrating solar radiation is better utilized.

Effective air circulation between "solar" rooms and "non-solar" spaces is vital to the success of direct gain systems when not all the rooms have solar access. In some circumstances, fan assisted circulation, through ducts or false ceilings, may be necessary.

6. Provisions of Night Insulation and Summer Shading

Night insulation, by definition, is "functioning" only during the night hours. Therefore it has no effect on the collection efficiency but can have a marked effect on the heat loss through the glazing during the night hours and on very cloudy days.

In regions with cold winters, night insulation becomes increasingly cost effective. In regions with average mid-winter temperature below 0°C it becomes essential for reasonable solar saving, except if triple glazing is used.

On the other hand, in regions with mild winters, e.g. with average mid-winter temperature above about 5°C and higher, the thermal effect of night insulation becomes increasingly smaller. As it always entails additional cost, its cost-effectiveness decreases and often it becomes unjustified from the point of view of the heating energy saving in winter.

However, often regions with mild winters have warm or hot summers. Effective shading, and even insulation, during daytime becomes increasingly essential.

Operable insulated panel can serve both as night insulation in winter and as insulated shading in summer, thus they can be in service year round. This factor increases their cost effectiveness in regions with warm summers. With large glazing areas they become, in effect, essential for the overall, year-round thermal performance of the building.

COLLECTING STORAGE WALLS

1. General Discussion

This system was first proposed and built by Felix Trombe and Jacques Michel at Odeillo, France in 1967. In the simplest form, it consists of glazing placed in front of a south facing massive, conductive wall e.g. of dense concrete, with an air gap in between. The exterior surface of the wall is painted a dark color or given a "selective surface" to enhance absorption of solar radiation. Solar radiation penetrating the glazing is absorbed into the massive wall, raising the external surface temperature and that of the air in contact with it. The rate at which heat is transmitted through the wall to the interior is determined by the conductivity of the material and its thickness. The building interior is then heated by long-wave radiation and convection from the wall's internal face. Typical thicknesses of such walls--in either concrete or brick--are 20-40 cm.

If vents are provided both at the bottom and at the top of the wall, then the warm air in the air space between the glazing and the dark surface rises and flows into the building through the upper vents. Room air flows through the bottom vents into the air space. Thus a themosyphonic air flow is established, transfering heat to the room by convection.

The major advantages of thermal storage walls are:

- The indoor temperatures are more stable than in most other passive systems.
- Direct sunshine, and its associated functional problems, are eliminated from the inhabited space.
- Installation is relatively inexpensive where construction would normally be masonry, or for retrofit to existing buildings with uninsulated massive external walls.

Some practical shortcomings and disadvantages are:

- A room relying only on this system is denied light and view from the south.
- In a climate with extended cold cloudy periods, the wall may become a heat sink without adequate precautions. This may be overcome by the use of a selective surface or by the use of operable insulation.
- Summer overheating problems may outweigh winter benefits in regions with mild winters and hot summers.
- This system can only be used in pratice to heat the southern rooms of which it forms one wall.
- In multi-story applications problems with maintenance may necessitate the provision of access balconies. Note, however, that such balconies can function as the shading overhang for the glazing below.

Some of the functional disadvantages of thermal storage wall systems may be eliminated by the incorporation of windows alongside or in the wall. Direct Gain can be used for quick heating of the space in the mornings, while the mass wall is still cold. The integration of windows within the wall will also avoid the darkness, blocking of view and air, and general "heaviness" associated with early examples of this system.

2. Design Factors Affecting Performance of Collecting Storage Walls

For optimal energy transfer through the collecting wall, materials of relatively high thermal conductivity are necessary. In practice, this usually means cast concrete, solid concrete blocks or dense brickwork. Materials of lower conductivity, like adobe, will result in lower efficiency.

From the point of view of total energy saving, the thickness will have small effect, but it is a major factor from the indoor temperature will be. From this aspect, and also from the time of peak heating aspect, the optimal thickness for concrete in residential buildings is approximately 30cm. For each 10 cm of concrete, there is about 2 hours of "lag" between peak solar absorption, and delivery at the inside. Below about 20 cm thickness the internal temperature may be excessive.

Thin conductive walls, of about 10 cm, will heat up rapidly at their interior and thus may be useful in winter in buildings which are used only during the day, like schools, offices, etc. However in summer, and also in spring and fall, they will cause severe heat stress unless they can be shaded effectively, and in regions with hot summers, also insulated externally.

The higher the absorbtivity of the external wall surface, the higher the gain through the system. The most common choice is therefore a dark paint. The heat lost by reradiation from a painted surface is, however, also very high, due to the high emissivity for longwave infared. This may be overcome by the use of selective surfaces, which are now available in the form of thin plastic films.

About th same performance will be obtained if, instead of painting the wall with an ordinary black (or other dark) paint and providing it with double glazing, it will have a selective surface with single glazing. Compared with a wall with ordinary dark surface and single glazing the one with a selective surface will have a significantly higher performance. For given energy needs a smaller area with thus be required, facilitating also summer and/or insulation.

3. Effect of Vents on Performance

Under optimal flow conditions about 30% of the total energy flow, in "vented" walls made of concrete about 30 cm thick, is by convection and 70% by conduction. As the temperature in the air space is lowered, less heat is lost through the glazing and the overall efficiency is higher by about 10% in systems with "vented" walls as compared with unvented walls.

Note, however, that if the vents are not closed effecively at night the reverse air flow lowers the efficiency of "vented" walls well below the level of unvented ones.

Experience in buildings where vents have been installed has shown that the daily handling of the vents is bothersome, and also that the vents interfere with "furnishing" the rooms. As a result new buildings which were built in Santa Fe, with collecting storage walls, have unvented walls.

4. Insulation and Shading for Collecting Storage Walls

In regions with mild winters (mid-winter average temperature about 5°C) night insulation may not be justified from the solar heating aspect. However, in regions with sunny summers and average mid-summer daytime temperature about 28°C, the elevation of the external surface temperature of th glazed-dark wall can cause serious overheating of the interior. A study of a UCLA student in Israel (7) has demonstrated that the external surface temperature of a collecting storage wall, made of concrete with a dark color (absorbtivity about .85), when the wall is completely shaded from direct radiation by a deep overhang, is elevated above the ambient air by up to 8°C. This elevation is caused entirely by the diffused and reflected solar radiation. It demonstrates that in regions with sunny warm summers it is essential to insure complete shading of the wall, also from radiation reflected from the ground. This can be accomplished only by vertical shading, either rollable or shading panels which are installed in summer and removed in winter.

5. Water Walls (3, 4)

As an alternative to masonry collecting storage walls, water in various containers can be utilized for collecting and storing solar energy. The main advantage of water as a heat storage material, compared with masonry materials, is its much higher specific heat. Compared with a value of $c = 1.16$ (wh/kg-C) for water, the corresponding value of almost all masonry materials is about $c = 0.25$. Even on a volumetric basis the heat capacity of one m^3 of water (1160 wh/m^3-C) is about 2.5 times that of dense concrete. With other masonry materials, like bricks, etc., the comparison is even more favorable. This factor is of particular importance in high rise buildings, where space itself is expensive and extra weight leads to stuctural expenses, to support the heavier load.

Because of the high rate of convective heat transfer in water, the whole mass in a container heated on one side by solar energy, participates instantaneously in the storage process, leading to lower temperature of the absorbing surface. Consequently the collection efficiency of a water wall is higher than that of a concrete wall with the same absorption and glazing conditions.

On the other hand, at night the surface temperature of a water wall will be higher than that of the concrete wall, resulting in a higher heat loss, unless the walls are insulated at night. Water walls have a very small time lag. But as their indoor tmeperature swing is usually very small, the problem of time lag has minor significance anyway.

The main design issue with water walls is th echoice of containers. A variety of ideas about suitable containers were actually implimented. Steve Baer of "Zomework" in Albuquerque, New Mexico, was the first tried in the experimental building No. II of M.I.T. in 1947). Baer has used water filled oil drums of 55 gallons, placed horizontally on racks behind glazing. a hinged insulation panel, with reflective layer, is opened during the day (acting as a reflector to increase the impinging radiation), and is closed for the night. In summer it is possible, of course, to reverse the timing of opening and closing to minimize the rate of heating and maximize the rate of cooling.

Steve Baer's house presents a very pleasing architecural interior, with natural light diffusing along the spaces between the drums. Such a drum wall may be inexpensive, because the oil drums are mass produced. Its drawback is the larger space consumed by the drums.

Jonathan Hamond, in Davis, California, has used vertical steel culverts as containers. Several buildings in Davis have used these culverts for water walls.

The containers can also be translucent plastic tubes. When filled with water they absorb part of the radiation and trasmit the rest of it indoors. In this way the result is a combination fo Direct Gain and a collecting storage wall.

SYSTEMS BASED ON CONVECTIVE LOOPS

I. General Discussion

The collection principle involved in all convective loop systems is that a fluid in contact with a collector plate is heated, expanded, and rises by natural thermosyphonic action to storage or for direct use, drawing cool fluid after it from the bottom fo the collector.

For space heating, the circulating fluid is normally air, rather than water. Air is a rather poor transfer medium, having low heat capacity. But, far outweighing that shortcoming is the simplicity of sonstructing air collectors and distribution systems, in comparison with the difficulties of plumbing and fabricaiton fo water systems.

Control of unwanted heat gain in summer is perhaps simplest with this system, if provision is made to vent off hot air from the glazed air space to the outside. By incorporating an air-to-water heat exchanger in the convective loop it is also possible to provide year-around hot water.

There is no thermal mass integrally associated with this system, and it must be provided elsewhere, either as a massive building fabric, or as specialized storage such as a rock bed. The best known examples are the Steve Baer system (and modifications by Mark Jones) where the hot air passes through and heat stored in an under-floor rock storage, and the Barra-Constantini system, where hot air from the collectors is passed through channels in a reinforced concrete ceiling.

Convective loops may be designed in two broad configurations:
- Insulatd collecting walls
- Remote collectors

2. Insulated Collecting Walls (4)

The simplest applicable of a convective loop is by integration into a conventional vertical wall (e.g. the Barra-Constantini system). With an insulated wall adjacent to a living space, unwanted heat losses in winter, especially during nights and cloudy periods, and heat gains in summer, are minimized, especially in comparison to the Trombe wall system.

2.1 Design Factors Affecting Performance

Thermal performance of this system depends largely on delicate natural convection currents. Airflow is low to nonexistent at times of little or no sun, but increases rapidly under sunny conditions. The slowly-moving air must come into contact with as much surface area of the collecting element as possible, without being slowed too much. This is typically achieved by routing the airflow over, undre or through corrugated or perforated metal surfaces.

Convective airflow is a result of temperature differences between two sides of the loop, and a chimney effect proportional to the square root of the height of the collector. To obrain the best airflows, insure that air is supplied at the coolest available temperature, and maximize the vertical distance between inlet and outlet.

In the Barra-Constantini system the hot air emerging from the insulated collecting wall flows horizontally, within channel embedded inside a concrete ceiling, and exits from these channels at the Northern part of the building. The air thus warms the Northern rooms first before flowing back through the building space, to the inlets at the lower part of the Southern collecting wall.

Because of its high operating temperatures, higher than in other passive systems, the collector is subject to large heat losses. The rear of the collector is insulated in any case, forming the wall of the interior. It is advisable to detail the collector to minimize exposed unglazed portions, especially at the upper parts. Polystyrene insulation should not be used, as collector temperatures may well exceed its melting point. Infiltration losses can be eliminated by good sealing, but allowance should be made for substantial thermal movements, especially around the glazing.

If no measures are taken to prevent it, the airflow direction will reverse when the collector is cool. There are three simple sutomatic methods to prevent such reverse convection: One is to build the collector below the level of the heat storage or the space to which the heat is supplied. This is the principle of the remote collectors discussed in the next session. A second is to install backdraft dampers, ideally to both inlet and outlet vents. In their simplest form, these consist of a light flap of plastic film acting as a one-way valve preventing reversed flow. The third is to design the collector itself with a cool air "trap", in which cooling air settles in both sides of a "U-tube", thus blocking further air flow.

3. Remote Underfloor Passive Collector

In some situations, it may be possible to locat the convective loop air-collector below the level of the inhabited space which it serves. Typically, this amy occur with single-story swellings on south-facing slopes, or two stories, where the lower story is at least in part garaging and other service spaces. Such systems were developed originally by Steve Baer and Scott Morrris in the USA.

There are three significant potential advantages of this configuration:

(i) The collector, free of a conventional wall, may be tilted to optimize winter energy collection. Note, however, that non-vertical glazing is much more vulnerable to physical damage, (e.g., from hail) and to reduction of transmission due to dust.

(ii) Possible storage potential is much greater. First, specialized thermal storage, such as a rock bed, is conveniently located under the floor, so it is easy to provide sufficient gross heat capacity. Second, utilizing the floor for heating has a number of advantages compared to the overhead storage elements associated with the Barra-Constantini system.

(iii) Prevention of reverse convection is inherent in the geometry, the system supplies heat when the sun shines, but cannot introduce cool air to the interior when the collector heat balance is negative.

SUNSPACES (3, 4)

1. General Discussion

In the section dealing with direct gain solar heating, a number of disadvantages-- arising from the admission of direct sunshine into the inhabited space--were discussed. Most of these problems may be eliminated by the use of aulixiary spaces for the collection fo heat, the so-called "sun spaces". Such "sun spaces" contribute to the thermal comfort of the principle spaces in two main ways:

- By becoming an intermediated environment between the interior and the exterior of the building, they buffer the main spaces from ectremes of exposure, thus reducing the potential temperature fluctuation;
- They optimize the heat collecting capacity of a facade, by allowing larger glazing areas than is practicable with direct gain. Because of their spatial isolation from the main building, a much greater "swing" may be accommodated in sun spaces than can be tolerated in non-isolatd direct gain systems.

By the appropriate provision of shading and ventilation in summer, such spaces may themselves be pleasant environments for intermittent use, during all seasons.

On the other hand, the collection efficiency per unit area of glazing, of sun spaces, as compared with direct gain, is lower, mainly due to the higher daytime temperature in the sun space, which causes a greater heat loss to the outdoors.

From the viewpoint of design and themal characteristics, two types of sun spaces may be distinguished:

- Modified greenhouses
- Sun-porches

2. The Modified Greenhouse

This form, with tilted or curved overhead glazing, serves to maximize incoming radiation, both by the use of the greatest glass area, and by its being tilted--thereby receiving winter sunlight perpendicularly for optimum transmission.

On the other hand, such a form is also subject to the maximum heat losses during periods without sunshine,. particularly by long-wave radiation to a large area of the night sky. Therefore, it has the larger temperature fluctuations, both winter and summer. Similarly, the technical difficulty and cost of using operable shading or insulation on the sloping surface, makes this configuration more susceptible to summer overheating.

3. The "Sun-Porch"

In this form, an opaque and insulated roof is used to eliminate the problems of overhead glazing. As a result, the potential heat gain is diminished, but that for control and human use is greatly extended, especially in hot regions.

As all the glazing is vertical, conventional window elements may be utilized, and if required, both shading and insulation are relatively easy to install. If a sufficient portion of the glazing is made openable, such a space becomes the equivalent of a shaded outdoor porch for summer use, and therefore has been a traditional device in regions with cool winters and hot summers.

4. Building Types with Sunspaces

Sunspaces may be attached to buildings of almost any type, height or size. But there are importnat functional differences between applications, both from the building design considerations and from the energy aspects.

Sun porches can be applied to any building, regardless of its height, because all the glazing is vertical. Sun porches can thus be placed one over the other in multi-storied buildings extending, if so desired, up to the whole facade of the building.

On the other hand, a greenhouse, by definition, has a horizontal or sloping glazing "roof". If placed one on top of the other, the floor of the upper greenhouse will block the sun from the roof of the lower one. Therefore they cannot be placed one on top of the other in multi-storied buildings. There is, of course, still the possibility to place the greenhouses, if they do not extend over the whole width of the facade, in a checkerboard pattern. On this way there is a vertical distance of one floor between the floor of the upper greenhouse and the roof of the lower greenhouse at the same vertical "slice" of the facade.

5. Sunspace/Buildings Plan Relationship (3, 4)

These share one wall with the larger building. They provide the greatest flexibility, for planning and construction, including retrofitting. On regions with favorable energy balance, they allow the use of glazed end walls, for maximum utilization of morning or afternoon sunshine. When the end walls are openable they provide good ventilation potential. especially when the wind direction is nearly parallel to the building.

On the other hand, in unfavorable climates, the end walls will have a negative energy balance, and therefore should be insulated. Having the greatest surface area exposed to the outside, this configuration is subject to both the greatest winter heat loss, and summer heat gain, and therefore the greatest temperature variation.

5.2. Semi-enclosed Sun Space

In this arrangement, the sun space is protected from some of the potential heat losses, thereby increasing its usefulness as part of the usable space. There is a greater variety of possible connections between the dwelling and the sun space, and for a given size of glazing, both the efficiency of collection and of hwat transfer to the habitable rooms are enhanced, compared with simply attached sun spaces.

5.3. Fully Enclosed Sun Spaces

These are sometimes referred to as an atrium. patio or even as a "solar courtyard". As the glazing has to be above the roof, its size is limited; but such designs compensate for their lower heat gain potential by the greatest efficiency of distribution to all living spaces. They have obvious applications in deep plan forms, and with suitably designed openings and shading, may also be used to enhance summer ventilation of the main building.

6. The Connecting Wall (4)

The sunspace may be connected to the main building by a number of design solutions, singly or in combination. Each has different effects on the amount and rate of heat transfer to the main spaces and on their radiant and lghting conditions, as well as on the thermal environment of the sun space itself.

The connecting wall may be one of the following:

- Thermally massive, conductive wall
- Natural convection by large openings (closed at night)
- Glazed wall
- "Internal" Trombe wall (glazed massive wall)
- Water wall

6.1. Thermally Conductive Massive WAll

This may be any of the conventional masonry materials. As in the Trombe wall, it combines the functions of transfer and thermal storage in one element, which is usually an integral part of the building structure as well. According to its thickness and material, it determines the "time lag" between peak collection at the outside face, and delivery of the heat to the interior. However, at night, most of the heat from the wall is actually given up to the sun space itself thereby decreasing its efficiency as a source of useful heat for the interior.

6.2. Operable Openings for Natural Convection

The separating wall in this case may be insulated, and the convection typically takes place through "conventional" openings, such as doors and windows, leading onto the sun space. The critical criteria for efficient natural circulation are the cross-sectional area of the openings, the vertical distance between "supply" and return air paths, and the temperature difference between the sun space and the interior. Air movement may be enhanced by the use of ceiling height door, rather than conventional doors.

6.3. Glazed Wall as the Connecting Element

By placing glazed, operable doors between the sun space and the rooms, the inhabited spaces may benefit from some direct gain, at a reduced rate, while the control of the incoming radiation is, of course, made much easier. For instance, controllable shading, while external to the connecting glazing, is within the protective environment of the sun space, and therefore structurally and functionally simple.

As the glazing is a poor insulation against conduction, operable insulation may need to be provided, both against nighttime heat loss in winter, and heat gain in summer. such insulation can be placed in the sun space where it is easily accessible and storable. The principal benefit of a glazed connection, however, is the light and view transmitted to the interior.

6.4. Collecting Storage Wall within the Sun Space

by placing an additional layer of glass over a massive conducting wall, an internal Trombe wall is created. While the solar energy penertrating the wall surface is somewhat reduced by the multiple glazing, other advantages compensate. First, the sun space protects the Trombe wall against its characteristic high heat loss to the outside - as any heat loss from the wall goes to maintaining temperatures in the sun space. Consequently, higher air temperatures are possible in the gap between the glazing and the wall. This increases the efficiency of transmission through the wall itself; the hot air may also be delivered to remote, north-facing spaces.

6.5. Insulated Glazed Wall within the Sun Space

An additional layer of glazing may be placed in front of an insulated connecting wall. Since the wall itself has no role in transmitting the heat, the principal purpose of this arrangement is to supply air at temperatures higher than those with a conductive wall.

This may then be used for quick heating of the adjacent occupied space--typical applications being schools and offices, where only daytime occupation need be considered. Or the warm air may be routed through air chanels in the structural ceiling, serving as thermal storage, and to heat remote spaces, such as Northern rooms, by convection.

7. Thermal Mass in the Sun Space

If the greenhouse is to be used for anything other than heating air, it must contain some thermal mass to moderate its temperature swings. Without thermal storage, temperature fluctuations of 30°C on clear, cold winter days would not be unusual. The necessary storage mass may be partly in the floor, massive connecting walls or other structural features, or it may be added in the form of large planters, or water containers. Such "additional" mass should ideally be located at the base of the glazing. There it intercepts sunshine which would not, in any case, irradiate the connecting wall, and where the heat given off serves to set up favorable convection patterns in the sun space. Because of the very large ratio of solar glazing to the volume of any practical sun space, relatively large temperature swings may still be experienced, even with the appreciable thermal mass. As discussed previously in dealing with natural convection, such temperature elevation may actually be useful in enhancing air movement from the sun space to the main spaces, thereby reducing the temperature rise itself.

REFERENCES

(1) Balcomb, J.D., Barley, D., McFarland, R., Perry, J., Wray. W,. and Noll, S., **Passive Solar Design Handbook,** Vol.II, U.S. Department of Energy, NTIS, 1980.

(2) Balcomb, J.D., **Heat Storage and Distribution Inside Passive Solar Buildings.** Los Alamos Lab. Report LA-9694-M.S., 1983.

(3) Givoni, B., Passive Solar Systems - An Overview. **Architectural Science Review,** Vol. 24, No. 2, 1981.

(4) Giconi, B., and King, S., **Passive Solar Heating Systems.** Research Report. Institute for Desert Research, Ben Gurion University, Israel, 1982.

(5) Givoni, B., A Generalized Predictive Model for Direct Gain. **Passive Solar Journal,** Vol. 2, No. 2 pp. 107-115, 1983.

(6) Givoni, B., The Effective Heat Capacity in Direct Gain Buildings. submitted to **Passive Solar Journal,** 1985.

(7) Mosed, A., **Experimental Study of Shaded Trombe Wall in Summer.** Research Report. Graduate School of Architecture and Urban Planning, UCLA, 1983.

BG#4

III.2 DAYLIGHTING APPLICATIONS in the UNITED STATES

Charles C. Benton

Assistant Professor of Architecture
University of California, Berkeley
Berkeley, California 94720

Faculty Research Associate
Applied Science Division
Lawrence Berkeley Laboratory

ABSTRACT

Daylight has been an essential element in architectural design through most of history. During the last few decades in the United States, the need for daylight and the architectural talents to harness it have declined due to the availability of inexpensive electrical lighting. However, interest in daylighting has returned with emphasis on energy savings and a higher quality of lighting. This paper surveys the current state of daylighting in the United States.

The paper provides a brief history of daylighting in the United States with an emphasis on the forces that led to the decline of daylighting as the practical illumination strategy. A case is presented for the return of daylight as a predominant source of interior illuminance. Savings are predicted through the reduction of total energy consumption and the peak power demand in commercial buildings. Generic techniques for admitting daylight into buildings are described with their strengths and limitations. A critical review of present daylighting prediction techniques provides coverage of calculation and model based simulation procedures. This is followed by a discussion of solar control and electric lighting integration issues. The paper concludes with the presentation of a case study describing a recently completed office structure featuring several major daylighting innovations.

INTRODUCTION

Light has always been recognized as the principal medium of architecture. Light is shape and perspective, distance, hue, color, shade and depth. Though architecture involves all of our senses it is primarily experienced through these patterns of light. Throughout history, the designers of buildings have carefully and cleverly manipulated the form and fabric of their creations to embrace the rhythms of natural light. Their deliberate efforts are evidenced in our heritage of architectural styles and in the exemplary buildings we collectively hold dear. Daylight constantly changes. While architects can precisely fix the dimensions, materials and patterns of their structures they can not specify a static daylight. Within a logical framework, daylight varies from morning to evening, from season to season and from cloudy skies to clear with countless combinations of direction, intensity, color and character. When all buildings were designed around the sun they shared a common discipline, an order related to the sun and sky as sources of light.

The relationship between architecture and light was profoundly and irreversibly changed a century ago by Thomas Edison's handiwork. Continuing refinements in electrical lighting systems have brought architects literally more light than they know what to do with. [1] By the end of the 1950s, new glazing materials and advances in building cooling systems combined with electrical lighting to displace daylighting as a mandatory architectural issue. With the limitless resources of electrical light, contemporary architects are no longer constrained by a programmatic relationship with the sun and sky. Our electrical light sources are easier to control than daylight and can provide more intense illuminance on a user defined schedule. Theoretically, these capabilities allow fantastic innovations in which sensitively designed lighting fulfills every occupant's needs. The reality has been more prosaic.

In the United States there has been a resurgence of interest in daylighting, largely spurred by efforts to reduce energy consumption in our buildings. Daylighting is an attractive energy conservation strategy for office buildings with their high levels of daytime occupancy and common reliance on electrical lighting. Designers are also rediscovering the qualitative implications of daylighting; an ability of daylight with its patterns and variation to satisfy a basic set of needs in man.

As contemporary designers consider the use of daylight they are faced with a formidable set of challenges. They seek to control a powerful force using skills fundamental to previous generations. Steve Selkowitz, of Lawrence Berkeley Laboratory's Windows and Daylighting Group notes that, "skills in daylighting have been rediscovered after 20 years of dormancy, but the experience which must temper knowledge to produce effective results is frequently lacking." Our current generation of architects has always followed building practices that emphasize mechanistic solutions to the physical aspects of building performance. Attempts to break this pattern in the lighting of buildings must contend with a scarcity of useful information on several fronts. Our collective lack of experience in daylighting is manifest in the difficulty of finding buildings to serve as exemplars or careful documentation of the few contemporary examples that do exist. There are a number of design methods available but many of these are inappropriate for the clear skies predominant in the U.S. and are therefore limited in their usefulness. Data characterizing annual patterns of illuminance from the sky vault are difficult to obtain. In short, there is a pressing need for the development of methods, data and documented examples in support of the new efforts in daylighting design.

This paper will survey the current state of daylighting in the United States. The events that led to our widespread dependence on electrical lighting will be reviewed in the next section. That will be followed by a discussion of traditional architectural approaches to the use of daylight with a few new twists from current research. The paper will also include a discussion of analytical techniques currently in favor for the evaluation of proposed daylighting schemes and a description of a recent building in which daylighting was a major design concern. The concluding section will contain a brief outline of topics for future research. The paper will concentrate on building types in which daylighting can achieve significant energy savings. Though daylighting is appropriate for almost any building type, significant energy savings will only be realized in buildings that are used regularly during daytime hours with lighting needs currently met by electrical lighting. These criteria establish office structures, schools, libraries, warehouses and low rise commercial buildings as prime candidates for the use of daylight. This paper will primarily address daylight in office structures.

BACKGROUND

The opening of the first electric mains in 1882 started the robust growth of the United States electrical utilities. Incandescent bulbs began to immediately replace gas lighting which, in turn, began a steady decline into disuse. The incandescent lamp provided the first practical competitor to open flame sources: the candles, lamps and gas lights that served for so long as the only alternative to daylight. The open flame sources were little competition to daylight in either the quantity or the quality of light that they produced. This, combined with the costs associated with fuels and the soiling from interior combustion, reserved lamplight for times when daylight was not available. Like the open flame sources, incandescent fixtures did little to displace daylight as the prime source of illuminance. The use of incandescent bulbs for the widespread lighting of offices was impractical because of the large amount of heat associated with these relatively inefficient bulbs. This scenario began to change around the 1940s.

Several factors converged in the late 1940s to make daytime electrical illumination practical. Recommended lighting levels were still quite low (when compared to more recent standards) at 161 lux for school classrooms and 215 lux for offices. [2] The fluorescent fixture was becoming a practical alternative to incandescent lighting and offered a substantial reduction in the amount of heat associated with electrical lighting. Electricity in the United States was relatively inexpensive and entering a period in which prices would actually fall over time. Finally, practical systems for the mechanical cooling of commercial structures were becoming available. In this period the British introduced a concept named Permanent Supplementary Artificial Lighting of Interiors (PSALI). This was the first proposal for a lighting system that routinely integrated daylight and electrical light during daytime hours. The PSALI system acknowledged that when deep interiors were daylighted there was often a harsh contrast between interior background surfaces and the bright sky visible through the windows, a range of luminances that exceed the human eye's ability to adapt. In consequence, the back of the room would look too gloomy while the windows appeared too bright. The PSALI system proposed to balance the brightness of exterior window by switching on an electric lighting system. When the daylighting component became brighter, the electrical lighting component would be adjusted upward as well. In fact, the system recommended higher levels of electrical lighting for daytime than for nighttime.

The United Nations Building in New York represents a turning point in the introduction of daytime electrical lighting for office interiors. The UN Building was oriented to view the East River, a decision that exposed the expansive east side of the building to ferocious solar heat gain. Another decision established the building's skin as a flush glass membrane, over the protests of Le Corbusier who desired a brise-soleil. The structure was rendered inhabitable by the talents of Willis Carrier, whose company installed over 5,000 tons of mechanical cooling. The glass which formed the building's skin was an early version of heat absorbing glass, a solar control solution that blocked useful daylight as well as unwanted solar gain. The daylight lost was replaced by electric lighting fixtures. The architectural press of the day hailed the solution as, "... air conditioning and venetian blinds pitted against the powerful sun ...". They might have added "against the heat of electrical lighting" as well.

The United Nations Building heralds several important trends in office building design that began about 1950. Rising land costs led designers to mass buildings as more compact forms. Large buildings traditionally used lightwells, courts and appendages to extend their daylighted perimeter zones. The new buildings had larger, simpler forms which included interior zone areas totally reliant on electrical lighting and HVAC systems. Land costs also led designers to building solutions that stretched from site line to site line. These flush skin buildings, like the UN Building, had to rely on material solutions for solar control rather than shading from building form or external devices. The material solution for solar control was low transmission glass using reflective surfaces or heat absorbing tints to prevent transmitted solar gain. These glazing materials often transmit less than 10% of the natural light available through clear glazing and effectively eliminate interior daylight. Electrical lighting was therefore used not to supplement daylight as in the PSALI concept but to replace it. Extensive mechanical systems were routinely required to remove the internal heat gains associated with electric lighting systems, equipment and occupants. The thermal character of the new office buildings was closely tied to these internal heat gains, and the buildings were often uninhabitable when the mechanical cooling equipment failed or electrical power was not available.

As these developments became standard fare in the 1960s and 1970s they were not considered problematic because of the low cost of energy. For several decades electrical consumption had grown at a fantastic pace, a growth rate that doubled generating capacity every 10 years. The lighting levels recommended for the interiors of office buildings doubled and then doubled again. In the meantime, the skills associated with designing for daylight were lost from the architect's vocabulary. Interiors of office buildings maintained a steady state illuminance that never varied and in the case of heat-of-light systems was maintained for 24 hours a day. These were bad times for daylighting as summarized by Bill Lam in 1979:

> "The current state of daylighting is terrible because the architects are designing the buildings as urban sculpture rather than focusing on user's environmental needs. Buildings are shaped and oriented with no consideration for the sun, then protected against that sun with low transmission and mirror glass. With the addition of interior blinds to control glare, buildings totally covered with glass are effectively windowless, daylightingwise, and require the use of artificial lighting at all times." [3]

A lack of professional interest in daylighting was also evident in architectural education. An entire generation of architects were taught to design with little or no mention of natural lighting in their curricula. Indeed technical issues in general became separated from training in architectural design. Electrical lighting, and other topics related to the physical performance of buildings, were relegated to secondary or tertiary level courses if they were covered at all. The situation was described by Professor Don Prowler in a 1982 report:

> "The success of environmental technology freed the architect of this century from pragmatic concerns of comfort and climate. This has been achieved by the application of increasingly sophisticated and energy-consuming devices which can be located remote from the spaces they serve. This circumstance has reinforced the widely held belief that technics in general, and environmental controls in particular, are independent of form. From this premise, the simple pedagogical result is that technology has become separated from the primary educational experience in schools of architecture today, the design studio." [4]

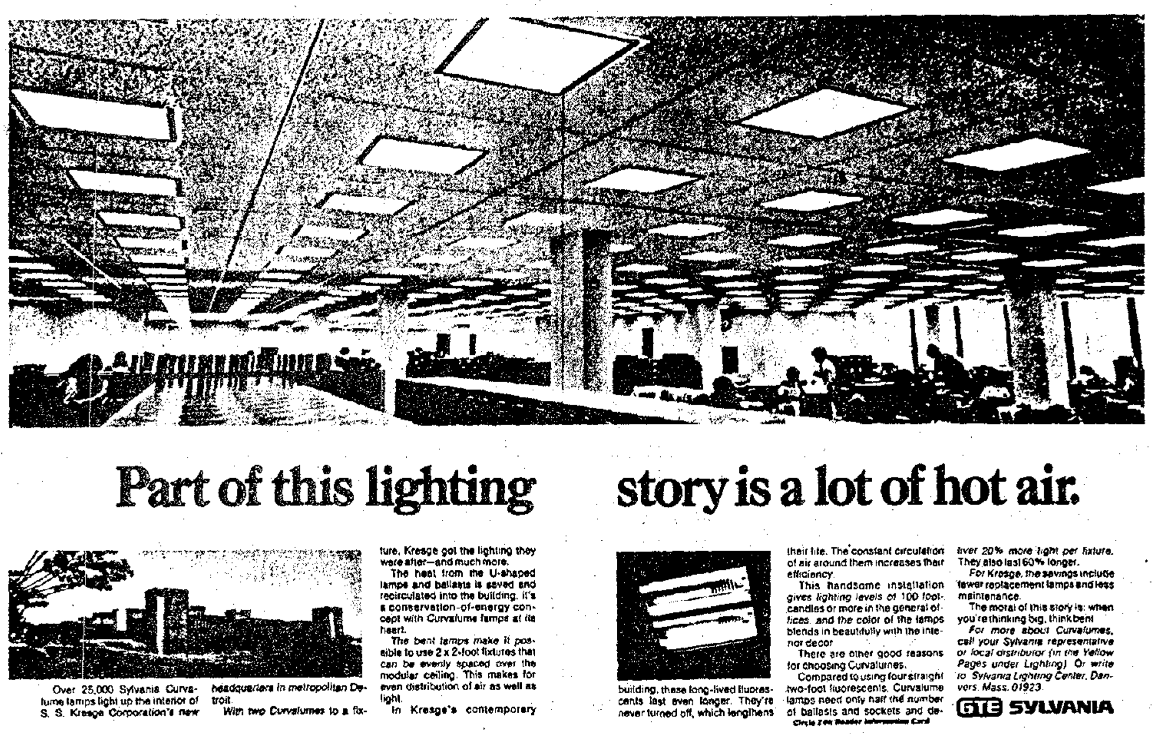
Modern times have brought new pressures to our building industry and the professionals that design buildings. The rapid escalation of fuel prices over the last decade instilled an awareness of fuel as a precious commodity and an honest desire to reduce energy consumption. Early efforts, in both research and practice, were directed toward increased efficiencies in the thermal performance of buildings. Professional research was directed toward issues related to active solar systems, passive solar systems and improvements in HVAC system performance. As these research programs examined the performance of commercial office structures, lighting, responsible for 30% to 50% of office building energy consumption, became an obvious target for belt tightening. Early attempts to improve lighting performance involved the delamping of fixtures and a reduction in illuminance levels. It also seemed that every energy improvement checklist suggested "utilizing daylight" but provided few details on this theme [5]. There is now substantial interest in daylighting as a strategy for the conservation of energy and as a means of deferring the expansion of electrical generating capacity. There are qualitative gains to be made as well.

Daylighting for the Conservation of Energy

The United States' electric utility companies have been through difficult times during the last 15 years. Electrical power is produced by regulated private sector companies in the United States. These companies in aggregate comprise the largest industry in our country and have grown at a phenomenal rate. Rapid growth is no longer possible from the utilities' viewpoint. The high costs of construction and finance (nuclear plants now cost several billions of dollars each and take over a dozen years to build) have dampened the industry's ability and enthusiasm to expand. In the absence of their historical growth rate the generating companies will carefully husband their existing capacity and encourage the conservation of electric power.

Even without major growth, the U.S. utilities have an impressive amount of power to manage. The current generating capacity of our electrical systems is approximately 630 gigawatts. Electrical lighting in commercial and industrial buildings is responsible for approximately 25% of all electrical power consumed (or 5% of total U.S. energy consumption).[6] Roughly another 3% of total U.S. energy is consumed for cooling these buildings. Furthermore, these categories of electrical use in buildings account for a substantial fraction of the peak electrical demand on U.S. utilities, the demand utilities now seek to limit.

FIGURE 1: An office interior from 1970, from an advertisement by Sylvania Lighting



Opportunities for the conservation of electrical power are clear in the case shown in Figure 1, an office building from 1970. This example, made infamous by Richard Stein's book Architecture and Energy, illustrates the excesses of preconservation commercial spaces. The office pictured is illuminated by fluorescent fixtures distributed indiscriminately, or to be more kind, uniformly, over banks of files, desks, corridors, storage and aisles. The fixtures demand about 43 watts of power for each square meter of office space and extend from exterior wall to exterior wall. Substantial conservation gains could be realized in this space through the design of a more sensible electric lighting system. Offices by today's standards will have a connected lighting load of around 21 to 27 watts/square meter instead of 43 watts/square meter. Efficient office structures have achieved lighting loads lower than 11 watts/square meter, and the trend continues downward. Daylighting could, and should, be used to displace electric lighting in the perimeter zones of this type of space. A reasonable objective would be the elimination of daytime electrical lighting in all areas within 5 meters of an exterior wall, a perimeter zone that represents about 25% of the occupied area in a typical, square plan commercial office. Even greater gains can be realized by the design of office structures to increase the amount of occupied area exposed to the perimeter sources of daylight.

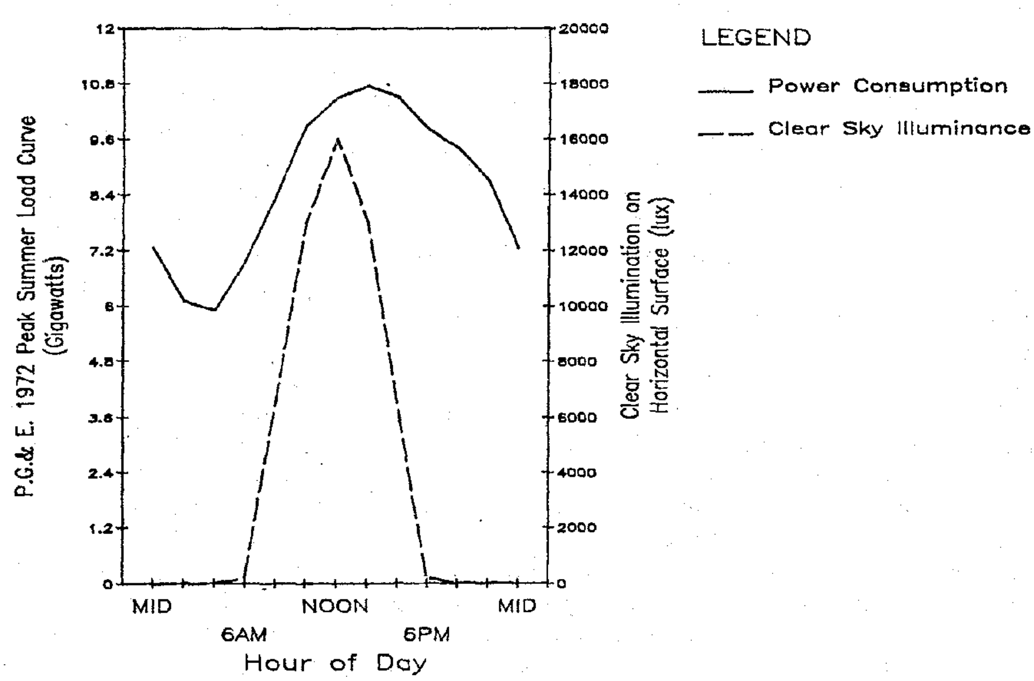
Daylighting for the Reduction of Peak Electrical Demand

Thirty years ago the United States electrical utilities experienced their heaviest demand for electrical power during a cold winter day, with consumption for heating a major component. Since that time the proliferation of air conditioning, principally in sealed commercial buildings, has shifted the period of peak demand to hot summer afternoons. This shift in demand timing began with cities on the Gulf of Mexico, spread steadily northward, and now is the norm nationwide. The use of electricity for lighting and air conditioning, to remove the heat of light, contributes a substantial part of today's peak loads. The utilities, in efforts to reduce the growth of their annual peak loads and consequent pressure to build new plants, use a number of load management strategies. Strategies to reduce peak load growth also minimize a utility's hours of operation near full system load. Overall utility efficiency is low near full load because all generating plants, including the old inefficient ones, must contribute their capacity during the peak hours. In the United States load management techniques are usually "soft", a category in which the utility has no physical control over the patterns of power consumption but seeks to control these patterns through its rate structures. These techniques make it financially disadvantageous for a customer to contribute to a utility's peak load.

Unlike the majority of countries, the United States does not have an electricity pricing policy that varies with time of day (though this pricing structure is beginning to appear). Residential customers pay for the electrical energy they consume with no charges for the pattern of their consumption or contribution to the utility's peak load. Commercial sector firms pay for energy consumed and also for their peak power demand from the utility network. The charge for peak power demand usually represents a significant fraction of a commercial customer's total electrical bill. A feature of the rate structure called "ratcheting" will repeat the monthly billing for a particularly high demand for a full year.

Consider the following example used by Steve Selkowitz in discussing the peak savings potential of daylighting.[7] A typical all electric office building uses 30 to 50 percent of its peak energy consumption for electric lighting.[8] Assume that one-third of the usable floor space occurs in perimeter zones with close proximity to windows. The maximum potential daylight savings is thus one-third of the 30 to 50 percent, or 10 to 15 percent of total energy. If 50 percent of the potential energy savings are actually achieved with dimming controls, daylighting can save roughly 5 to 8 percent of the total building energy consumption. This is an attractive reduction of energy consumption, and parallel gains are made in reducing the peak power demand. With a connected lighting load of 33 watts/square meter for the entire structure, daylighting can be expected to eliminate the entire perimeter zone lighting portion of peak demand. As shown in Figure 2, one of the handsome relationships between daylight and peak demand is that they have coincidental peaks. When the incentives to reduce power consumption for electrical lighting are the greatest there is ample daylight available to fill in. Daylighting can thus trim 11 watts/square meter (one third of the 33 watts/square meter lighting load) from the peak demand. Under summer peak conditions, typical cooling loads amount to 50 to 100 watts/square meter. With a net COP of 2, the cooling power requirement is then 25 to 50 watts/square meter of which perhaps 15 watts/square meter represents cooling loads due to lighting. Under peak load conditions if we turn out the electric lights in the one-third of the building for which daylighting is adequate then we have reduced the building's peak power consumption by 16 watts/square meter, 11 watts/square meter for the lighting and an additional 5 watts/square meter for the reduced cooling load. This reduction is roughly 10 to 20 percent of the building's normal peak power consumption, a significant improvement.

FIGURE 2: Timing of peak electrical power demand and daylight availability



The cost of new power plant construction is frequently in the range of $1.00 to $2.00 per peak watt of installed power. In a new building, a 14 square meter office with lighting at 33 watts/square meter requires an investment by the utility company of $450 to $900 in new generating capacity if the lighting is a contributor to the utility system peak demand. It appears that responsive dimming controls could be installed in such a perimeter office for considerably less money than the utility investment to supply electricity at periods of peak demand. Thus good daylighting design and effective lighting control systems not only save energy, but reduce the pressure for new electrical power generating resources. In fact, a number of utilities have begun programs that provide attractive incentives for their customers to include daylighting features in new buildings. These incentives include financing by the utility for preconstruction daylighting studies and the rebate of utility fees for customers with high performance buildings.

Daylighting for the Benefit of Building Occupants

The building occupant can benefit from more than energy savings if his building has an effective daylighting scheme. Studies by the General Services Administration and the IBM Corporation calculate that, over the 40 year life-span of an office, personnel costs amount to 92 percent of owning and operating a structure. These findings were supported by a four year intensive study conducted by the Buffalo Organization for Social and Technological Innovation (BOSTI). BOSTI released a detailed report in 1982 which concluded that a corporate investment in quality workspaces can be worth up to $8,000 per employee with regard to productivity and job satisfaction. In any event, personnel costs far exceed those for all energy consumption. A small increase in employee productivity, therefore, can translate into considerable savings. Recent research also indicates that job performance is associated with worker satisfaction with office environments [9]. In research by Jean Wineman at the Georgia Institute of Technology, lighting quality, daylighting and view were identified as particularly important features affecting worker satisfaction with the work environment. [10] The ability of daylight to affect worker satisfaction with office environments is germane to the architectural decision-making process.

Daylight as a source of light varies over time in a predictable manner (daily and seasonal cycles) as well as in unpredictable patterns due to cloud cover and other climatic variables. The variable nature of this source might appear to be an undesirable feature for our indoor environments characterized by uniform temperature and uniform electric lighting levels. However, there is evidence to suggest that, when compared to uniform electric lighting, people value and even prefer the changes and variability introduced by daylight in a room. Daylighting from windows introduces modeling effects which, if well controlled, are pleasing and desirable. Since the eye and brain evolved under daylight, its color temperatures are pleasing and its color rendering properties excellent.

In addition to these positive qualities, William Lam, in his book Lighting and Perception as Formgivers in Architecture, makes the case for a set of lighting criteria that are related to man's subconscious needs for information. Lam defines a set of issues that are subconsciously important to our survival as biological organisms, issues which he labels "biological needs". In patterns as old as man, Lam asserts that when we are explicitly engrossed in a task we become relatively unconscious and unconcerned about the events around us, and any irrelevant visual information may be an undesired distraction.

> "But as formal tasks demand less focus, or as our attention strays, the focus of perception turns to the search for information related to the satisfaction of biological needs. We subconsciously seek facts of orientation: where we are, the shape and structure of the space, the nature and quality of the furnishings and finishes, the identity of our neighbors, who they are and what they are doing, the time of day and the weather. Our senses are constantly monitoring the environment for signs of change."[11]

This process at times becomes conscious. Among the most important biological needs for environmental information, Lam lists an awareness of the following:

TERRITORY, its boundaries and the means available within a given environment for the personalization of space.

PLACES of REFUGE, opportunities for shelter in time of perceived need.

OTHER LIVING THINGS, an awareness of other living things, plants, animals and people.

TIME, and environmental conditions which relate to our innate biological clocks.

WEATHER, as it relates to the need for clothing and heating and cooling, the need for shelter, opportunities to bask in the beneficial rays of the sun, etc.

LOCATION, with regard to water, heat, food, sunlight, escape routes, destination, etc.

ENCLOSURE, the safety of the structure, the location and nature of environmental controls, protection from cold, heat, rain, etc.

RELAXATION and STIMULATION of the body, mind and senses.

Changes in the perceived status of these important aspects of the environment trigger warning signals in the brain, demanding attention. It should be noted that the last five items on the list above have direct relationships to daylighting systems. Daylight provides an excellent information for time orientation, on both a daily and seasonal cycle. Visible evidence in the presence of sunlight provides important clues about three dimensional form and orientation in addition to indicating the state of the weather. It is axiomatic that the view outdoors associated with daylighting provides relaxation and stimulation for the occupants of buildings. Unlike the sources of daylight, light fixtures seem arbitrary and out of place, distracting, glaring and informationless rather than pleasing. They are the providers of light and little else. Thus the qualitative aspects of a daylighting scheme can provide incentives to use daylight that equal those related to energy savings and peak power reduction.

In summary, strong arguments exist for the use of daylight in lieu of electrical lighting. Daylight can lower electrical energy consumption by reducing daytime perimeter zone electrical lighting and the cooling associated with it. It can also shave valuable kilowatts from a building's peak electrical demand for the year. Finally, there is a tangible improvement in the quality of light from a well designed daylighting system, a qualitative improvement that satisfies basic biological needs of the building's occupants and thus increases worker satisfaction.

Despite the attractive advantages that daylighting offers there is still a reluctance by the design community to fully embrace its use. In part this is due to inertia; historically change comes slowly in the building industry. As previously mentioned, there are institutional barriers to the implementation of daylighting such as the absence of daylighting from professional curricula, a shortage of well-documented examples of daylighted buildings and lack of effective, practical design methods. There is, however, progress on several fronts. The codes and regulations that govern the way we build are requiring more efficient designs. For example, the State of California has enacted legislation that establishes the maximum office structure electric lighting density as 16 watts/square meter effective 1986. This reduction in allowable electric lighting from a previous maximum of 33 watts/square meter will force designers to choose between fairly dim interiors and the use of daylighting. Research programs, like the Windows and Daylighting Group at Lawrence Berkeley Laboratory (LBL), are beginning to provide the design community with daylighting methods and documented case studies. The dissemination of this information fills a void that has hampered daylighting efforts in recent years. The next few pages will review a series of approaches for the use of daylight in buildings and cover the system components required for a successful job.

DAYLIGHTING SYSTEM DESIGN

In passive solar design, it is axiomatic that the building envelope should be insulated to relatively high efficiencies before investment is made in the passive solar components. As the building envelope increases in efficiency the heating load remaining for the solar system becomes smaller and smaller. In recent times, some passive heating schemes have dropped the solar component altogether and rely on superinsulated envelopes alone to protect the house from the harsh winter. An analogous situation exists for daylighting schemes; electric lighting systems that supplement daylight should be relatively efficient and include effective controls. As the electrical lighting system becomes more efficient, the savings from operation using daylight instead of electricity are reduced. Though this increases the amount of time required to pay back investments in a daylighting system, there are normally adequate economic incentives for the inclusion of daylighting. In addition, there remain strong qualitative reasons to opt for daylighting instead of the electric lighting system. Approaches to efficient lighting system design will include the following:

EFFICIENT LIGHTING HARDWARE - Lighting conservation technologies exist that permit lighting power densities in offices as low as 8 to 11 watts/square meter. Current fluorescent lamps and ballast systems have a combined efficiency of 50 to 70 lumens/watt, with most common 1.2 meter units averaging 60 lumens/watt. Electronic ballasts, improved phosphors, narrow lamp tubes and higher output fixtures are currently available and can boost fluorescent system efficacies to the 100 lumens/watt range. The high pressure sodium and other HID light sources are also gaining acceptance in office environments despite poor color rendition properties.

IMPROVED DESIGN PRACTICES - As installed lighting power densities decrease, effective lighting design becomes critical to achieve acceptable lighting environments. For instance, the differentiation between task lighting (limited in area, task specific) and ambient lighting (widespread, general circulation) is an effective design strategy in reducing electric lighting levels.

IMPROVED OPERATION and MAINTENANCE - As with HVAC systems even the best system design and hardware will not function well in the absence of good management. Lighting schedules and maintenance become critical factors when dealing with high efficiency lighting systems.

INTEGRATION with DAYLIGHTING - Even the most effective strategy to daylight building interiors will fail to save energy if the electric lights are left on. The proper integration of electrical and daylighting systems poses an interesting and challenging set of issues. The designer must decide to what extent the user can provide effective lighting management and establish a system that captures the maximum possible benefit from interior daylight.

With a commitment to the design of an effective electrical lighting system the designer can turn his attention to the elements of the daylighting system. Several major issues must be considered in the course of this task. The designer must identify the building design strategy that will admit natural light into his interiors. The process should include analysis to evaluate the tradeoffs between thermal and luminous energy gains. It is important in the early stages of design to identify methods for control of the system. Two major control categories are the control of solar gain to minimize adverse thermal impacts and the control of electric lighting systems to claim the energy savings made possible by daylighting. This section will review these design and control issues.

ADMITTING DAYLIGHT

Natural lighting techniques encompass both the use of diffuse light from the sky (daylight) and direct beam radiation from the sun (sunlight). There are two major categories for the schemes that admit this light into buildings. Sidelighting is the use of natural light transmitted through vertical building surfaces, the windows common to single and multistory buildings. Toplighting involves the use of skylights either in the form of horizontal aperture or vertical roof monitors to admit light into an interior from above. Toplighting is characteristically limited to structures of one or two stories. Another relatively small category of daylighting is the rather esoteric use of optical systems to transmit beam daylight into deep interior spaces. Each of these approaches has its merits, and each is receiving attention in today's daylighting designs.

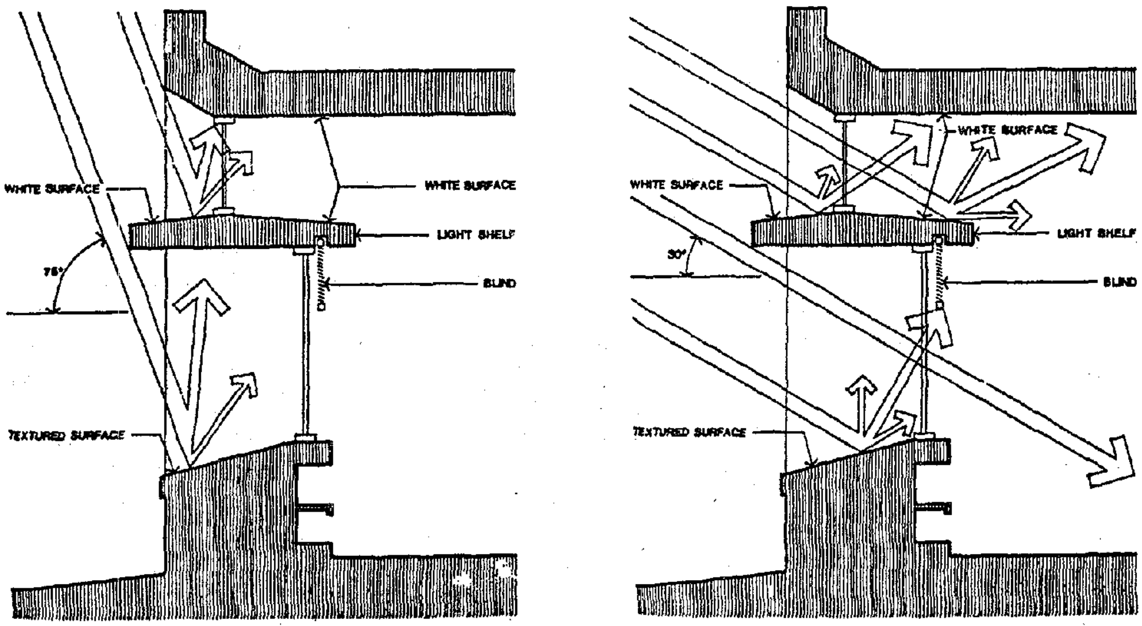
Sidelighting

Sidelighting is the most widely applied of daylighting strategies requiring elements already common to perimeter zone offices. Sidelighting approaches can be divided into two categories: 1) the lighting of perimeter zones adjacent to vertical glazing and 2) the distribution of sidelighting into interior zones more remote from the exterior glass. A rule of thumb developed for diffuse daylight is that useful daylight penetration rarely exceeds 2 to 3 times the height of vertical glazing. Using this guideline, perimeter zone daylighting is limited to depths of 6 to 8 meters for buildings with conventional ceiling heights of about 3 meters. Daylighting within these limits can be accomplished using relatively conventional window designs which rely on the diffuse component of daylight as a source and specifically exclude direct beam solar radiation. Daylight penetration deeper than 8 meters, however, typically requires the use of beam sunlight and an accurate means of directing it toward the interior of the building. Systems that control direct sunlight, whether they are composed of architectural or optical elements, are sensitive to the position of the sun and thus window orientation, hours of use and time of year.

The greatest opportunities for sidelighting exist in easily lit exterior zones. As in discussions of thermal performance, the exterior zone of a building is taken to be areas within 4 to 6 meters of the exterior wall. Within these limits it should be possible to provide daylighting at a level of 500 lux for 70 to 90 percent of daytime operating hours (depending on details of climate and orientation). In fact, it is relatively easy to provide daylight levels in excess of the nominal 500 lux typical of office lighting design. Excessive daylight levels, however, frequently introduce unnecessary cooling loads and suggest a shortcoming in system design or control. Though daylighting the perimeter zone is easily accomplished with conventional building elements, a survey of contemporary U.S. office buildings would reveal few daylighting applications. Current design practices exclude the electric lighting control systems necessary to realize savings from available daylight. Solutions to the control of solar gain and glare commonly rely on low transmission glazing which also rejects daylight. Small changes in design attitude could produce large daylight benefits.

The introduction of daylight beyond the 6-meter perimeter zone boundary requires a different type of design. Apertures for deep penetration systems are typically larger and feature provision for the reflection of beam sunlight. The use of direct sunlight challenges the designer to solve simultaneous requirements for deep light penetration and the control of glare. Most techniques for deeper lighting involve architectural manipulation to raise the height of the window head and ceiling. The increased window height provides more daylight penetration due to larger glazed areas and a higher daylighting source. It also exposes occupants near the window to higher levels of glare (view of the upper sky) and direct sunlight. The larger window provides too much light for the zone immediately adjacent to the exterior wall. It would be useful to displace the light flux

FIGURE 3: A generic lightshelf



unneeded in the perimeter to locations deeper within the building. One architectural approach to achieving this objective is the use of a horizontal light reflecting/shading element between the upper and lower portions of glazing. Such an element, popularly called a lightshelf, is illustrated in Figure 3. The lightshelf is typically located 2 to 2.5 meters above the floor with a meter or more of clear glazing above it. The upper surface of the shelf is finished as a diffuse or specular reflector and serves to bounce beam sunlight deeper into the space. The shelf also serves the space below it as a shading device and delimiter of space. This exterior space will normally have some type of glare control for the lower glazing.

Lightshelves have gained popularity due to their apparent simplicity. An example of one lightshelf application will be provided in the case study section of this paper. Sidelighting the deeper interior zones is somewhat less dependable than applications in the perimeter areas. The lightshelf scheme requires beam sunlight for effective performance and may not project light effectively under cloudy, diffuse conditions. Under these conditions daylight may be inadequate for task illuminance but perform admirably as a source of ambient light.

Toplighting

As illustrated by the Pantheon in Rome, toplighting is a venerable strategy for the admission of daylight. Toplighting, or the admission of daylight through the roof plane, is a technique appropriate for single story buildings and the top floors of multistory structures. Occasionally, toplighting systems are used to light more than one floor level when the upper floors have openings to allow light to filter through. Unlike sidelighting, where spatial relationships limit the penetration of natural light, toplit spaces can rely entirely on daylight.

Daylighting systems in the roof plane will use one of two geometries: 1) flat or bubble glazing in a horizontal plane or 2) vertical or sloped glazing in a roof monitor. Though most modern skylights adopt the horizontal plane configuration it is the least desirable of the two. The fundamental difficulty with horizontal glazing is the pattern in which it receives solar radiation. Heat gains peak in the summer, and represent a major cooling liability, while winter gains are relatively low. Nevertheless, horizontal glazing remains popular because skylights are available as manufactured, single unit components which are easy and relatively inexpensive to install. Recent developments in the use of horizontal apertures for daylighting include the development of reflecting devices that enhance skylight performance and the use of fabric roofs. The reflector scheme involves the placement of a specularly reflecting surface to the north of a horizontal skylight to increase its apparent aperture and redirect beam sunlight. In some cases the reflector is mounted on a motorized carriage and serves as a single axis tracking system. The fabric roof solution has been used in a number of structures, a majority of which are athletic facilities. The approach uses a low transmission translucent fabric to form a major area of the structure's roof. Both of these developments are subject to the adverse heat impact problem previously mentioned.

Roof monitors were once a common element in the architectural vocabulary and can be found in some diversity when inspecting older warehouses and industrial buildings. In these older buildings, with their high ceiling heights, roof monitors provided excellent control of incident daylight as well as openings for natural ventilation. As a rule the older examples of roof monitors excluded all direct radiation. This property is a characteristic of glazing orientation and geometry. North facing monitors admit diffuse light but very little solar heat while southern orientations provide diffuse light, beam sunlight and winter heat.

ANALYTICAL TECHNIQUES - CALCULATION

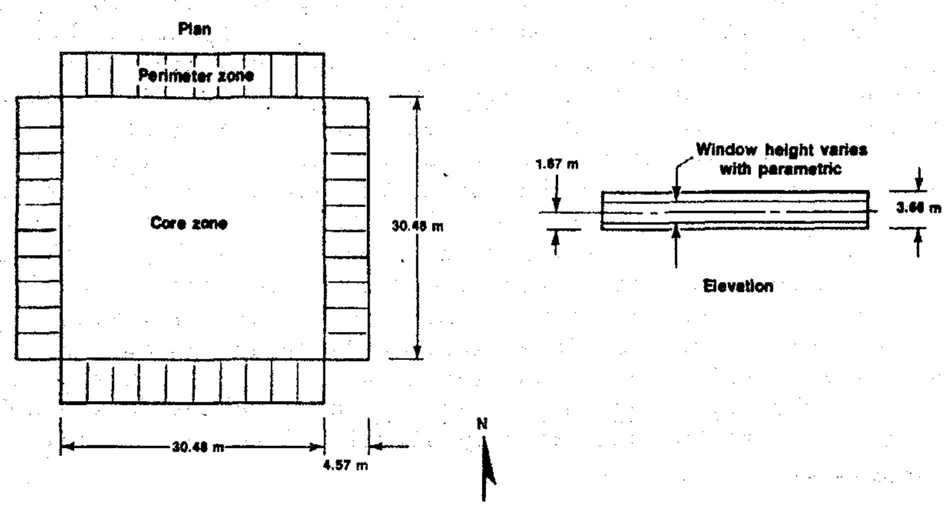
Having identified a daylighting strategy, the designer's next challenge is evaluating its performance. The ideal calculation method would provide a designer with information on system performance during the early stages of the design process when decisions regarding architectural form and materials are first made. The calculations would ideally provide insight into the interaction of building lighting and HVAC systems and a profile of the relative merits of various control strategies. Such a tool does not exist. At this time there is a shortage of effective, widely used daylighting design methods in the United States. The problem is not a lack of design methods; 58 are listed in a 1970 CIE publication. [14] However, the majority of these calculation techniques were developed for European countries with their predominantly cloudy climates, for instance, the Daylight Factor Method. The United States, in contrast, features clear skies in many areas and therefore requires different calculation procedures. Clear sky calculation techniques do exist in the Lumen Method, documented in the <u>IES Recommended Practices</u> and its cousin the LOF method. These calculation techniques are very simplified and of limited use in actual practice.

The calculation methods that are available take many forms: microcomputer programs, diagrams, protractors, nomographs and tabular methods. There has been a long succession of advancements to both the Lumen Method and the Daylight Factor Method but despite the efforts of many contributors they remain only marginally useful. The assumptions that allow the calculations to be simplified play a major role in limiting their usefulness. The simplified techniques might be considered more educational than analytical. At the other end of the spectrum are a set of relatively complex mainframe computer simulation programs. Major routines like LUMEN II, SUPERLITE and DOE 2.1B combine a more detailed set of computational procedures with the ability to model more complex situations. In the case of DOE 2.1B, the computer can conduct an integrated analysis of lighting and thermal performance. These programs exact the price of complexity for their ability to simulate detailed building performance. This complexity limits their usefulness during the critical early stages of building design.

The simulation program DOE 2.1B is an extremely complex tool and is rarely used except in the later stages of the design process or in research programs. The program can, however, provide some valuable insight regarding the interaction of thermal and daylighting issues when used to simulate generic building schemes. An example of this process is provided by a recent Lawrence Berkeley Laboratory study on glazing systems and design optimization. [15] The study systematically explored the influence of glazing systems on component loads and annual energy use in prototypical office buildings. Parametric studies examined the sensitivity of total building energy use to changes in orientation, window area, glazing properties (U-value, shading coefficient, visible transmittance), window management strategy, installed lighting power, and lighting control strategy. The results provided a fascinating view of the interdependence of thermal and daylighting components and the pitfalls associated with designing for one and ignoring the other.

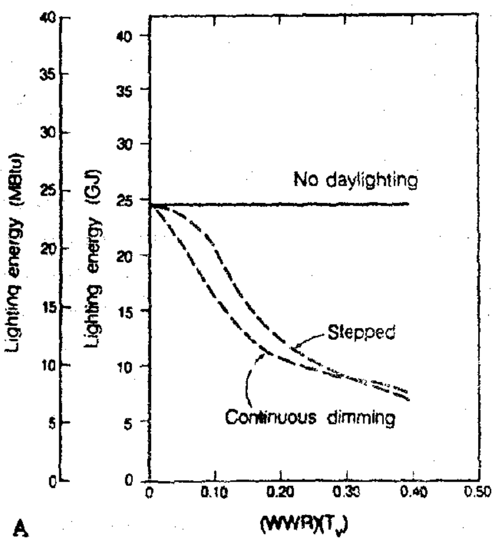
Though a complete description of LBL's study is beyond the scope of this paper, a brief description of their process is in order. To study the effects of fenestration design on building energy performance, a five zone

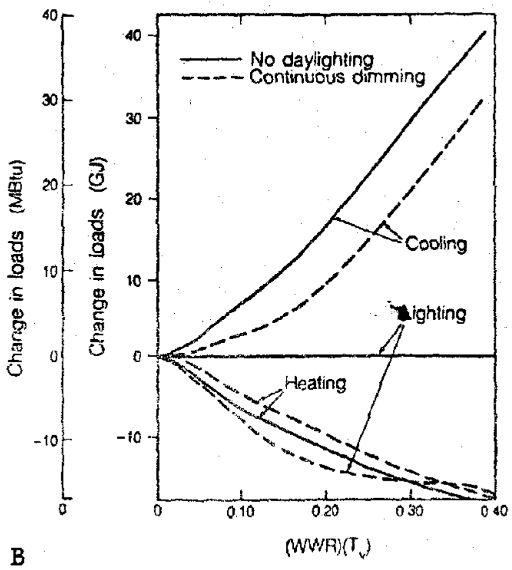
FIGURE 4: Zone diagram DOE 2.1B simulation runs [15]



module was designed to represent typical commercial office design (see Figure 4). DOE 2.1B computer simulations were conducted on this base model and variations that represented systematic changes in each design variable. The numerous parametric runs provided a data base that demonstrates the complexity of daylighting energy analysis relative to each of the varied features. Figure 5 provides an example of the reduced data from simulation runs for a south facing perimeter zone in Madison, Wisconsin, a heating dominated climate. These graphs plot various types of annual south zone energy consumption against a composite parameter, the "effective aperture" (WWR)(Tv), which is the product of the floor-to-ceiling window-to-wall ratio (WWR) and the glazing's visible transmittance (Tv). The first plot illustrates lighting energy consumption with three control strategies. The

FIGURE 5: Results of DOE 2.1B simulations

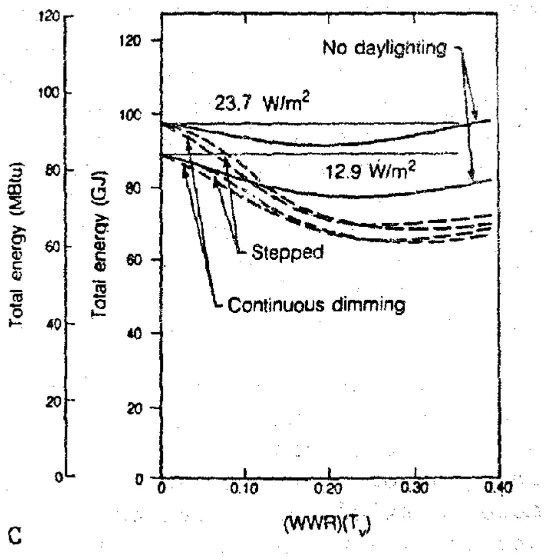




A) Annual lighting energy as a function of effective aperture for Madison, WI, south zone, 18.3 watts/square meter.

B) Changes in annual zone load component energy quantities as a function of effective aperture for Madison, WI, south zone, 1.7 watts/square meter.

C) Annual total energy use as a function of effective aperture for Madison, WI, south perimeter zone, 23.7 watts/square meter and 12.9 watts/square meter.



base case of no daylighting is compared to an on-off control system and a continuously dimming control system designed to maintain a 550 lux illuminance level. As expected both daylighting control strategies produce tangible savings. The second plot examines the various components of the building's annual energy consumption and their relationship to effective aperture. As expected, increased window areas prove to be an asset for heating and daylighting while a liability for cooling. The final plot examines the combination of thermal and lighting issues in a plot of total energy consumption against effective aperture for two different electric lighting densities. The data indicate continuously improving building performance until the effective aperture reaches a value of approximately 0.20. This type of data could prove very useful to the building designer if it were accessible for his building during the formative stages of design.

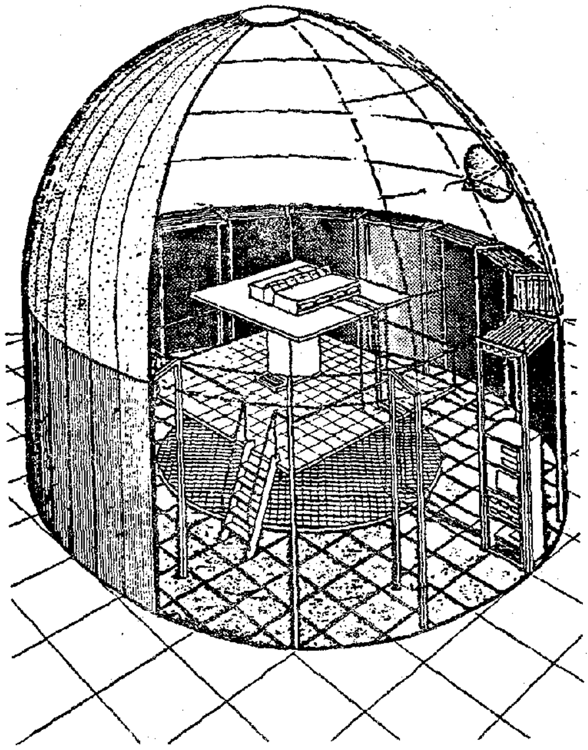
The developers of design tools are faced with exciting challenges in the areas of building energy simulation. There is a marked need for integrated tools that combine analyses of thermal and luminous performance at the early stages of the design process. A second layer of complexity is introduced with the problem of accurately modeling the interaction of building occupants with these energy consuming systems. Recent developments in the area of microcomputer workstation hardware offer encouragement that the processing horsepower will exist for this type of tool. The availability of such a validated computer model will have important implications for the building designers who must now make difficult decisions regarding optimization, frequently without sufficient information. In the absence of an effective computer-based method, many designers are using three dimensional models for daylighting analysis.

ANALYTICAL TECHNIQUES - THREE DIMENSIONAL MODELS

Design studies using scale models are a traditional technique in architectural practice. Scale models constructed specifically for daylighting analysis can provide valuable information at all stages of the design process. Lighting effects are scale independent and can be accurately simulated in scale representations of architectural space. Quantitative measurements in an accurate model will match corresponding measurements in the actual space. Glare conditions noted in a model will occur in the full-scale space as well. Visual photographic images from an exacting model will strongly correspond to the space it represents. The model is a tool of practical use to the building designer. Models can be used to evaluate the performance of daylighting components such as glazing systems or shading devices. During the early design phase, scale models can replace or compliment other simplified calculations and they provide essential information about the quality of daylighting in the later stages of design. An important characteristic of three dimensional studies is their ability to simulate rather complex geometries which defy other analytical approaches.

Daylighting models are constructed at different levels of precision and time investment. During the early stages of the design process, quick sketch models can be used for making comparative studies of the size and location of apertures and reflecting surfaces. During design development, more detailed models can assist in the fine tuning of daylight distribution and provide visual checks for the presence of glare and contrast. In the

FIGURE 6: The sky simulator at the University of California, a Lawrence Berkeley Laboratory facility



final stages of contract document preparation, full-scale mock-ups of spaces are sometimes constructed as the ultimate modeling exercise. These spaces are used to test occupant reactions to daylighting systems, controls, electrical lighting, furniture, and interior visual comfort.

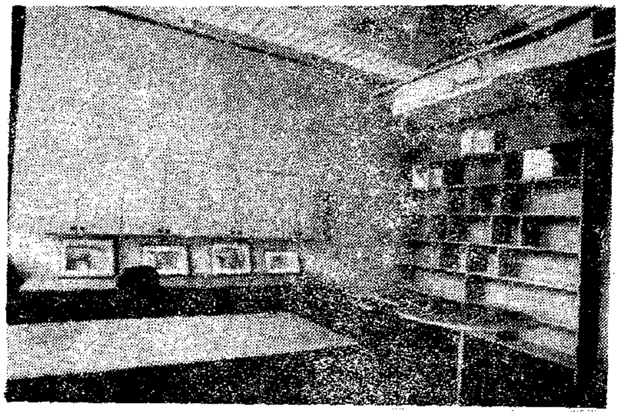
Daylighting models are also used in the support of research. While the typical design model is tested under real sky conditions, research applications demand a constant sky for comparative studies. The Lawrence Berkeley Laboratory and several U.S. universities maintain artificial skies for exacting model studies. These electrically illuminated sky simulators provide the stable reference sky conditions necessary for research.

The visual accuracy of daylighting models can be illustrated with the products of a student exercise. In a series of graduate studios at the College of Architecture at Georgia Tech, daylighting models were used to introduce an analytical method in the studio. Rather than asking the students to accept the validity of the modeling technique, the studios began with a proof-of-concept exercise. In the studio's first week, students worked in groups of two to construct a modular model of an existing space.

This model was then compared to the space it represented using photographic techniques for qualitative documentation and photometric meters to compare illuminance levels (figures 7-10). The iterative exercise included the development of isolux contours in plan form and refinement of the model until comparative measurements differed by no more than 20%. After verifying the predictive powers of the modeling technique, students used the model to redesign the space in question.

FIGURE 7: Actual office space

FIGURE 8: Scale model of existing office space



The exercise provides a convincing demonstration of models as a powerful tool for analyzing and presenting the daylighting performance of a design scheme. In addition, the model-based analysis uses skills commonly found in the studio setting. The most common problem with the project is a tendency for students to become overenthusiastic in modeling the details of the space. Though this increases the realism of the model photographs, the majority of this detail has minimal effect on light distribution in the space. The introduction of analytical techniques during a studio exercise provides a welcome yardstick with which students can measure the consequences of their design decisions.

Though models are an extremely powerful visual tool they still do not provide analytical data that integrates thermal and luminous performance. There are some techniques in which data from model studies are used to profile electric lighting schedules in hourly simulation programs. Until advanced simulation tools are developed for the early stages of design, models will remain the most versatile and popular analytical technique.

FIGURE 9: Model of redesigned office space

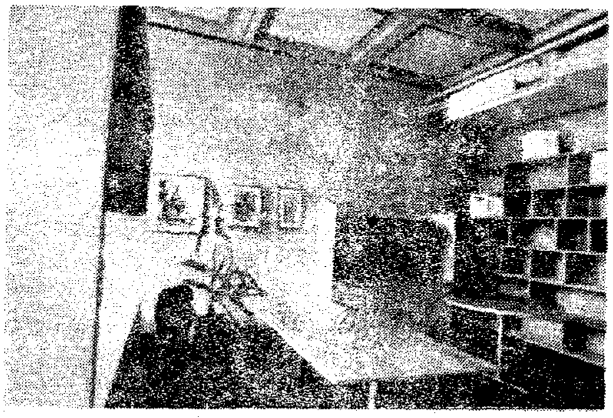
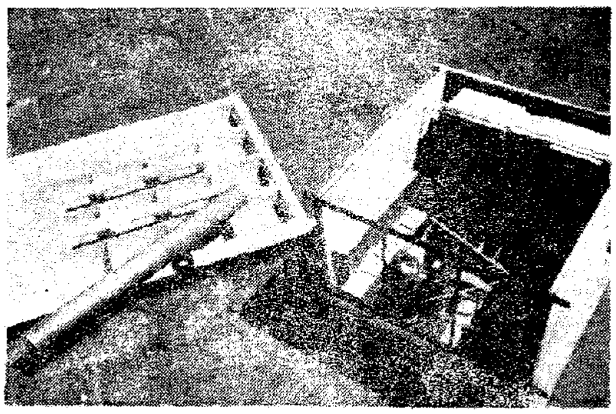


FIGURE 10: Scale model, exterior view



SOLAR CONTROL SYSTEMS

After a preferred technique for daylighting analysis is established, there remains the challenge of balancing fenestration design to meet both thermal and luminous design criteria. The sleek, all glass buildings that dot our modern landscape could not have been built without the use of high performance solar control glazing systems. However, high performance glazing is but one of many solar control options available for protection from solar heat gain. Alternatives include exterior architectural appendages such as screens, shutters and blinds and interior devices like drapes, louvers and venetian blinds. The exterior devices are more effective at blocking solar gain but are usually fixed in a single position. The interior options provide user control at relatively low expense but are less effective at reducing heat gain. A wealth of solar control devices have been investigated and documented during the course of this century. [16]

As a rule, if both thermal and lighting criteria are taken into consideration, a fixed shading device is the least effective. A simple solution which is permanent and fixed lacks the flexibility to meet performance criteria that shift with season and time. For example, the low transmittance glazings are a fixed solution that shades effectively but also eliminates daylighting potential in a building. Optimal shading performance would probably come from an exterior mounted, motorized device with automated controls. Unfortunately this type of solution is burdened by high costs and maintenance. A compromise solution involves user controlled, operable shading devices. In this case costs are lower but there is uncertainty regarding the effectiveness of the human component. The sensitive and well informed occupant can become an important part of the system.

A shading system also becomes a line of defense against glare. In this case occupants can be relied on to implement protective measures. The building designer must balance requirements for sun control and glare control against the necessity for relatively high light transmission required for adequate daylighting in buildings. A variety of automatic and manually controlled strategies are available to the designer although the ramifications of user participation and actual product performance are not well known. If undesired solar gain is not effectively excluded from a daylighted room, the resultant cooling energy consumption may reduce or eliminate daylighting energy savings.

ELECTRIC LIGHT CONTROL SYSTEMS

All buildings with windows or skylights are daylighted. Only those buildings with effective control systems for their electrical lights will save energy and reduce peak loads. The earliest electric lighting control systems were manually operated switches that existed as part of the lighting fixture. As electric lighting hardware became more advanced, switching systems were centralized until by the 1960s it was not uncommon for an entire floor to have a single light switch. This trend reduced hardware costs but also eliminated the means for individual control of local lighting. As energy conservation criteria increased in importance, switching systems became more sophisticated. The trend in electric fixture switching is toward automated controls that serve a number of purposes. With fluorescent lighting systems these controls can operate as on-off switches, provide a step series of possible lighting outputs by switching individual bulbs or, with advanced ballasts, provide a continuous range of light output. Control systems are applied to the following tasks:

OCCUPANCY SCHEDULING - Electric lights should be turned off or dimmed during periods of low occupancy or periods when visual tasks are not demanding. There are an array of control techniques to provide this switching ranging from the simplest, manual switches, to time clocks, microprocessor-based systems and motion detectors.

FINE TUNING - This strategy refers to tailoring the illuminance level to the specific requirements of a particular time and place. In speculative office buildings lighting systems are commonly designed without knowledge of the visual needs of the ultimate occupants of the space. The normal processes of changing occupancy and furniture placement suggest a corresponding ability to revise lighting fixture performance. The cost of moving fixtures is often too expensive for minor changes and, historically, designers have simply sized fixtures for the worst case lighting needs. A more sensitive solution would allow an adjustment of individual fixture output using multilevel switching or dimming controls.

LUMEN MAINTENANCE - The light produced by newly installed lighting systems is normally 20% to 40% higher than the lighting design level. This is due to a calculated factor that accounts for decreases in light level as lamps, fixtures and hardware age. Thus new fixtures provide illuminance in excess of the design target. Lumen maintenance systems are designed to sense the actual illuminance level in the space and reduce lighting system output so that only the desired illuminance is maintained.

DAYLIGHTING CONTROLS - Where daylighting lights an interior space through windows and/or skylights, the electrical illuminance can be reduced correspondingly. The simplest control hardware is capable of turning lights on and off. More sophisticated systems can dim fixtures through a continuous range of light outputs. In offices, schools and other spaces where critical visual tasks are performed, continuously dimming control systems are preferable to step or on-off techniques. In warehouses and spaces housing less visually critical activities, on-off, one step dimming techniques may be adequate and more cost effective. Because of the dynamic effects of daylighting illumination, centrally controlled systems are not optimal solutions for large spaces. A high performance approach combines solid-state ballasts and front-end current limiters that respond to independent control of smaller spaces.

Despite an apparent logical simplicity, switching systems for the control of daylighted spaces are quite difficult to implement. A variety of questions face the designer. For example, should photocell sensors be placed on the ceiling looking downward? On the window looking out? On the workplane looking up? In single or multiple locations? Photosensors require certain time delays to prevent their response to transient effects yet must be sensitive enough to respond to more significant changes in interior illuminance. The issues of control design are solvable but a lack of experience with installed control applications hinders confidence at this time.

Given either a dimmable or on-off control system, the controls can be operated either manually or automatically. According to Steve Selkowitz, "manual controls are flexible, combining sensitivity and judgment at their best, and are fallible, characterized by neglect or laziness at their worst. The main danger is simply that the switch or control will be forgotten or unused." [17] Prior experiments have suggested that occupants, if given the opportunity of setting their own artificial light levels in a daylighted room, will select even higher lighting levels than in a room without windows. Automatic controls should be more reliable but must be kept simple to avoid adding undue costs and run the risk of getting out of synch with the occupant's lighting needs. A study of electric lighting control strategies leads to issues of some complexity.

TABLE 1: Lighting control scenarios, including cost and types of equipment required for implementation [18]

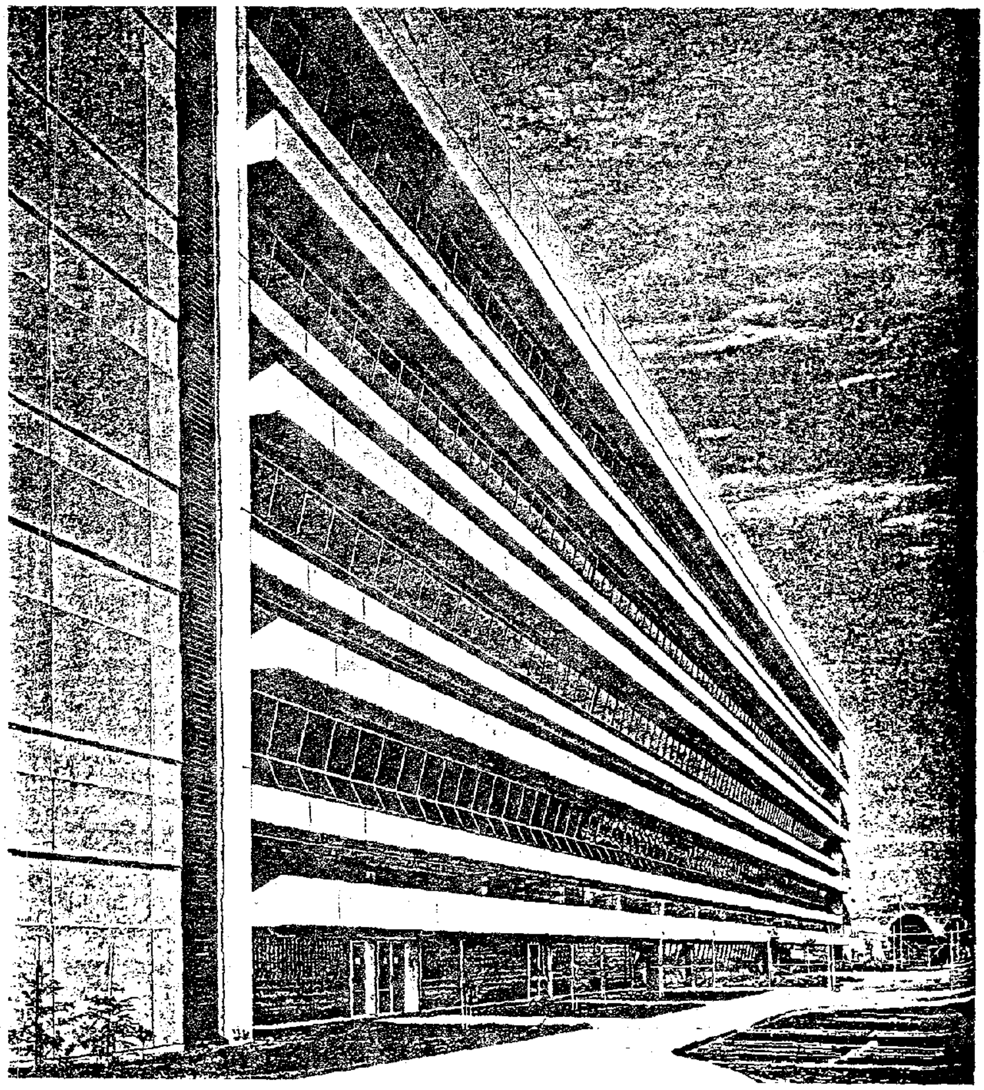
Scenario	Equipment	Cost ($1/square meter) Equipment	Cost ($1/square meter) Annual savings	Payback period (Yr.)
Occupancy Scheduling	Relay - microprocessor	2.08	2.80	0.74
Fine Tuning	Lamp change	0.62	1.29	0.48
Lumen Maintenance	Voltage amplitude control	6.73	1.51	4.46
Lumen Maintenance + Daylighting	Front-end current limiter	11.30	6.35	1.78
Lumen Maintenance, Tuning and Daylighting	Solid-state ballasts	13.02	7.75	1.68
All strategies	Relay - microprocessor solid-state ballasts			
10% Daylighted		15.18	6.46	2.35
30% Daylighted		15.18	6.89	2.20
60% Daylighted		15.18	7.64	1.99
100% Daylighted		15.18	8.50	1.78

CASE STUDY - A CALIFORNIA OFFICE BUILDING

The Windows and Daylighting Group of Lawrence Berkeley Laboratory recently completed a comprehensive assessment of commercial-sector energy conserving strategies.[19] In the category of daylighting the study identified four major data gaps, areas of information deemed critical for the design of effectively daylighted buildings. As one gap, the study identified a lack of monitored data from daylighted buildings and concluded that:

> "Performance data for daylighted buildings is virtually nonexistent. A review of over 40 "daylighted" buildings described in the architectural and engineering press provided virtually no useful data on the magnitude of daylight savings. These data are necessary, not only to validate computer models that provide guidance to designers, but also to convince hardnosed decision makers that these approaches are viable and cost effective."

FIGURE 11: Exterior view, daylighted office structure



This post occupancy case study of an office structure in the San Francisco Bay Area has collected performance data in a building that includes a number of innovative daylighting features. The structure represents a major experiment in the use of daylighting by a large U.S. corporation, an experiment in which the owner hopes that daylighting will significantly reduce energy consumption and improve employee productivity. The building is a 46,450 square meter office facility housing over 3,000 technical personnel engaged in engineering tasks. It is interesting to note a few points about the history of the building. In the early stages of its development, in fact far beyond the commencement of working drawings, the building was to be similar to other offices in the South Bay Area. These existing buildings were quite straightforward structures with few if any windows. A construction moratorium by the city of Sunnyvale paused the building's development and allowed the architect's office to propose a more innovative program for the building. In joint meetings between the architect and the owner it was reasoned that lighting represented almost half of the original proposal's energy consumption and that daylighting was a natural strategy for reducing this consumption. The owner was also concerned about the quality of work environments and was interested in daylighting as a means to higher quality workspaces.

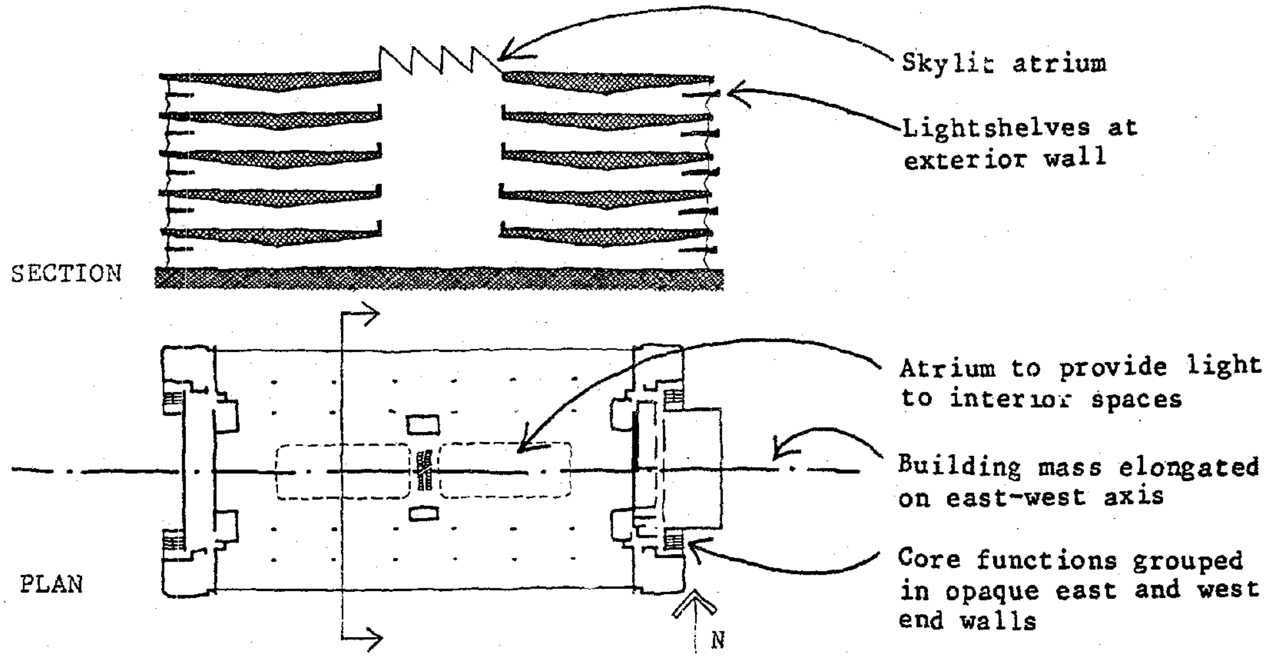
In 1980 the owner gave the architect permission to redesign with daylighting as a major objective. The daylighting of contemporary structures was a relatively new strategy in 1980 and few tools were available to guide the design team. They had already used the DOE 2.1A energy simulation program to study energy consumption patterns in the original building proposal. To this technique they added analyses based on scale models, first with a small mass/shading model then with larger scale daylighting models. The models, when combined with LBL's Sky Simulation Facility, provided the major tool for the analysis of daylighting related decisions. The modeling technique concluded with a full-scale mock-up of one office bay. The full-scale model, constructed at the Owens Corning Fiberglas Research Facility in Granville, Ohio, was not extensively tested for daylighting but did provide useful construction and systems information. The resulting building was a structure in which daylighting related criteria played a major role. The following building features are directly tied to daylighting:

Building Massing

The rectilinear mass of the building was elongated on an east-west axis. This decision produced major fenestration surfaces facing roughly north and south (the building is actually turned approximately 25 degrees west of south). The north and south facing surfaces are subject to a relatively benign pattern of solar radiation through the year and receive natural light in a symmetrical daily pattern.

The design team grouped a majority of the building functions that lacked a strong relationship to daylighting (computer facilities, conference rooms, rest rooms, copy rooms, etc.) into explicit core groups. The cores were designed with opaque surfaces and placed on the east and west ends of the building to mitigate the adverse radiation impacts associated with these orientations.

FIGURE 12: Building plan and section



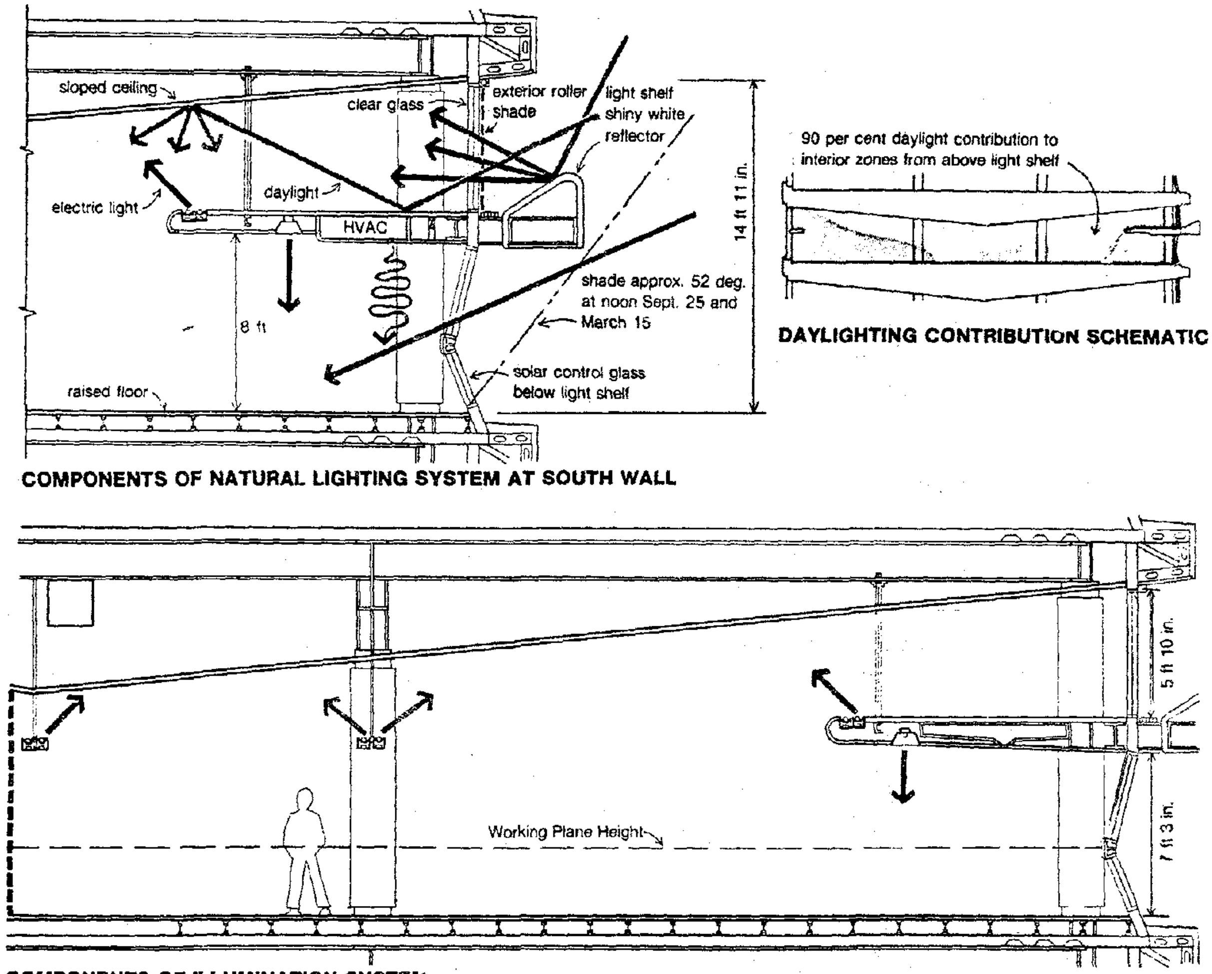
Realizing that even the most effective perimeter daylighting system could not project light more than about 12 meters into the building, the architect identified the atrium as a strategy for providing natural light to the building's large interior zones. The atrium became a major organizing feature of the building, a central node that provides light, visual relief, circulation and drama.

Design Features to Admit Daylight

The building's daylighting strategy requires a substantial penetration of daylight from the exterior fenestration into the building's interior spaces. To increase the depth of this penetration the designers established a fairly radical floor-to-floor dimension of 5.5 meters.

Each floor has exterior walls with glazing from floor level to a height of 4.6 meters above the floor. Glazing this tall with its associated view of the upper sky vault is usually a source of severe glare. The design included two features to prevent excessive glare from the exterior glazing. The architect specified large lightshelves along both north and south facing exterior walls. The lightshelves are horizontal interior elements located about 2.3 meters above the floor. They extend from the exterior glazing inward for a distance of 4 meters. In addition to the interior lightshelf, the south side of the building has an exterior lightshelf featuring a gloss white upper reflective surface. As architectural elements the lightshelves play the multiple roles of light reflector, shading device and glare shield. As a further measure against glare, and unwanted winter solar gain, the glazing below the lightshelf has a relatively low transmittance (18% on the south side and 40% on the north).

FIGURE 13: Diagram of daylighting features



COMPONENTS OF NATURAL LIGHTING SYSTEM AT SOUTH WALL

DAYLIGHTING CONTRIBUTION SCHEMATIC

COMPONENTS OF ILLUMINATION SYSTEM

Another architectural feature common to each floor is a sloped ceiling plane. The ceilings, built with standard modular ceiling materials, are sloped to effectively intercept and reflect illuminance from the lightshelves. This flux has a strong sideways component and the ceiling redirects it in a more useful vertical direction.

Lighting System Design

A major strategy employed in the office building is the explicit separation of systems providing ambient and task illuminance. Ambient illuminance, the light used for circulation and casual tasks, is provided by daylighting whenever possible and supplemented by a system of indirect fluorescent ceiling fixtures when daylight is inadequate. Task lighting is provided by fixtures built into each individual's workstation. These fixtures are under the individual's control and illuminate a specific, limited work surface.

There are special controls for the indirect fluorescent lighting system designed to supplement daylight and maintain target levels of ambient illuminance. These controls use a photosensor to drive a sophisticated dimming system capable of continuously adjusting the electrical light output to exactly match the difference between the amount of available daylight and the 350 lux target level for ambient illuminance.

Using a different type of control system, the overhead lights are tied to a computer control system that diligently turns the lights off during periods of low occupancy. Occupants can manually restore the lights during these periods.

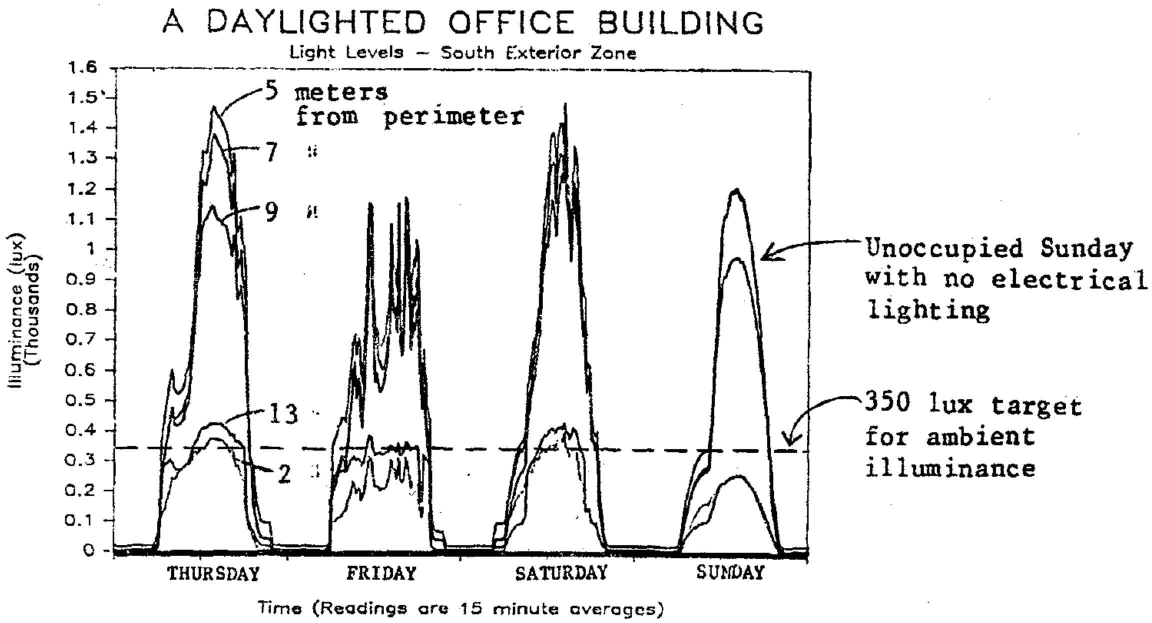
HVAC Features Directly Related to Lighting Design

The sloped ceiling geometry of a typical floor led the designers to route the return air flow path through the volume above the exterior wall lightshelves. This routing theoretically intercepts solar gains in the lightshelf area before they become a problem in the occupied space.

The high, sloped ceiling at the exterior walls is not a practical location for the supply air routing from the building's HVAC system. The perimeter zones were therefore served by air ducts routed through the interstitial spaces of the lightshelf itself.

It becomes clear from this roster of features that the building design is strongly driven by daylighting criteria. The architects responded to a challenge by exploring daylighting techniques for which no firm precedent was established. This exemplary innovation, fostered by a supportive client, has produced a building that strives for some impressive goals. The architect has projected a 70% reduction in electric power consumption for ambient lighting needs. If the building is indeed capable of these savings it will serve as a welcome model for future efforts in this area. The LBL Windows and Daylighting Group is conducting a study of the building with the goal of profiling the efficacy of its daylighting features. It should be noted that this study is based on the structure as it was built and not as designed by the architect. Though these two schemes are largely the same there are a few differences as a result of budget cutting measures near the end of the building's construction. For example, in an effort to reduce construction costs the owners decided to omit lightshelves designed for the vertical openings between each floor and the atrium.

The field study includes the on-site measurement of illuminance levels and electrical power consumption using automated data acquisition systems. The data presented from this study illustrate the building's performance during a relatively clear four day period in April. The data in Figure 14 indicate illuminance levels on a typical office area stretching from the south side exterior glazing to a depth of 12 meters from the perimeter.



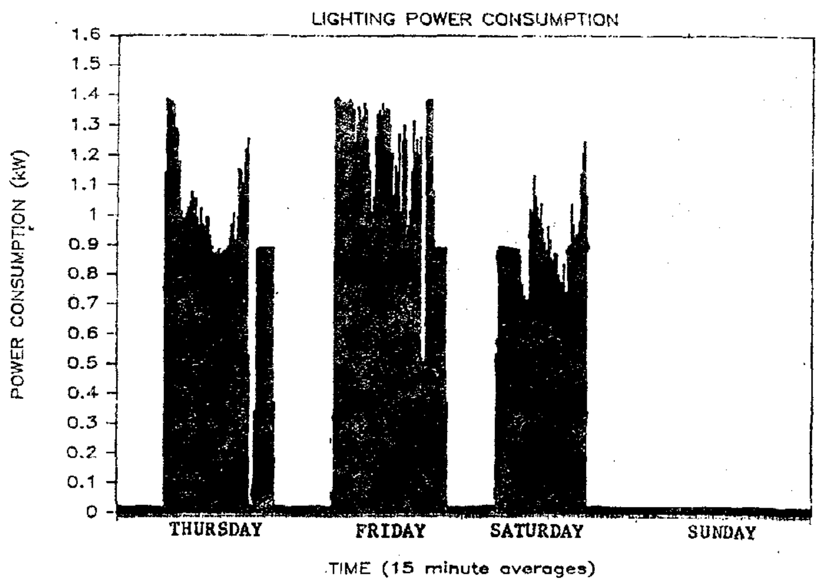
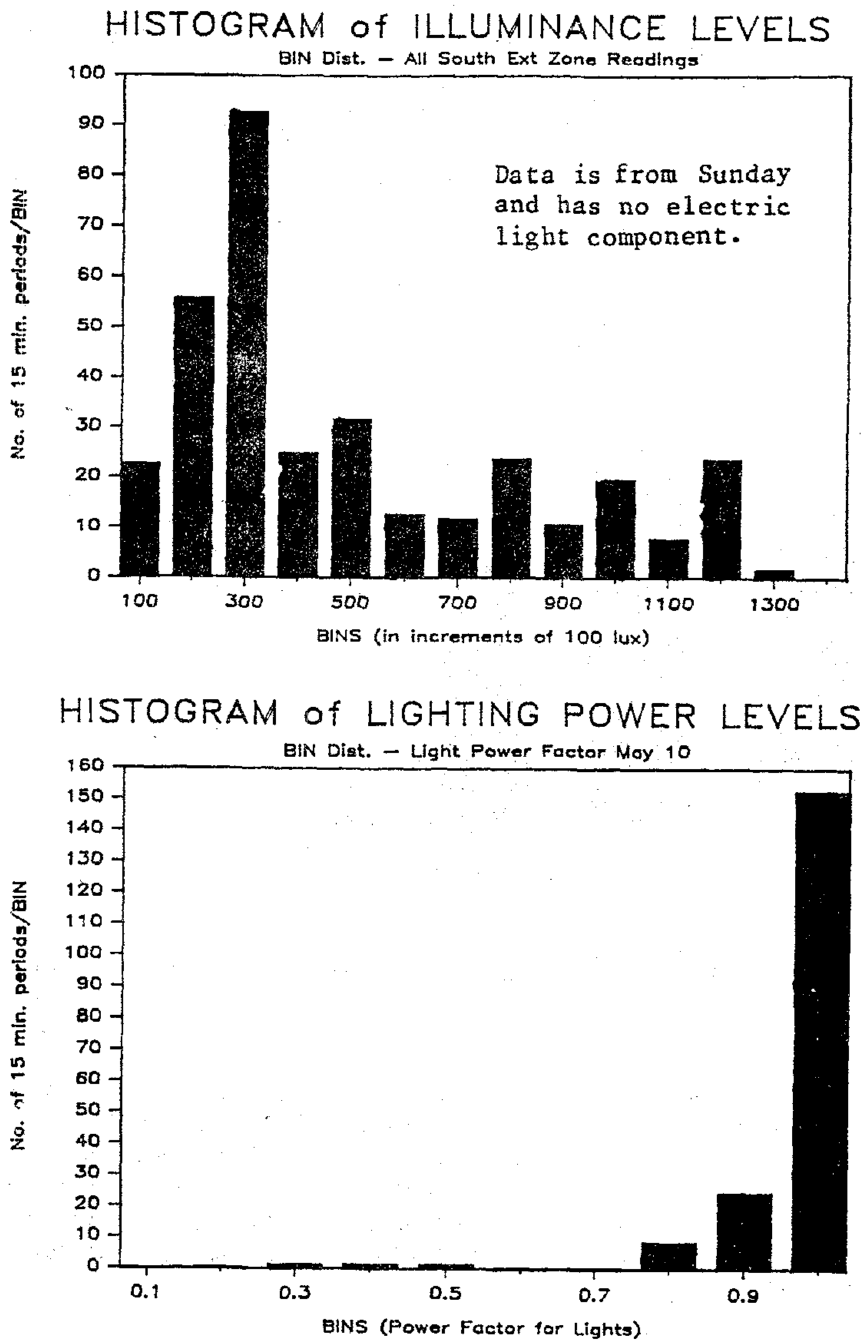


FIGURE 14: Monitored data from daylighted building's south side exterior zone

Illuminance readings were taken in a horizontal plane located 2 meters above the floor. The figure also includes a profile of electrical power consumption for the indirect, ambient electric lighting fixtures located 3.7 meters in from the exterior wall. As shown by the power consumption profile, for the first three days of this data office illuminance is from the combined sources of daylight and electrical light while the final day has daylighting only.

At first glance, the illuminance graph indicates a pattern in which the middle portion of the office space far exceeds the target illuminance level of 350 lux. This zone, extending from the interior edge of the lightshelf at 4 meters from the exterior to a depth of over 9 meters, has illuminance levels that frequently exceed 1,000 lux. The two remaining sensors indicate an illuminance profile that is more consistent with the target level. One of these sensors represents illuminance at 12.8 meters from the exterior wall. An examination of the Sunday data shows that this location is illuminated by daylight to 50% of the target level. The other sensor, the darker of these two locations, is ironically underneath the

FIGURE 15: Daylighting level and dimming distributions for a clear day



lightshelf just 1.8 meters from the exterior wall. The architect's low transmission glass solution to glare and solar gain control has resulted in a permanently dim office area just next to the windows. This area requires electric lighting even on the brightest of days.

An examination of the lighting power consumption data reveals several trends. These data represent power consumption by the fixture located at the inward edge of the interior lightshelf and serving the bright interior areas beyond the lightshelf. Of all fixtures this one is closest to the source of natural light and should show more dimming and earlier dimming than the other fixtures. Though the graph does show some dimming it is considerably less than what might be expected given the high interior light levels. In fact, the record should show a consistent dimming down to the 20% power consumption level that is the ballast's minimum. Instead, the electric light system was near full operation despite a light level in excess of 1,000 lux. The power consumption graph also indicates the effectiveness of the computer-controlled light switching scheme. There is little evidence of power consumption during low occupancy periods.

The building's lighting performance is summarized in Figure 15 which shows the distribution of interior daylight levels over a clear day and a distribution of dimming action for a similar sunny day. The figure indicates that daylight alone is adequate for over 50% of the time while dimming rarely drops power consumption below 90% of full power. This performance data is good news and bad news for the office building owners. The good news is that they have constructed a building that does a handsome job of collecting and distributing daylight to its interior spaces. The scheme provides ample daylight which is widely distributed with little glare. The bad news is that they are not realizing the energy saving potential that is built into their building. The control system that adjusts electric light levels is functioning poorly and electricity is wasted as a result. This example illustrates the importance of an effective lighting control system. The one installed has the capability of providing a high level of performance but will obviously require additional work before this goal is realized.

CONCLUSIONS

Daylighting is an area well worthy of its increased emphasis in the United States. As interest in the subject grows so will the base of tools and techniques that allow a rational approach to daylighting design. This process is already underway with research programs involving the universities, government laboratories and domestic utilities. For instance, current research efforts by the Windows and Daylighting Group at Lawrence Berkeley Laboratory have suggested a series of conclusions on daylight:

1. Effective use of daylight and lighting controls will produce large reductions in electrical lighting consumption.

2. Increasing window area and/or transmittance to improve daylight savings can reach a point, depending on climate and orientation, beyond which total energy consumption increases due to cooling loads.

3. Control of solar gain is vital if daylighting strategies are to provide net energy benefits.

4. Installed lighting power and lighting control characteristics are major factors in determining the energy savings of daylighting systems.

5. Daylighting optimization is sensitive to climate, orientation, building use and occupancy patterns.

6. Effective daylighting evaluation techniques should combine thermal and luminous effects and be applicable in the early stages of the design process.

These conclusions, and the issues raised in this paper, suggest a series of topics appropriate for future consideration. There are pressing needs in the following categories:

Daylight Resource Availability - There is a shortage of data describing the amount and quality of daylight available to buildings at various locations in the United States. Designers need accurate profiles of their individual climates to guide the development of appropriate daylighting schemes.

New Technologies for Fenestration and Control - An interesting area for future research is the development of high performance building materials tailored for daylighting applications. Current developments in selective transmitting glazing materials for residential heating suggest the possibility of similar selective transmitters for daylighting. Such a material would provide a high transmittance in the visible portion of the spectrum and be a poor transmitter for wavelengths in the near infrared and longer. Research is also needed to characterize the performance of solar control systems with emphasis on both thermal and light transmissive properties.

Electric Lighting System Controls - Our limited experience to date with electric lighting system controls indicates that they are difficult to successfully implement. Studies should be conducted to optimize control system components for various types of daylighting systems. Design guidelines should be developed including instructive cautions to the developers of control systems.

Energy Consumption and Peak Load Simulations - Computer simulations of energy consumption and peak load patterns in generic office building configurations can provide useful guidance for designers. A carefully designed set of computer simulations using an advanced program like DOE 2.1B could provide the basis for a correlative model of daylighting system performance. Such a model should predict performance in both thermal and daylighting modes.

Measurement of Existing Building Performance - Many of our current theories about daylighting have not been tested in the field. The study of existing daylighted buildings would provide a significant contribution to our understanding of the subject. Monitoring projects should include measurements of illuminance levels, energy consumption and peak power demands. This data would preferably be combined with accurate profiles of window/daylighting management patterns and occupant satisfaction with the system. A standardized monitoring protocol would be quite useful. Monitoring projects should be distributed to the practicing profession in the form of well documented case studies.

The use of daylight requires additional care during the design process and generally means a higher dollar investment from the building owner. In return, a daylighted building provides lower operating costs for electrical lighting. A large portion of the savings are related to peak power reductions, a pattern that reduces utility pressures for expansion. Perhaps the most important benefit from the daylighting of our structures is occupant satisfaction with an environment that is more humane for having daylight.

ACKNOWLEDGMENTS

Much of this paper benefits from prior research conducted by the Windows and Daylighting Group at Lawrence Berkeley Laboratory in programs sponsored by the U.S. Department of Energy, New York State ERDA, American Society of Heating Refrigeration and Air-Conditioning Engineers and others. Current research examining the daylighting performance of existing structures is funded by Pacific Gas and Electric. The daylighting model illustrated in this paper was constructed by Georgia Tech students Ray Hitt, Bonnie Kilpatrick and Richard Stevens. Berkeley student Barbara Erwine provided valuable assistance in the preparation of this paper.

REFERENCES

(1) Lam, William C., Lighting and Perception as Formgivers in Architecture, McGraw-Hill, New York, 1977, pp. 10.

(2) Ne'eman, Eliyahu, "A Comprehensive Approach to the Integration of Daylight and Electric Light in Buildings", Energy and Buildings, Vol. 6, No. 2-4, 1984, pp. 97-108.

(3) Heschong, Lisa, "An Interview with Bill Lam", Solar Age, August 1980, pp. 32-35.

(4) Fraker, Harrison and Don Prowler, Project Journal: Teaching Passive Design in Architecture, University of Pennsylvania, Philadelphia, PA, 1981.

(5) American Institute of Architects, Energy in Design: Techniques, AIA, Washington, DC, 1981.

(6) McMahon, Jim, et al, "A Review and Analysis of Commercial Building Energy Consumption Studies", Report LBL-10620, Lawrence Berkeley Laboratory, California, 1983.

(7) Selkowitz, S., "Effective Daylighting in Buildings", Parts I and II, Lighting Design and Application, Feb. and March 1979.

(8) Turiel, I., "Energy and Life-Cycle Cost Analysis of a Six-story Office Building", Report LBL-12837, Lawrence Berkeley Laboratory, California, 1981.

(9) Louis Harris and Associates, "The Steelcase National Study of Office Environments: Do They Work?", Steelcase, Inc., Grand Rapids, Michigan, 1978.

(10) Wineman, J.D., "Office Design and Evaluation: An Overview", Environ. Behavior, 14 (3), 1982, pp. 271 - 298.

(11) Lam, William C., Lighting and Perception as Formgivers in Architecture, McGraw-Hill, New York, 1977, pp. 18 - 21.

(12) Usibelli, A. et al, "Commercial-Sector Conservation Technologies", Report LBL-18543, Lawrence Berkeley Laboratory, Berkeley, CA, 1985, pp. 6-70 - 6-73.

(13) Eijadi, David A., "Solar Optics: Development and Implementation", General Proceedings, 1983 International Daylighting Conference, Phoenix, AZ, 1983, pp. 261-265.

(14) "International Recommendations for the Calculation of Natural Daylight", Commission Internationale, De L'Eclairage, Publication No. 16 (E-3.2), 1970.

(15) Johnson R., et al, "Glazing Energy Performance and Design Optimization with Daylighting", Energy and Buildings, Vol. 6, No. 2-4, 1984, pp.305-317.

(16) Olgyay, A. and V. Olgyay, Solar Control and Shading Devices, Princeton University Press, Princeton, NJ, 1976.

(17) Selkowitz, S., "Effective Daylighting in Buildings", Parts I and II, Lighting Design and Application, Feb. and March 1979.

(18) Ne'eman, E., "A Comprehensive Approach to the Integration of Daylight and Electric Light in Buildings", Energy and Buildings, Vol. 6, No. 2,3&4, 1984, p. 101.

(19) Usibelli, A. et al, "Commercial-Sector Conservation Technologies", Report LBL-18543, Lawrence Berkeley Laboratory, Berkeley, CA, 1985, p. 6-4.

III.3 USE OF SOLAR ENERGY IN ROMANIA

Liviu Dumitrescu x)

In order to make conventional fuel and especially hydrocarbon fuel more available, research programs have been developed in Romania since 1970 to initiative the use of new energy sources, particularly solar energy.

The first research work on solar energy in Romania was begun in 1971 by the Building Research Institute and led to a number of experimental works. The first experiments consisted of the construction of two solar hours, one with a passive solar heating system and the other with an active solar heating system, in the town of Cîmpina, 80 km north of Bucharest.

Also, two experimental solar installations were built: an installation for drying wood and an installation for drying bricks.

Four pilot installations for dwellings were built during 1980 - 1982. The first was a water-heating installation for 473 apartments in the "Sun District" -- Timişoara, 500 km west of Bucharest. The installation in Timişoara is provided with a collecting surface of 2,000 m^2, which made it the largest hot-water installation in Europe in 1981. This installation produces a daily hot water flow of 150,000 l, with a temperature of 50°C, using classical heating sources for only 30% of the water heating needs.

The results obtained from the pilot stations during 1975 - 1981 allowed us to develop the use of solar energy elsewhere in Romania. Thus, in 1979 - 1984, solar water heating facilities were constructed for 1,046 industrial buildings, and installations for 20,761 apartments, with an energy contribution of 43,600 tcf, are underway.

In 1983, a water-heating installation was constructed for a building complex in the Baneasa district of Bucharest. This installation includes 2,897 flats and a collecting area of 8,640 m^2. The installation saves 653 tcf annually.

The following other solar heating installations constructed between 1980 and 1984 are worth noting:

Installations for domestic use:

---

x) Dr.Eng. General Inspector - Central Institute for Research, Design and Codes in Constructions (ICCPDC), Bucharest, Romania.

- Precision Fine Mechanics Industry - Bucharest, collecting capacity 57,000 l/day at 50°C, with a collecting surface of 760m^2.

- Ovidiu Hotel in Neptun, a resort on the Black Sea border, capacity 22,800 l/day at 50°C, collecting surface 326 m^2 (Fig.7).

Industrial installations:

- Integrated Wool Enterprise - Constanta, collecting capacity 60,000 l/day, hot water of 50°C, with a collecting surface of 800 m^2 (Fig.3).

- Enterprise of Microproduction and Experimental Building Works - Bucharest, capacity 12,500 l/day at 50°C, collecting surface 196 m^2 (Fig.4).

- "Zarea" wine and champagne enterprise, Bucharest, capacity 6,500 l/day at 50°C, collecting surface 100 m^2 (Fig.5).

- "Energoreparatii" Enterprise - Bucharest, capacity 18,500 l/day at 50 C, collecting surface 288 m^2 (Fig.6).

Measurements already made on the solar installations indicate that they were successful, exceeding the expected water temperature (up to 56°C), as well as the expected fuel savings.

Romania has passed the implementation stage and has reached the stage where solar installations can be used widely for both industrial and domestic water heating.

Furthermore, one can notice the rapidly developing program of new sources between 1984 and 1985:

1984 - 13,000 tcf capacity.
1985 - 35,790 tcf capacity.

By the end of 1984, more than 400,000 m^2 of solar collectors and assured production capacities of 300,000 m^2/year of solar collectors had been constructed at "Aparata and accessories" Enterprise - Alexandria and at "Frigocom" Enterprise - Bucharest. At these two enterprises 8 types of plane solar collectors are produced from which 7 types are for hot water and 1 type for warm air.

Besides the plane solar collectors, cylindrical-parabolical collectors with 1 m and 4 m openings to produce steam and hot water with temperature of more than 100°C, are also manufactured.

The plane solar collectors produced in Romania are of the type of reduced focalization, with the collecting element made of serpentines or registers of oval pipes, and the type of sheet collecting elements which is welded or fixed and a register or a serpentine made of round or plate pipes.

At the same enterprise in Alexandria, for zootechnical farms modulated consumption installations with a collecting surface of 24 m^2 and with storage tanks of 750 l=are produced for zoological farms.

Comparing the solar collectors produced in Romania with those produced in Italy, France, and the Federal Republic of Germany, we find that the performances are similar and the prices lower.

Besides the use of solar collectors for the domestic and consumption warm water preparation for dwellings and industrial buildings, a large number of solar installations were developed for different drying processes, namely:

- solar installations for drying fruits and vegetables;
- solar installations for drying bricks;
- solar installations for drying cereals;
- solar installations for drying pastes.

At a cereals silo base in Oltenița, a 60km south from Bucharest, a cereals drying installation was developed with solar collecting surfaces of 1,200 m^2 and with a flow of hot air of 70,000 m^3/h hot air that provides a saving of 110 tcf/year(fig.8).

Solar energy was also used to produce ice thus setting out two experimental solar installations, one with a capacity of 150kg of ice per day and the other one with a capacity of 1,000 of kg ice per day (fig. 9).

In order to extend the period of solar energy use for the preparation of domestic warm water, two solar installations were built with antifreeze liquid (of the propylenglycol), one for 8 apartments at Vălenii de Munte (80 kmnorth of Bucharest) and another one for 76 apartments in Bucharest.

The result of the tests showed an increase of energy of about 10-15% for5 months during the cold season.

Analyzing the efficiency indicators of the solar installations built in Romania, we may ascertain that they are favorable:

-- specific fuel savings per collecting surface unit	70 - 90 kg cf/m^2 year
-- investment costs recovery time from the energy saving	8 - 11 years
-- energy recovery time embodied into solar installations	2,5- 4 years

In Romania, research activity in the fields of solar energy use had in view the development of some experimental pilot stations, the improvement of solar collector performance, collecting efficiency growth, and enlargement of the use field.

Also of great interest is research concerning the growth of solar collector performance, conducted at the Building Research Institute - Bucharest an account of some standard norms.

The research connected by the adoption of the fitting and fixing solutions of the solar collectors were specially executed by measurements into the aero tunnel at the Hydrotechnic Faculty-Bucharest and Construction Faculty - Iaşi because of the final results simple and economical solutions were accepted.

The Building Research Institute has also carried out many experiments concerning the use of some heat exchangers which are very efficient for solar installations and the use of propylene - glycol as an antifreezing liquid.

Also carried out were important experiments concerning the efficiency of solar energy collecting systems, which established the optimum flow of the thermal carrier circulation through solar collectors and the correlation between the circulation flow volume and the influence of water stratification considering the temperature level in the storage tanks.

Another research problem of great interest is the solar energy storage with or without phase exchangers for daily and long terms.

As concerns the use of solar energy for heating the buildings the problem is still in the experimental stage in the pilot stations, where the establishment of the optimum heating systems is studied comparatively analyzing the active, passive with circulation heating systems in the solar house of Building Research Institute - Bucharest.

In Romania there are also preoccupations concerning the use of solar energy to produce electric energy in solar power stations with thermal-dynamic cycle and plane solar collectors, the solar power station 30 kW from Bucharest was established by the help of Research and Energetical Modernizations Institute.

In order to provide the necessary conditions for solar energy implementation, besides the research activity, some designs for the use of solar energy at the Design Institute for Typified Buildings - Bucharest.

So far, 22 types of solar energy use projects have been carried out and six more are in progress this year, representing a total of 95% of projects.

Among the projects of using solar energy the following are very important:

-- Installation for solar energy collection at dwellings for warm water preparation for assemblies of 470 apartments;

-- Assemblage supports of solar collectors on the dwellings terraces;

-- Installations for solar energy collection with capacities between 14,000 and 115,000 l/day, for the consumption warm water preparation at the social additions for the industrial buildings;

-- Stations for the consumption warm water preparation with capacities between 14,000 and 115,000 l/day by means of solar energy at industrial buildings;

-- Systems for the use of solar energy for heating in passive system and consumption warm water preparation for dwellings (one... four storied buildings);

-- Installations for consumption warm water by means of solar energy for buildings placed on the border of the sea and motels;

-- Schools linked with kindergarten rooms with different destinations all of them using solar energy for installations of the domestic warm water preparation;

-- Solar energy use for preparation of thermal carriers required by the technological processes in the construction materials industry;

-- Solutions of solar collectors with air for cereals drying.

In 1985, design activities for ice production, drying of the pastes and fruits and vegetables drying were goals. More design activities for 1-3 storys dwellings, for domestic warm water preparation and for passive system heating and for ventilation and heating of the industrial buildings using solar energy by means of air or air - water collecting elements for industrial halls,- are also planned.

For solar energy use, Romania achieved the necessary automatation apparata for starting and stopping the pumps, functioning of of the warm water difference of temperature from the storage tanks, and from solar collectors. Also carried out was the necessary apparata for recording the solar radiation required for the check-up of solar installation performances.

x

x x

Taking into consideration the results obtained in Romania in the solar energy field, and the research, design, and execution capacities of solar collectors and of the necessary automatization apparata, the possibility exists of cooperation in the field of research, of elaborating designs and of providing the special equipments for solar installations.

- Summary -

This paper deals with main achievements in Romania in the field of solar energy, as well as with the measurements undertaken for the extensive use of this from of energy.

The results obtained in the preparation process of the warm water for the housing units, socio-cultural facilities, and the in dustrial and agricultural units, will be submitted.

The paper also presents the results obtained in the field of drying processes in agriculture and industry by using solar heated air.

Also specified are the types of solar collectors made in Romania, their physical and heat engineering characteristics, as well as the possibility at producing and delivering them so as to meet home and export trade requirements.

Another issue which is tackled in this paper is the use of solar energy for the heating of housing and industrial units - in active and passive systems - and the results obtained by the pilot plants.

FIG. 1 Collecting instalation for solar energy, for 1.200 places at Alfa, Beta and Gama hotels in Saturn resort. The place of the collector being on auto parking roof.

FIG 2

Solar installation for the domestic warm water preparation for dwelling assembly of 473 apartments Timisoara Solar collectors places on a sloped roof.

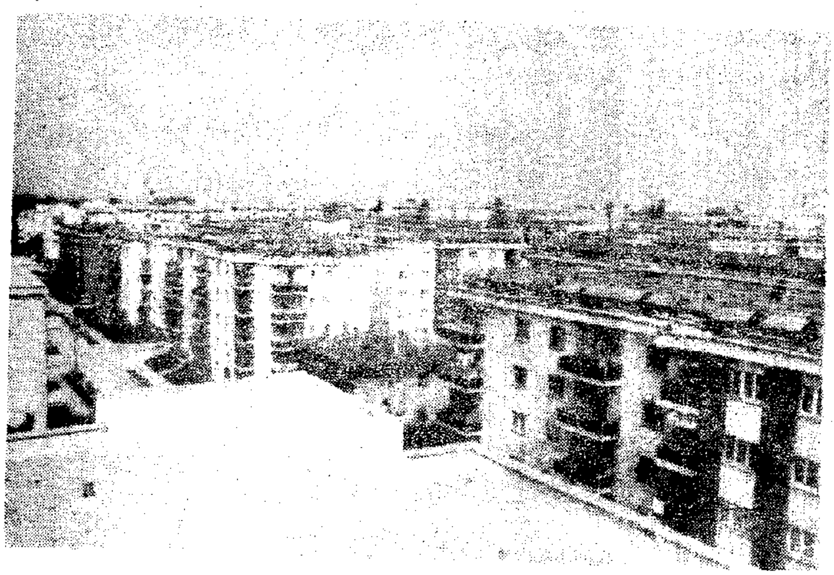


FIG 3 Solar installation for domestic warm water preparation for dewlling assembly of 2897 apartments in Baneasa district Bucharest

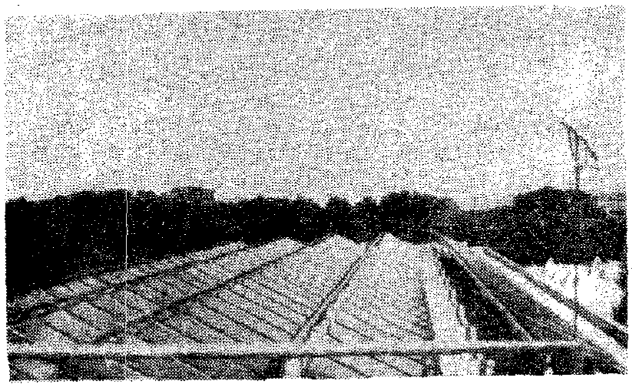
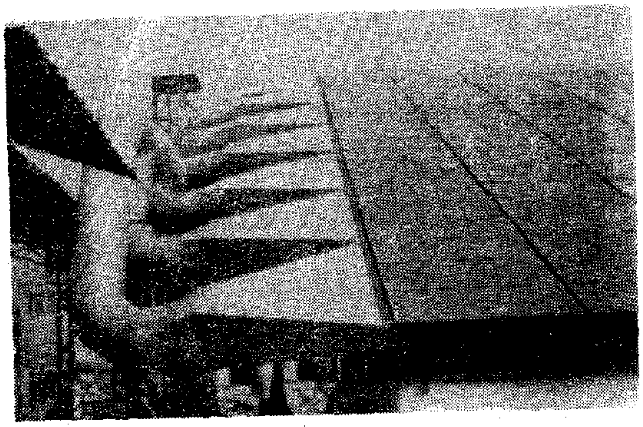


FIG 7 Solar installation for consumption warm water preparation for OVIDIU HOTEL at NEPTUN resort. Solar collector are placed on the hotel terraces.

FIG.8. Solar installation for drying cereals at Oltenia.
Wiew of the cereals ware house over wich the solar collectors are placed.



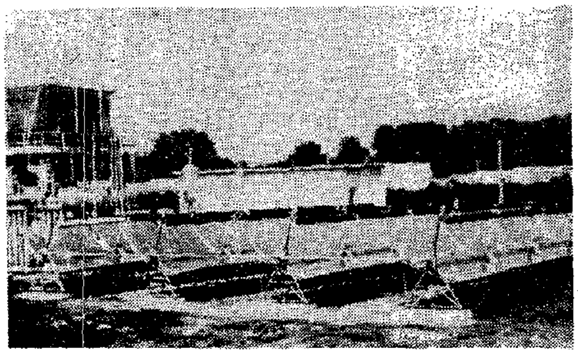


FIG. 9. Solar installation with capacity of 1000 kg ice per day.

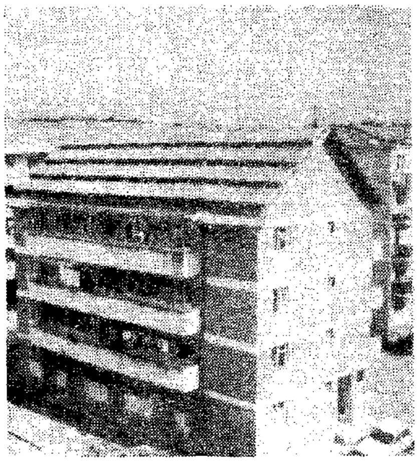


FIG. 10 Solar installation for the domestic warm water preparation at Valenii de Munte, for 8 apartaments using propylen glycol as an antifreeze solution.

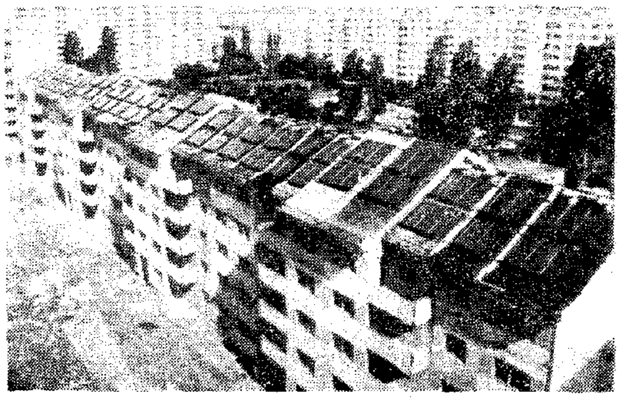


FIG 11 Solar installation for the domestic warm water preparption at the block of 76 apartments in Bucharest using propylen glycol as an antifreeze solution.

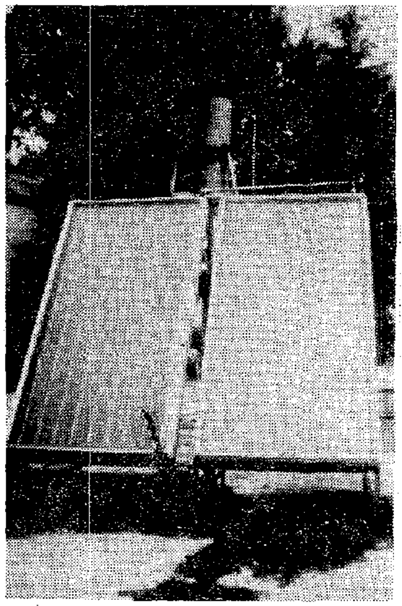
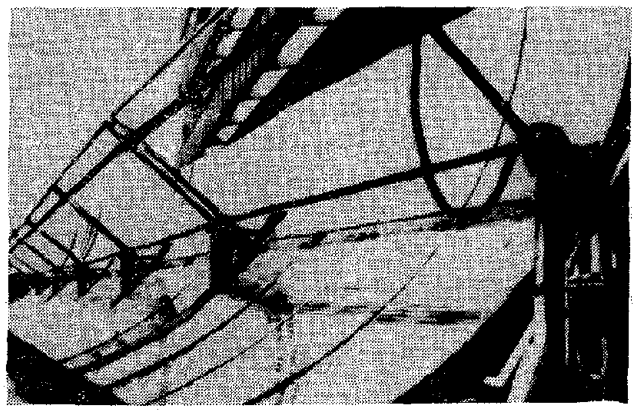


FIG 12 Plane solar collectors register tipe produced from aluminium extruded

FIG.13. Cylindrical parabolic solar collector with a 4 m opening to produce hot water an steam.



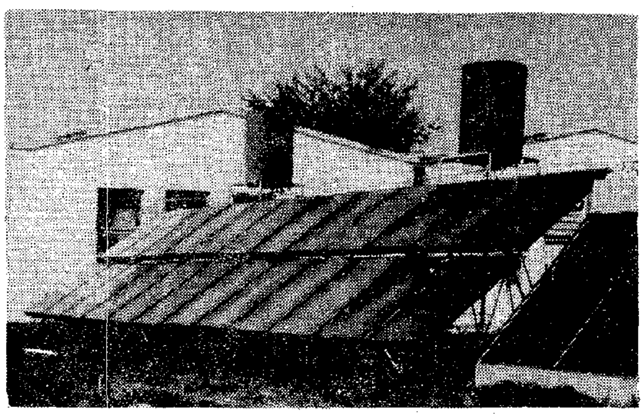


FIG.14. Modulus solar equipment for consumption warm water preparation, with a collecting surface of $24 m^2$; in this figure there are 2 modulus.

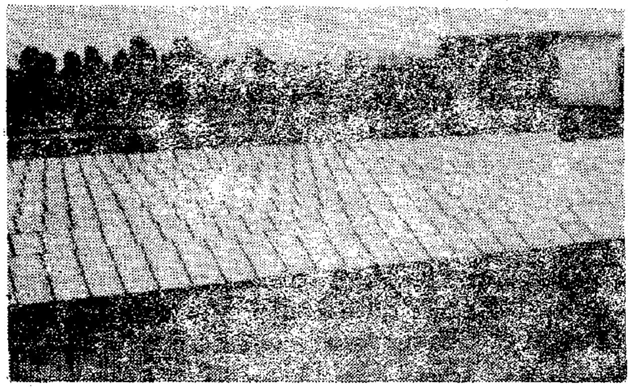
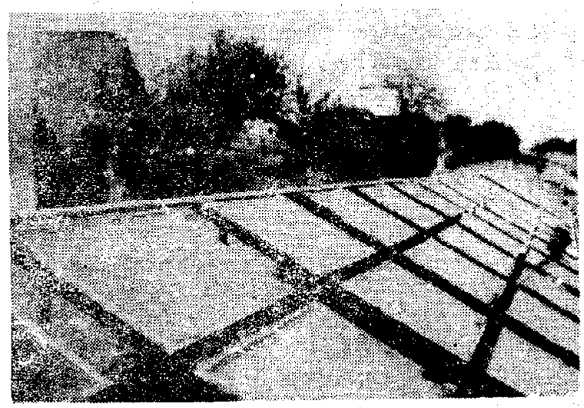


FIG.4. Solar installation for the consumption warm water at Wool Integral Enteprise-Constanța.

FIG. 5 Solar installation for the consumption warm water preparation at "Zarea" Wine and champagne Enterprise Bucharest. Solar collectors placed on a sloped ground.



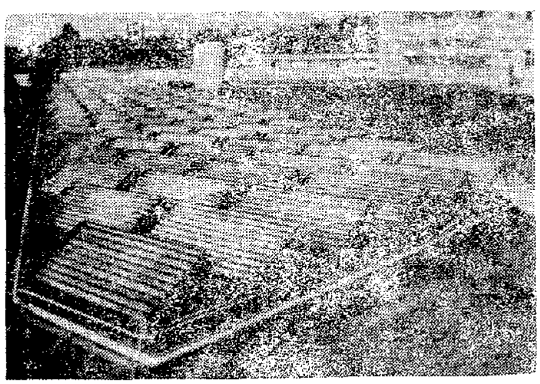


FIG.6 Solar installation for the consumption warm water preparation at Energoreparations Bucharest. Ground floou placed solar collectors.

III.4 ANALYSIS OF THERMAL PERFORMANCE OF ACTIVE SOLAR SYSTEMS USED FOR DOMESTIC HOT WATER PRODUCTION

Dan Constantinescu x)

Florin Iordache xx)

Domestic hot water heating solar installations are presently the most practical way of revaluating the studies worked out in Romania and abroad with a view to using solar energy in low temperature thermal processes. Since 1976, a few hundred solar installations have been put into service; they cover 500,000 m^2 solar collectors and work both for civil and industrial consumers. The results of theoretical and experimental studies on the thermal characteristics of solar collectors, heat exchangers and warm water storage tanks are used in dimensioning the constituent parts of solar installations.

The solar collectors extensively produced in Romanian factories are simple glazed and equipped with flat absorbing plate or low focussing element.

Several experiments /1/ and theoretical studies proved that the use of coil pipes generates the increase of heat transfer from plate to pipe; this type of collector is mainly used by Romanian industry. Most experiments were performed on the INCERC outdoor stand and observed the flat-plate collector testing methodology worked out by INCERC /2/. The circulation flow-rate of the primary heat carrier is a = 30 kg/m^2h; the other characteristic values for $a \neq 30$ kg/m^2h flow-rates are obtained by the conversion provided by flat-plate collector characteristic equation/3/.

The studies performed prove, however, that in the range of low circulation flow-rates ($a < 30$ kg/m^2h) the classical thermal characteristic /3/ of solar collectors changes generating reduced thermal efficiency of the absorbing element /2/ caused by water laminar flow in the solar collectors. Still, considering the extensive use of the book /3/, the overall heat transfer model described in the above mentioned paper was further adopted. The present paper refers to the collector general theory and emphasizes the differences from the traditional theory (H.B.W.)as well

X) Senior Research Officer, INCERC

xx) Research Officer, INCERC, Bucharest, Romania

as the effects on solar installation performances.

The lack of variance of the collector heat loss overall coefficient as against the variation of the absorbing plate temperature is another important element worth mentioning.

The theoretical demonstration of this characteristic /4/ allowed the variation linear model $\eta = \eta(\varepsilon)$ to be adapted to the requirements; this model was experimentally proved valid on the INCERC stand.

The thermal response of the heat storage unit was determined by the impulsional function method taking into account the laminar flow of water in cylindrical tanks /5/. The complex mathematical modelling adapted to tanks with uniform temperature or with perfect thermal stratification /6/, /7/ was used in a simplified study on the thermal response of active solar installations. Detailed studies /8/ on installation water heating were used in working out two mathematical models which are the basis for the solar installation calculus. The first one was preferred as a unique method presently used in solar installation design /9/,/10/ as it is very simple.

The model and implicitly the problem solution are based on two hypotheses partially proved valid experimentally:

-- collector thermal characteristics are provided by (H.B.W.) model /3/;

-- water in storage tanks is circulated once on a sunny day and thus perfect thermal stratification is reached.

This study presents a detailed analysis of the thermal performance of a solar installation considering all its service hypotheses. These hypotheses practically correspond to the two mathematical models (with thermal stratification; with uniform temperature in storage tanks) and the results are unitarily presented emphasizing the highest temperature level of the water supplied by the solar installation. While the thermal characteristic model of overall heat transfer solar collectors /3/ required adapting low primary heat carrier flow-rates (a = 10 kg/m^2h) /11/, this paper proves that other solar installation service and dimensioning strategies may also be adapted.

II. Influence of water flow in flat-plate solar collectors on thermal performance

Paper /1/ emphasized the fact that for low heat carrier flow rates, flow is laminar even if the heat carrier circulates through coil pipes. Laminar flow generates a considerable reduction of the coefficient specific to the heat transfer from pipe to the fluid circulating and heated.

Paper /1/ treats analytically the problem of water heating in stabilized laminar flow with parabolic distribution of velocities in the flow section. Heat exchange reduction has an influence on F_R coefficient which further emphasizes the thermal efficiency of flat-plate solar collectors when the reference temperature is the temperature of the water admitted in the collector. The performance reduction emphasized analytically is highly significant as stabilized flow is taken into consideration. Stabilized flow is reached after a period of unstabilized flow when the velocity profile varies from uniform section temperature to parabolic profile. The length of the hydrodynamic stabilization may be determined using relation:

$$l \geqslant 0.056 \cdot Pe \cdot d \tag{1}$$

For 1/2" pipes (used in producing solar collectors) the resulting maximum length of the hydrodynamic stabilization is 8.50 m (Re = 2,320).

In case of coil solar collectors, the length of each coil bar is of about 2.00 m and the flow from one bar to the other requires a change of direction. This point represents a hydrodynamic perturbation and therefore the velocity profile, even parabolic, is resettled uniformly on the flow section. The limit of value Re and therefore of "a" specific flow-rate with a corresponding hydrodynamic stabilization length of about 2.00 m may be determined using relation (1). A simple calculus leads to Re 700 and a = 10.30 kg/m^2h corresponding value. Lower flow-rate values for a length of 2.00 m generate unstabilized and stabilized flow which further causes a worse heat transfer.

The influence of laminar flow is put into evidence by comparison to the classical model of heat transfer in flat-plate solar collectors (H.B.W.) /3/.

The equations describing heat transfer in unstabilized laminar flow are the following: /12/

$$w\frac{\partial \theta}{\partial x} = a\left(\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r}\cdot\frac{\partial \theta}{\partial r}\right) \tag{2}$$

with boundary conditions:

$$\lambda \left.\frac{\partial \theta}{\partial r}\right|_{r=r_0} = K_\Sigma\left(t_E - \theta\big|_{r=r_0}\right) \tag{3}$$

$$\left.\frac{\partial \theta}{\partial r}\right|_{r=0} = 0 \tag{4}$$

$$\theta\Big|_{x=0} = \theta_0 \tag{5}$$

Using the following dimensionless variables:

$$\Theta = \frac{t_E - \theta}{t_E - \theta_0} \quad ; \quad \dot{r} = \frac{r}{r_0} \quad ; \quad \dot{x} = \frac{x}{L}$$

solution (6) in obtained by integration:

$$\Theta(\dot{x}, \dot{r}) = 2 \sum_j \frac{J_1(m_j)\, J_0(m_j \dot{r})}{m_j\, J_0^2(m_j)\left[1 + 0{,}25\left(\frac{Nu}{m_j}\right)^2\right]} \exp\left(-2 m_j^2\, Pe^{-1} \frac{L}{r_0} \dot{x}\right) \tag{6}$$

The useful heat flow is determined by relation (7):

$$q_1 = a c_p (t_E - \theta)\left\{1 - 2 \sum_j \frac{J_1(m_j) \int_0^1 J_0(m_j \dot{r})\, d\dot{r}}{m_j\, J_0^2(m_j)\left[1 + 0{,}25\left(\frac{Nu}{m_j}\right)^2\right]} \exp\left(-2 m_j^2\, Pe^{-1} \frac{L}{r_0}\right)\right\} \tag{7}$$

where the mj eigenfunctions are determined by equation (8):

$$\frac{m_j}{Nu} = 0{,}50\, \frac{J_0(m_j)}{J_1(m_j)} \tag{8}$$

The mathematical model used in the literature /3/ represents the overall heat balance described by the differential equation:

$$\frac{d\theta}{dx} = \frac{\pi d \cdot K_\Sigma}{G c_p}\left(t_E - \theta\right) \tag{9}$$

The solution is dimensionless and is provided by the following relation:

$$\Theta(\dot{x}) = \exp\left(-2 St \frac{L}{r_0}\right) \dot{x}) \tag{10}$$

In this case, the useful heat flow is determined using relation:

$$q_2 = a c_p (t_E - \theta_o)\left[1 - \exp\left(-2St \frac{L}{r_o}\right)\right] \tag{11}$$

The previous calculus was performed considering that the temperature of the water admitted in the solar collectors is the reference temperature. The correction applied to the calculus model in paper /3/ refers therefore to the modification of R_F coefficient. The new coefficient is specific to laminar flow in solar collectors and is provided by relation:

$$F_R^c = \frac{q_1}{q_2} \cdot F_R \tag{12}$$

F'_R coefficient specific to the reference temperature represented by the average of inlet and outlet heat carrier temperature values is determined by relation:

$$F_R^c = 2\frac{a c_p}{K_\Sigma} \cdot \frac{\frac{F_R^c \cdot K_\Sigma}{a C_p}}{2 - \frac{F_R^c K_\Sigma}{a C_p}} \tag{13}$$

The numerical tests prove that beginning with values $a \geqslant 30$ kg/m^2 h, F'^c_R and F'_R coefficients /3/ and identical matter values $K_{\Sigma 2}$. So, considering the characteristic curve measured for 30 kg/m^{2}h specific flow-rate, the characteristic curve corresponding to low flow-rates may be determined by calculus applying the laminar flow correction. As the linear characteristic is $\eta = \eta(\varepsilon)$, two principal point to be used in its determination were defined:

$$\eta(0)\big|_{a=30} = F_R'(\alpha\tau)\big|_{a=30}$$

$$\varepsilon(0) = \alpha\tau / K_\Sigma$$

Both points are determined by stand measurements for a primary heat-carrier flow-rate of a ≈ 30 kg/m^2 h principal points of new characteristics are determined using relations

$$\eta(0)\Big|_{a<30} = F_R'^{c}(\alpha\tau)\Big|_{a<30}$$

$$\varepsilon(0) = \alpha\tau / K_\Sigma$$

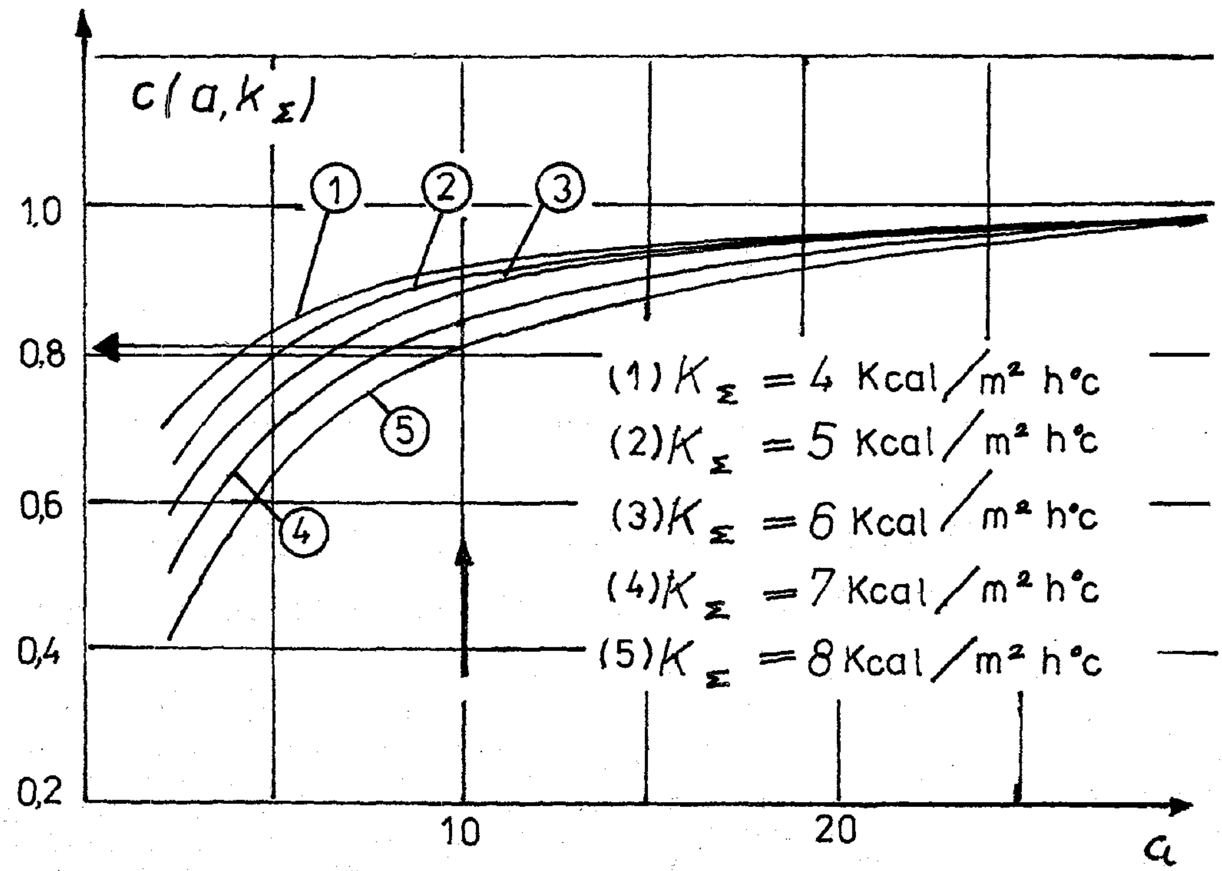
So:

$$\eta(0)\Big|_{a<30} = \frac{F_R'^{c}}{F_R'}\,\eta(0)\Big|_{a=30}$$

Ratio $F_R'^{C}$ = C (a, K_Σ) is represented in the diagram in fig.1.

III. Influence of primary and secondary heat carrier flow-rates on solar installation thermal performance

In the present condition of energy requirements and consumption, the solar installations designed and produced in Romania work as exclusive sources of warm water production in the warm season (April-September). The dimensioning of the constituent elements is meant to ensure both the necessary heat quantity and the temperature level required by the consumer. The conclusion easily drawn is that if secondary heat carrier flow-rate is reduced, water temperature reaches satisfactory values since the first hours of the morning (in the sunny days) and may be supplied to the consumer. In Romania, a characteristic of the energy saving strategy is warm water supply according to a presettled program. This program is justified by the high consumption required by industry in the morning hours. The warm water is supplied in the afternoon when the actual domestic requirement is considerable. As energy production is based on traditional energy sources (gases, liquid or solid fuel) the revaluation of warm water solar sources will naturally be adapted to the national strategy which is similarly applied to both heat sources; the heat supplied by both types of sources do not differ in terms of cost. The solar installation will therefore work mainly for storing in the sunny hours, and the temperature level required is reached at the end of the sunny period. Considering the initial requirement of solar installations to provide rapid thermal response, the calculus method worked out in paper /9/ takes into account this problem; the value of the secondary heat carrier flow-rate will therefore ensure the recirculation of the water in the tanks through the heat exchanger secon-



$c(a,k_\Sigma)$
1,0
0,8
0,6
0,4
0,2
10
20
a
1
2
3
4
5
(1) K_Σ = 4 Kcal/m² h°c
(2) K_Σ = 5 Kcal/m² h°c
(3) K_Σ = 6 Kcal/m² h°c
(4) K_Σ = 7 Kcal/m² h°c
(5) K_Σ = 8 Kcal/m² h°c

Fig.1

dary loop only once a day. Thus the temperature of the water admitted in the heat exchanger will be constant and equal to the cold water temperature; heat transformation from solar collectors to storage tanks may therefore be performed. This type of service implies perfect stratification of the water in storage tanks during the service hours.

The mathematical model used in the calculus method /9/ is based on the heat balance equations for solar collectors and for the heat exchanger. The model is noninertial and therefore the significant temperature values (t_{TP}, t_{RP}, t_{TS}) are functions of the climatic values (represented by t_E equivalent temperature) and for cold water.

In the numerical testing of solar installation performance characteristic of solar collectors was taken into account as mentioned in paper /3/; the conclusion was to adopt a value a 10kg/m^{2}h of the primary heat carrier specific flow-rate.

It is worth mentioning that function t_{TS} (a) for a given value "b" admits a maximum point. This is not always corresponding to value a = 10 kg/m^{2}h but the solution max. (t_{TS}) - a = 10 kg/ m^2 h represents of solar installations designed. The analysis described in this study is based on the numerical calculus of an installation characterized by the following technical data:

$S_P = 5.012\ m^2$

$V = 200\ m^3$

$S_{SCH} = 156\ m^2$ (IPB-85 counterflow heat exchanger)

The following values are specific to solar collectors :

$\alpha\tau = 0.80$; $K_\Sigma = 7\ W/m^2K$; $F' = 0.90$

Climatic data are represented by $t_E = 87.50^o$ C equivalent temperature as daily mean value.

For the storage circuit specific flow-rate, value b = 4.43 kg/m^{2}h is provided by the necessity of circulating the water in storage tanks once a day.

Variation $t_{TS} = t_{TS}$ (a) for the uncorrected (I) and corrected (II) variant of collector thermal characteristic is presented in fig.2. In variant I the solution proves to admit t_{TS}=62.4^{o}C maximum for a = 6.20 kg/m^{2}h. Considering variant II corrected, t_{TS} has the form of a monotonous function reaching a stable value of about 58^{o}C. Comparing the values resulted from the noncorrected calculus, a measurable energy deficit of about 22 % as compared to the value estimated by calculus /3/. The increase of primary heat-carrier flow-rate from a = 6.20 kg/m^{2}h to a = 30 kg/m^{2}h generates temperature increase from 53^{o}C to 58^{o}C (in the corrected variant) which is expressed by 15 % energy gain.

The high thermal efficiency of the heat exchanger in these cases ($\bar{\varepsilon} > 0.92$) is worth mentioning. This value is associated with rather steady heat exchange coefficients ($K_{SCH}\big|_{a=6}$ =855 W/m^{2}K, $K_{SCH}\big|_{a=30}$ = 1,700 W/m^{2}K) which proves an irrational service of heat exchangers.

The second analysis model is represented by installation service for heat carrier flow-rates not depending on thermal stratification requirements. The heat balance equations modelling the phenomenon are, for solar collectors and heat exchanger, identical with those specific to the noninertial model completed with the differential equation of heat storage tanks.

The model is inertial and requires the selecting of a $t_E(\tau)$ function used in determining $t_{TS}(\tau)$. The conclusion of the numerical testing is that daily mean value t_E may be used insteadof $t_E(\tau)$ function; deviations for final values are of 3 % maximum. The equation system was integrated analytically taking into account the nonlinear characteristic of K_{SCH} coefficient according to heat carrier temperature /13/. Integration implies an interative algorithm and was performed on a TI-59 computer.

The numerical calculus basis is the same installation used in the previous case (noninertial model).

The secondary heat carrier flow-rates are between 15kg/m^2 h and 40 kg/m^2 h. The calculus results are presented as function $t_{TS} = t_{TS}(a,b)$ in fig.3 diagram.

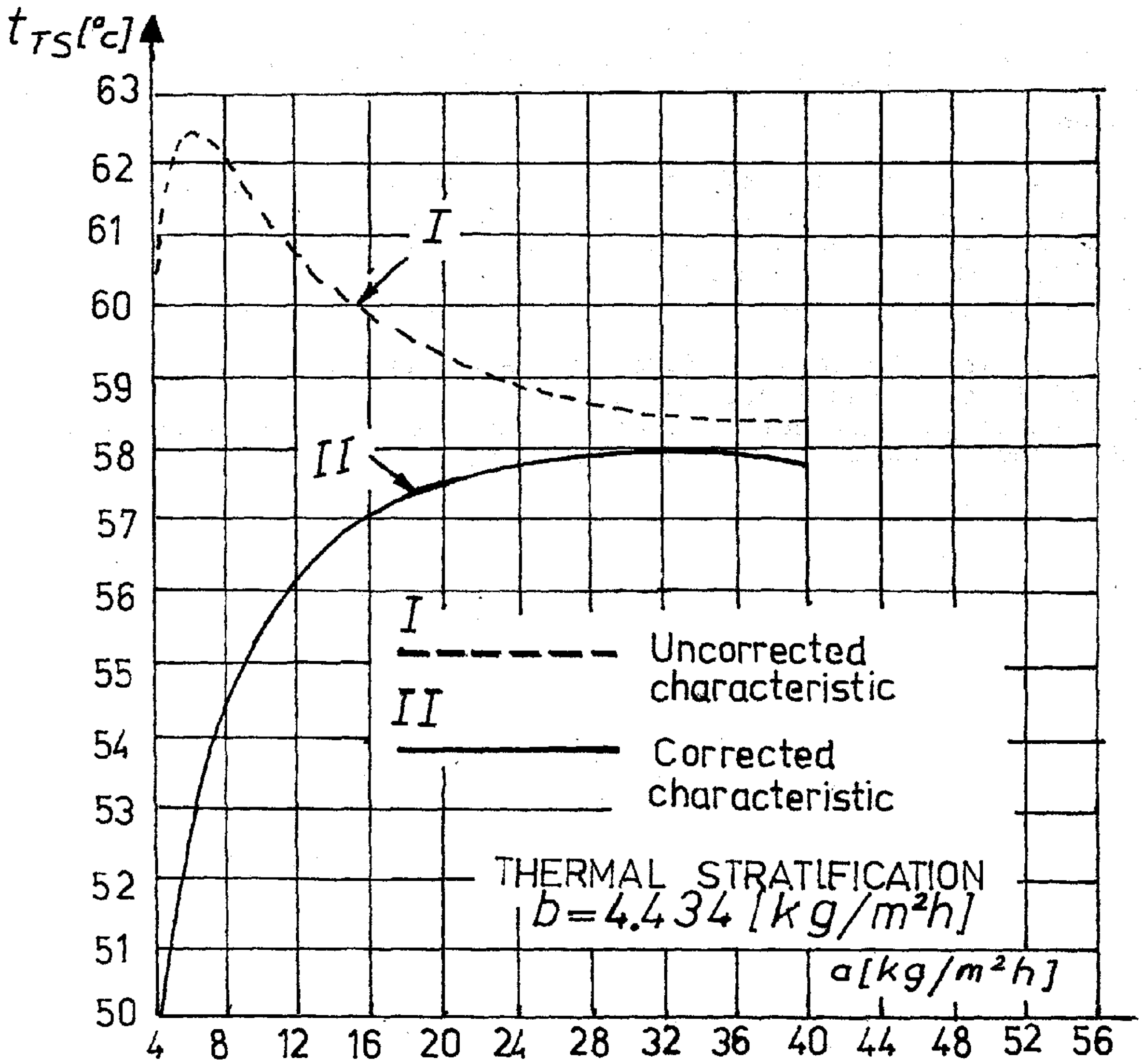
Variants (I) uncorrected and (II) corrected of the solar collector thermal characteristic were analyzed for this case too. The thermal performance of the installation increases proportionally with values "a" and "b". Values t_{TS} exceed the values calculated in the previous case both in variant (I) and in variant (II). May we consider that the actual thermal performance of the installation corresponds to values a = 30 kg/m^{2}h and b = 30kg/m^{2}h characterized by value t_{TS} = 64°C.

In this situation K_{SCH} varies between 3,000 W/m^{2}K and 3,800W/m^{2}K and the average efficiency $\bar{\varepsilon}$ = 0.76 which proves a satisfactory service of the heat exchanger.

It is worth mentioning that for specific flow-rates b$\geqslant$25kg/m^{2}h function $t_{TS} = t_{TS}(a)$ is monotonous and has no maximum value; no matter variants (I) or (II) the thermal performance calculated by the inertial model for b$\geqslant$25 kg/m^{2}h and a$\geqslant$30 kg/m^{2}h exceeds the highest performance calculated by the non-inertial model.

The conclusions of the study refer only to the case subjected to analysis but the analysis leads to a general conclusion:

-- specific flow-rates of about a=b=30 kg/m^{2}h and heat ex-



t_{TS}[°C]
63
62
61
60
59
58
57
56
55
54
53
52
51
50
4
8
12
16
20
24
28
32
36
40
44
48
52
56
a[kg/m²h]
I
II
I
Uncorrected characteristic
II
Corrected characteristic
THERMAL STRATIFICATION
b=4.434 [kg/m²h]

Fig.2

changer efficiency of about 80 % are recommended. Referring again to the calculus exemple, the calculated thermal performaance exceeds by 24% the value supplied by the non-inertial method /9/ in corrected variant of the solar collector thermal characteristic.

IV. Conclusions

1. For a $\leq 30\ kg/m^2h$ specific flow-rate of primary heat carrier in solar collectors, their thermal characteristic changes as compared to the traditional model (H.B.W.) /3/ as flow in solar collectors is laminar;

2. The calculus of the thermal performance specific to a solar installation of 5,012 m^2 area and 200 m^3 storage volume was performed using the non-inertial model for laminar flow; the thermal performance is reduced by about 22% as compared to the value provided by the uncorrected characteristic variant /3/;

3. The thermal performance calculus was performed on non-inertial model and leads to selecting values $a = 30\ kg/m^2h$ and $b = 30\ kg/m^2h$; performance increases with 24% as compared to the value estimated using the non-inertial model.

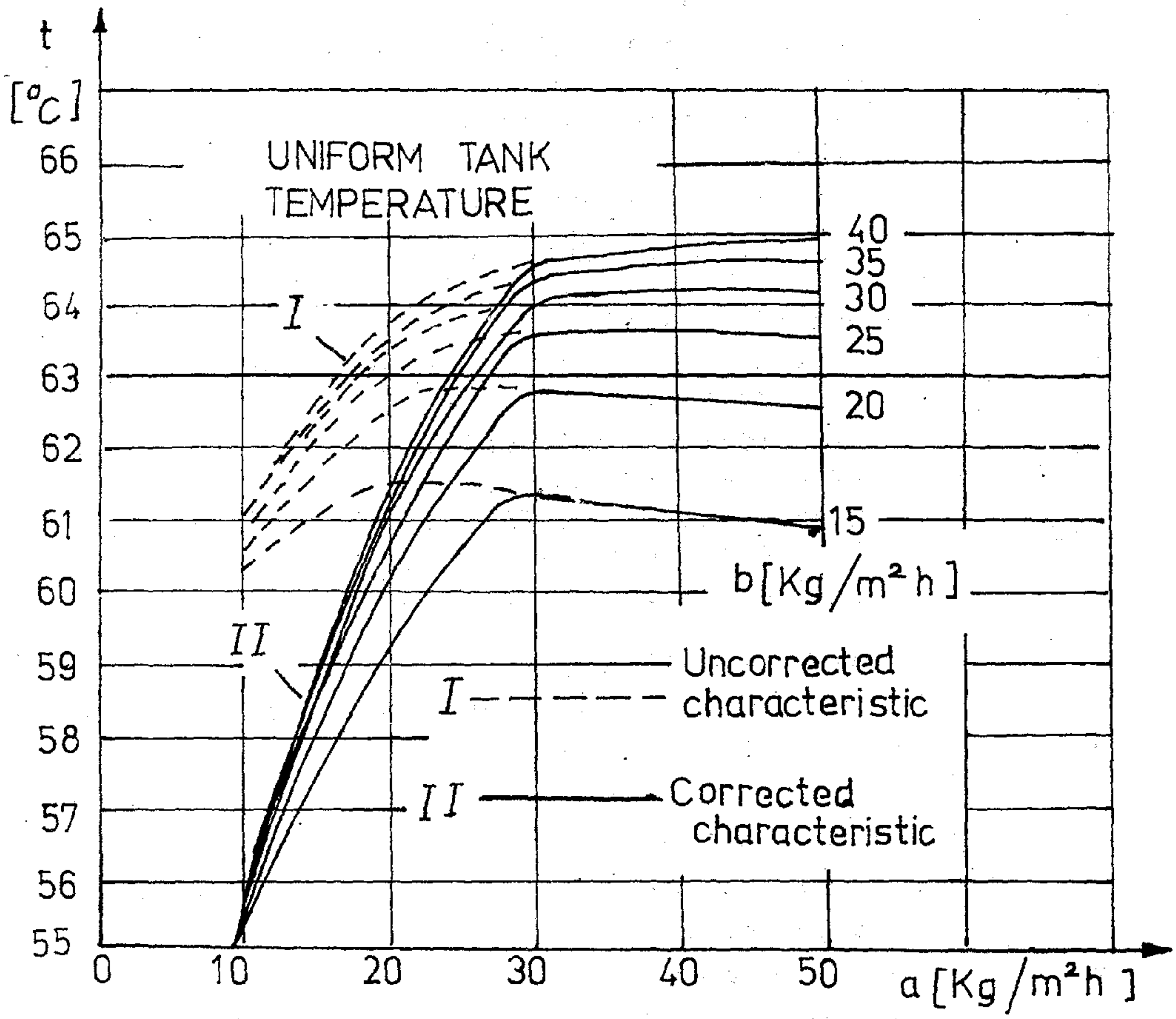

t
[°C]
66
65
64
63
62
61
60
59
58
57
56
55
UNIFORM TANK
TEMPERATURE
40
35
30
25
20
15
b[Kg/m²h]
I
II
Uncorrected
characteristic
Corrected
characteristic
0
10
20
30
40
50
a [Kg/m²h]

Fig.3

<u>NOMENCLATURE</u>

ϑ	- fluid temperature	(^{o}C)
t_{TS}	- temperature of secondary heat carrier at heat exchanger outlet	(^{o}C)
t_{TP}	- temperature of primary heat carrier at heat exchanger inlet	(^{o}C)
t_{RP}	- temperature of primary heat carrier at heat exchanger outlet	(^{o}C)
ϑ_o	- fluid temperature in solar collector coil	(^{o}C)
t_E	- equivalent temperature $t_E = \frac{\alpha \tau}{K_\Sigma} I + t_e$	
t_e	- outside temperature	(^{o}C)
I	- solar radiation intensity on solar collector plan	(W/m^2)
K_Σ	- heat loss overall coefficient of solar collector	(W/m^2)
K_{SCH}	- heat exchange coefficient of counter-flow heat exchangers	(W/m^2)
	- equivalent thermal resistance	(m^2K/W)
C	- heat carrier specific heat	(KJ/kgK)
W^p	- heat carrier circulation velocity	(m/s)
l	- start line length	(m)
L	- pipe length	(m)
d	- pipe diameter	(m)
r	- usual radius	(m)
r_o	- pipe radius	(m)
r	- normed radius	-
x	- normed length	-
a	- specific mass flow-rate on collecting circuit	(kg/m^2h)
b	- specific mass flow-rate on storage circuit	(kg/m^2h)
τ	- time	(h)
Nu	- Nusselt dimensionless number	-
Re	- Roynolds dimensionless number	-

P_e	- Peclet dimensionless number	-
St	- Stanton dimensionless number	-
$\alpha\tau$	- absorptivity - transparence product	-
$\bar{\varepsilon}$	- heat exchanger thermal efficiency	-
η	- solar collector efficiency	-

REFERENCES

/1/ Constantinescu Dan - Contributions to the theoretical and experimental study on flat-plate solar collector service "Installations" 2/1979

/2/ x x x - Test Methodology of Flat -Plate Low Focissing Solar Collectors INCERC-1979.

/3/ Duffie, I.A., Beckman, W.A. - Solar Energy Thermal Processes, I.Wiley, N.Y., 1974

/4/ Iordache Florin Flat-Plate Solar Collectors. On the K (I) Heat Transfer Over-all Coefficient "Installations" 9/1984

/5/ Constantinescu Dan - Analysis Model for Short-Time and Liquid Storage Solar Installations "Installations" 12/1983

/6/ Constantinescu Dan, Mitrofan Rodica, Iordache Florin - Domestic Warm Water Producing Using Solar Energy (I) "Installations" 4/1979

/7/ Constantinescu Dan, Mitrofan Rodica, Paponi Anca - Theoretical Study on the Determination of Calculus Parameters Specific to Warm Water Producing Solar Installations (II) "Installations" 3/1980

/8/ x x x - Studies on the Use of Solar Energy in Domestic Warm Water Producing INCERC Contract 855/1978

/9/ x x x - Dimensioning Methodology for Solar Warm Water Producing Installations INCERC, ICCPDC - 1981

/10/ Iordache Florin - Dimensioning Method for Warm Water Producing Solar Installations Using Thermal Characteristics "Installations" 4/1981

/11/ Dumitrescu Liviu - Extensive Use of Solar Energy in Building Installations "Installations" 1/1980

/12/ Constantinescu Dan - Influence of Primary Heat Carrier Flow-Rate on the Thermal Performance of Warm Water Producing Solar Installations

/13/ Iordache Florin - Analysis of Solar Installations Performance on Non-inertial and Inertial Models - to issue in "Installations"

III.5 SOLAR ENERGY USE FOR DOMESTIC WATER HEATING DOR DWELLINGS

Marcel Dumitrescu x)

Radu Filip x)

Dan Vartanian x)

Among the applications of solar energy the most widespread now is domestic water heating. In order to transform solar energy into thermal energy centralized or local systems are used.

The centralized systems are efficiently applied to dwelling assemblies in towns. These systems are provided with solar collectors, placed on the roofs of the dwellings, and heat exchangers wherein the thermal energy from the sun heats domestic water.

The local systems are used for isolated buildings without central heating. These are simple installations with solar collectors and storage tanks placed on the roofs of the houses whose inhabitants use that not water. These installations provide important fuel savings which allow a payback time of less than ten years.

1. Generalities

The stringent necessity, due to the present energy crisis, to reduce conventional fuel consumption, especially petrol products (oil), imposed the use of inexhaustible unconventional energy sources, among which the sun is one of the most important.

As from the thermal viewpoint, at ground, there is a source with a low potential, and one of the most adequate application is the domestic hot water preparation, for dwellings. Solar energy being available, at random and, with variable time intensities, the peak efficient use for the domestic water heating is achieved especially during the hot season of the year.

It is well known that the higher the efficiency of the installation for water heating is the greater the conventional fuel saving is. The conception of the achieved works aimed that all the elements of the systems should work at the best parameters.

---

x) Engineers, Design Institute for Typified Buildings - IPCT Bucharest, Romania

For a higher efficiency the hot water was prepared centralized systems urban assemblies. According to these solutions, solar installations have been made and set to work for many thousands of apartments.

2. The used working systems

The basical scheme of a solar installation consists of solar collectors, through which cold water is heated, and then is transferred into storage tanks, where it is then transported, and the user, where it is transported from the storage tanks.

Hot water preparation is achieved using in the main two systems:

- centralized systems;
- local systems.

The centralized systems, that are now largely spread, out, are characterized by an installation that prepares hot water using solar energy for a dwelling assembly varying from 200 to 2000 apartments, or even more. This solution is preferred for communities that allow a centralized operation with qualified staff that can ensure a good energy efficiency.

Generally speaking, this system uses a scheme with two loops: the primary loop consisting of solar collectors, circulation pumps, heat exchangers, and the secondary loop having its own pumps and heat storage battery. The primary loop is a closed circuit in order to avoid the deposition of limestone or impurities into the collectors. The thermal energy, transmitted through heat exchangers, heats the domestic water from the secondary loop, which is an open circuit.

The hot water is delivered at a temperature of +45°C. During the time periods of reduced or no solar radiation, when it is not possible to provide a + 45°C temperature, the water will pass through an additional heating installation using conventional fuel.

For these systems the solar collectors are placed on the roofs of dwellings, and the equipment (pumps, heat exchangers , storage tanks) mounted in central stations, at the same place with the thermal energy generators that are necessary for heating the dwellings.

-- In order to provide more efficient operation of these systems, the installations are endowed with automation equipment that must switch -off the solar installations operation during the lack of solar radiation periods and switches it on when the sun shines- the adjustment being established according to the temperature difference between the water in solar collectors and the water in the storage tanks.

2.2. The local systems, used for small buildings (2-8 apartments are characterized by a simple installation consisting of solar collectors required for a flat and the respective storage tank placed into the attic.

This sort of installation is used for isolated buildings or even for small rural assemblies where there are no central heating systems. These systems operate without pumps, only due to the gravity effect of the temperature difference of the water circuit between solar collectors and storage tanks.

3. Design premises

In the condition of using solar energy the hypotheses for the domestic hot water preparation, have been properly established. In order to increase the percentage of hot water prepared only by using solar energy, the temperature of the hot water supplied was established at +45°C. Thus, during the hot period of the year (April-October) the activity of the auxiliary heat source is reduced to minimum.

Based on experimental data the installations have been designed to operate 7 months per year, April-October, within this time span, the solar energy represents 85% of the amount of energy available yearly. The countinous use, for 12 months, of the solar installation would imply supplementary running costs by using antifreeze solution that is not economically efficient.

Standard flat solar collectors having the dimensions of 1,00 x 2,00 m and provided with coiled pipes and multi-parallel pipes are used to collect solar energy. The absorption, of the solar radiation is worked either through a black painted metal plate that includes a hair pin bent pipe with the heat carrier flowing inside, or by the means of pipes placed into the focuses of cylindro-parabolic mirrors.

These collector types may ensure a flow of 90 l/day sqn.collector. The best seasonal average efficiency is ensured by mounting solar collectors toward the South with a slope of about 30°.

Almost 85% of the whole quantity of domestic hot water is supplied during the hot season through the use of solar energy. In order to avoid heat losses especially during the days with lower air temperature (below 20°C) the pipe's thermal insulation thickness has been established based on the technical and economical calculation.

4. Aspects concerning the layout of the solar energy installations.

For dwellings, the solar collectors -- the main element of the installation that require special conditions for achieving higher efficiency -- are generally placed on the roofs.

In the case of dwellings (or residential buildings) with flat roofs the south orientation of solar collectors is not conditioned by the orientation of the buildings. For dwellings with a sloped roof, solar collectors placed on this roof impose a certain orientation to the buildings..

The collectors are placed on supports provided by the same supplier. In order to avoid displacement or overthrowing of the collectors, by the wind, they are anchored with steel strings as a result of the tests made in the aerodynamic tunnel.

For large assemblies, the central stations for domestic hot water preparation with solar energy, are coupled also with the water pumping station and the thermal and electric transformation station in order to ensure a good distribution of the running maintenance staff.

As concerns solar energy, all the equipment (heat exchangers, pumps, electric devices) is installed in a building usually placed in the geometric center of the assemly. Due to the difference between the daily period of solar energy collection and the hot water consumption time, it is necessary to use storage tanks for thermal energy, representing about 50-60% from the daily consumption.

These storage tanks are usually steel made and they are placed near the central station building. For the constituent parts of a solar installation for hot water preparation, standard projects, are drawn up as follows:

-- dwellings provided with solar energy collectors on the roofs;
-- central stations for domestic hot water preparation using solar energy.

In order to provide a more accurate execution and running of the installation, different regulations are established that specify the mounting procedure, the measure that must be taken during the performing periods and finally, all the data that have to be recorded in order to check the systems energy efficiency.

5. Aspects of the technical and economical efficiency

The energy efficiency transposed into the conventional fuel saving is of about 90 kg.c.f./sqm.collector or of about 280kg.c.f/ apart.-year.

Due to the organizing measures for manufacturing solar collectors, their prices have been lessened to half during the last five years, limiting the price of a solar installation for producing domestic hot water to the maximum of 50% out of the value of an apartment.

Thus, the investment for this solar installation for hot water preparation may be recovered from the value of the saved fuel in less than 10 years.

As concerns the local systems, the energy efficiency of isolated dwellings, is very close to that of the assemblies and the time recovery is even smaller with about 10% in comparison with other solutions.

From the economic analyses of such a type of installation it results that, in future, the costs will decrease especially as a result of the better organization of the equipment manufacturing (solar collectors) and accordingly the use of such installations will become more efficient.

BIBLIOGRAPHY

1. Design : I.P.C.T. — Solar energy collecting installations the domestic hot water in dwellings (nr.5694).

2. Design : I.P.C.T. — Local solar installations for domestic hot water preparation for dwellings with a few appartments (nr.9525).

III.6 COLLECTING INSTALLATIONS AND STATIONS FOR HOT WATER PRODUCTION WITH THE HELP OF SOLAR ENERGY IN INDUSTRIAL UNITS

Maria Kuharts x)

Paula Ciubotaru x)

Elisabeta Pătruţ x)

The paper presents solutions for the collecting installations and the devices of heating using solar energy in industrial units.

The installation works only for the hot period of the year (April-October) and it consists of plane solar energy collectors and the station for the hot water preparation (heat exchangers, pumps, storage system).

The collecting device may be assembled over one or more buildings that are suited to this purpose, (as orientation, strength etc,) and the hot water preparation station is placed in the neighbourhood of a common hot water supply source (district thermal station or thermal power station),

The necessity of finding solutions for domestic hot water preparation using means other than the thermal source with fossil fuel (classical source) determined the typical design direction towards elaboration of some adjusting project of the presentthermal sources (thermal power stations or district thermal power stations) for the complementary use of solar energy.

The elaboration activity of some studies and typical projects concerning solar energy use covered in a very short time period all the specific stages for typification documentation,optimization of the main parameters and charts, adjustment of installations considered to be classical, in order to be couplled with the special ones for new energy sources.

An installation for domestic hot water preparation using solar energy is composed of different parts, namely:

-- the part of the solar energy collector consisting of solar collectors where the solar thermal carrier is heated and the pipeline network usually placed on the buildings;

---

x) Engineers, Design Institute for Typified Buildings - IPCT 21, T.Arghezi Street, sector 2, Bucharest, Romania

-- the part of the hot water preparation consisting of the equipment of the hot water preparation with thermal solar carrier This equipment is generally placed at the classic fossil source that supplies hot water into the respective precincts;

-- the network system that makes the connection between the solar collectors and the hot water preparation equipment with solar heat carrier.

The solar collectors used are plane solar collectors with or without focusing with coil or pipes register and they are placed on the roofs of the ground floor rooms. These solar collectors are included in metallic skylights with light oriented on the roofs of the multistoried industrial buildings and of the annex buildings.

The collectors, placed on roofs of the multistoried industrial buildings and industrial annexes, are mounted into parallel rows directed south, at distances necessary to avoid the reciprocal shadowing.

The equipment for the hot water preparation using solar energy is composed of: heat exchangers, circulation pumps, hot water acumulators, command and automation electric aparata.

All these are usually grouped at the classical source for hot water preparation and they represent the station for hot water preparation using solar energy.

Excepting the hot water acumulators that are placed outside, in the open, all this equipment is placed in a building, usually the classical source for hot water preparation.

The adjustment of the classic thermal sources for the solar energy use, consists mainly of adding the special equipment -- necessary for the preparation of the hot water using solar energy -- to that already existing in the thermal source, this one becoming an auxiliary source for the period of solar energy collection(April -October).

When solar radiation is not enough and the temperature of the hot water resulted from the solar installation is lower then that required by consumption, the sun-heated water, will increase the temperature in the heat exchanger of the classic source, the two installations being serially connected.

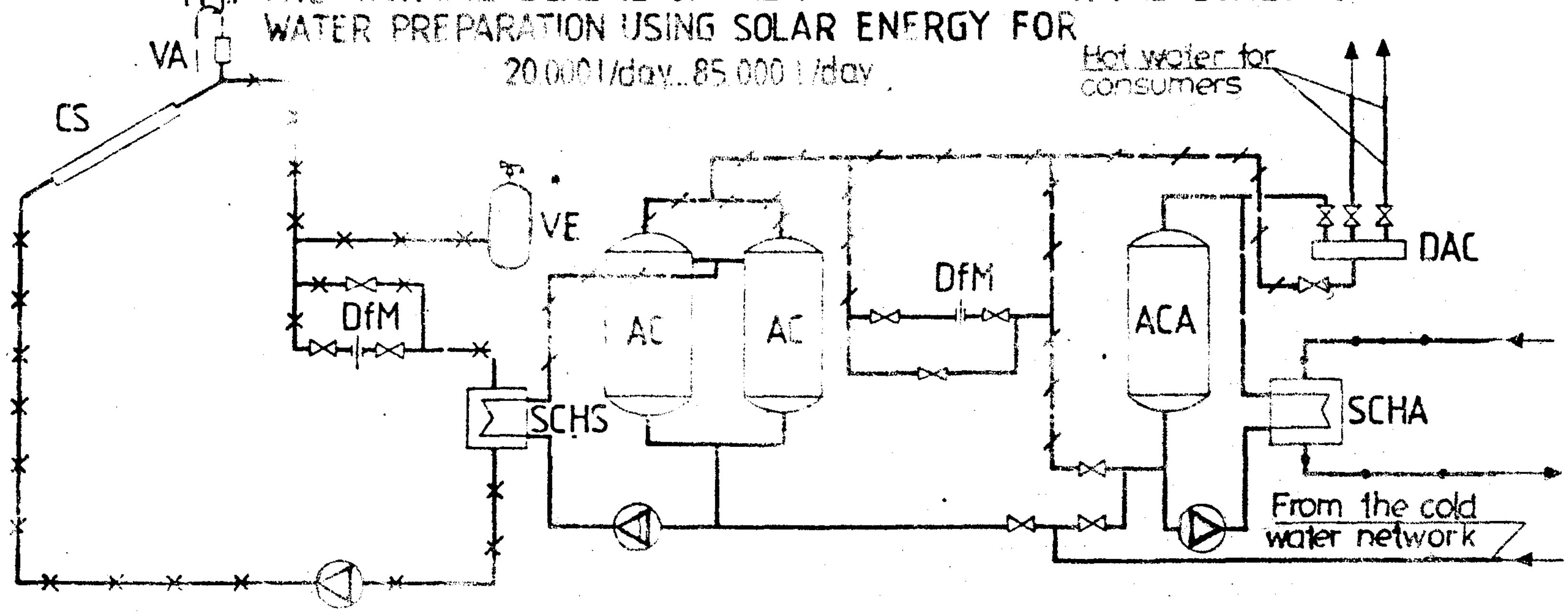
The hot water preparation using solar energy is achieved an electronic regulator that monitors the function of the solar installation when the water temperature at the outlet of the collector is higher than that from the storage tank bottom and the stopping of thepumps when it is not possible to collect solar energy (the temperature at the outlet of the collector is smaller than that from the accumulator).

The basic set-up of the installation already presented is is used on a larger scale when having two circuits and providing a better protection of solar collectors against impurities.

In the circuit of the solar collectors the heat carrier is in a closed circuit, and consumption water is in open circuit on the secondary circuit of the heat exchanger.

In I.P.C.T. there were carried out, on the account of this typical project for collecting installations and for preparation stations of the domestic hot water using solar energy on capacities between 8000 - 115000 l/day hot water of 45°C.

Fig1-THE WORKING SCHEME OF THE INSTALATION FOR THE DOMESTIC HOT WATER PREPARATION USING SOLAR ENERGY FOR 20.000 l/day...85.000 l/day



LEGEND

- COLD WATER PIPELINE
- SOLAR HEATED WATER PIPELINE
- THE PIPELINE FOR THE HOT WATER FROM THE AUX. SOURCE
- SOLAR CARRIER PIPELINE
- HEAT CARRIER PIPELINE - AUXILIARY SOURCE

DfM MEASURING DIAPHRAGM
DAC - HOT WATER DISTRIBUTOR

CS - SOLAR COLLECTOR
SCHS - SOLAR HEAT EXCHANGER
SCHA - HEAT EXCHANGER - AUXILIARY SOURCE
AC - STORAGE TANK FOR SOLAR HEATED WATER
ACA - STORAGE TANK FOR AUXILIARY SOURCE HEATED WATER
VE - CLOSED EXPANSION TANK

NOTE

COUNTERING SYSTEM
- MEASURING DIAPHRAGM AND MANOMETER
- DIFFERENTIAL WITH WITH „U" TUBE ON THE
- PRIMARY AND SECONDARY CIRCUITS

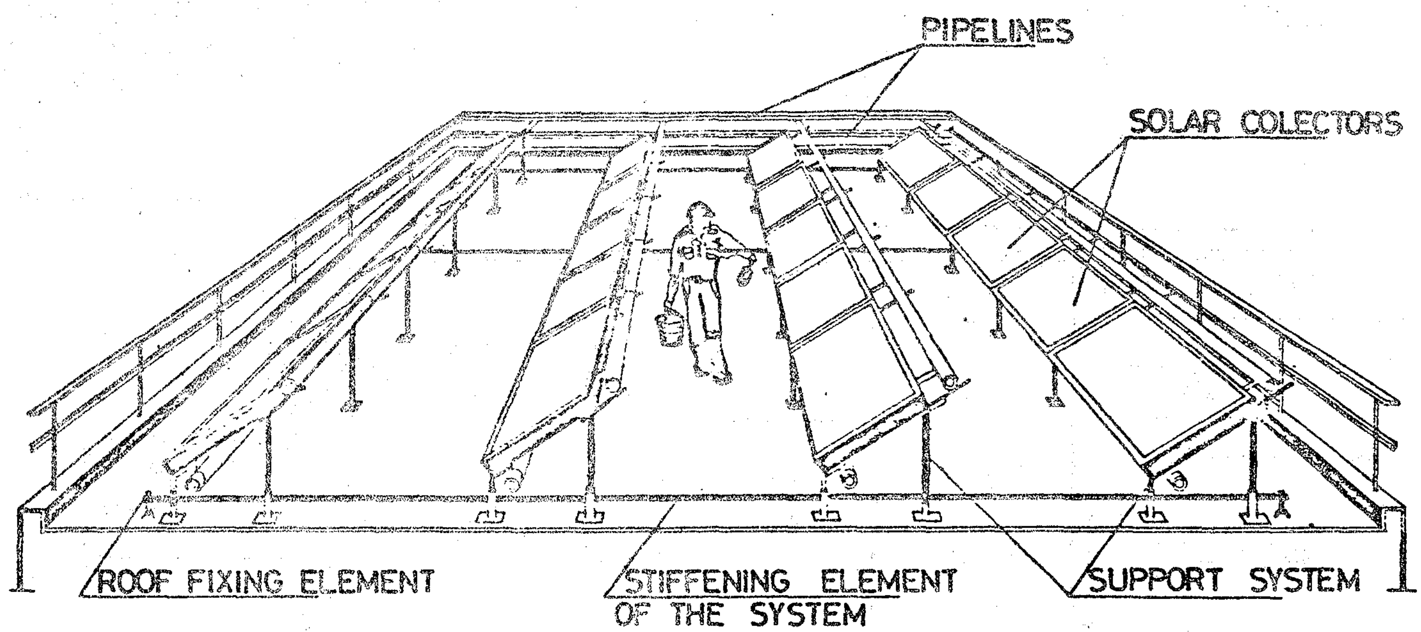


FIG. 2 SOLAR COLLECTORS MOUNTAGE ON THE REINFORCED CONCRETE BUILDINGS

III.7 COUPLED SYSTEMS OF HEAT PUMPS AND SOLAR INSTALLATIONS USED IN SPACE HEATING AND WATER PREPARATION

Florin Iordache[x]

1. INTRODUCTION

The coupling of solar installations with heat pumps offers the possibility of creating hybrid systems that may be in service the whole year. Winter is characterized by a rather low solar energy potential and therefore a simple solar installation is not efficient. The coupling of a solar installation with a heat pump allows the extensive service of the system even in hours of low energy potential.

The heat pumps included in the hybrid systems under study are compression heat pumps with low capacity: 36.64 kW and 116.3 kW and are produced by Tehnofrig - Cluj-Napoca. Absorbtion flat-plate solar collectors are produced by IAA Alexandria.

This paper presents the mathematical modelling of hybrid systems service as well as the analysis of the heat performances that are obtained for several variants of building and service parameters. The systems were optimized and a proper dimensioning calculus method was worked out. Two types of systems were studied: for dwelling space heating and for warm water producing. They differ, as this paper will prove, both from the viewpoint of structure and service.

II. SYSTEM DESCRIPTION AND SERVICE

Both types of systems consists mainly of three sections (fig.1.):

- solar collectors
- heat pump
- warm water tank supplying the consumer

The system works differently according to the consumer. Thus, in case of the space heating system the service includes two distinct stages:

- 1st stage: only the solar installation and the heat pump

x Research Officer - INCERC, Bucharest, Romania

for warm water tank charging work. This is valid for the sunny hours when the heating installation does not work and the house undergoes a cooling process.

- IInd stage: only the heating installation works and the house undergoes a heating process.

In the sunless period the solar installation and the heat pump do not work.

In the case of the system for producing warm water the two service stages may overlap for certain periods or may be distinct, as during heating.

In winter, during a succession of sunless hours the heat pump works using a waste water tank as a cold source.

III. MATHEMATICAL MODELLING

This chapter refers separately to the two systems; as the service and the consumer's requirements are rather important, a specific analysis will be performed for each system.

a) Coupled system of solar installation and compression heat pump used in space heating.

Three stages were covered for the analysis and dimensioning of such a system:

a. dimensioning of the heating system and of warm water storage tank (V)

b. dimensioning of solar energy collecting space (S)

c. determining systems annual average performance.

In the first stage of the heating system dimensioning, the usual working possibilities of the two heat pumps were taken into account so as to supply warm water of 40 - 60°C. Consequently the heating installation worked to supply heat in conditions of rather low heat carrier temperature which generated increased surfaces of heating units. The intermittent operation of the heating installation was also taken into account.

House cooling:

The inside temperature evolution in this period was given by the differential equation solution:

$$A\,(t_i - t_{es}) = -Mc\frac{dt_i}{d\tau} \tag{1}$$

The integration proves an exponential variation of inside temperature (t_i) in this period so that relation (2) links the maximum and minimum values:

$$\frac{t_{im} - t_{es}}{t_{iM} - t_{es}} = e^{-\frac{A}{Mc}N} \tag{2}$$

The minimum and maximum inside temperature values are considered to be symmetrically placed as against the normal inside temperature (t_{io}) so that part of the normal heat consumption should be presented and no inside temperature drops should occur.

$$t_{im} + t_{iM} = 2t_{io} \tag{3}$$

House heating:

The house heat balance in this period considered in terms of house and heating unit is:

$$\begin{cases} G_R \cdot c_a (t_T - t_R) - A(t_i - t_{ens}) = Mc \dfrac{dt_i}{d\tau} \\ G_R \cdot c_a (t_T - t_R) = K_R S_R \cdot \Delta t_{ml} \end{cases} \tag{4}$$

where

$$\Delta t_{ml} = \frac{t_T - t_R}{\ln \dfrac{t_T - t_{io}}{t_R - t_{io}}} \tag{5}$$

The following linear differential equation is obtained:

$$\frac{dt_i}{d\tau} = -\frac{A + G_R \cdot c_a E^*}{Mc} t_i + \frac{G_R c_a E^*}{Mc} t_T + \frac{A}{Mc} t_{ens} \tag{6}$$

where

$$E^* = \frac{t_T - t_i}{t_R - t_i} = \exp\left(-\frac{K_R \cdot S_R}{G_R \cdot c_a}\right) \tag{7}$$

(the variation of the heating unit heat transfer overall coeffo - cient K_R according to temperature was considered and the solution of using a mean value of this coefficient 5.23 W/m^2 ^{o}K was chosen).

The solution of equation (6) is:

$$t_i = \left(t_{im} - \frac{Q}{P}\right) e^{-P\tau} + \frac{Q}{P} \tag{8}$$

where:

$$p = \frac{A + G_R c_a E^*}{Mc} \qquad (9)$$

$$Q = \frac{G_R c_a E^*}{Mc} t_T + \frac{A}{Mc} t_{ens} \qquad (10)$$

If relation (8) is particularized for the whole period of house daily heating, the result is:

$$t_{iM} = \left(t_{im} - \frac{Q}{p}\right) e^{-p(24-N)} + \frac{Q}{p} \qquad (11)$$

which provides:

$$\frac{G_R}{A} = \frac{1}{E^*} \frac{(t_{iM} - t_{ens}) - E(t_{im} - t_{ens})}{(t_T - t_{iM}) - E(t_T - t_{im})} \qquad (12)$$

where:

$$E = \exp\left[-(24-N)\left(1 + E^* \frac{G_R}{A}\right)\frac{A}{Mc}\right] \qquad (13)$$

Relation (12) is a transcendent equation with ratio C_R/A as unknown value.

We may conclude that in general the house heat loss coefficient (A) and the house thermal capacity (Mc) are to some extent proportional. The following relation was therefore determined:

$$\frac{Mc}{A} = 0{,}0815\, p \qquad (14)$$

where p represents the building specific loading.

The heating installation dimensioning will be performed under more severe climatic conditions than those of a usual winter, namely for the average conditions of the coldest month. An average year in the period 1976-1984 in a hill zone was considered.

MONTH	NOV.	DEC.	JAN.	FEB.	MARCH	MEAN VALUES
N	6	5	5	8	9	6.6
t_{es}	7.3	3.5	0.5	2.6	8.8	4.54
t_{ens}	3.4	0	-2	-1.5	4.1	0.8
t_{E1g}	35.2	37.5	34.5	40.9	53.6	40.34
t_{E2g}	44.49	48.82	45.82	53.65	68.52	52.26

Three variants were tested for the heat carrier values in the climatic conditions specific to January:

- $t_T = 60^{o}C$; $t_R = 50^{o}C$
- $t_T = 50^{o}C$; $t_R = 42^{0}C$
- $t_T = 42^{o}C$; $t_R = 30^{o}C$

All these three variants have lower values than the corresponding ones in the classical control diagram. The lower the couple of heat carrier temperature values at the heating unit inlet and outlet is, the larger the required heating area is. Moreover, a considerably reduced collecting area is necessary. May we mention that for the variants previously presented the heating area is 2 up to 4 times larger than in the classical case. The heating area is determined using relation (7) after the necessary heat carrier flow-rate (G_R) is known. Both are provided by the solution of the transcendent equation (12) which was solved using a TI-59 programmable computer; the successive approximations method was used for each variant.

The maximum and minimum values of the inside temperature were provided by the solution of the system including relations (2) and (3); for a building specific loading of p= 550kg/m ; $t_{iM}=19^{o}C$ and $t_{im}= 17.05^{o}C$.

The heating system was thus conceived that heat carrier having t_T temperature and G_R flow-rate should be continuously supplied in the heating units in the (24-N) sunless hours; the storage tank volume should therefore have a value so that water with G_R flow-rate should be recirculated once in the (24-N) hours. So:

$$V = (24-N)\,G_R \qquad (15)$$

In order to fulfill this dimensioning stage the control diagram should also be plotted. Solution (11) of the differential equation also provides:

$$t_T = \frac{(t_{im} - t_{iM} E)(1+E^* \frac{G_R}{A}) - (1-E) t_{ens}}{E^* \frac{G_R}{A} (1-E)} \qquad (16)$$

$$t_R = (1-E^*)\,t_T + E^* t_{io} \qquad (17)$$

Several combinations of the following parameters were analized using the method previously described:

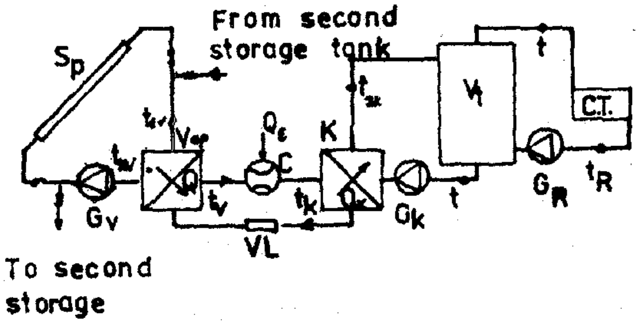

From second storage tank
S_p
V_{ap}
Q_E
C
K
V_t
C.T.
t_v
t_k
G_v
VL
G_k
t
G_R
t_R
To second storage

FIG. 1

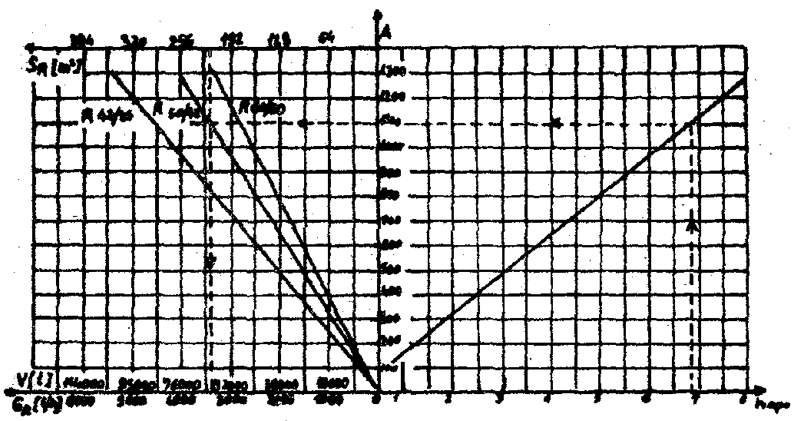


FIG. 2

- control temperature values of the three variants
- specific building loading
$p = 550\ kg/m^2$ and $p = 1{,}000\ kg/m^2$

The result proves that the specific building loading(p) is less important in heating installation dimensioning, but the heat carrier temperature values are significant. The actual values resulted for each variant are centralized in fig.2.

As the warm water storage tank volume and the temperature to be reached by the water in the tank after N sunny hours in calculus conditions are known, the collecting area may be dimensioned. The mathematical model includes the heat balance equations for each system component:

$$\begin{cases} F_k S_p K_\Sigma (t_\varepsilon - t_{2v}) = G_v c_a (t_{1v} - t_{2v}) \\ G_v c_a (t_{1v} - t_{2v}) = a_v t_v + b_v t_k + c_v \\ G_k c_a (t_{2k} - t) = a_k t_v + b_k t_k + c_k \\ G_k c_a (t_{2k} - t) = V c_a \dfrac{dt}{d\tau} \\ t_v = t_{2v} - \delta_v \\ t_k = t_{2k} - \delta_k \end{cases} \tag{18}$$

The second and the third equations of the system (18) include the expressions of the heat flow-rate at the heat pump vaporized and condenser in the second member as linear functions of freezing temperature (freon 12). The linear form offers a satisfactory approximation of the two heat flow-rates for rather large range of heat carrier vaporizing and condensing temperature values. The constant values a_v, b_v, c_v, a_k, b_k, c_k, c_k were experimentally determined by the heat pump producer.

The whole system may be easily reduced to a linear differential equation:

$$\frac{dt}{d\tau} = -P^* t + Q^* \tag{19}$$

where:

$$P^* = \frac{G_k}{V}\left[1 + \frac{1}{\Delta}\left(1 + \frac{a_v}{\Delta G_v}\right)\right] \tag{20}$$

$$Q^* = \frac{1}{\Delta V}\left[G_K c_2 \left(1 + \frac{a_V}{\delta G_V}\right) - a_K (t_E + C_1)\right] \tag{21}$$

where:

$$C_1 = \frac{(a_V - b_V)\delta - e_V}{\delta G_V} \tag{22}$$

$$C_2 = \frac{(a_K - b_K)\delta - e_K}{G_K} \tag{23}$$

$$\Delta = \left(1 + \frac{a_V}{\delta G_V}\right)\left(\frac{b_K}{G_K} - 1\right) - \frac{b_V}{\delta G_V}\,\frac{a_K}{G_K} \tag{24}$$

and:

$$\delta = 1 - \exp\left(-\frac{F' K_\Sigma}{G_V c_e} s_p\right) \tag{25}$$

The solution of equation (19) is:

$$t = \left(t_0 - \frac{Q^*}{P^*}\right) e^{-P^*\tau} + \frac{Q^*}{P^*} \tag{26}$$

After N sunny hours the temperature of the water in tank V will be:

$$t_f = \left(t_0 - \frac{Q^*}{P^*}\right) e^{-P^* N} + \frac{Q^*}{P^*} \tag{27}$$

Temperature values t_{2k}, t_{2v}, t_{1v} will be determined using relations:

$$t_{2K} = \frac{1}{\Delta}\left[\left(1 + \frac{a_V}{\delta G_V}\right)(C_2 - t) - \frac{a_K}{G_K}(t_E + C_1)\right] \tag{28}$$

$$t_{2V} = \frac{1}{\Delta}\left[\left(\frac{b_K}{G_K} - 1\right)(t_E - C_1) - \frac{b_V}{\delta G_V}(C_2 - t)\right] \tag{29}$$

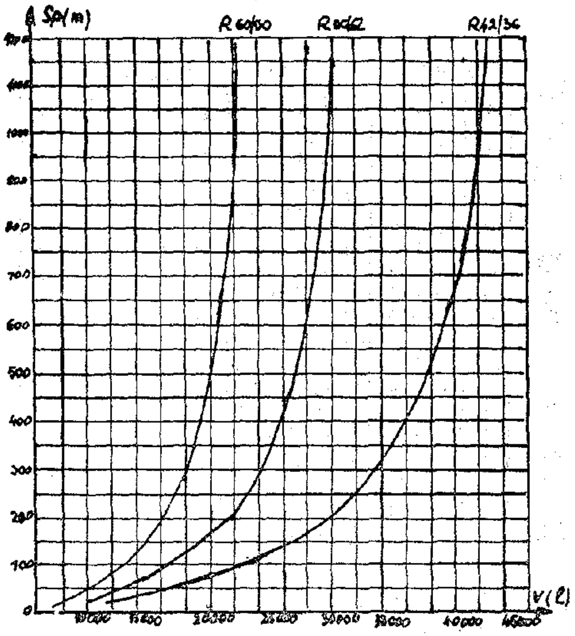


FIG. 3 GPCF 31,5/2 Simple glazed solar collector

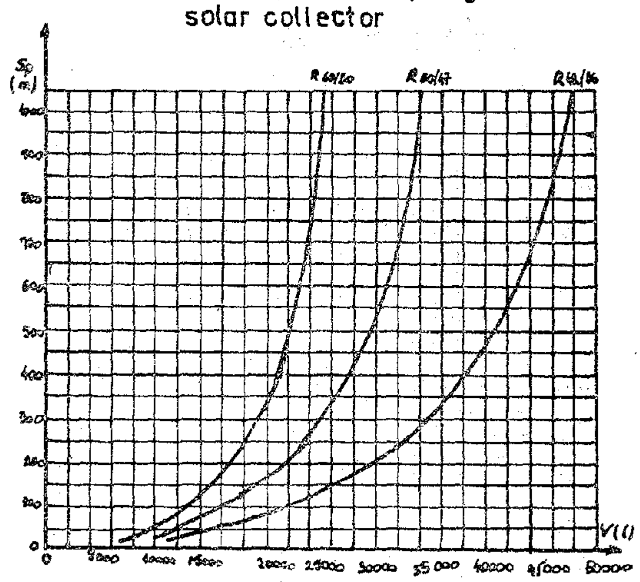


FIG. 4. GPCF 31,5/2 Double glazed solar collector

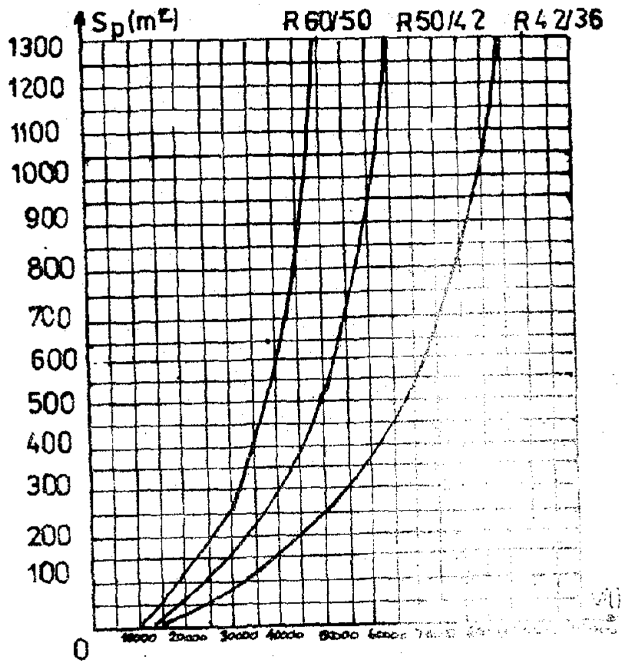


FIG.5 GPCF – 100 Simple glaze
solar collector

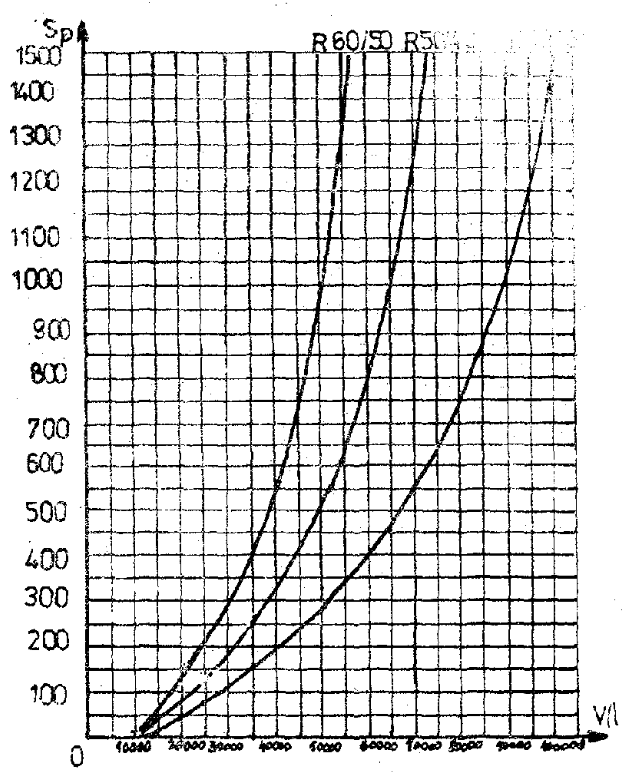


FIG 6 GPCF 100 Double glazed
solar collector

$$t_{1V} = t_{2V} + s\,(t_E - t_{2V}). \tag{30}$$

The basic relation used in dimensioning the collecting area is (27) where the initial temperature in tank to is identical with t_R - heat carrier outlet temperature for the heating section and the final temperature in tank, t_f, is equal to cost - heat carrier inlet temperature. Relation (27) represents a transcendent equation in S_p which was solved by the successive approximations method using a computer 12 variants defined by the following elements were thus studied:

- the three sets of heat carrier temperature values in dimensioning conditions;
- two types of solar collectors with simple and double glazing;
- two types of compression heat pumps GPCF-31. 5/2 and GPCF-100;

The results were plotted in fig.3,4,5 and 6. Each variant has a corresponding boundary value of the storage volume that may be heated from temperature t_R to temperature t_T. This value is determined by the relation:

$$V_L = \frac{G_K \cdot N}{\ln \frac{t_R - L}{t_T - L}} \left[1 + \frac{1}{\Delta}\left(1 + \frac{\alpha_V}{G_V}\right)\right] \tag{31}$$

where:

$$L = \frac{C_2\left(1 + \frac{\alpha_V}{G_V}\right) - \frac{\alpha_K}{G_K}\left(t_E + C_1\right)}{\Delta + \left(1 + \frac{\alpha_V}{G_V}\right)} \tag{32}$$

As the collecting area is now known, system dimensioning is finished and the following stage, devoted to thermal performances determination, may be started. In order to perform a rapid study of system thermal efficiency for the whole cold season, the service in an average winter day will be considered. The service in real conditions requires the determination of certain parameters:

- water flow-rates at vaporizer G_V and condenser G_K
- warm water volume of tank V
- heat carrier flow-rate of consumer G_R

No matter the climatic situation of the day, the consumer heating period will be (24-Nc) hours, namely 19 hours. But according to the climatic conditions of the day, the temperature of the water in the tank will correspond to the control diagram previously presented. The tank thermal loading in a usual day from outlet temperature to inlet temperature will be performed in N^x / Nc hours. In case of an annual average day, $N^* < Nc$.

Thermal performances for an annual average day requires the following determinations:

- daily heat quantity supplied to the condenser, which is obviously equal to the heat storage in tank:

$$Q_K = V \cdot c_a (t_T - t_R) \tag{33}$$

- daily heat quantities taken over by the vaporizer:

$$Q_V = N^* \frac{\Delta G_V}{\Delta} \left\{ \Delta t_E - \left(\frac{b_K}{G_K} - 1 \right)(t_E + C_1) + \frac{b_V}{\Delta G_V} \left[C_2 - \frac{Q^*}{P^*} - \frac{1}{N^* P^*} \left(t_E - \frac{Q^*}{P^*} \right) \left(1 - e^{-N^* P^*} \right) \right] \right\} \tag{34}$$

- energy recovery rate:

$$F = \frac{Q_V}{Q_K} \tag{35}$$

- heat pump efficiency

$$\varepsilon = \frac{1}{1 - F} \tag{36}$$

The above mentioned elements may be determined after the actual number of service hours N^* is settled using relation (27) :

$$N^* = \frac{1}{P^*} \ln \frac{t_R - \frac{Q^*}{P^*}}{t_T - \frac{Q^*}{P^*}} \tag{37}$$

where t_T, t_R and Q^x is calculated for the climatic situation of an annual average day according to relations (16), (17) and (21) respectively. As the number of variants to be analysed is large and the relations are rather sophisticated, computer calculus was used again. According to fig.2 ÷ 6, several cases, related to consumers with consumption capacity corresponding to up to 9 conventional apartments.

The results analysis proves which variants are suitable both from the view point of solar installation dimensions as well as energy recovery and heat pump efficiency. These variants generally correspond to an efficiency of 2.5÷3.2. for GPCF - 31.5/2 pump and 3.2 ÷ 4.8 for GPCF-100 pump. Therefore the solar installation coupled with GPCF-31, 5/2 heat pump meet the requirements of 2 ÷ 3 conventional apartments and a solar installation with GPCF-100 corresponds to about 3 ÷ 6 conventional apartments.

Note that only N^* hours are necessary to heat the wate the storage tank V; N^* represents 50 ÷ 70 % of the average ...ny hours. Therefore in the $(N-N^x)$ sunny hours the hybrid system may be used in preparing domestic warm water in a tank separate from the heating one. The heating of 200 l/warm water from 10°C to 60°C will further be analysed. The calculus algorithm, results by combining the calculus algorithm characteristic to the second and the third heating stage. The results prove that about 35 min.are required in heating the specific water consumption;possibilities of further using the system are therefore to be considered. A large water volume may consequently be heated; this volume corresponds not only to the specific consumption but also to a larger consumer that does not require heat from the thermal station to prepare warm water. This type of service represents an efficient use of the system and increases its efficiency and rate of energy recovery. In order to estimate quantitatively the system performances in this variant, it is necessary to determine the increased volume of water that may be heated,which is rather simple as the heated water volumes and the heating time are proportional.

The consumer's energy recovery increase considerably. The consumer's overall heat requirement specific to the cold season may be covered entirely by solar means.

It is worth mentioning that this study did not consider the energy quantity supplied in summer by the solar installation for producing warm water. Taking into account the winter heat consumption, the dimensioned collecting area exceeds considerably the area required by warm water producing about 10-15 times larger,for the same consumer.

Therefore in the warm season the solar installation may prepare domestic warm water for a larger consumer. This generates system efficiency increases and a reduced number of investment payback years. The system energy recovery is satisfactory (between 85% and 95%) from the viewpoint of the range of possible consumers mentioned above, namely 2 - 3 apartments conventional apartments for systems using. GPCF-31.5/2 heap pump and 3 - 6 apartments for systems using GPCF-100 heat pump. These energy recovery rates correspond to system efficiency values of 6 to 20. From the economic viewpoint the investment payback period is of 11-18 years as the compression heat pumps and the solar collectors are expensive at present.

b) Solar installations coupled with heat pumps used in producing warm water.

The possibilities of daytime water heating using hybrid systems both in the warm and in the cold season are further presented. Two variants are studied: one of a system working simultaneously with the consumer in the sunny hours and the other of a system and a consumer working separately (as in case of heating).

The results provided by the analyses performed on the two variants are so similar that our study will refer only to a few remarks on system dimensioning in the second variant.

The following parameters will be correlated: collecting area (S_p), storage volume (V) and resulting temperature of warm water in tank (t_f). The characteristics of the average day considered in dimensioning:

- in case of warm season:
  - . number of sunny hours (system serv ice) N_2 = 9h
  - . solar radiation intensity - I_o = 580 W/m^2
  - . outside temperature - t_e = 20^{o}C
  - . cold water temperature - t_o = 15^{o}C
- in case of cold season:
  - . number of sunny hours (system service) N = 6.5h
  - . solar radiation intensity - I_o = 290 W/m^2
  - . outside temperature - t_e = 5^{o}C
  - . cold water temperature - t_o = 10^{o}C

The mathematical model used in system (18) previously described.

The analysis performed on simple and double glazing did not generate considerable differences. The results obtained are presented in fig. 7 ÷ 10. The diagrams may be easily used if the consumer's requirements are known.

The use of these systems in preparing warm water is recommended mainly in the cold season and only in the secondary loop or partially in the cold season.

In case of coupling a GPCF 31.5/2 heat pump consumers of 8,000 ÷ 14,000 l/day may be supplied with warm water of 40 - 46^{o}C; in case of coupling a GPCF-100 pump consumers of 14,000÷32,000 l/day may be supplied with warm water of 40-54^{o}C. The solar collecting areas in the two situations and the efficiency of the heat pumps are 150 ÷ 750 m^2 and 3 ÷ 3.8 in case of GPCF-31.5/2 pump and 450 ÷ 1,700 m^2 and 3.7 ÷ 5.5 in case of GPCF-100 pump.

A few particular situations using the two heat pumps and secondary cold sources (domestic waste water) were analyzed. From the economic viewpoint, a payback period of 8-15 years resulted; the low values correspond to the GPCF-100 pump and the high values correspond to the GPCF - 31.5/2 pump. The considerable difference between the two situations is caused by the usual efficiency of the two systems: 3 in case of GPCF 35.5/2 pump and 4.5 in case of GPCF -100 pump. Tehnofrig Cluj presently produces an improved variant of the 36.64 kW small heat pump: GPCF - 31.5/4, which may work with efficiency of 4 - 5.

The use of waste water as heat pump cold source involves technological problems to be solved: separate sewerage installation for washstands and bathrooms with proper hygenic conditions.

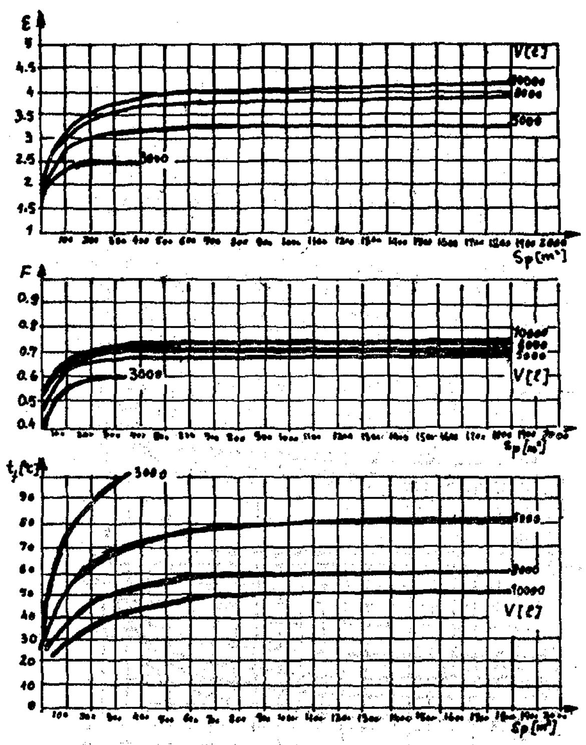


FIG.7-SI+ GPCF 31,5/2 - Cold season

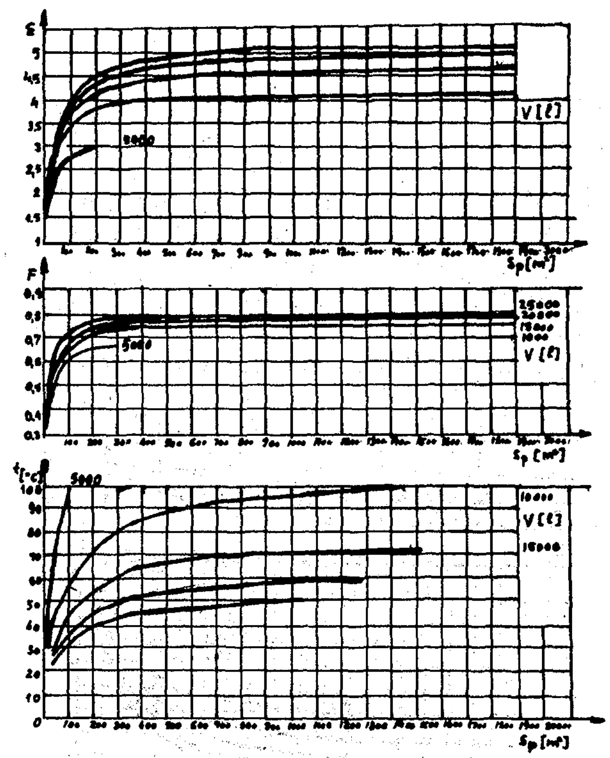


FIG.8-SI + GPCF 31,5/2 - Hot season

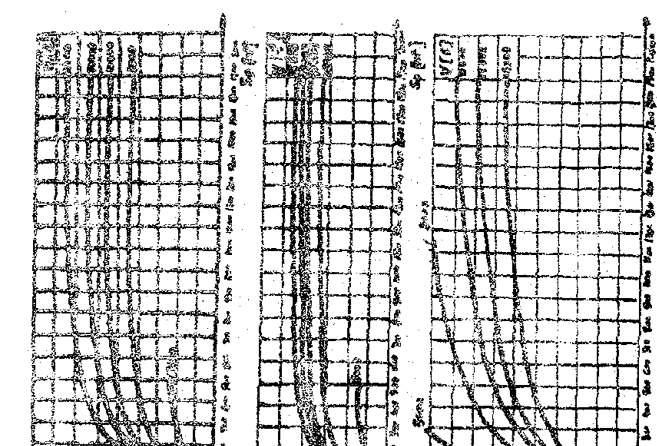


FIG. 9 - SI + GPCF 100-Cold season

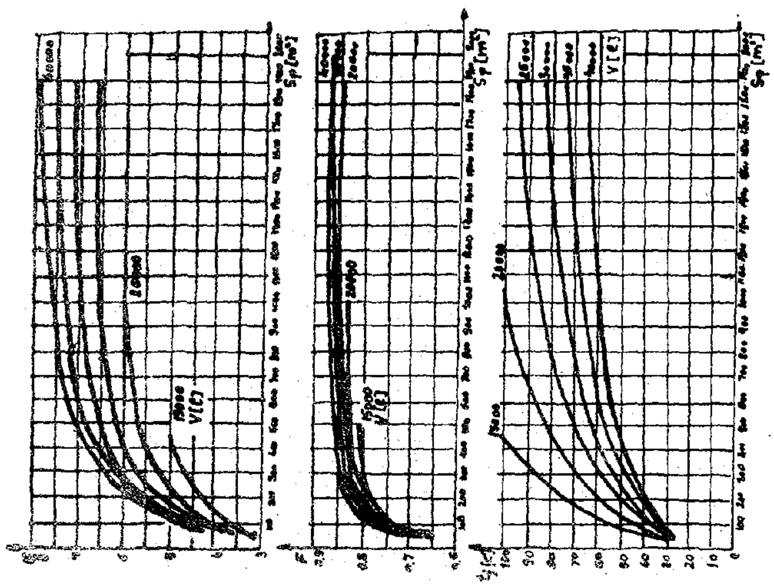


FIG. 10-SI + GPCF 100 - Hot season

NOMENCLATURE

t	- current temperature in storage tank	(^{o}C)
t_i	- building inside temperature	(^{o}C)
t_{io}	- normed inside temperature	(^{o}C)
t_{es}	- outside temperature in sunny hours	(^{o}C)
t_{ens}	- outside temperature in sunny hours	(^{o}C)
t_{im}	- minimum inside temperature	(^{o}C)
t_{iM}	- maximum inside temperature	(^{o}C)
t_E	- equivalent temperature	(^{o}C)
t_T	- heat carrier temperature at heating unit inlet	(^{o}C)
t_R	- heat carrier temperature at heating unit outlet	(^{o}C)
t_{1v}	- water temperature at vaporizer inlet	(^{o}C)
t_{2v}	- water temperature at vaporizer outlet	(^{o}C)
t_{2k}	- water temperature at condenser outlet	(^{o}C)
t_v	- vaporizing temperature	(^{o}C)
t_k	- considering temperature	(^{o}C)
δ_v, δ_k	- temperature differences at vaporizer and condenser	
G_R	- heat carrier flow-rate	(l/h)
G_V	- heat carrier flow-rate in vaporizer	(l/h)
G_K	- heat carrier flow-rate in condenser	(l/h)
G_T	- daily warm water consumption	(l/day)
V	- storage tank volume	(l)
S_p	- collecting area	(m^2)
S_R	- heating unit area	(m^2)
N	- number of sunny hours	(h)
N^*	- number of service hours for heating	(h)
τ	- current time	(h)
K_Σ	- heat transfer overall coefficient of solar collectors	(W/m^2k)
K_R	- heat transfer overall coefficient of heating units	(W/m^2k)
A	- building thermal characteristics	$(W/C^{o}K)$
M	- building massiveness	(kg)
Q	- heat quantity	(Kwh)

F - energy recovery rate

ε - heat pumps efficiency

REFERENCES

(1) - Iordache, Florin - Solar Installations with Heat Pumps for Warm Water Producing, Installations, 7/1984.

(2) - Iordache, Florin - Use of Systems Coupled with Heat Pump Solar Installations in Dwelling Space Heating Installations, 9/1985.

III.8 ASPECTS REGARDING THE ECONOMIC ENERGY OPTIMIZATION IN THE USE OF NEW ENERGY SOURCES IN BUILDINGS

Achile Petrescu[x]
Dan Berbecaru[x]
Victor Cucu[x]

The use of new energy sources, including solar energy and the energy recovery from secondary sources, requires an increase of the investment expenses in comparison with the situations when the traditional fuels are used, especially when the energy source can not be used at constant capacity.

The paper deals with a methodology of calculating the recovery period of those supplementary investment expenses, by reducing the expenses in foreign currency necessary for the fuel import as a result of the new energy sources utilization. Also is presented the methodology of calculating the total heat cost and the way it varies in comparison with the previous heat cost, before the use of the new energy source.

The paper also presents three examples of economic-energy calculus for an installation of solar energy for an assembly of 1000 apartments, of an installation of geothermal energy use for heating and domestic hot water preparation for an industrial consumer of 1,07 KW and for a heat pump station that feeds up an industrial consumer.

1. GENERAL FRAME OF THE ANALYSES

Over the last decade energy problems have become more and more important in social and economic activity. They influence the personal, family and collective life in all the countries, the social-political form of government, economic level of geographical placement having no importance.

x Engineers - Design Institute for Typified Buildings - IPCT
70132 - Str.Tudor Arghezi nr.21
Bucharest, Romania

Without reconsidering the events of history that generated the present situation, it is enough to mention that all over the world precautions were taken for energy saving in all fields of activity. At the same time use of some substitute energies, new energy sources and recovery from the secondary sources, where till now it had been lost, were increased.

Acting in this field, the authors have elaborated solutions to use some new energy sources (as solar, geothermal) and to recover heat from secondary sources (water, air) in order to satisfy heat requirements for industrial buildings and dwellings. Participating in the achievement of some programs with a wide applicability, working out different designs and helping the use of new solutions in Romania, the authors were obliged to find technical solutions that also had to deal with the energy - economic aspects of this field too.

It has to be mentioned that the respective solutions that were not officially legislated in Romania, but they are accepted and used now in the decisions concerning the presented domain, enlarging the respective methodology for other directions using some new sources other than those presented as being the author's experience.

For a better understanding of the economics of the new energy sources it is necessary to describe very briefly the Romanian special conditions, as it concerns the achievement of the new investments and the establishment of the heat costs, with a special reference at the use of the new energy sources.

We consider it a mistake to generalize the Romanian way of dealing with the economic-energy aspects for all the socialist countries even through in some countries the conditions are the same.

2. THE INVESTMENT PAYBACK

Although Romania has its own oil production, it has to import an important quantity from the outside market. For this resson, any primary energy saving resulted from the use of new sources or by recovering energy from secondary sources leads to a decrease of the oil imports and implicitely a decrease of the expenses in foreign currency, for the life of the equipment especially created. Since the effort is influencing the national economy, this concept is applied even when the energy consumer uses a heat source with fuels other than liquid.

Practice has showed that the use of new sources and energy recovery from secondary sources leads, in almost all cases, to an increase of the investment expenses in compasison with the use of traditional fuels, especially when the energy source can't be used at a constant capacity, as the solar energy case.

As supplementary investment expenses appear, these are to be recuperated by diminishing the expenses using foreign currency necessary for the fuel import (petrol) as a result of the new inside sources utilization as well as of the energy recovery from the secondary sources.

The payback period of the investment is not indifferent;it must not exceed that of the traditional energy sources and that is why in Romania a solution is economic when the payback period is up to 10 years.

We may include in the payback period calculus an increase of the oil prices with an average percentage of recent years representing an anticipation for the future years.

The investment expenses are supported from the state fund that offers also the material means necessary for the investment achievement. As the investment is not made on credits, in the calculus of the payback period a reconversion of the investment expenses is not made along this period.

It has to be mentioned that although energy recovery from secondary sources decreases the general energy consumption, it also requires an increase of the electrical power consumption from the national system. Also included in the investment expenses calculus are the expenses for the supplementary electric power included in the national system.

As a result of those already presented, the general calculus relation of the payback period of the supplementary investment expenses is :

$$N = \frac{I + c \cdot \Delta P_e}{p \cdot \Delta G} \quad \text{(years)} \qquad (1)$$

N - is the payback period, in years;
I - the investments growth required by the use of new source of of the secondary source, in lei (the national currency in Romania)
Δ Pe-the electrical power growth required by the use of the new source or of the secondary source, in kW;
c - the specific investment cost for the installation in the national system of an electrical power growth, in lei/kW;
ΔG-the annual fuel saving as the result of use of the new sources or secondary sources in kg.f.s./year;
p - import cost of the oil, coverted into national currency, in lei/kg.e.c.

We remind you that for the national economy any energy saving leads to an important oil saving, and determines the relation:

$$\Delta G = \frac{\Delta Q}{\eta \cdot P_{ci}} \quad \text{(kg.e.c./years)} \qquad (2)$$

ΔQ - is the yearly thermal energy saving as the result of the use of new sources and secondary sources in kJ/year (kWn/year);

η - the average efficiency of burning the liquid fuel; it refers to the liquid fuel as the use of the new sources is in order to diminish the oil import;

Pci-low caloric power of the conventional fuel, as a reference in all the statistical calculus

P_{ci} Pci = 29.298 kJ/kg.e.c. (7000 Kcal/kg.e.c.)
kg.e.c.-represents the fuel mass in equivalent coal.

In the solutions where the thermal energy saving is acompanied by the increase of electrical power consumption the net economy is determined considering the used fuel in order to produce the respective electrical energy. As the result

$$\Delta G = \frac{\Delta Q}{\eta \cdot P_{ci}} - e \cdot \Delta E \quad \text{(kg.e.c./year)} \qquad (3)$$

ΔE - is the excess electric energy consumption as the resultof the use of the new or secondary sources, in kWh/year;

e - special fuel consumption , average consumption on the whole country, for the electric energy production, in kg.e.c./kWh.

3. HEAT COST

For dwellings the heat cost is supported by habitants and in industry it is a part of the production cost.

The use of new sources and the energy recovery from the secondary sources influences the total cost of the heat. The heat cost in this case is not analyzed by its absolute value, but only by the way it varies in comparison with the anterior cost of the heating, before the use of the new energy sources.

The elements of the first cost may be grouped as it follows:
- the elements proportional with the investment expenses (redemption expenses, general overhauling; running services); as the investment grows with the central part of the new source, these elements of the first cost are also growing;
- expenses for energy: expenses for fuel (at local price, intern) are decreasing at the same time with the decrease of the consumed fuel quantity per year, but in some situations this decrease is subdued by the growth of the cost for the supplementary used electric energy;
- other expenses, that generally are not at all or very little influenced by the supplementary installation required by the use of new energy sources or by the energy recovery from secondary sources.

In many situations the total cost of the heating does not grow since the decrease of the expenses for the energy consumption is bigger than the growth of the elements proportional with the investment expenses. There are also situations when, although the payback period of the investments growth is between economical limits, however the increase of the heating total cost may direct the elimination of the respective solution especially for dwellings, where the Cost is supported by the inhabitants.

As the result of the heating first cost variation is:

$$\Delta C = \frac{a \cdot \Delta I - b \cdot \Delta G}{\Delta Q} \qquad (\text{lei}^x/\text{kWh}) \qquad (4)$$

a - is the annual quota (in percentage) from the investment growth required by the use of new or secondary sources in order to cover the redemption expenses, general overhauling, running services in 1/year;

ΔG-it is determined by the 2^{nd} or the 3^{rd} relation, with the observation that η and Pci have the specific values of the effectively used fuel and as the result ΔG represents the mass of this fuel in kg/year;

b - the effectively used fuel cost (intern cost) in lei/kg.

From the relation 4 it results that in order to have a reduction of the heating cost at the same time with the use of new sources or with the energy recovery from the secondary sources, it is necessary as ΔC value to be negative.

4. EXEMPLE OF THE ECONOMIC CALCULUS FOR ENERGY

a) The analysis of the payback period of the investment growth for an installation using solar energy for consumption hot water preparation in an assembly of 1000 appartments (fig.1).

The installation works during the period of April-October and it is additional for another heating supply installation for winter (heating and consumption hot water) or during clouded summer time (for consumption hot water). The supplementary installation does not require an increase of the already fixed up electric power.

Heat requirements for consumption hot water preparation, at the temperature of 323 K, during summer time, is of Q = 8788 GJ for the whole assembly. The climatic zone where are the dwellings placed and the used solar collectors type allow an energetical efficiency of F = 0.77.

---

x "lei" is the Romanian currency

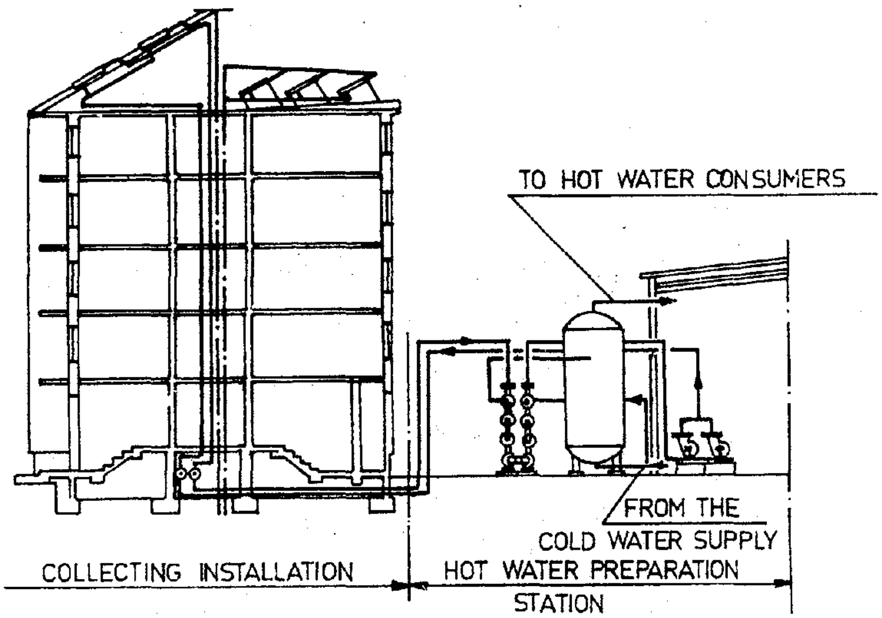


Fig.1

As the result the heat used resulting from the solar energy (ΔQ) is of:

$\Delta Q = F.Q = 0.77 \cdot 8788 = 6767$ GJ/year

The fuel saving is determined by the relation 2, where:

$\eta = 0.735$ and $Pci = 29{,}298$ kJ/kg.e.c.

$$\Delta G = \frac{\Delta Q}{\eta \cdot Pci} = \frac{6767 \cdot 10^{6}}{0.735 \cdot 29{,}298} = 314.250 \text{ kg.e.c./year}$$

The equipment for hot water preparation by the help of solar energy does not require the installation of some supplementary electric power.

The payback period of the investment expenses is determined by the help of the imported oil value that was saved, using the 1st relation, where:

$\Delta I = 8.232.000$ lei; $\Delta Po = 0$ kW; $p = 2{,}95$ lei/kg.e.c.

It results that:

$$T = \frac{\Delta I + c \cdot \Delta Pe}{p \cdot \Delta G} = \frac{8.232.000}{2{,}95 \cdot 314.250} = 8.88 \text{ years}$$

The payback period being under 10 years, the solution is considered to be an economical one.

b) The analyses of the payback period of the investment growth for an installation that uses the geothermal energy for heating an consumption hot water preparation, for an industrial consumer (fig.2) of 1.07 MW (total thermal load at the peak consumption).

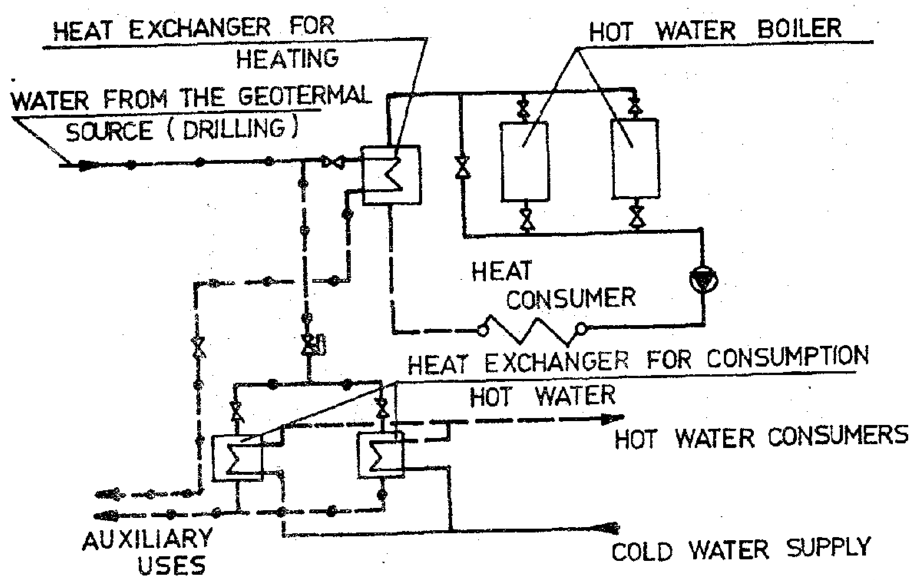


Fig.2

The thermal source consists of a geothermal water drilling having the artesian flow of 18 m^3/h and a temperature of 343 K, completed with a peak thermal power station of 0.56 MW, with solid fuel.

The distance between drilling zone and the consumer is of 1,5 km.

The nominal temperature parameters of the thermal carrier accepted in the inside heating installation are 368/313 K.

Before the implementation of the geothermal energy solution, all the thermal load (1.07 MW) is provided by a thermal power station with solid fuel, and the temperature parameters of the heat carrier in the inside heating installation were of 368/348 K; by using geothermal energy the thermal power station capacity is reduced at 0.56 MW. The investment growth required by the use of geothermal energy, consisting of drilling, the treatment- pumping station, the feedpipe, the geothermal district heating and the modifications of the inside heating installation has the value of 5.235 lei, including the equivalent expenses for placing into an electric power station of a supplementary electric power (ΔPe = 15 kW).

The heat requirement for heating and consumption hot water preparation is of 7910 GJ/year. If we consider this consumer the geothermal energy covers about 84% from the annual heating requirements.

Thus, the used heat resulted from the geothermal energy is: ΔQ = o.84 . 7910 GJ/year,

The increase of the installed electric power drives to a supplementary fuel consumption at the electric source of 9375 kg. e.c.

Applying the relation(3) the fuel net saving is of:

$$\Delta G = \frac{\Delta Q}{\eta \cdot Pcc} - e \cdot \Delta E = \frac{6644 - 10^6}{0.735 \cdot 29.298} - 9375 =$$

$$= 299.160 \text{ kg.e.c./year}$$

Including the above mentioned values into the 1st relation it results:

$$N = \frac{\Delta I + c \cdot \Delta P e}{P \cdot \Delta G} = \frac{5.235.000}{2.95 \div 299.160} = 5.93 \text{ years}$$

The payback period of the investment being under 10 years the solution is considered to be an economical one.

c) The analysis of the optimization of the equipment solution for a heat pumps station that will supply an industrial consumer (fig.3).

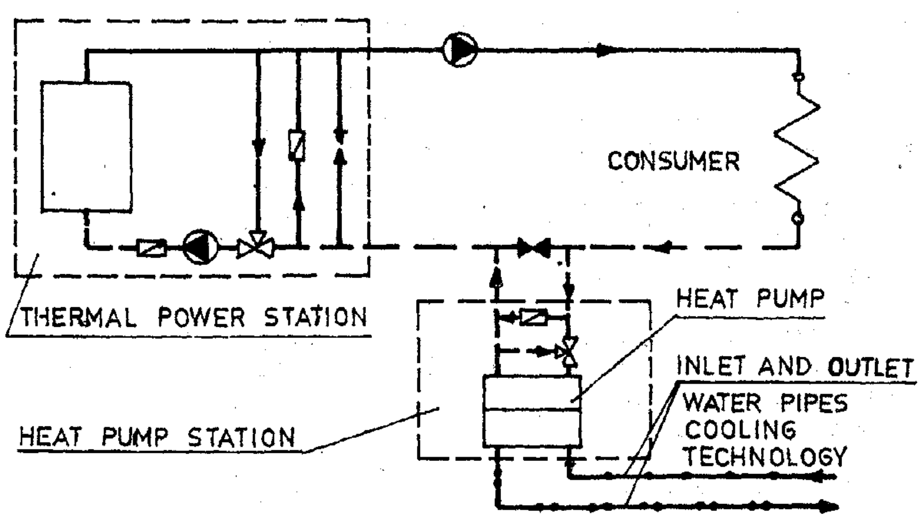


Fig. 3

The heat consumption is made for the heating installation having a capacity Of 7.44 MW. In the standard solution the equipment can be achieved by 4 boilers, 1,86 MW each for solid fuel, providing hot water of 423 K, with a temperature difference of 80 K.

The industrial unit has technological cooling water so that the heat may be recovered by the help of some water-water heating pump, with compressor, having the capacity of 1.45 or 3.65 MW.

Numerous solutions analyzed and only those 9 solutions where the supplementary investment, in comparison with the standard solution, is recovered in less than 7 years.

The optimizing analyses help to both chose the equipment of the heating sources and at the selection of the temperature parameters from the inside heating installation. The solutions consists of nominal inlet temperatures of 353 - 403 K, with a temperature difference of 30 - 80 K between the nominal inlet and outlet temperatures of the heating installations.

The heat source supply is made, in the 1st solution, only with heat pumps, and in all the others above the heat pumps (1 - 3 pieces) there are also used boilers of 1.86 MW, that use inferior solid fuel, necessary for the consumption peak.

The investment expenses consisted of the consumer installation (inside installations and outside networks) the heat source composed of heat pumps and boilers as well as the equivalent instalment expenses for supplementary electric power (required by the compressor heat pumps works) that had to be installed into an electric central power.

The fuel saving represents the net value, after the fuel mass necessary for the electric energy consumed by the compressor heat pumps (relation 3).

Although all those 9 selected solutions (tab.1) are listed in values close of the payback period (5.1 - 6.7. years), there can be a separation between two solutions groups:

- solutions 1-5 where the heat pumps provide over 90 % of the annual heat quantity. These solutions require an investment growth of more than 70% in comparison with the standard solution and they offer a fuel saving of 29.8%.

- solutions 6-9 where the heat pumps provide less than 63% of the necessary heat, the investment growth in comparison with the standard solution is of maximum 48.1%, and the fuel saving is of no more than 21%.

We have to mention the fact that these two groups are cha-

TEMPERATURES		EQUIPMENT PIECE			THERMAL PRODUCTION WITH HEAT PUMPS		FUEL SAVINGS		INVESTMENTS BENEFIT		PAYBACK PERIOD
INLEL K	DIFFERENCES K	HEAT PUMPS		BOILERS 1,86 MW							
		1,45MW	3,65MW		GJ/year	%	tec/year	%	10^3 lei	%	years
353	30	5	—	—	46.855	100	715	32,8	16.179	81,7	6,6
363	50	—	2	1	45.917	98	713	32,7	15.494	78,2	6,4
363	40	—	2	1	44.518	95	691	31,6	15.228	76,9	6,5
373	60	3	—	2	43.578	93	665	30,4	14.815	74,8	6,55
373	50	3	—	2	42.636	91	651	29,8	14.596	73,7	6,6
383	40	1	—	3	14.898	31,8	227	10,4	4.308	21,7	5,7
393	60	—	1	3	26.896	57,4	418	19,1	9.538	48,1	6,7
393	50	1	—	3	17.535	37,4	266	12,2	4.405	22,2	5,1
403	80	1	—	3	29.516	63	459	21	9.495	47,9	6,15

Tab.1

racterized by imediate efforts of different investments, but also of an immediate difference in fuel saving, although if we consider the payback period criteria, they have a closed economy. The selection of the solution is made considering the immediate financial conditions to which are added other facts, such as: the cost of the delivered heat and the possibilities of using some temperature parameters.

5. CONCLUSIONS

The use of some new energy sources and energy recovery from secondary sources may be achieved by different technical solutions.

The selection of the solution must be made after considering energy saving criteria that must consider both the reduction of the traditional fuel consumption and the thermal energy obtained as cheap as possible.

The paper reflected the authors experience over the energy-economic optimization of different solutions of using the new energy sources in bluidirgs and some aspects connected with this action

III.9 SOLAR ENERGY DISTRIBUTION SYSTEM FOR LOW TEMPERATURE HEAT CONSUMERS

Dan Constantinescu[x]

Key words: exergy, anergy, solar energy, hollow walls, rockbed storage, liquid storage

ABSTRACT

This paper introduces basic theoretical elements of an active solar heating system using air as a heat carrier and the inside and outside walls of the dwelling space as static heating units. The heat balance relations specific to this heating type as well as the project solution of an experimental house performed at the Building Research Institute (INCERC) Bucharest are presented in order to prove the solution valid. The paper also introduces a few experimental results provided by tests performed on double service flat plate collectors supplying CS 3 Bucharest solar house. The possible performance of CS 3 Bucharest solar house is also estimated.

I. INTRODUCTION

The energy conservation principle proves that the present energy crisis should be correctly presented as an exergetic crisis. The immediate solutions consist in conceiving technologies meant to provide the necessary exergy; the differentiation level between exergy and anergy is usually an invariant of the system under study. In the case of space heating using solar energy, the invariant element is represented by the inside temperature value.

Entropy is another important parameter in system analysis. If traditional heating is used, the entropy flow-rate is superior to the one specific to low temperature heating systems, including solar heating systems too. In order to compensate for this effect, namely the reaching of the inside temperature, large heating areas at a low temperature level are necessary. This technology may be used in solar heating and is partially described in this paper. The thermal protection of the heated space is an important technological element too and may be practically performed in two ways:

- an increase of thermal resistance of outside elements;
- an artificial increase of environment temperature, with entropy flow-rate decrease as immediate consequence. The tendency of entropy to increase is diminished and the heated space tempe-

rature value is close to the environment temperature value.

Analysis of the temperature field in the exterior walls of the heated room proves the decrease of temperature values from inside towards outside. By temperature increases in any plane parallel to the exterior wall surfaces, the heat flow supplied from the dwelling space to outside is diminished. Dynamic thermal protection is therefore obtained if a moving heat carrier supplies heat. The use of the heat collected by means of flat plate collectors leads on the one hand to an increase in collecting efficiency as against the solar heating systems used up to new and on the other hand to dwelling space thermal protection. Considering the low temperature levels specific to solar radiation collecting in the cold season, this function seems reasonable and anyway superior to traditional solar heating, using flat plate collectors with liquid heat carrier. Moreover, in the case of a hollow wall system (solar heated warm air circulates through walls), called by us MC system /1/, air temperature when exhausted from the circulation lines through the outside walls is lower than the inside temperature and therefore the collecting efficiency is even better than that of warm air active systems. Noxious gases recirculation in the dwelling space is completely avoided.

A similar system may be also applied in case of used air exhausted from the heated space; in this case the window works as an economizer.

The mathematical models specific to the system under study as well as some design elements determining the CS 3 Bucharest solar house built according to MC system will be presented further on.

II. CALCULUS ELEMENTS

This chapter describes the method of determining the thermal response of the system as well as that of the following constituent parts:

a. outside hollow walls
b. hollow partitions
c. double-glazed windows adapted to the function of recovering heat from the viciated air exhausted from the dwelling space.

II.1 Calculus model

In all cases air circulation through building units is performed using mechanical means and the phenomenon is specific to forced flow with heat exchange in non-circular channels.

The air circulation conditions in the air channels are determined both by the requirement of limiting pressure drops and of avoiding noise on flowing lines. In most cases, laminar flow covers these requirements.

If the Kirchhoff - Fourier and Navier - Stokes equations are integrated, a very complicated solution is obtained, which cannot be easily used in heat engineering design calculuses.

A simplified mathematical model has been consequently worked out, to be used in usual design activity. The approximate solution has been proved valid by comparison with the accurate solution provided by integrating the movement and energy equations in the Cartesian coordinates for steady state plane parallel laminar flow.

The accurate solution is obtained by considering the rod-like velocity profile with third type boundary conditions for incompressible flow /2/.

Air temperature variation along the flowing line and in the air channel section is given by relation:

$$\vartheta(x,y) = A + By + \sum_k B_k\left[\beta_k \cos\left(z_k \frac{y}{\delta}\right) + \sin\left(z_k \frac{y}{\delta}\right)\right] \exp\left(-z_k^2 \frac{2}{Pe} \cdot \frac{x}{\delta}\right) \tag{1}$$

where

$$A = \frac{k_2 t_e + k_1 \left(1 + \frac{k_2}{\alpha_r + \lambda/\delta}\right) t_i}{k_2 + k_1 \left(1 + \frac{k_2}{\alpha_r + \lambda/\delta}\right)} \; ; \quad B = -\frac{1}{\delta} \, \frac{k_1 (t_i - A)}{\alpha_r + \lambda/\delta} \; ;$$

$$\beta_k = \frac{\alpha_r \sin z_k + \lambda/\delta \cdot z_k}{\alpha_r (1 - \cos z_k) + k_1} \; ,$$

$$B_k = \frac{\int_0^1 \Psi(\dot y)\left[\beta_k \cos(z_k \cdot \dot y) + \sin(z_k \cdot \dot y)\right] d\dot y}{\int_0^1 \left[\beta_k \cos(z_k \dot y) + \sin(z_k \dot y)\right]^2 d\dot y} \; ;$$

$$\Psi(\dot y) = \vartheta_0 - A - B\delta \cdot \dot y \; ;$$

$$\dot y = y/\delta \; ;$$

Eigenvalues z_k are provided by equation:

$$2\alpha_r \frac{\lambda}{\delta} z_k - \left[\alpha_r (K_1 + K_2) + K_1 \cdot K_2\right] \sin z_k + \left(\frac{\lambda}{\delta}\right)^2 z_k^2 \sin z_k -$$
$$- \frac{\lambda}{\delta}\left(K_1 + K_2 + 2\alpha_r\right) \cdot z_k \cos z_k = 0$$

Air average temperature when exhausted from air channel is given by expression

$$\tilde{\vartheta}_{fl} = A + 0{,}5\delta B + \sum_k B_k \left(\beta_k \frac{\sin z_k}{z_k} + \frac{1 - \cos z_k}{z_k}\right) \exp\left(-z_k^2 \frac{2}{Pe} \frac{L}{\delta}\right) \quad (2)$$

and the heat flow-rate is provided by

$$Q_L = H \delta w \gamma c_p \left(\vartheta_0 - \tilde{\vartheta}_{fl}\right) \quad (3)$$

The final temperature values of the air and the values of the flow-rate (relations (2) and (3)) represent the thermal response of the element under analysis.

The approximate solution, based on the overall heat balance relations /2/, is represented by relations corresponding to the thermal response, namely:

$$\Theta = \Theta_0 \exp\left(-\frac{a_1}{g c_p} \dot{x}\right) - \frac{a_2}{a_1}(t_i - t_e)\left[1 - \exp\left(-\frac{a_1}{g c_p} \dot{x}\right)\right] \quad (4)$$

$$Q = H \delta w \gamma c_p \left[\Theta_0 - \Theta(1)\right] \quad (5)$$

where

$$\Theta = \vartheta - t; \quad \Theta_0 = \vartheta_0 - t; \quad \dot{x} = x/L;$$

$$a_1 = \alpha \left[\left(1 + \frac{\alpha_r}{\alpha + \alpha_r + K_2}\right) \cdot \frac{(\alpha + \alpha_r + K_2) K_1 + \alpha_r \cdot K_2}{(\alpha + \alpha_r + K_1)(\alpha + \alpha_r + K_2) - \alpha_r^2} + \frac{K_2}{\alpha + \alpha_r + K_2}\right];$$

$$a_2 = \alpha \left[\left(1 + \frac{\alpha_r}{\alpha + \alpha_r + K_2}\right) \cdot \frac{\alpha_r \cdot K_2}{(\alpha + \alpha_r + K_1)(\alpha + \alpha_r + K_2) - \alpha_r^2} + \frac{K_2}{\alpha + \alpha_r + K_2}\right];$$

For Re $\geqslant$ 1,000, the deviations between the accurate solution and the approximate one are of a few percentages (lower than 3%); this proves valid the possibility of using the approximate solution in calculus.

II.2. MC system functioning analysis

The analysis is performed considering a few possible schemes which may be combined to provide the actual constructive solution.

a. The first scheme (Fig.1) refers to air circulation the outside walls supplied with hollows.

The calculus refers to the ideal case when the hollow rate is m = 1. The inside temperature value is t_i, the outside temperature value t_e and the heat exchange area specific to one wall is s_j, "j" characterizing one wall.

The final temperature value, after the air has circulated through "j" hollow walls is given by relation:

$$\Theta_{s_j} = \left[\Theta_0 + \frac{a_2}{a_1}(t_i - t_e)\right]\prod_{1}^{j} \varepsilon_j - \frac{a_2}{a_1}(t_i - t_e) \tag{6}$$

where

$$\prod_{1}^{j} \varepsilon_j = \exp\left(-\frac{a_i}{g c_p}\right)$$

Considering the fact that, from the architectural viewpoint, it is practically impossible to heat the entire dwelling space only by this system, an auxiliary heat source exists inside, whose heat flow-rate is Q_{AUX}.

The dwelling space heat balance is provided by relation

$$Q_{AUX} = K_1 S_T \int_0^1 (t_i - t_{p_2})\, dx \tag{7}$$

which becomes:

$$Q_{AUX} = K_1 S_T \frac{\alpha_r K_2 + \alpha(2\alpha_r + K_2 + \alpha)\frac{a_2}{a_1}}{(\alpha + \alpha_r + K_1)(\alpha + \alpha_r + K_2) - \alpha_r^2}(t_i - t_e) -$$

$$- K_1 S_T \frac{\alpha(2\alpha_r + K_2 + \alpha)}{(\alpha + \alpha_r + K_1)(\alpha + \alpha_r + K_2) - \alpha_r^2} \cdot P\left[\Theta_0 + \frac{a_2}{a_1}(t_i - t_e)\right] \tag{8}$$

where

$$p = \frac{g\varphi}{a_1}\left[1 - \exp\left(-\frac{a_1}{g\varphi}\right)\right]$$

Of course, if the entire heating is to be performed only by hollow walls, $Q_{AUX} = 0$.

The heat consumption required by the heating of the air circulated through the walls is given by relation:

$$Q_{SI} = a_1 S_T P\left[\Theta_0 + \frac{a_2}{a_1}(t_i - t_e)\right] \tag{9}$$

The overall heat consumption results:

$$Q_T = Q_{SI} + Q_{AUX} = S_T A_1 (t_i - t_e) + A_2 Q_{SI} \tag{10}$$

where

$$A_1 = K_1 \frac{\alpha_r K_2 + \alpha'(2\alpha_r + K_2 + \alpha')\frac{a_2}{a_1}}{(\alpha' + \alpha_r + K_1)(\alpha' + \alpha_r + K_2) - \alpha_r^2};$$

$$A_2 = 1 - \frac{\alpha'(2\alpha_r + K_2 + \alpha')}{(\alpha' + \alpha_r + K_1)(\alpha' + \alpha_r + K_2) - \alpha_r^2} \cdot \frac{K_1}{a_1}.$$

The terms of relation (10) are divided by the outside area S_T and become: (10_1)

$$q_T = q_{aux} + q_{SI} = A_1(t_i - t_e) + A_2 q_{SI}$$

The result is that sum $(q_{AUX} + q_{SI})$ has a minimum value for $q_{SI} = 0$ ($q_{SI} \geqslant 0$ for all cases). In this case, the heat consumption corresponds to the situation when the outside walls are double, but there is no warm air circulating. This condition also leads to maximum q_{AUX} value. If the auxiliary source is f fossil fuel or electric power traditional heating, the system operation cost is of course high. On the other hand, if the auxiliary source is a traditional active solar heating system using flat plate collectors with liquid heat carrier, the collecting efficiency is very low (less than 0.20 at about 45-50°C average temperature required). Consequently, even if the overall heat consumption decreases with q_{SI} value decrease, the solution proves disadvantageous from the viewpoint of system efficiency. This conclusion is rendered evident by a calculus example represented graphically in Fig.2. The following functions are represented in the analysis diagram:

$$q_T = f_1(q_{SI});\ q_{aux} = f_2(q_{SI});\ \Theta_0 = f_3(q_{SI})$$ and

$$S_p = f_4(q_{SI})$$

where s_p is the specific area of collecting solar radiation (as against S_T area).

The collecting areas required in supplying q_{AUX} and q_{SI} are determined according to the thermotechnical characteristics of the solar collectors extensively produced in Romania at present. An obvious difference between values $s_p = 0.55\ m^2/m^2$ corresponding to $q_{SI} = 0$ on the one hand and $s_p = 0.28\ m^2/m^2$ corresponding to $q_{AUX} = 0$ on the other hand results. Although q_T increases from value $q_T = 7.85\ W/m^2$ in the first case to value $9.86\ W/m^2$ in the second case, the solar radiation collecting area is reduced at about a half.

This is the direct consequence of the low temperature required by the solar installation functioning in MC system.

b. Another case that has been studied (Fig.3) is a room using partitions as heating elements with warm air circulating through them. The warm air returns to the heat storage unit or to the solar collectors through the outside hollow walls.

The heat balance is described by the relation

$$Q_{pi} + Q_{AUX} = Q_{PE} \tag{11}$$

where

$$Q_{PE} = k_1 S_T \int_0^1 (t_i - t_{p1})\, d\dot{x} \tag{12}$$

Air temperature variation in the partition circuit is provided by relation:

$$\Theta = \Theta_0 \exp\left(-\frac{1}{g c_p} \frac{S_i}{S_T} \frac{\alpha_1 k_1}{\alpha_1 + k_1} \dot{x}\right) \tag{13}$$

The following relation results:

$$Q_{pi} = g c_p S_T \Theta_0 \left[1 - \exp\left(-\frac{1}{g c_p} \frac{S_i}{S_T} \cdot \frac{\alpha_1 k_1}{\alpha_1 + k_1}\right)\right] \tag{14}$$

The heat consumption required by air circulation through the outside walls is given by relation (9) where Θ_0 is replaced by value

$$\Theta_0' = \Theta_0 \exp\left(-\frac{1}{g c_p} \frac{S_i}{S_T} \frac{\alpha_1 k_1}{\alpha_1 + k_1}\right) \tag{15}$$

Relation (9_1) results therefore

$$Q_{Si}^{1} = S_T \rho \left[\Theta_0 f\left(\frac{S_i}{S_T}\right) + \frac{a_2}{a_1}(t_i - t_e)\right] a_1 \qquad (9_1)$$

where

$$f\left(\frac{S_i}{S_T}\right) = \Theta_0' / \Theta_0$$

Relation (12) becomes

$$Q_{PE} = S_T A_1 (t_i - t_e) - (1 - A_2) Q_{Si}^{1} \qquad (16)$$

Considering relation (11) as an equation,

$$Q_{AUX} = Q_{PE} - Q_{Pi}$$

results.

According to expressions (16) and (14) of Q_{PE} and Q_{PI} as well as to expression (9_1) for Q_{SI}^{1}, (17) results:

$$q_{AUX} = f(\Theta_0, S_i/S_T) \qquad (17)$$

For the boundary case $q_{AUX} = 0$, relation (17) gives correlation

$$\Theta_0 = \psi(S_i/S_T) \qquad (18)$$

Fig.4 represents the geometrical locus for which $q_{AUX} = 0$ (C curve) in the above calculus example. The influence of ratio S_i/S_T on solar installation dimensioning is reduced. For the case that has been studied, $S_P \sim 0.25\ m^2/m^2$ associated with value $\Theta_0 = 1°C$ for any $S_i/S_T > 1$.

The cases under analysis refer to the ideal situation m= 1. The thermal calculus for actual situations when $m < 1$ is rather simple as the calculus relations specific to each element do not change. Only the heat balance general relation will change by adding a term representing the heat balance of the outside surfaces without air circulation hollows.

c. The third case is the double-glazed window working as economizer (heat recovered from the exhausted viciated air).

Air temperature variation when air passes through the interspace between the glass pieces is given by relation

$$\Theta = -\frac{a_2}{a_1}(t_i - t_e)\left[1 - \exp\left(-\frac{a_1}{g c_p}\dot{x}\right)\right] \qquad (19)$$

The heat flow by transmission is given by relation

$$q_T = k_1\left[\frac{\alpha_1(2\alpha_\gamma + k_2 + \alpha_1)}{(\alpha_1+\alpha_\gamma+k_1)(\alpha_1+\alpha_\gamma+k_2)-\alpha_\gamma^2}\cdot\frac{a_2}{a_1}(1-\rho)+\right.$$

$$\left.+\frac{\alpha_\gamma k_2}{(\alpha_1+\alpha_\gamma+k_1)(\alpha_1+\alpha_\gamma+k_2)-\alpha_\gamma^2}\right](t_i-t_e) \tag{20}$$

The following relation results for average winter conditions:

$q_T = 1.43\ (t_i - te)$ $\qquad$ W/m^2

as against the traditional situation

$q_T^{CL} = 2.10\ (t_i - te)$ $\qquad$ W/m^2

The transmission heat consumption is therefore reduced with about 30% by this method.

II.3 RHSU thermal response[x]

The unitary thermal response method /3/, /4/ provided the air temperature variation along the flowing line as well as that of the rockbed in different sections. The functions of response at impulsional excitations with unitary energy content are:

$$\vartheta(\dot{x},\dot{\tau}) = \vartheta_0 + \exp(-A\dot{x})\left[f(\dot{\tau}-c\dot{x}) + \int_0^{2A\sqrt{\dot{x}(\dot{\tau}-c\dot{x})}} f\left(\dot{\tau}-c\dot{x}-\frac{m^2}{4A^2\dot{x}}\right)\cdot\right.$$

$$\left.\cdot\exp\left(-\frac{m^2}{4A\dot{x}}\right)\cdot I_1(m)\,dm\right] \tag{21}$$

$$\vartheta_R(\dot{x},\dot{\tau}) = \vartheta_0 + A\exp(-A\dot{x})\int_0^{2A\sqrt{\dot{x}(\dot{\tau}-c\dot{x})}} f\left(\dot{\tau}-c\dot{x}-\frac{m^2}{4A^2\dot{x}}\right)\exp\left(-\frac{m^2}{4A\dot{x}}\right)\cdot$$

$$\cdot I_0(m)\,dm \tag{22}$$

---

x RHSU - rockbed heat storage unit

where

$$m = 2A\nu\sqrt{\dot{x}(\dot{\tau}-t)}$$

$I_0(m)$ and $I_1(m)$ - modified Ressel functions of the first type and of 0 respectively 1 order.

$$A = \frac{\alpha_v V}{G c_{pF}}; \qquad C \simeq 0{,}26\,\frac{\rho_F c_{pF}}{\rho_v c_{pp}};$$

$$\dot{\tau} = \tau/\tau_c; \qquad \dot{x} = x/L; \quad \tau_c = \frac{\rho_v c_{pp} V}{G\cdot c_{pF}};$$

The experiments performed at INCERC /4/ proved the accuracy of the solutions. The measurements were performed on a test stand, using the unit function as excitation function. The theoretical thermal response provided by the convolution product between the actual excitation function (Heaviside type) and the unitary thermal response (relations (21) and (22)) is in accordance with the measurement results. The RHSU of CS 3 Bucharest solar house in MC system has been dimensioned using the calculus program resulted.

II.4 LHSU thermal response

The experimental house under construction at INCERC, CS 3 Bucharest, is equipped with air-water double service collectors (Annex 1). In the cold season, these collectors supply warm air and in the warm season they supply warm water to cover domestic needs. The collecting area and implicitely the water heat storage unit provide a heat quantity which is necessary to be stored for a period of 1-4 days. In this case the stratified flowing model is no longer correct /5/, thermal diffusion being important. The thermal response has been studied according to the method previously described and provided a rather complicated response function, which has been used in an INCERC numerical calculus program /6/.

The function is quantitatively represented by relation

$$\Theta = \sum_j \Theta_1(\tau,\dot{x},\dot{r}) + \sum_j \Theta_2(\tau,\dot{x},\dot{r}) + \sum_j \Theta_3(\tau,\dot{x},\dot{r}) \tag{23}$$

where

$$\Theta_1(\tau,\dot{x},\dot{r}) = \exp c(\dot{x})\,\frac{1}{\nu_j}\,\frac{J_0(\nu_j \dot{r})}{J_1(\nu_j)}\left[f(\tau) * F_1(\tau,\dot{x})\right]$$

---

x LHSU - liquid heat storage unit

$$\Theta_2(z,\dot{x},\dot{r}) = -\exp C(\dot{x}) \frac{1}{\sqrt{j}} \frac{J_0(\nu_j \dot{r})}{J_1(\nu_j)} \left[f(z) * F_2(z,\dot{x}) \right]$$

$$\Theta_3(z,\dot{x},\dot{r}) = \exp C(\dot{x}) \frac{1}{\sqrt{j}} \frac{J_0(\nu_j \dot{r})}{J_1(\nu_j)} \left[f(z) * F_3(z,\dot{x}) \right]$$

where

$$C(\dot{x}) = f(\dot{x}, \dot{L}, Pe) \; ; \; \dot{x} = x/L \; ; \; \dot{L} = L/R \; ; \; \dot{r} = r/R \; ;$$

$$\Theta(z,\dot{x},\dot{r}) = \vartheta(z,\dot{x},\dot{r}) - t_e$$

V_J -eigenvalues given by equation

$$J_0(\nu_j) = J_1(\nu_j) \cdot \nu_j \, Bi^{-1}$$

$F_{1,2,3}$ - functions according to the geometrical characteristics of the heat storage unit.

The unitary thermal response, namely the water temperature at storage unit outlet is determined using relation

$$r(z) = \frac{2}{R^2} \int_0^R r \, \vartheta(z, L, r) \, dr$$

III. THERMAL PERFORMANCE ESTIMATED FOR CS 3 BUCHAREST SOLAR HOUSE

CS 3 Bucharest solar house, presently under construction at INCERC Bucharest, is two story house with four apartments; it is equipped with an MC solar heating system. It also has a passive solar heating system for the South facade rooms. In order to compare the results, two apartments are heated using only an INCERC passive system /7/, and the other two are equipped with an MC heating system as well. The active collecting area is formed of 48 m^2 double service solar collectors and 88 m^2 overall passive collecting area. The rockbed heat storage unit required by MC system has a capacity of 12 m^3. The circulated air flow-rate is 2,500 m^3/h and the rate of air circulation hollows is 25%. Air is circulated both through the outside walls and through the partitions. System functioning is entirely automatic. The auxiliary heat source is electric.

The calculus based on the model intriduced in chapter II lead to the following estimated values for average winter conditions:

- temperature of the warm air introduced in the hollow walls:

  $\vartheta_0 = 23.60^{\circ}C$

- heat flow-rate of the auxiliary source for the two apartments heated in MC system:

$$Q_{AUX} = 850 \text{ W}$$

- the annual energy consumption covering thanks to the warm air active heating as well as to the passive heating is

$F = 0.80$ (as against the heat consumption of a traditional house with the same architecture)

- the period of additional investment payback, taking into account the warm water quantity supplied in summer as well, will be

$T = 14$ years

- the average energy productivity of solar radiation collecting elements (active and passive) is

$P = 56$ kg cf^{x}/m^{2}year

IV. CONCLUSIONS

The conclusions provided by the theoretical study of MC system are the following:

1. The flat plate solar collectors with air as heat carrier may be effciently used during the cold season by using the building units - outside walls and partitions - as low temperature level heating elements.

2. This type of system (MC) is firstly, a thermal protection solutions for the dwelling space and, secondly, a solar heating solutions.

3. The low temperature levels - close to the inside temperature - of air when admitted in the hollow walls lead to the increase of solar radiation collecting efficiency.

4. The use of water-air solar collectors increases their annual functioning efficiency with about 40%.

5. The use of double-glazed windows working as economizer(s) (recovering heat from the exhausted viciated air) decreases the transmission heat consumption of windows with about 30%.

---

x cf - conventional fuel; 1 kg cf = 21,500 kJ/kg

NOMENCLATURE

ϑ_o	- warm air initial temperature	$/^oC/$
$\bar{\vartheta}_f$	- warm air final temperature	$/^oC/$
t_i	- inside temperature	$/^oC/$
t_e	- outside temperature	$/^oC/$
t_{p1}	- temperature of hollow partitions on inside surface	$/^oC/$
t_{p2}	- temperature of hollow outside on inside surface	$/^oC/$
τ, t	- time	/h/
λ	- air thermal conductivity	/W/mK/
k_1	- heat exchange overall coefficient (heat exchange from circulation hollow inside surface to inside air)	$/W/m^2K/$
k_2	- heat exchange overall coefficient (heat exchange from circulation hollow outside surface to outside air)	$/W/m^2K/$
α	- convection heat exchange coefficient	$/W/m^2K/$
α_r	- radiation heat exchange coefficient	$/W/m^2K/$
α_v	- heat transfer volumetric coefficient	$/W/m^3K/$
δ	- thickness of air circulation hollows	/m/
L	- flowing line length	/m/

R	- water storage tank radius	/m/
S_T	- overall area of outside hollow walls	/m^2/
S_I	- hollow partition area	/m^2/
V	- RHSU volume	/m^3/
Q_{AUX}	- auxiliary source heat flow-rate	/W/
Q_{PE}	- heat flow-rate supplied to outside hollow walls	/W/
Q_{PI}	- heat flow-rate supplied by partitions	/W/
Q^1_{SI}	- heat flow-rate required by heating of air circulating through hollow walls	/W/
c_{pF}	- air specific heat at constant pressure	/J/kgK/
c_{pP}	- rockbed specific heat	/J/kgK/
G	- air flow-rate	/kg/s/
g	- air specific flow-rate	/kg/m^2s/
ρ_v	- rockbed volume density	/kg/m^3/
Pe	- Peclet's dimensionless number	
Bi	- Biot's dimensionless number	
Re	- Reynolds's dimensionless number	
m	- rate of air circulation hollows	

APPENDIX 1

CHARACTERISTIC CURVE OF WATER-AIR SOLAR COLLECTORS IN CS 3 BUCHAREST SOLAR HOUSE BUILT IN MC SYSTEM

The measurements performed in 1982 on the INCERC outdoor climatic condition stand provided the thermal characteristics of air-water collectors, plotted in Fig.A.1.1.

Constructive characteristics:

-- module dimensions 2 x 2 m
-- simple glazing
-- water flowing through serpentine tubes with 30 kg/m^2h specific flow-rate
-- air flowing with 600 m^3/h flow-rate (resulted from the necessity of simulating collector functioning in the system)

η - solar radiation collecting efficiency
t_{in} - air inlet temperature /^oC/
t_c - air outlet temperature /^oC/
I - overall radiation intensity /W/m^2/

REFERENCES

/1/ Constantinescu, Dan; Miclescu, Sandu - An Experimental Solar Building Conf.Liège 1980

/2/ Constantinescu, Dan - Functioning Principles and Engineering Calculus Elements Specific to MC Active Solar Heating System (in Romanian) SCI Bucharest 1982

/3/ Constantinescu, Dan - Use of Solar Energy in Dwelling Space Heating - Theoretical Contribution in System Analysis (in Romanian) Ed.Academiei Bucharest 1982

/4/ xxx - Solar Energy Heat Storage (in Romanian) Contr.INCERC 552/1979

/5/ Constantinescu,Dan; Iordache, Florin; Mitrofan, Rodica - Theoretical Analysis of Warm Water Solar Installations (in Romanian) Rev.Instalaţii, 1/1979,3/ 1980.

/6/ Constantinescu, Dan - Analysis Model for Solar Installations with Short-time Storage and Liquid Storage Medium (in Romanian) 2nd National Conference on Solar Energy, Iaşi 1982

/7/ xxx - Studies on Solar Heating (in Romanian) Contr.INCERC 12/ 1978.

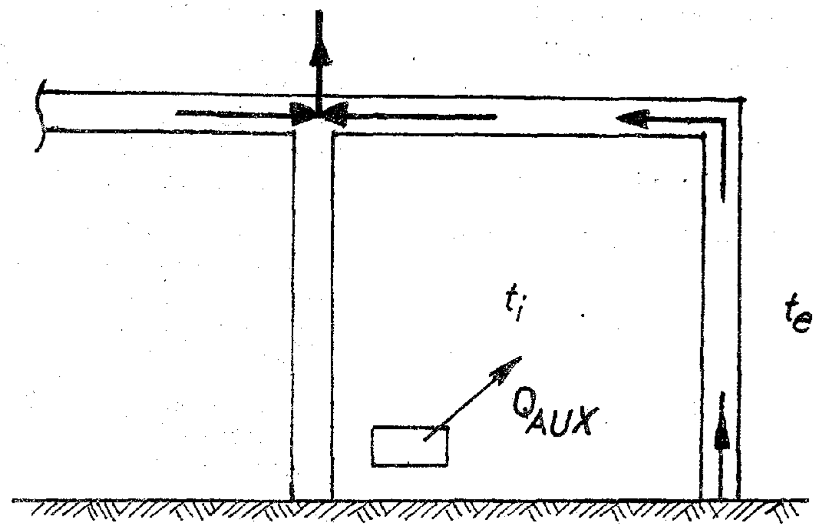


Fig.1 Calculation scheme air circulation through outside walls supplied with hollows.

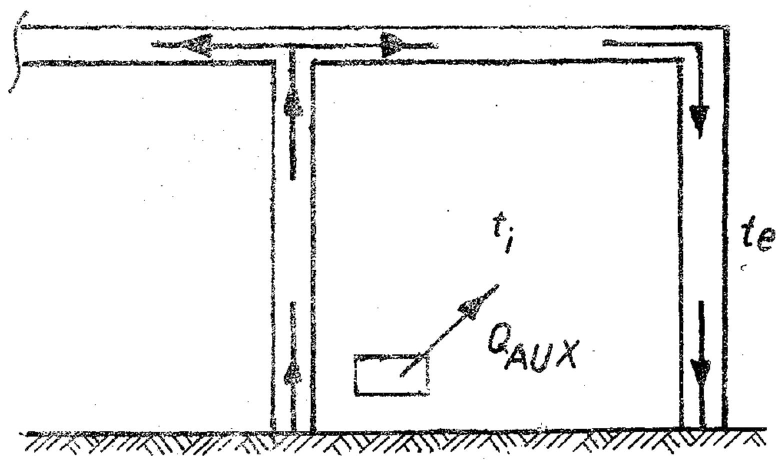


Fig.3 Calculation scheme partitions warm air circulating through them.

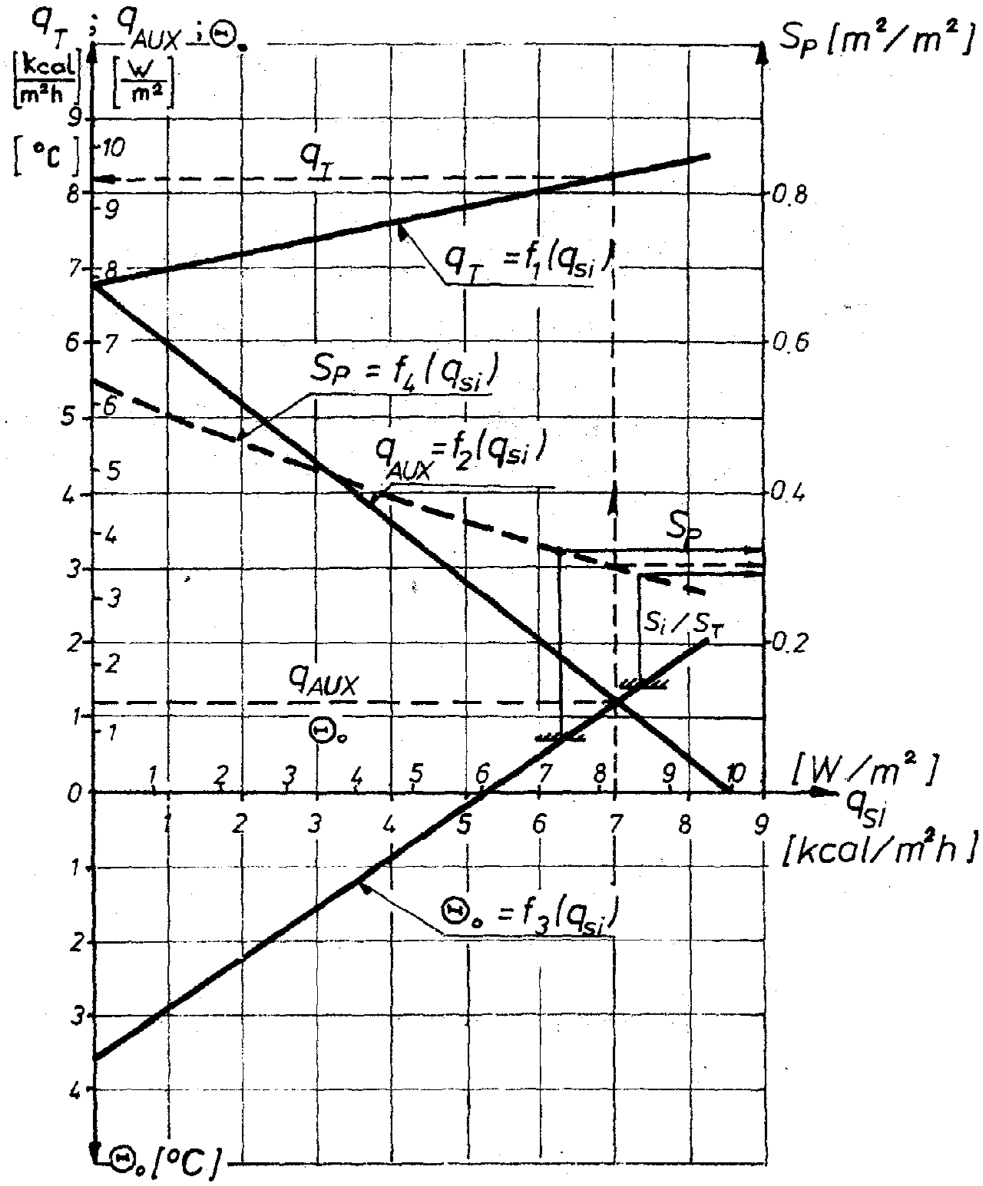


Fig. 2 MC Calculation analysis diagram

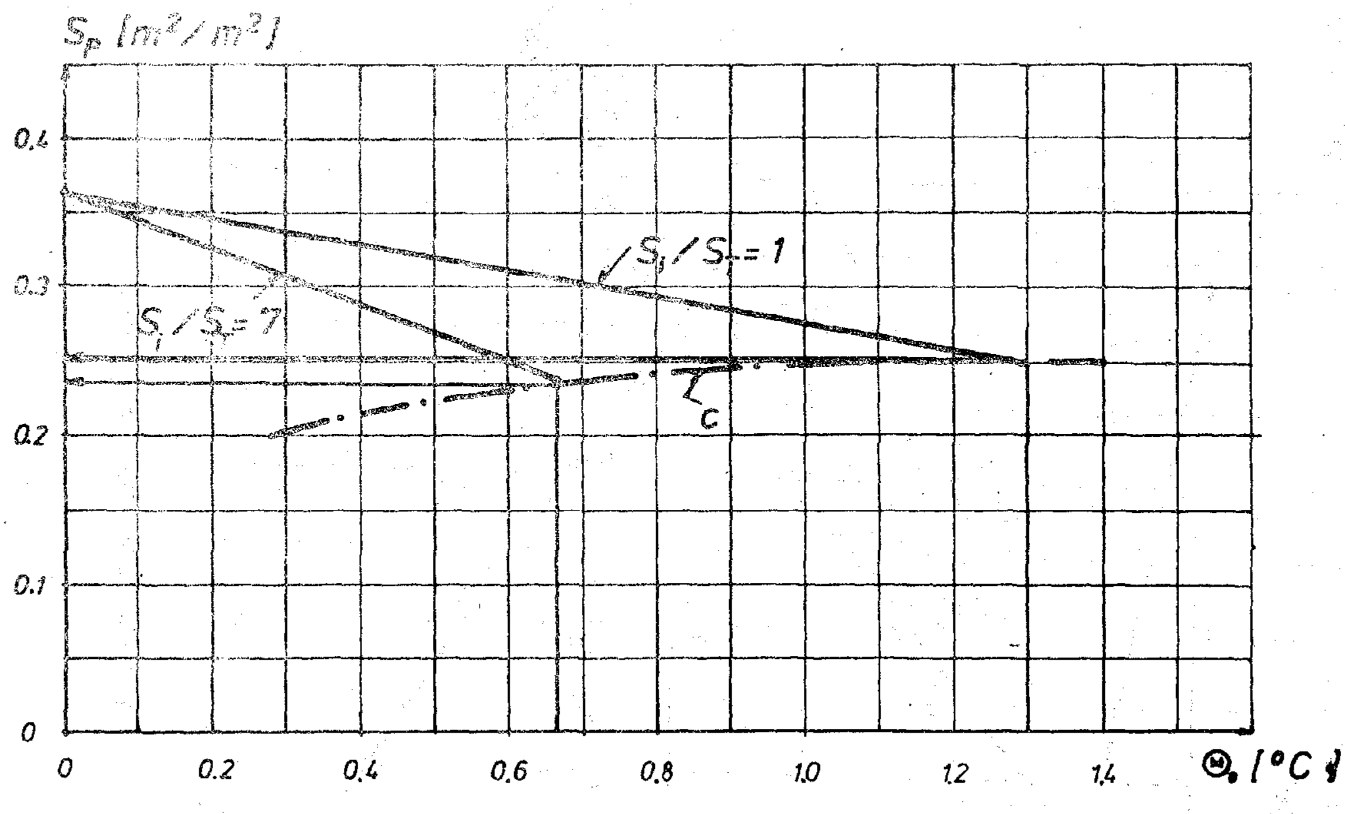


Fig. 4 Θ_o vs S_I/S_T correlation for $q_{AUX}=0$

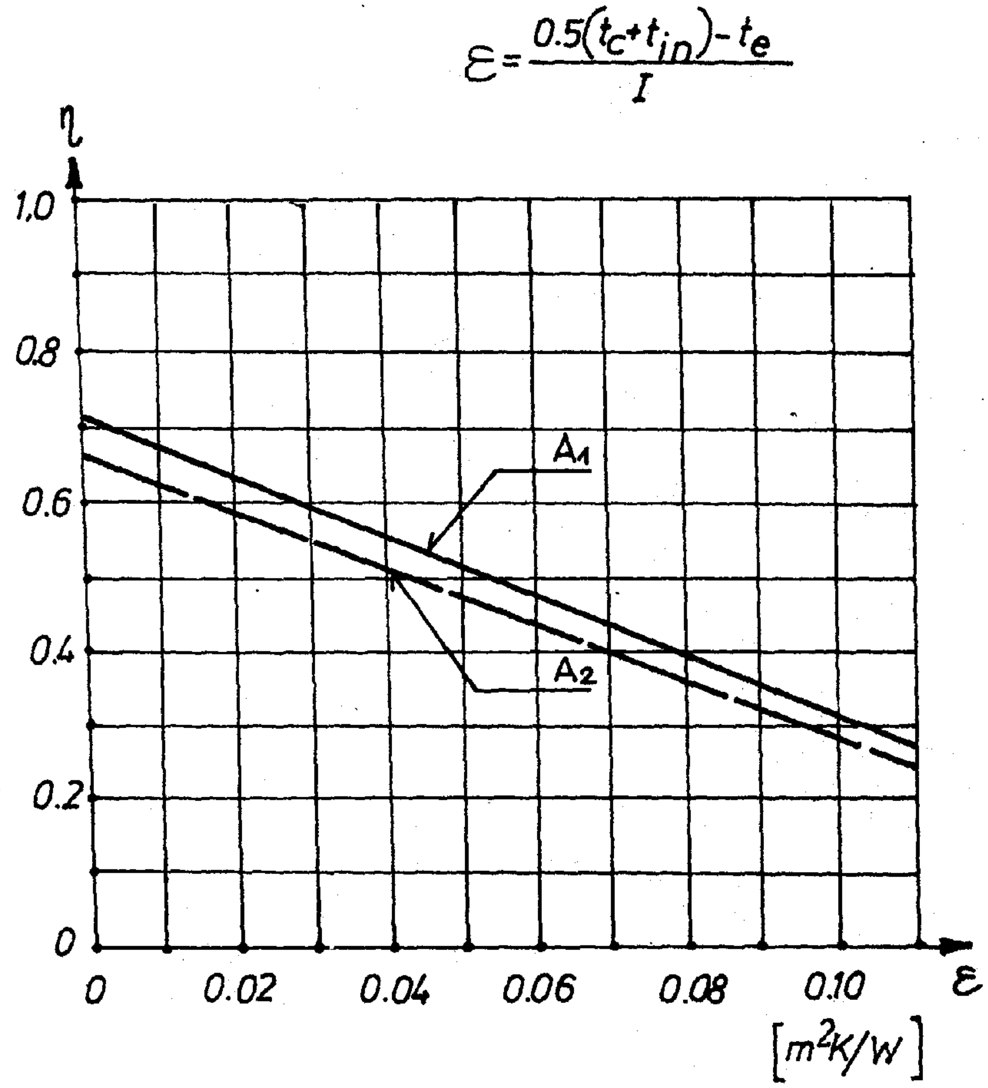


FIG. A1.1 Thermal characteristic of air collectors

A_1 - water curve

A_2 air curve

III.10 EXPERIMENTAL RESULTS ON THE PASSIVE HEATING PERFORMANCE OF CS 3 BUCHAREST SOLAR HOUSE

Dan Constantinescu x)

Rodica Mitrofan xx)

The solar house built at INCERC Bucharest is endowed with an 18 m^2 passive collecting area for each of the 4 apartments.The system is of INCERC type and represents a variant of the Trombe-Michel classical system. The main difference between the two systems is collector performance. As the radiative climatic loading specific to Romania is highly irregular, the INCERC collecting wall consists of a heat insulating layer (autoclaved lightweight concrete) at the outside and a hollow brick layer at the inside /1/. The important oscillation of the overall radiation intensity generates a rapid thermal response of the collecting wall outside surface; the immediate result is the rapid start of natural air circulation in the collecting greenhouse. Inside temperature peak values are neutralized by heat storage in the brick mass adjoining the dwelling space. This wall structure proves to be favorable in the continental climate and is superior in terms of energy requirements to the classical concrete Trombe-Michel wall.

The INCERC wall ensures a satisfactory space heat insulation in the sunless hours ($K_{P.INCERC} = 0.56\ W/m^2K$; $K_{P.TROMBE} = 0.80\ W/m^2K$) which determines the fuel saving required in space heating. The high heat insulation rate also ensures protection in the warm season. The disadvantage of the system is represented by rather considerable heat losses in the sunny hours determined by the high temperature level of the absorbing area. Nevertheless, on a clear day, the heat quantity emitted to outside is lower in the case of the INCERC wall. The Trombe wall continues to lose heat immediately after sunset and the thermal wave penetrates its structure from inside to outside. The slot placing in the case of the INCERC system /3/ facilitates turbulent flow even in case of solar radiation low intensity ($I \geq 250\ W/m^2$).

The thermal and aeraulic measurements performed in the season 1984-1985 in the solar house were focused on determining the correlations specific to the INCERC passive collecting wall required in determining solar radiation collecting efficiency.

x) Senior Research Officer, INCERC

xx) Research Officer, INCERC, Bucharest, Romania

I. Description of standard rooms and of measurement system.

In order to determine the collecting wall thermal efficiency, two rooms were arranged in the apartments on the first and second floor respectively. The difference between the two rooms is seen in the collecting wall slot system. In the second floor standard room, the bottom slot admits air on a line parallel to the collecting wall black surface and the top slot exhausts warm air normally on the collecting wall surface (fig.1). In the ground floor room both slots are placed so that the air is circulated in parallel with the collecting wall surface (fig.2).

Although it proved thermally unsatisfactory, this solution offers certain constructive advantages, as the collecting wall piercing is avoided. Each room has two collecting walls noted in this paper by A and B indices. The collecting areas are therefore

$$S_{PA} = 2.70\ m^2\ (2.00\ m \times 1.35\ m) = S_{E.A}$$

$$S_{PB} = 1.40\ m^2\ (2.00\ m \times 0.70\ m) = S_{E.B}$$

where P and E indices represent ground floor and second floor respectively.

Temperature is measured using thermocouples on the two areas of the collecting walls (mean value of 9 points on each) and in 7 points in wall thickness. The mean temperature values of the air admitted in the greenhouse and exhausted in the dwelling space as well as outside temperature are also measured. The temperature variation in time is recorded on a paper strip and data processing is performed using an optical reader and magnetic print.

The flow-rate of the warm air circulated in the greenhouse space is determined by measuring the air velocity field at air inlet and outlet using a hot wire anemometer. This type of measurement raises difficulties as it requires continuity in time. To avoid this, a method of determining air flow-rate according to temperature values continuously recorded was worked out (temperature of the collecting wall black surface, outside and inside temperature).

Experimental data measurements and processing depend on the putting into operation of the solar passive heating system. The main element conditioning the correct service of the system is greenhouse tightening against environment (outside air, dwelling space). Tightening control was performed using a fuming substance; AGA 780 color infrared photos were used for thermal bridges. The tightening tests proved that if the green ouse is built in usual site conditions, about 50% of the warm air is exhausted. If all spaces were tightened, continuity of air volume flow-rate in the greenhouse space was ensured. In this case the flow tests using the same fuming substance emphasized the fact that air flow in greenhouse is turbulent.

Fig.3 and 4 present two flowing exemples for the two room arrangements: floor (fig.1) and ground floor (fig.2) standard room. In both cases the cold air jet horizontally admitted in the greenhouse space on a line parallel to the collecting wall surface generates a vortex in the first third of the greenhouse and further produces turbulent flow. The differences in flowing are caused by slot position. In the case of ground floor standard room the heat exchange area between air and wall is 55% of the passive surface.

In the case of second floor standard room the same area is about 90% of the overall built area. The direct consequence is that the convective heat flow specific to the system under analysis is reduced by about 42%.

II. Experimental data processing

This paper introduces the method of processing the measured data with a view to determine the heat flow convective and conductive components.

II.1. Determination of air volume flow-rate

The flow-rate of the warm air circulated in the greenhouse was determined using the energy equation written for the air circuit. For calculus simplification, an approximate method was conceived: natural flow in greenhouse was assimilated with a series of forced flows, for each moment; V volume flow-rate is circulated in the greenhouse. In this case, for each moment, the pressure potential is equal to the pressure drop. The equality of the two expressions generates an equation with V volume flow-rate as unknown value.

The pressure potential is given by expression:

$$H_{DISP} = H \rho_0 \left(\frac{1}{1+\beta_i t_i} - \frac{1}{1+\beta_m t_m} \right) \tag{1}$$

The pressure drop is given by

$$H_p = \frac{V^2}{2g} \rho_0 \left(\frac{\xi_R}{S_R^2} \cdot \frac{1}{1+\beta_c t_c} + \frac{\xi_A}{S_A^2} \cdot \frac{1}{1+\beta_i t_i} \right) \tag{2}$$

$$H_{DISP} = H_p \tag{3}$$

It is obviously necessary to know values t_c, t_i, t_m depending on V.

The heat balance specific to turbulent flow is given by equation:

$$\frac{dt}{dx} = \frac{l}{V \bar{\rho} c_p} \left[\alpha_{cv}^{P} (t_P - t) + \alpha_{cv}^{G} (t_G - t) \right] \tag{4}$$

Considering the expressions of convection heat exchange coefficients:

$$\alpha_{cv}^{M} = A \ (t_M - t)^{0.33} \ ; \quad M \equiv P, G$$

equation (5) is obtained:

$$\frac{dt}{dx} = \frac{A \, l}{\bar{\rho} \, c_p} V^{-1} \left[(t_P - t)^{1.33} + (t_G - t)^{1.33} \right] \tag{5}$$

Unknown temperature t_G is determined by the glazing heat balance equation:

$$\alpha_r \ (t_p - t_G) = A \ (t_G - t)^{1.33} + K_G \ (t_G - t_e) \tag{6}$$

Using notations

$$\Theta_1 = t_p - t; \qquad \Theta_2 = t_G - t$$

equation (6) provides an approximate linear correlation

$$\Theta_2 = A_1 \cdot \Theta_1 + A_2$$

which if included in equation (5) leads to the final equation:

$$\frac{d \ \Theta_1}{dx} = - \frac{A \cdot l}{\bar{\rho} \cdot c_p} V^{-1} \left[\Theta_1^{1.33} + (A_1 \Theta_1 + A_2)^{1.33} \right] \tag{7}$$

Values A, l, $\bar{\rho}$, cp, K_G, α_r are practically constant, therefore air temperature variation on the greenhouse height depends on measured values t_p (τ) and t_e (τ) which particularize coefficients A_1 and A_2.

The equation was integrated for several values, t_p, t_i, t_e taking into account values "l" determined by a flow visualizing test. Value K_G was determined considering glass absorptivity , namely the modified t_G temperature as compared to the one provided by equation (6) by including a source function.

The diagrams in fig.5,6 and 7 introduce in parallel the measured and the calculated values both as temperature distribution and as warm air volume flow-rates. The values provided by the measurements performed in October, November and December 1984 and January 1985 were used in simple correlations such as

$$f\ (V,\ t_p,\ t_i,\ t_c) = 0$$

In fig.8 and 9 these correlations are plotted as

$$V = V\ (t_e,\ t_p)\ \Big|\ t_i = ct$$

Values V are proved independent of values t_e and highly dependent of t_p and t_i.

The curve sets thus determined by PDP 11 computer processing allow the rapid calculus of the convective heat flow using relation

$$Q_{conv} \cong V \rho_c \left(i_c - \rho_i i_i \right) \tag{8}$$

where

$$i = c_p t$$

II.2 Conductive heat flow determination.

The conductive heat flow is calculed using the U.T.R. method /2/; temperature values of the collecting wall surfaces $y = 0$ and $y = \delta$ are known. Linear matrices $\{X\}$ and $\{Y\}$ containing the structure thermal response at triangular impulse are formed using the laboratory characteristics of the collecting wall materials.

The data thus obtained were proved valid by comparisons with the heat flows calculated using temperature distribution and collecting wall thickness. Temperature distribution at moment τ has the form:

$$t(y,\tau) = \sum_{j=1}^{7} a_j y^j$$

where

$$a_j = a_j\ (\tau)$$

The resulting forms of $y = 0$ and $y = \delta$ heat flow are

$$q_0 = -\lambda \cdot a_1$$

$$q = -\lambda_\delta \sum_{j=1}^{7} j\, a_j\, \delta^{j-1}$$

Moreover:

$$q = \alpha^{i}_{cv} (t_{pi} - t_i)$$

where:

$$\alpha^{i}_{cv} = A (t_{pi} - t_i)^m$$

where

$$A, m = f(Ra)$$

III. Data specific to collecting wall service

In the season 1984-1985 the solar house worked in natural heating conditions without auxiliary source. The mean values of air volume flow-rate circulated in greenhouse are 35 m^3/m^2h (S_A) and 55 m^3/m^2 h (S_B).

The solar radiation collecting efficiency is of about 30% for the floor standard solution and about 16% for the ground-floor standard solution. In the heating season 1985-1986 measurements and data processing will be performed in conditions of dwelling space constant temperature: $t_i = 18^oC$.

IV. Conclusions

1. For temperate-continental zones, solar collecting walls of INCERC type are recommended (rapid thermal response and high thermal resistances).

2. The air circulation slot distribution in the floor standard room is most favorable.

3. The collecting greenhouse must be tightened on its outside perimeter.

4. The mean flow-rate of the air circulated in the greenhouse is of about $40m^3/m^2h$ for the floor standard room.

5. The mean solar radiation collecting efficiency is 30% for the floor standard room.

REFERENCES

/1/ x x x - Dwelling Houses Using Solar Energy in Space Heating INCERC Contract 12/1978

/2/ Constantinescu, Dan - Use of Solar Energy in Space Heating - theoretical Contribution in System Analysis, Ed.Academiei, Bucureşti, 1980

/3/ x x x - Studies on the Use of Solar Energy in Building Heating INCERC Contract 32/1982

NOMENCLATURE

t_i	- inside air temperature	$/^0C/$
$t_c^{C,M}$	- air mean temperature at top slot outlet (C - calculated M - measured)	$/^0C/$
t_e	- outside air temperature	$/^0C/$
t_p	- black surface temperature	$/^0C/$
t_G	- glazing surface temperature	$/^0C/$
t	- current temperature in x section on greenhouse height	$/^0C/$
H_{DISP}	- pressure potential	$/mmH_2O/$
H_p	- pressure drop with air flowing in greenhouse	$/mmH_2O/$
β	- volume expansion coefficient	$/K^{-1}/$
V	- volume flow-rate of air in greenhouse	$/m^3/h/$
ξ	- local loss coefficient	-
ℓ	- collecting wall width	/m/
ρ	- specific mass	$/kg/m^3/$
c_p	- specific heat at constant pressure	/k J/kgK/
α_{cp}	- convection heat exchange coefficient	$/W/m^2K/$
α_r	- radiation heat exchange coefficient	$/W/m^2K/$
K_G	- coefficient of overall heat exchange through glazing	$/W/m^2K/$
i	- air entalpy	/kJ/kg/

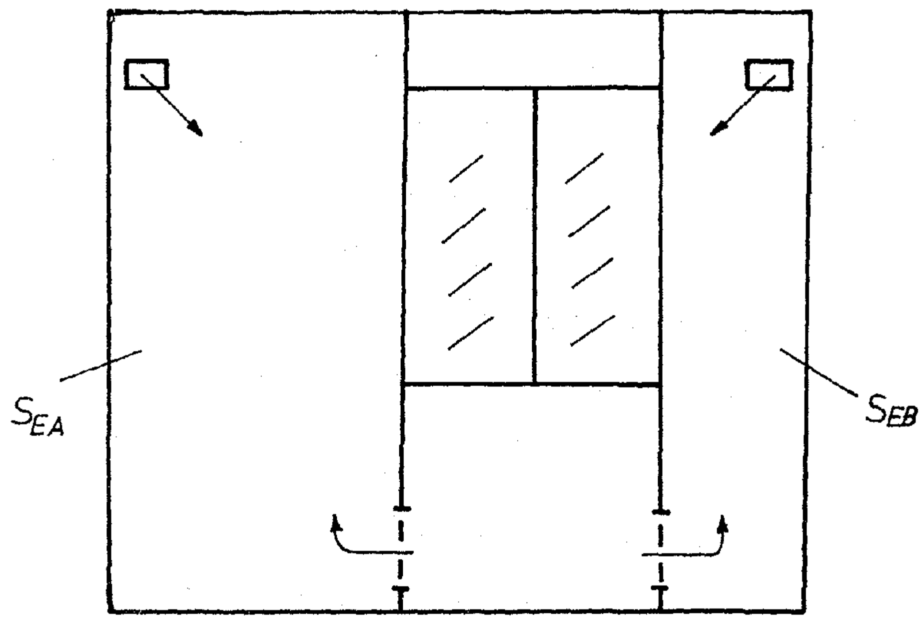


FIG.1. Standard room-flat.

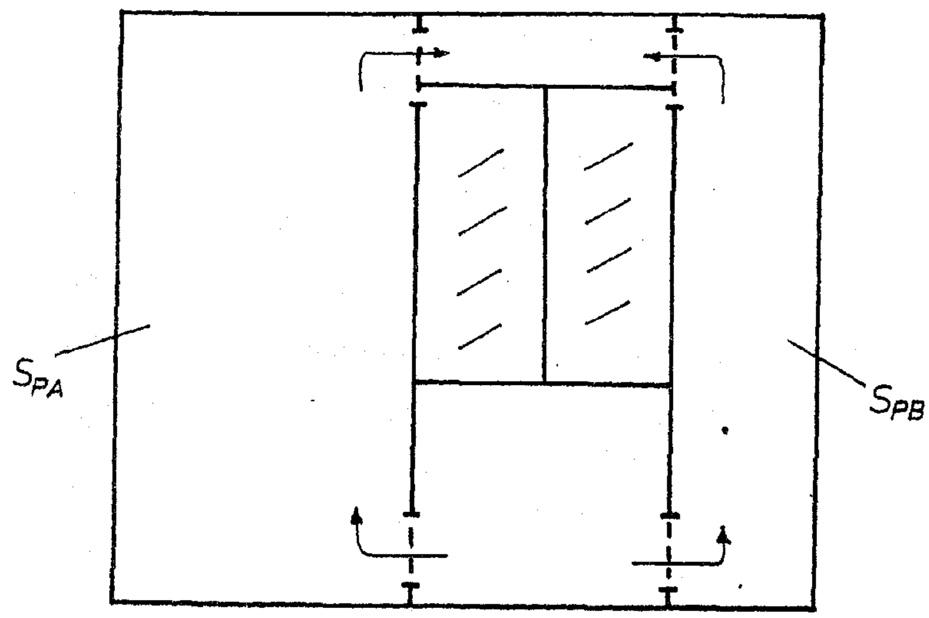


FIG.2. Ground floor room.

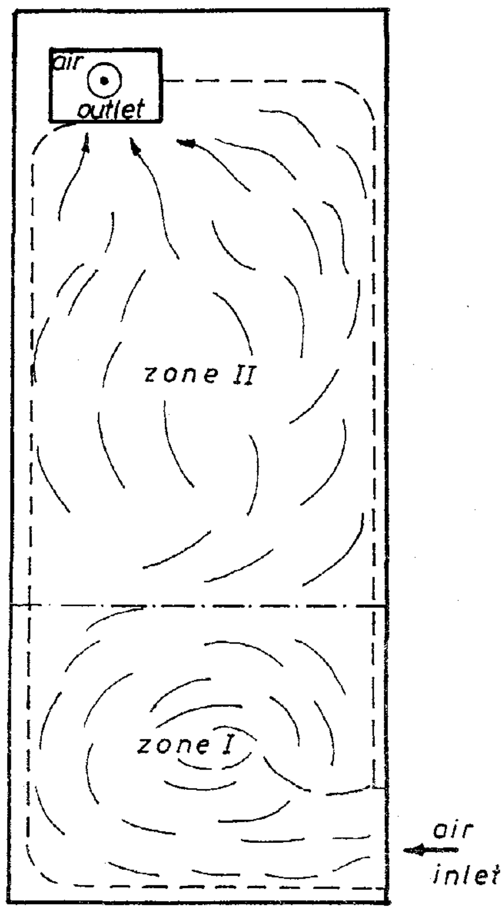


FIG.3.Standard room-flat
-air flow-

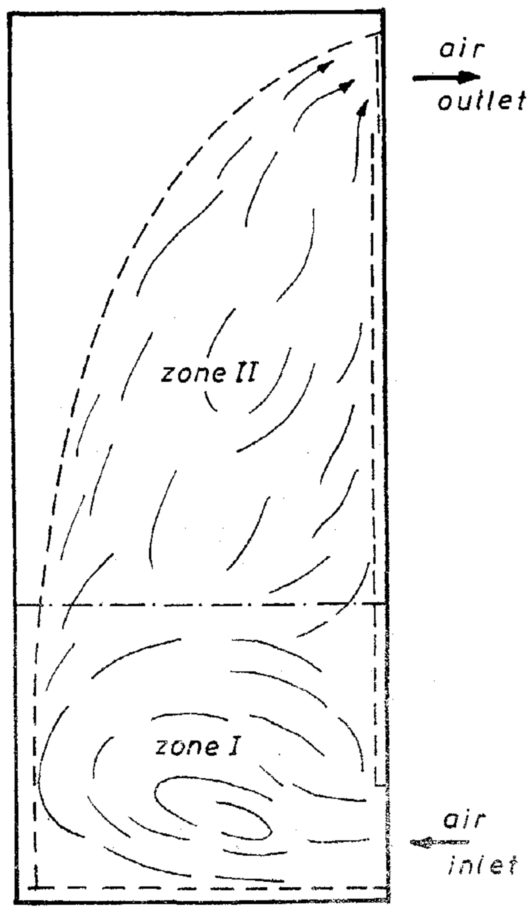


FIG.4.Standard room-ground
floor-air flow.

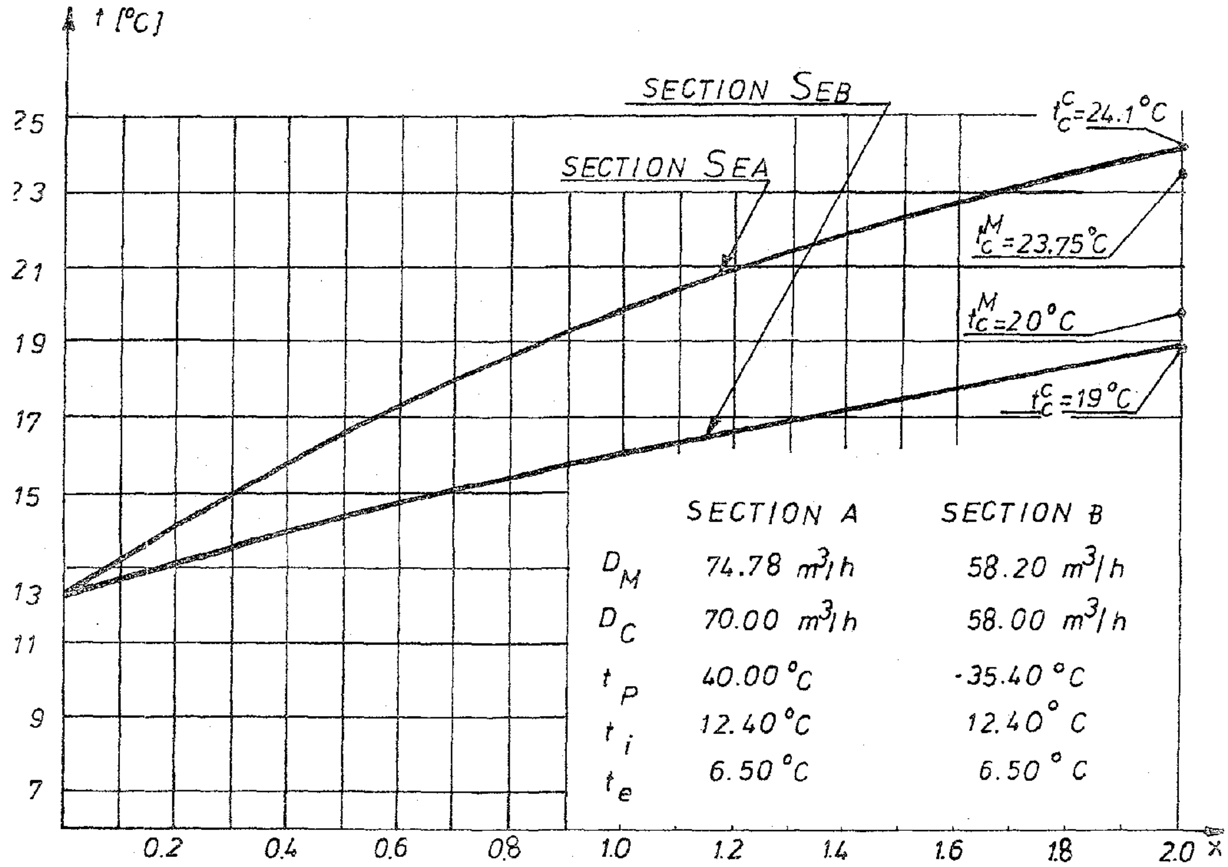


FIG.5. Air temperature distribution.

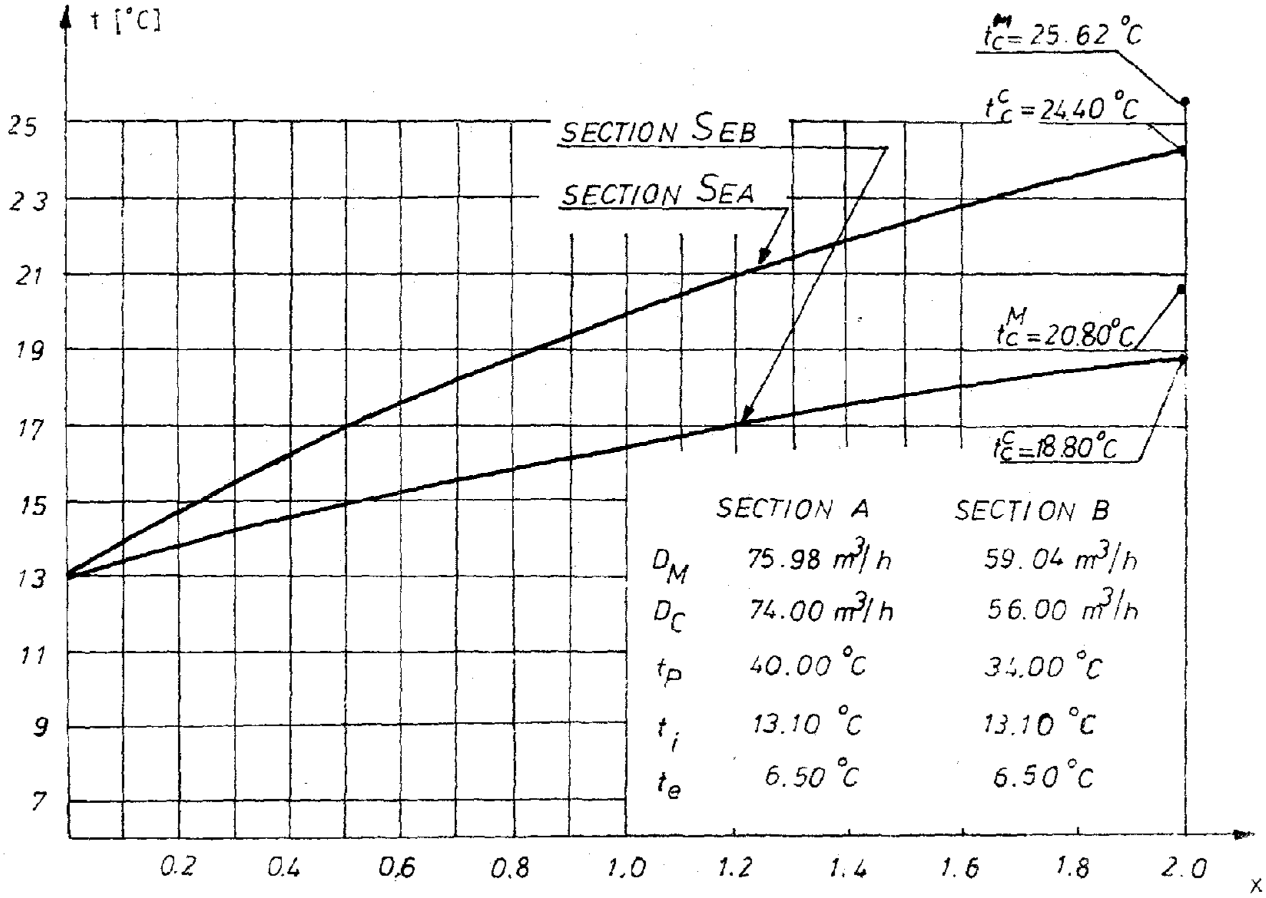


FIG.6. Air temperature distribution.

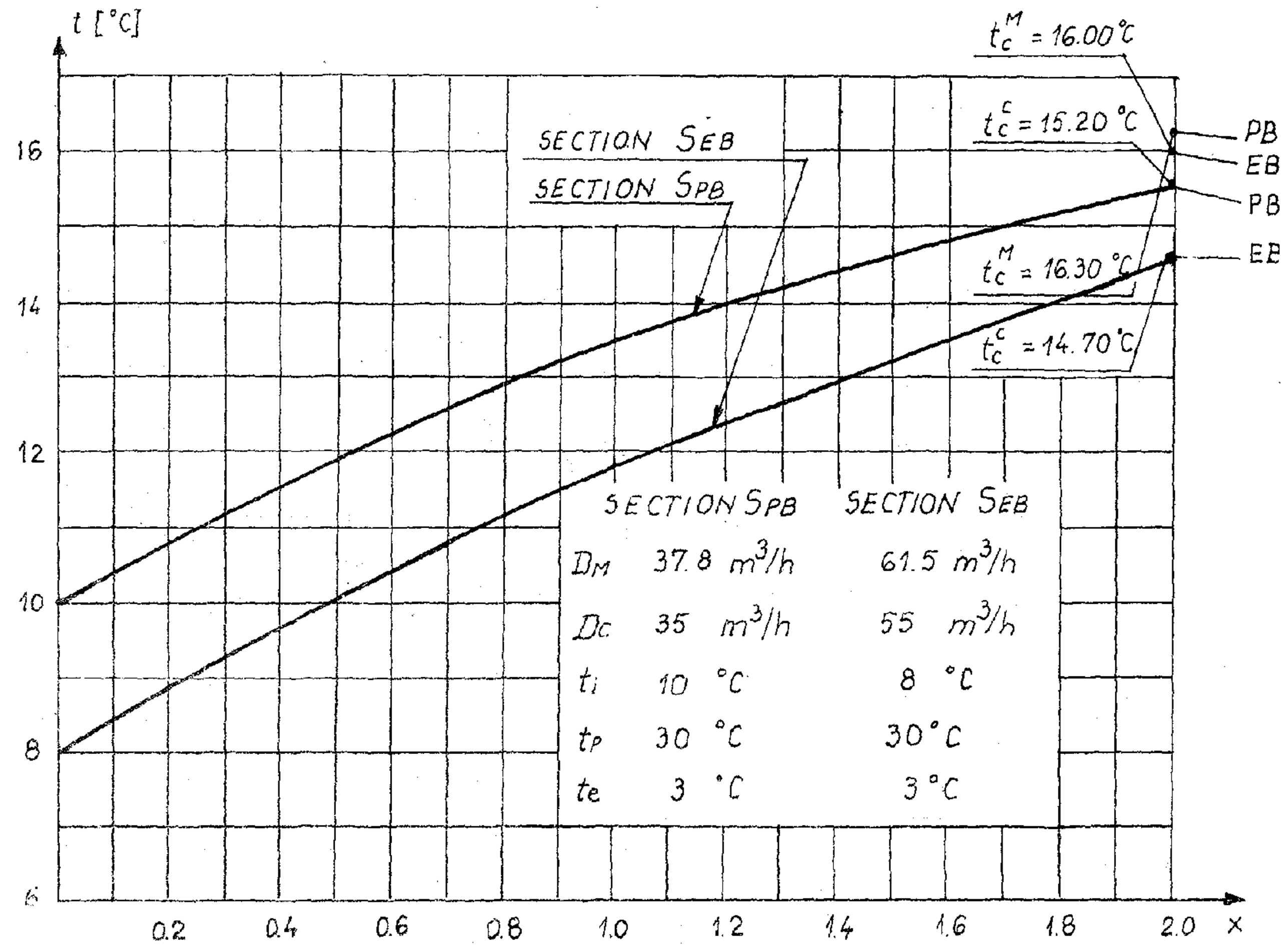
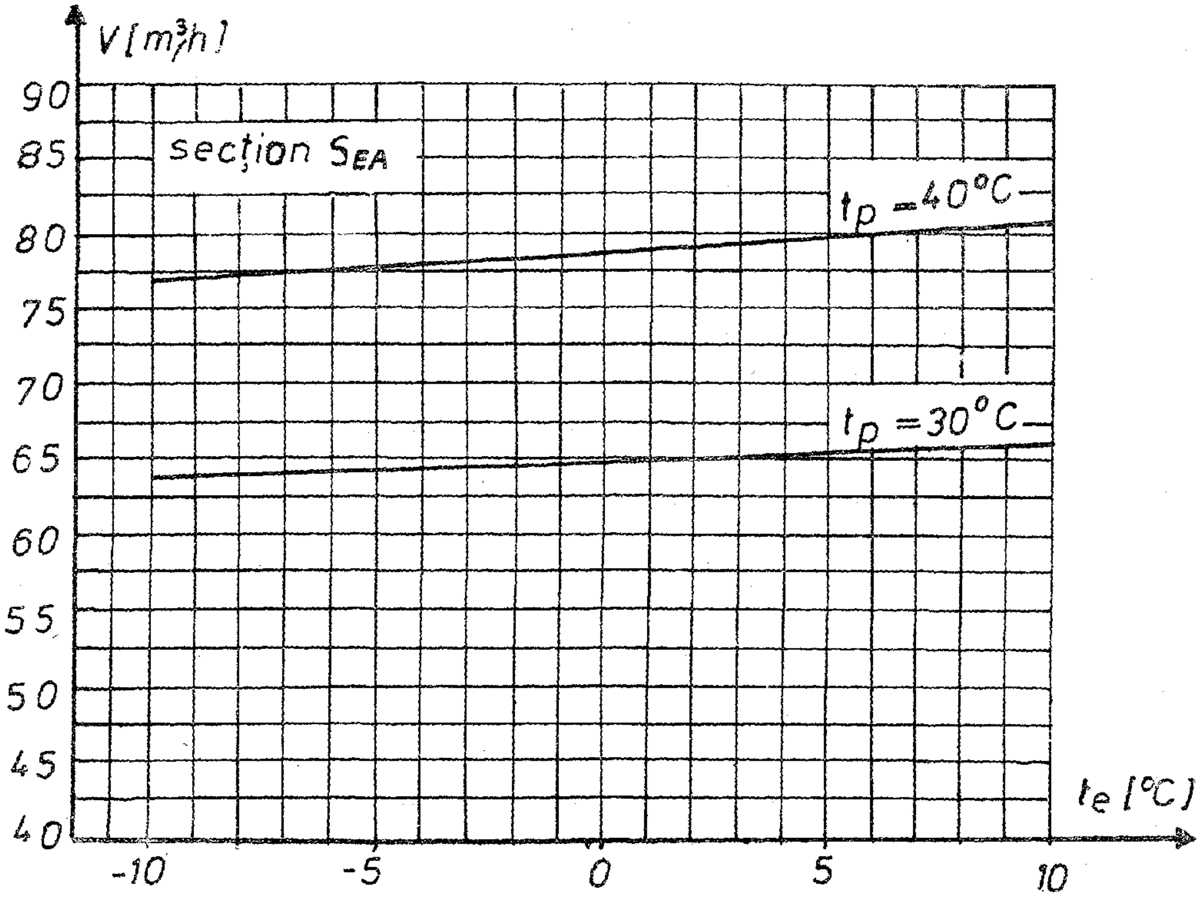


FIG7 Air temperature distribution.



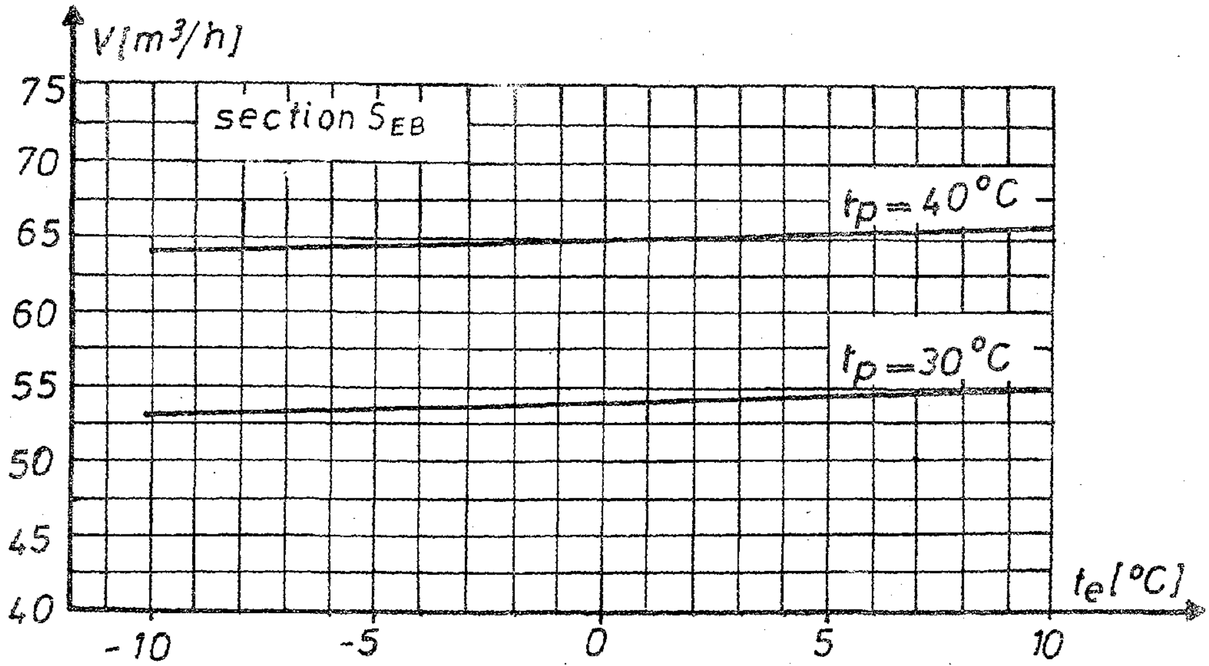


FIG. 8. Standard room-flat t_i=18 C ; H=2.00m

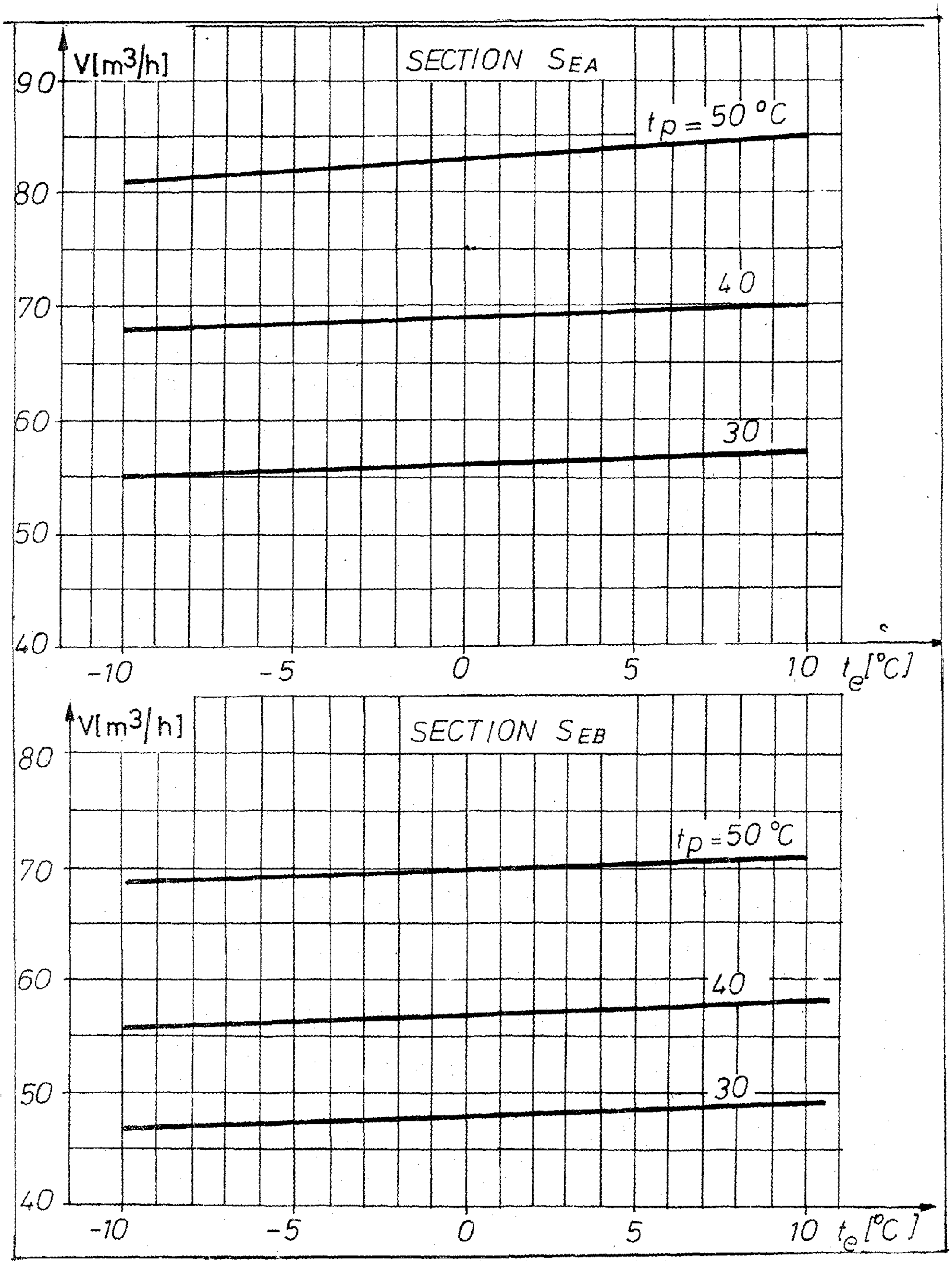


FIG.9.Standard room-flat t_i=18C;H=2.00m

III.11 SYSTEMS FOR SOLAR ENERGY USE FOR SPACE HEATING IN DWELLINGS

Gheorghe Savopol[x]

The use of solar energy for heating spaces in dwellings is achieved by collecting, storage and delivery heating passive systems. The passive solar endowment of the south facades of the dwellings is carried out in 3 construction and energy solutions:

- with trombe wall and triple windows;
- with trombe wall, triple windows and greenhouses collecting solar energy;
- with solar energy collecting greenhouses.

There are presented the techno-economic effects of the application of the passive systems, achieving a fuel saving of about 300 kg.c.f./appartment; representing 25% of the necessary fuel for heating.

The active system may be applied in order to obtain larger amounts of fuel savings. This system may achieve a fuel saving of about 400 kg.c.f./appart./year, but the necessary additional investments make this system unacceptable. It will become suitable if the fuel cost will increase 4-5 times.

Also analyzed was the mixed system (passive+active) that will improve in a way the disadvantages of the incidental costs of applying the active system.

The research on the use of solar energy for space heating in dwellings has led to the development of two systems, namely: the designed passive system, that has been experimented and applied for about 10 years and the designed active system with the experimental phase in progress.

During the last years, the application of solar energy passive systems used for space heating in dwellings revealed two requirements: the efficiency increase of the passive systems used for collecting, storage and delivery of solar energy on one side and the improvement of building layout from the thermal-energy and

x Engineer, Design Institute for Typified Buildings, IPCT, 21, T.Arghezi Street, sector 2, Bucharest.

functional-constructive viewpoint on the other side.

Three solutions were analyzed for passive solar equipment and carried out into three variant solutions for the interior lay-out and especially for the solar collector facade:

1. - providing a Trombe wall and triple windows on the south facade;
2. - providing a Trombe wall, triple windows and green-houses for solar energy collecting on the south facade;
3. - providing collecting greenhouses on the south facade.

Solutions have been studied for the application of these variants both for two storey buildings and for 4 storey buildings, these variants requiring solar equipment without influencing the apartments functionality. The auxiliary source consists of a central heating installation connected with a thermal power station with solid fuel for four story buildings, and stoves with solid fuel for the one story buildings.

The thermal energy and economic preliminary analyses led to the conclusion that in order to efficiently apply the passive solar systems, it is necessary to the building endow with an improved thermal protection. The required measures necessary for the increase of thermal protection adopted delivered in the papers are: the tightening and tripling of the windows, the increase of thermal resistance of the opaque building elements and the protection of the penetrated thermal bridge.

The following table will present the main technical and economic indices of the analysed solutions for a conventional appart ment of 80 m^2 unfolded built area (u.b.a.):

INDICE	two story solution			four story solution		
- supplementary investment for solar equipment (lei/apt)	11900	8800	4900	11600	10000	5000
- fuel saving as a result of the solar energy use(kg.c.f./year)	295	245	190	350	325	215
- recovery period of the supplementary investment(years)	13,7	12,2	8,7	11,2	10,4	7,9

From the indices analyses it can be noticed that the investment has a faster recovery period for the third solution (collecting greenhouses), while the saved fuel quantity is more reduced. In the first solution (Trombe wall) the more expensive investment is recovered with more difficulty while the yearly saved fuel quantity is greater.

The second solutions (Trombe +greenhouse) have the specific indices between 1 and 3. The option for one of these 1,2 or 3 solutions is achieved according to the economic and energy situation. We mention also that in all the analyzed cases, the delivered heat cost is under 200 lei/Gcal, having values around 50% of those for thermal power stations with solid fuel.

One of the most delicate problems that is taken into consideration for the drawing up of the typical projects is the correlation between the tendency to lengthening the collecting surface - for a maximum revaluation of the solar energy contribution - and the tendency to achieve a compact building with a minimum perimeter - in order to reduce heat losses.

Achieve thermal protection degree, one square meter of a non-solar wall (North, East, West) loses a heat quantity of the same value of about 8 kg.c.f./year.

A solar collector wall has an energy balance sheet that represents an equivalent contribution of 15-18 kg.c.f./m^2 year.From the comparative analyses of more partition variants it has resulted that the growth of the collecting surface with 1m^2 requires a growth of the exterior perimetral surface with 1,2, 1,5 m^2, that will justify the adoption of some solutions with increased solar collecting surfaces and with less compact layouts.

The possibilities of fuel saving by means of passive systems are limited. The equipment on the south facade could not usually exceed more than 15-16 m^2 of solar collectors/apart. conv. Under these conditions the yearly saved fuel quantity (about 300 kg.c.f./year) represents only 25% from the necessary fuel for heating, considering the thermal protection degree that corresponds to a specific nominal heat outfit under 20 kg.c.f./m^3/h.

After exhausting the possibilities of solar passive systems, in order to save a greater quantity of fuel by the help of solar energy, it would become necessary to use another system whose main characteristic is the forced circulation of a working medium. This system was called an active system of solar energy utilization.

IPCT in cooperation with INCERC (Building Research Institute) has drawn up the first design project for dwellings using the active air system(air being the working medium prefered in comparison with the antifreezing solution). But IPCT in cooperation with INCERC also carried out a tipical project for this system with antifreezing solution and the experimental phase is in progress at the solar house No.2 at Cîmpina..

The technical advantages of the active air system are the following:

- avoiding the corrosion risk of the installation in contact with antifreezing solution;
- avoiding the liquid losses;
- avoiding the liquid freezing;
- safer and more confortable operation;
- the possibility of energy storage in building elements;
- the use of radiant walls instead of steel heating radiators;
- the increase of the comfort degree of the inhabitants.

During this period the system presents a series of economic disadvantages. According to the typical project it has been possible to provide the necessary installation for an conventional apartment with an active collecting surface of 20 m^2 and an annual fuel saving of about 400 kg.c.f./ap.year.

The supplementary investment for this system is of about 100.000 lei/ap.resulting a specific investment of 250 lei/kg.c.f. yearly saved, in comparison with the specific investment for the passive system that is only 40-50 lei/kf.c.f. yearly saved. It has to be mentioned that these values do not comprise the investment afferent to experimental requirements.

At the present fuel cost the recovery period of the suplimentary investment for the active system is over 70 years.It is considered as a very long period for our present economic situation. This has confirmed the conclusions delivered by IPCT works during 1980-1981, where it was shown that the active system was not profitable in that period because of that fuel cost. The solution will become truly efficient for a fuel cost 4 - 5 times higher than the present one and anyway it must be accepted after the more efficient solutions of fuel saving are used u p (the improvement of the thermal protection, the use of waste thermal potential, the use of passive system for solar energy colection, the use of thermal, geothermal and biogase potential).

In order to decrease the economic disadvantage of the active system in the design of the experimental solar house CS 3 a mixed (passive and active) system used on the eastern part of a building.

Each of the apartments in the mixed section are equipped with 16 m^2 passive solar collectors and 20 m^2 active solar collectors.

The supplementary investment of 115,000 lei leads to an yearly saving of 700 kg.c.f./ap/year, resulting in a specific investment of 160 lei/kg.c.f.yearly saved. The recovery period o f the supplementary investment is of about 50 years, pointing out that the mixed solution is not advantageous in the present economic situation. But which it will be possible to be used if the fuel cost grows 3 times higher than this one.

From the construction view point the system consists in solar collectors that use air, and are mounted on the rooftruss, in rocks storage, circulating ventilator and a system of heat yielding into the apartments. This system consists of closing walls and spaces for tight circulation, the heat being carried out by transmission, radiation and convention and not by hot air directly introduced into the rooms.

III.12 THE USE OF SOLAR ENERGY FOR SPACE HEATING IN PASSIVE SYSTEMS FOR INDUSTRIAL BUILDINGS

Ilinca Bogdan[x]
Nicolae Petraşincu[xx]

ABSTRACT

For multistoried industrial buildings (of the "bar" type) and for buildings of small industries, solar energy is changed into thermal energy by the help of structure elements, namely b y the help of well collectors South directed.

Using this solar energy collecting system, the hest requirement of the respective building will be covered, achieving the decrease of the fuel consumption.

The paper deals with the passive hesting system by the help of solar energy use the South directed walls of the industrial buildings for heat collecting, storage and delivery.

The authors elaborated designs for different solutions that proved to be economic.

1. GENERALITIES

The continuous growth of energy requirements and the limitation of the stocks promptee scientists world wide to look f o r new energy sources. Among the new energy sources that a r o s e a great interest among scientists, solar energy has an important place scoring successful experiments.

Our country is counted among those that adopted a research-development national program concerning the problems of solar energy use in different conversion forms such as the thermal one.

Considering all these, our institute, the Design Institute for Typified Buildings - IPCT - elaborated a large series of studies and designs that implement solar energy use systems for industrial buildings.

x Engineer xx Architect
Design Institute for Typified Buildings - Bucharest

On account of these results and as a conclusion of the experiments carried out in Cîmpina at the solar house CS 1, INCERC started, in cooperation with IPCT, to design some heating installations using solar energy. They use wall solar energy collectors and storage tanks for multistoried industrial buildings and small work units. In the heating installations of the industrial buildings, solar energy is changed into thermal energy using the building elements, namely South directed walls. This solar energy collecting system will cover 35-40% of the heat necessary for the respective building, generating the decrease of the fuel consumption,

Using solar energy we have to consider the advantage of an inexhaustible and free energy source, as well as the disadvantage of a variable solar radiation. We must also consider the day-night cycle, the seasonal cycle and local weather conditions.

2. PASSIVE HEATING SYSTEMS USING SOLAR ENERGY

For collecting storage and solar energy release the passive heating system uses one of the closing elements of the building namely the South directed wall. The heat quantity transferred through the collecting wall is determined by the following:

- positioning of a selective guard for radiations (the glass wall) that will allow the penetration of small wave sun-radiations and will keep inside the long wave sun radiations of the wall collector;

- the use of an absorbing layer - the flat black point layer in order to increase the heat absorbtion;

- the use of some building materials with a great thermal capacity for the massive wall, in order to achieve thermal inertia as great as possible;

The South wall is made of autoclaved cell concrete(b.c.a.) or of masonry made of hollow light concrete bricks (GVP) of 30cm. thickness. The house is placed at 10 cm greenhouse distance towards the wall collector and it is glass protected.

The main principles that will influence the heating of the building by solar energy in the passive system are:

- the use of vertical walls, South directed, as solar energy collectors;
- the use of house effect;
- the natural circulation of the air heated by sun;
- heat storage into the massive wall;

The short length solar radiation penetrates the glass and is absorbed by the wall that is heated. This wall utters long wave radiations. Due to the thermal capacity of the wall-collector it will continue to radiate heat almost the whole night.

The air enclosed into the glasshouse formed between the double glass and the perforated brick wall will be heated through the "glasshouse" effect. It will rise to the upper part of the wall and it will pass to the hall through the slits in this wall area and it will pass to the collector. Its place is taken by the cold air that penetrates into the hall through the kerfs practiced on the bottom area of the wall.

Besides releasing heat into the hall due to solar energy accumulated, the massive wall that also will release a certain heat amount after the sunny hours too.

During the summer time, in order to avoid to overheat the air from the hall, the possibility of closing the upper kerfs from the wall collector and of opening some mobile window pane for a natural air ventilation in the hall and for the air ventilation in the collecting glasshouse was provided by opening the windows from the North wall.

3. USING THE SOLAR COLLECTOR FOR GROUND FLOOR INDUSTRIAL BUILDINGS FOR SMALL UNITS

I.P.C.T. designed the South-facing solar energy collecting wall for multistoried industrial halls or of the halls meant to small units (fig.1 and 2). In order to make possible the maintenance and the cleaning of the house, the glazed wall is composed of greenhouse mobile window panes alternatively disposed in check. Mobile window panes also provided at the upper side of the wall which are closed during the cold season and opened during summer time.

The kerfs from the bottom of the brick wall are closed with wire net on metallic frames and the upper kerfs are provided with adjustable blinds.

4. AUXILIARY HEATING SYSTEM

The passive heating system using solar energy for the industrial buildings may be used only for a limited number of hours. At the begining and at the end of the heating seasons, the buildings may be totally heated with the help of solar energy, taking care as the consumption peaks to be covered with the help of classical heating.

The whole or partial operation of the heating auxiliary system depends on the existence of the solar radiation. The auxiliary heating installation is dimensioned, and it is achieved for heat loses covering of the respective building because of the possibility of many years of solar radiation breakdown.

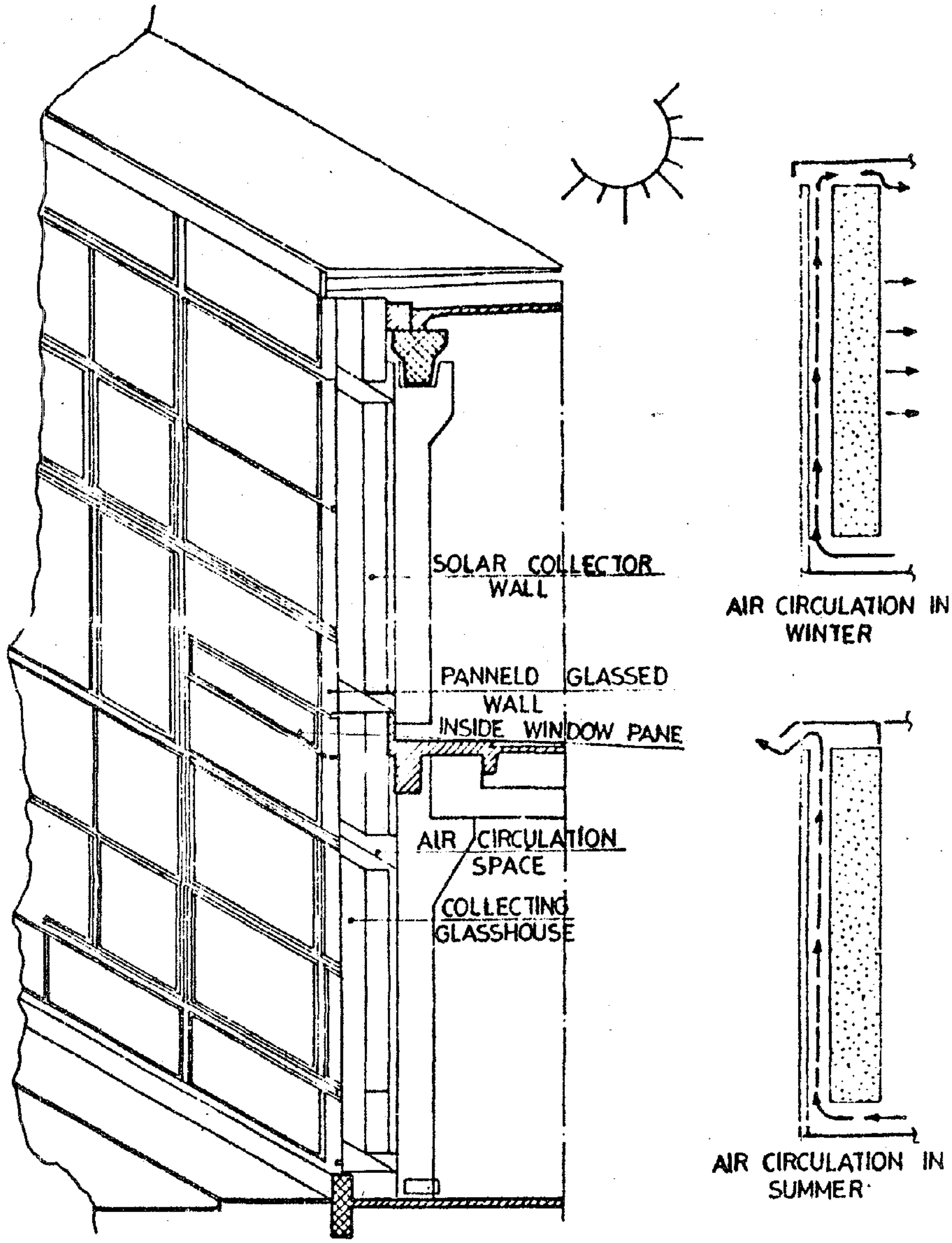
The auxiliary heating system may be worked out as a function of the local conditions:

- the heating system with panel convector radiators of the CRP type, with delivered heat carrier from a neighbour thermal power station or from a district thermal station (for the multistoried industrial buildings or for those necessary for small units);
- local heating system with stores only, for the buildings of the small industry.

An analysis of the economic efficiency of the studied solutions for the buildings with intermittent functionality is also achieved (2 shifts daily).

When the building is continually used (3 shifts daily) the specific supplementary investment costs remain the same, the annual energy saving in serving increasing from 2,5 kg.c.f./m^2 wall collector to 28 kg.c.f./m^2 wall collector, with the recovery period of the supplementary investment decreasing accordingly.

The industrial buildings where there is only one shift will not be provided with a passive heating system using solar energy.



STORIED INDUSTRIAL HALL HEATED WITH SOLARY ENERGY IN THE PASSIVE SYSTEM

FIG. 1

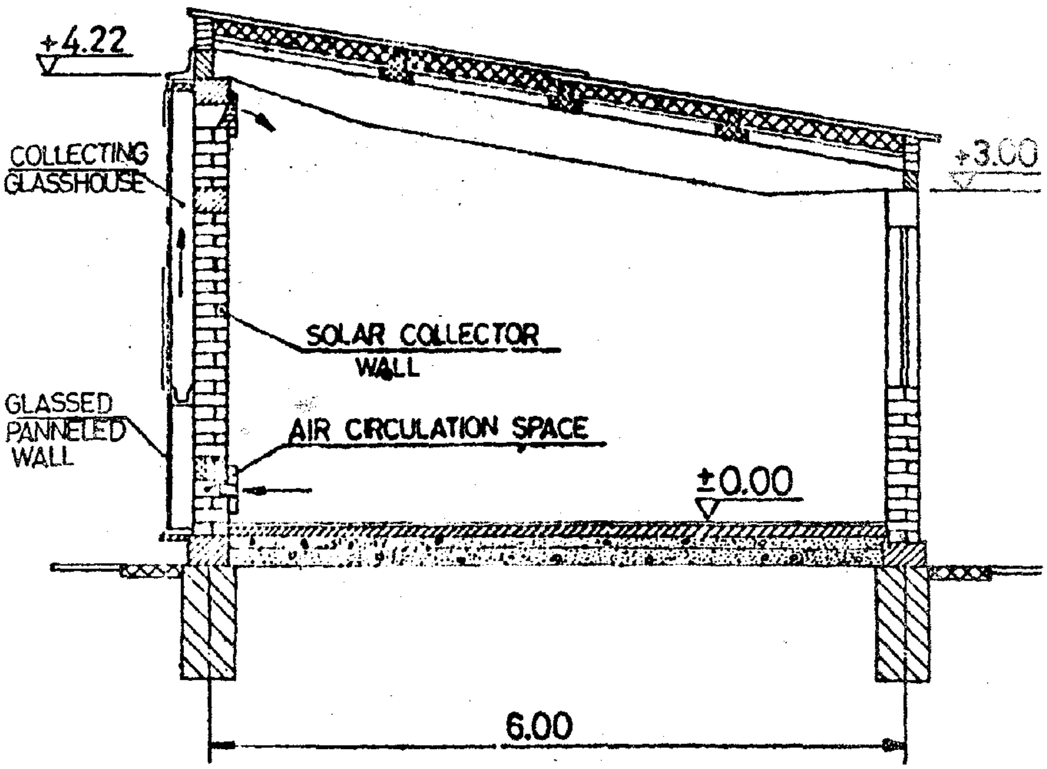


FIG.2. SMALL INDUSTRIAL HALL HEATED WITH SOLAR ENERGY PASSIV SYSTEM

III.13 INDUSTRIAL BUILDING RECONSTRUCTION

USING NEW ENERGY SOURCES

FOR HEATING AND VENTILATION

Ilinca Bogdan x)

Gabriel Ivănescu x)

Dan Atanasescu xx)

In the case of an industrial building, updating from the construction point of view in order to meet certain improved technologies, the central installations may be involved. The main problem for the design specialist is to facilitate the use of new energy sources for industrial hall heating and ventilation.

The paper deals with the solutions for heating and ventilation installations in ground floor industrial buildings using local equipment for heating. The air is preheated in air solar collectors. The local equipment is provided with a rock-storage unit for the supplementary heat from solar energy.

The solar collectors provide collecting surfaces for the solar energy being incorporated into the oriented skylights. Also provided in the hall is equipment to recover the heat from the exhausted foul air using a heat recovery unit with heat carrier. The authors performed studies and designs for different solutions that proved to be economical ones.

The ceaseless growth of the energy requirements and the limitation of the fuel stocks prompted the researchers to look for new energy sources. Among the new energy sources the researchers are interested in, the solar energy has an important place. Romania is one of the countries that adopted a national program of research and development. In this context in the Design Institute for Typical Buildings (IPCT) a series of studies and designes were prepared to implement systems of solar energy use for the industrial buildings.

A first step used solar energy for consumption and technol-

x) Engineers
xx) Architect
Design Institute for Typified Buildings - IPCT
21, T.Arghezi Street, sector 2

Bucharest

ogical hot water preparation. Then the use of solar energy needed for heating the industrial buildings in the passive system (the Trombe Michel wall) began. Romanian research institutes have proceeded to the design of some heating or heating-ventilation installation with hot air in active system.

These systems for solar energy collection may be used both in designing some new industrial buildings as well as in rebuilding already existing industrial buildings. At the same time, for the heating-ventilation installations the use of solar energy in the active system for preheating the absorbed air from exterior to the solar collector can be combined with recovery from the outgoing viciated air from the industrial buildings by the help of heat recovery devices with intermediate fluid.

The present paper deals with heating or ventilation-heating problems using solar energy in the active system for the reconstruction of one story industrial halls. The active system of heating by help of solar energy uses an assembly of collectors, storage devices and transport means that transforms the solar energy into thermal energy, on operation where it is necessary to have a complementary energy for air circulation.

The use of solar energy for totally heating the industrial buildings may be used only a certain number of hours for the whole heating period. For the rest of the time air must be heated in the collecting surfaces, and the maximum consumptions are covered by the help of classical heating with the thermal carrier provided by a thermal station. The use of solar energy in the active system for heating or ventilation of one-story industrial buildings covers 20-40% from the heat necessity of the respective buildings.

2. Types of surfaces for collecting used solar energy for the heating-ventilation equipment.

Solar heating installations use collecting surfaces. These surfaces were incorporated in the skylights of the existing buildings or the newly designed ones, with spares of 3 m. These collecting surfaces work with the help of air thermal heat during the October-April period. When a coil or damper is incorporated in the solar energy collecting plate during the summer period, these will also be used for heating water.

The plane collecting surfaces were made either using the collecting elements of the solar collectors of (2 x 1)m; or using only certain elements of the solar collectors, creating collecting surfaces with sizes adequated to the skylights sizes, considering the shadow too (see Figure 1).

By making some collecting surfaces that have to fit the whole opaque surfaces of the skylight, up to the shadowing limit, the use degree of this method is expanded. A collecting surface through which air passe as a thermal carrier is composed of the following parts:

-- the glass surface - which is double (a glass layer and a sheet);
-- the absorbant plate - steel plate painted in black;
-- the thermal insulation made of mineral wool in a layer of 50 mm., that forms, together with the absorbant plate, the channel for the air circulation.

3. Solutions for the heating or heating-ventilation installations with hot air produced by the help of solar energy.

The heating-ventilation equipment using hot air produced with the help of solar energy are made of:

-- solar collectors or collecting surfaces of the solar energy for air heating;
-- air channels that collect the hot air from the solar collectors;
-- air circulating ventilators through the solar collector;
-- the storage of the excess heat in rock-type materials for heating installations.

This solar heating-ventilation equipment can be conected to the traditional heating installations by the local agregates existing in the one-story industrial buildings. The heating and heating-ventilation installations, with hot air provided by solar energy, may use numerous solutions as follows:

-- Solution 1 (Figure 2) presents a functional scheme for a solar energy heating installation without storage. The hot air absorbed from the hall through absorption inlets, passes through the channel by the absorbing plate and the thermal insulating layer of the solar collector or of the collecting surface. It takes the heat from collecting surface and, further, the air is transmitted through air circulation channels, to the local aggregate used as heating aggregate in the hall.

In the hall air temperature excedes 16°C, (temperature stated by prescription 1907-80 for industrial buildings where an easy work is carried out) the supply of the heating battery with heat carrier, produced by a thermal station, is stopped. The traditional installation is adjusted by a tap with a direct temperature regulator.

The admission of the hall air into the installation is carried out not only by a solar collector but also by a network that permits the collecting installation by-pass during the sun-free periods.

-- Solution 2 (Figure 3) presents the functional scheme of a solar heating installation that is provided with a thermal storage unit in rock-type materials. The scheme is similar to that presented in solution 1, having in addition the storage unit.

The storage supply is created by an air circulation channel that comes from the solar collector or from the collecting surface and than a valve that is provided, automatically worked in function of the air temperature which comes through the solar collector. The storage unit is conceived as an underground recipient with concrete walls. The recipient is divided into three rooms:

-- air admission room, where the air comes from the solar collector through the circulation channels;
-- the so-called storage room whose partition walls are made of U-shaped angles and wire mesh ,and where are put granite stones;
-- the air exhaustion room towards the heating-ventilation local aggregate.

Each hall's local aggregate that is connected to the local installation could be provided with a storage unit in the case this solution is used.

-- Solution 3 (Figure 4) presents the functional scheme of the heating-ventilation installation in the one-story industrial buildings without storage. In this case, the air is no more absorbed from the hall but from outside. The solar collector has the role to preheat or heat the fresh air sending it in the heating local aggregate through the circulation channels. The operation of the traditional installation is performed similarly to that presented in solution 1.

-- Solution 4 (Figure 5) presents the functional scheme of the heating-ventilation installation provided with a recovery installation with intermediate fluid. The recovery installation takes over the heat from the outgoing fuel air that is exhausted into the ventilation installation. But the scheme is similar to the one presented is solution 3 but has only moreover the component parts of a recovery installation with intermediate fluid.

The Design Institute for Typical Buildings has studied the presented solutions and applied them to one-story industrial buildings with large dimensions (72 x 73 m) that allow the obtaining of as large as possible surfaces.

x

x x

The analysis of the efficiency of the heating or heating-ventilation solution using solar energy in active system has shown an energetical contribution of:

-- 20 - 35 kg.c.f./m^2 year for the solar installation solutions without storage unit, depending on the selected solution and on the collecting surface dimension;

-- 25 - 40 kg.c.f./m^2 year for the solar installation solutions with storage unit.

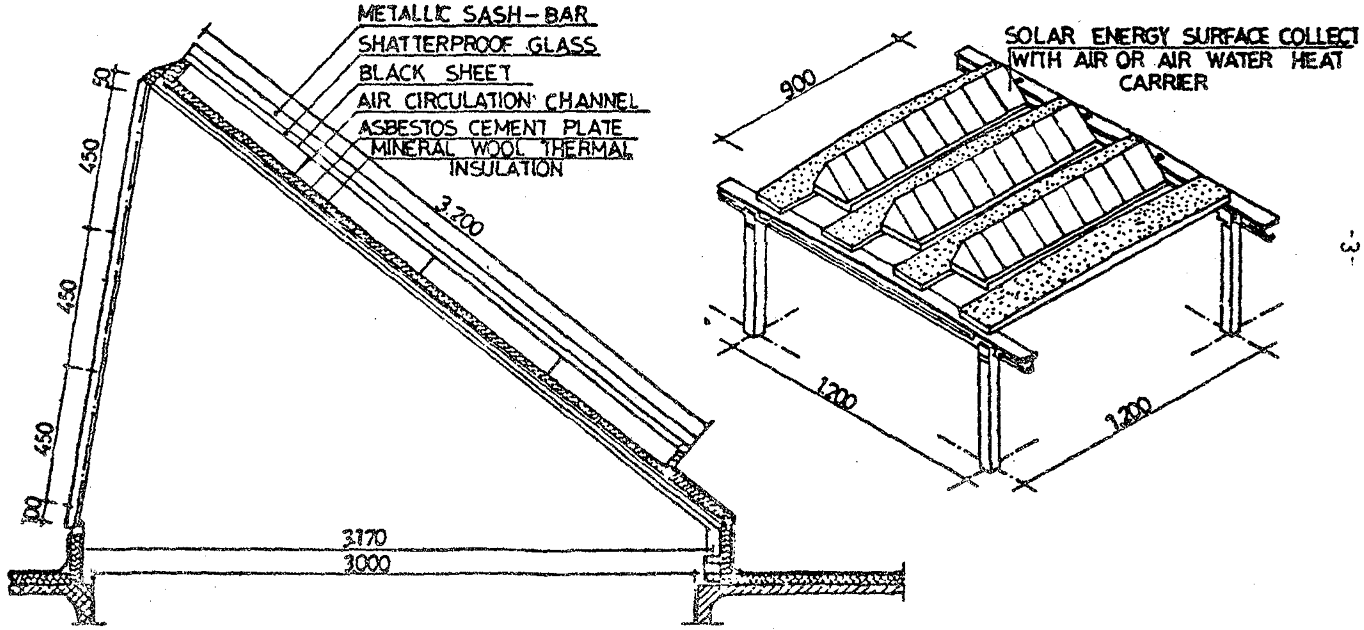

METALLIC SASH-BAR
SHATTERPROOF GLASS
BLACK SHEET
AIR CIRCULATION CHANNEL
ASBESTOS CEMENT PLATE
MINERAL WOOL THERMAL INSULATION
3.200
50
450
450
450
100
3170
3000
SOLAR ENERGY SURFACE COLLECT WITH AIR OR AIR WATER HEAT CARRIER
900
1200
1200

FIG. 1

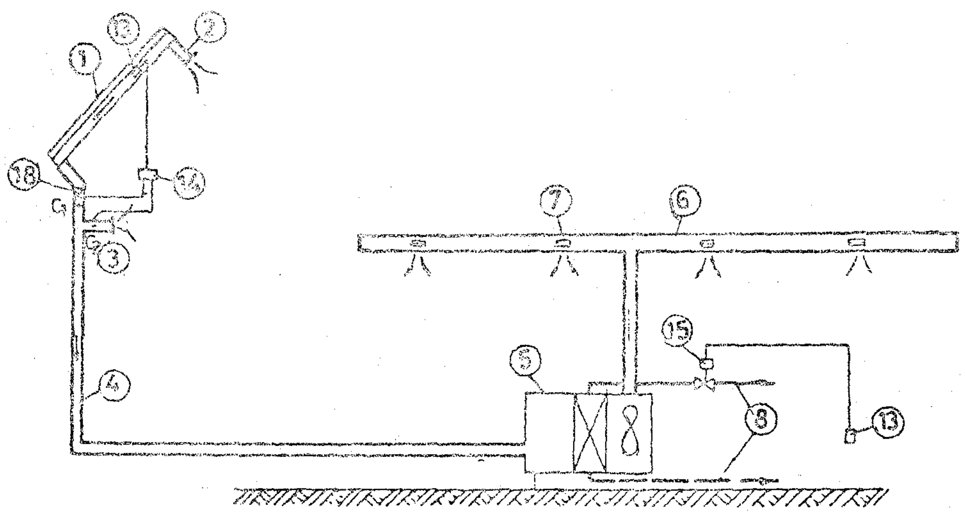
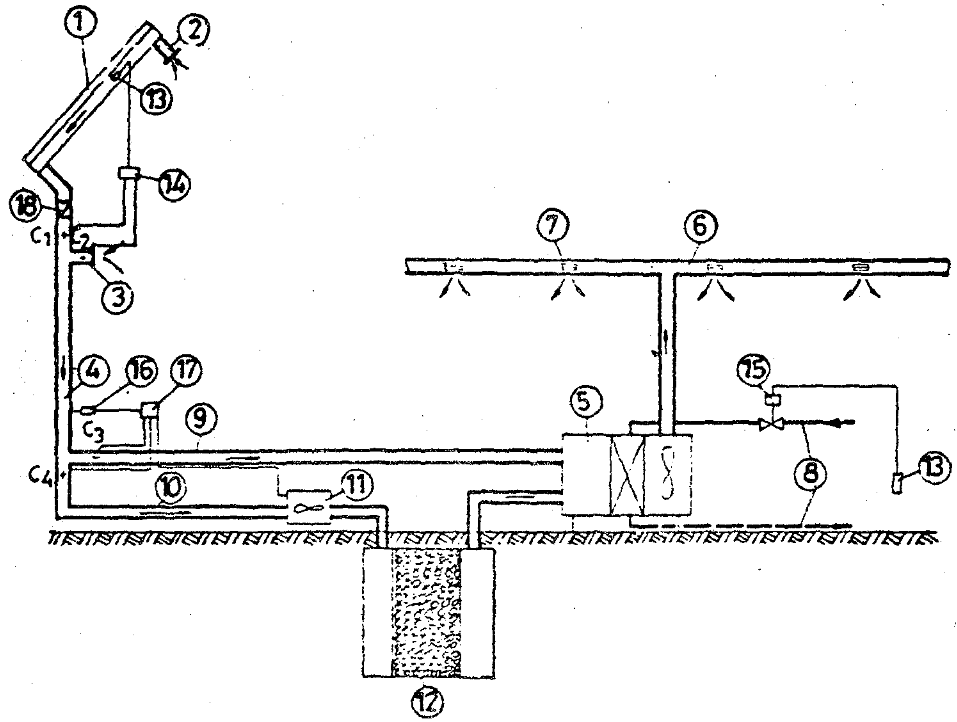


FIG. 2

LEGEND

1. SOLAR COLLECTOR WITH AIR –WATER HEAT CARRIER.
2. ABSORBING INLET FOR RECIRCULATED AIR FROM THE SOLAR COLLECTOR.
3. ABSORBING INLET FOR RECIRCULATED AIR FROM THE HALL DIRETLY.
4. COLLECTING CHANNEL OF THE ABSORBED AIR.
5. LOCAL AGGREGATE FOR THE HAT AIR PREPARATION.
6. INLET CHANNEL OF THE HAT AIR INTO THE HALL.
7. INLET FOR THE HAT AIR INTO THE HALL.
8. RECIRCULATION PIPES FOR THE HEAT CARRIER COMING FROM THE THERMAL STATION.
13. TEMPERATURE.
14. ELECTRICAL CONTACT THERMO MANOMETER.
15. TEMPERATURE DIRECT REGULATOR.



LEGEND

1...8,13,14,15 - SEE THE LEGEND OF FIG. 2
9 BY-PASS CHANNEL FOR STORAGE
10 AIR CIRCULATION CHANNEL THE STORAGE
11 AIR CIRCULATION VENTILATOR IN THE STORAGE
12 STORAGE
16 THERMALRESISTANCE
17 ELECTRICAL REGULATOR ARF-192 TYPE
18 HOT AIR COLLECTING CHANNEL FROM SOLAR COLLECTORS

FIG. 3

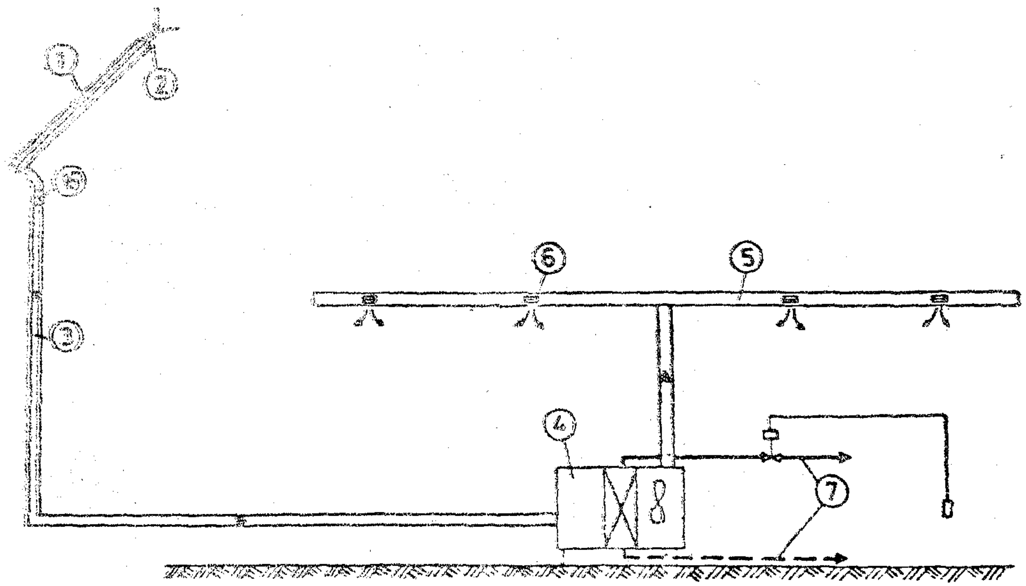


FIG. 4

LEGEND

1- SOLAR COLLECTOR WITH AIR OR AIR-WATER CARRIER

2- ABSORBING INLET FOR FRESH AIR FROM EXTERIOR

3- COLLECTING CHANNEL FOR THE SOLAR PRE-HEATED AIR

4- LOCAL AGGREGATE FOR THE HOT AIR PREPARA-TION

5- INLET CHANNEL OF THE HOT AIR INTO THE HALL

6- INLET FOR THE HOT AIR INTO THE HALL

7- CHANNEL FOR THE HEAT CARRIER CIRCULATION FROM THE THERMAL STATION

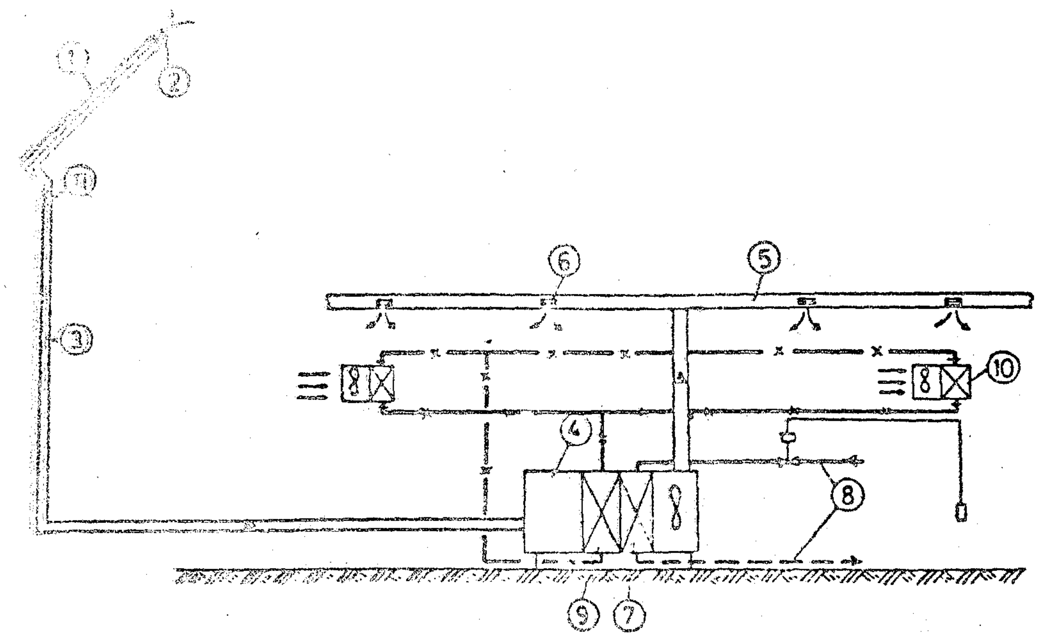


FIG. 5

LEGEND

1.. 6-SEE THE LEGEND OF FIG. 4

7-BATTERY FOR AIR HEATING BY THE HELP OF HEAT CARRIER FROM THE THERMAL STADION

8-CIRCULATION PIPES FOR THE HEAT CARRIER

9-BATTERY FOR AIR HEATING WITH INTERMEDIATE FLUID

10-OUTLET AGGREGATE FOR THE AIR FROM BATTERY WITH INTERMEDIATE FLUID FOR HEAT RECOVERY

11-COLLECTING CHANNEL OF THE HOT AIR FROM SOLAR COLLECTORS

III.14 THERMAL CHARACTERISTIC METHOD -

-METHOD OF DIMENSIONING

SOLAR INSTALLATIONS USED IN HOT WATER PREPARATION

Florin Iordache x)

A. Thermal characteristics of solar installations used in water heating.

The dimensioning method to be introduced in this paper addresses - by its structure - designers working on solar installations used in warm water preparation; it is a graphic dimensioning method and refers to two concepts to be further determined: collection loop thermal characteristic and solar installations thermal characteristic.

This solar installation dimensioning method is based on the idea of extending the concept of a "thermal characteristic" from the solar collectors to the collection loop and further to the entire solar installation.

In order to define concretely the two thermal characteristics mentioned above, this paper refers to the solar installations counterflow heat exchanger, short-time storage tanks, and an auxiliar source connected in series with the solar installation (Fig.1).

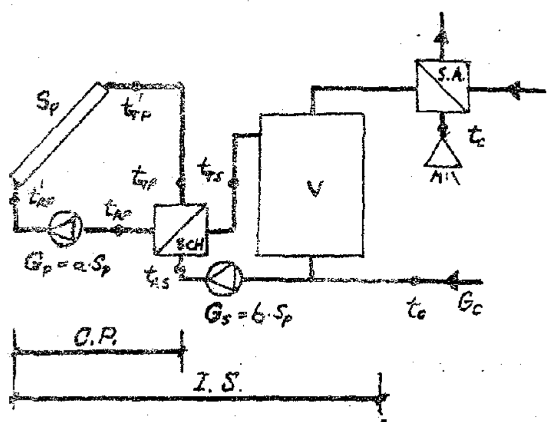


FIG.1

x) Engineer, Building Research Institute (INCERC) - Bucharest Romania

Curve $\eta_{C.P.} = \eta_{C.P.}(\mathcal{E}_{C.P.})$ is the collection loop thermal characteristic (see Fig.2).

$$\eta_{C.P.} = \frac{a\ (t_{TP} - t_{RP})}{I}$$

$$\mathcal{E}_{C.P.} = \frac{0.5\ (t_{TP} + t_{RP}) - t_e}{I}$$

In order to plot the collection loop thermal characteristic ($C_{C.P.}$) when the thermal characteristic of the collectors that the solar installation is equipped with (C_c) is known, it is enough to determine the homologues of two points on characteristic (C_c) as follows:

-- may M ($\mathcal{E}_c$, η_c) be a point on characteristic (C_c) and ($\mathcal{E}_{C.P.}$, $\eta_{C.P.}$) its homologue on characteristic (C_{CP}); the coordinates of M' and of M are related as follows:

$$\mathcal{E}_{C.P.} = -\frac{0.25}{a} \cdot \frac{1-(1-c_T)\ (1-c_R)}{(1-c_R)}\ \eta_c + 0.5\ \frac{1+(1-c_T)\ (1-c_R)}{(1-c_R)}\ \mathcal{E}_c \tag{1}$$

$$\eta_{C.P.} = 0.5\ \frac{1+(1-c_T)\ (1-c_R)}{(1-c_R)}\ \eta_c - a\ \frac{1-(1-c_T)\ (1-c_R)}{(1-c_R)}\ \mathcal{E}_c$$

Relation (1) is related by simple algebric operations performed on the expressions defining

I) - the collection loop temperature drops (inlet and outlet) /1/:

$$t'_{TP} - t_{TP} = (t'_{TP} - t_e)\ c_T$$

$$t_{RP} - t'_{Rp} = (t_{RP} - t_e)\ c_R \tag{2}$$

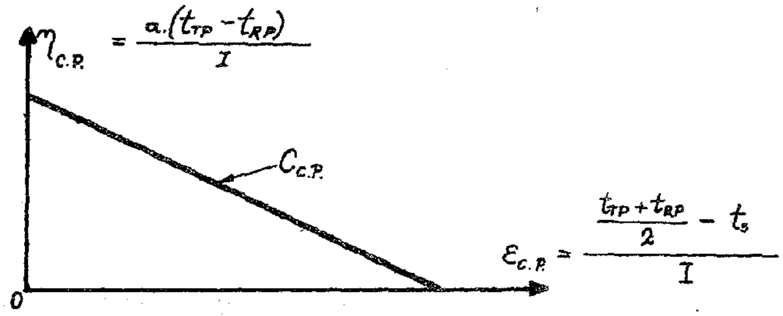


FIG.2

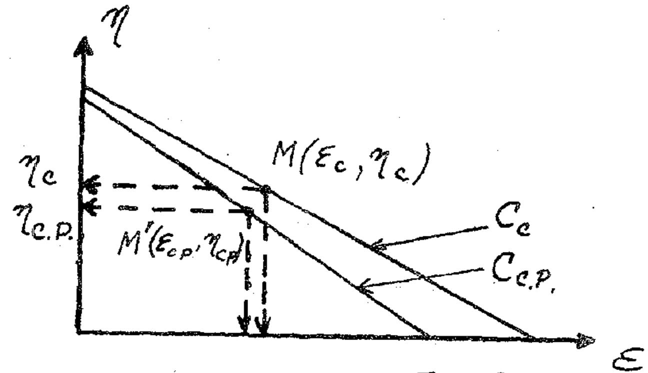


FIG. 3

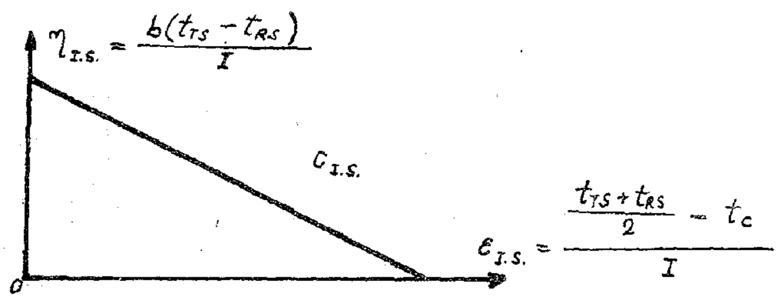


FIG .4

II) - the coordinates of a solar collector service point (e.g.M) placed on their thermal characteristic (C_c)

$$\mathcal{E}_c = \frac{0.5\ (t'_{TP} + t'_{RP}) - t_e}{I} \qquad \eta_c = \frac{a\ (t'_{TP} - t'_{RP})}{I} \tag{3}$$

III) - the coordinates of the homologue service point (M') the collection loop placed on its thermal characteristic (C_{CP})

$$\mathcal{E}_{C.P.} = \frac{0.5\ (t_{TP} + t_{RP}) - t_e}{I} \qquad \eta_{C.P.} = \frac{a\ (t_{TP} - t_{RP})}{I} \tag{4}$$

It has been stated above that in order to plot characteristic C_{CP}, it is necessary to know only two points on it; this statement assumes beforehand that this curve has the form of a line, proved by expression (1). We define now the "solar installation thermal characteristic", curve $\eta_{IS} = \eta_{IS}\ (\mathcal{E}_{IS})$, where

$$\mathcal{E}_{I.S.} = \frac{0.5\ (t_{TS} + t_{RS}) - t_e}{I} \qquad \eta_{I.S.} = \frac{b\ (t_{TS} - t_{RS})}{I} \tag{5}$$

(see Fig.4)

For the time being, only characteristic C_{IS} will be defined its plotting - when the other two characteristics, C_{CP} and C_c are known - is explained in the second part of this paper. It has been defined in order to conclude:

$$\eta_{IS} = \eta_{CP} \tag{6}$$

As $b\ (t_{TS} - t_{RS}) = a\ (t_{TP} - t_{RP})$, according to the heat balance of the counterflow heat exchanger.

The energy supplying rate of consumer (F_o) and the solar installation energy efficiency (η_{IS}) are defined as follows:

$$F_o = \frac{q_s}{q_N} \quad \text{and} \quad \eta_{I.S.} = \frac{q_s}{q_I} \tag{7}$$

and therefore they are related:

$$F_o = \eta_{IS} \cdot \frac{q_r}{q_N} = \eta_{CP} \cdot \frac{q_I}{q_N} \quad \text{(acc.to rel.6)} \tag{8}$$

where

$q_I = 9\ I$ (considering the calculus annual average day)

$$q_N = \frac{G_T}{S_T}(t_c - t_o) = 9b(t_c - t_o)$$

The result is

$$F_o = \frac{1}{b} \cdot \frac{1}{t_c - t_o} \cdot \eta_{C.P.} \cdot I$$

$$F_o = \frac{1}{b} \cdot \frac{1}{t_c - t_o} \eta_{I.S.}\ I \tag{9}$$

As $F_o = \dfrac{t_{TS} - t_{RS}}{t_c - t_o}$ it follows that

$$t_{TS} = t_{RS} + \frac{1}{b} \cdot \eta_{CP} \cdot I \tag{10}$$

If the collecting loop service point is known, according to relation (4), the temperature values on the heat exchanger collection loop are given by expressions

$$t_{TP} = (\varepsilon_{C.P.} + \frac{0.5}{a} \eta_{C.P.})\ I + t_e$$

$$t_{RP} = (\varepsilon_{C.P.} - \frac{0.5}{a} \eta_{C.P.})\ I + t_e \tag{11}$$

The minimum temperature difference between the primary heat carrier and the secondary heat carrier at the heat exchanger is given by expressions:

$$\Delta t = t_{TP}-t_{TS} = \left[\mathcal{E}_{C.P.} + \left(\frac{0.5}{a} - \frac{1}{b} \right) \eta_{C.P.} \right] I + t_e - t_{RS} \quad \text{if } a \geqslant b$$

$$\Delta t = t_{RP}-t_{RS} = \left[\mathcal{E}_{C.P.} - \frac{0.5}{a} \eta_{C.P.} \right] I + t_e - t_{RS} \quad \text{if } a < b \quad (12)$$

Relations (9) and (12) represent the two basic equations to be used in determining the solutions for dimensioning a certain solar installation, as the energy supply values (F_o) and the minimum temperature drop for the heat exchanger (Δt) usually represent imposed values in the calculus of solar installation dimensioning.

Explaining value b in relation (9) and replacing it in (10) -- first relation, case $a \geqslant b$ -- we obtain

$$\frac{0.5}{a} \eta_{C.P.} + \mathcal{E}_{C.P.} = \frac{F_o(t_c-t_o)+t_{RS}-t_e+\Delta t}{I} \qquad (13)$$

where the right member represents a numerical value ($t_{RS}=t_c$) the hypothesis in the dimensioning calculus of one change per day of the storage tank water. Using the graphic representation of the collection loop thermal characteristic C_{CP} determined as it has been shown above relation (13) is solved by successive attempts; the service point on characteristic C_{CP} is determined by its coordinates $\mathcal{E}_{CP}^{PE}$ and η_{CP}^{PE} (the service point P.F. may be determined at the crossing of equation (13) line with characteristic C_{CP}).

Using relation (9), "b" and therefore collecting area S_p may be further determined, as may the heat exchanger calculus temperature values, using relations (10) and (11). Would like to present a synthesis of the ideas introduced above in order to show a dimensioning method for solar installations used in preparing domestic warm water:

<u>Thermal characteristic method - dimensioning method for solar installations used in preparing domestic warm water:</u>

(1) the collection loop thermal characteristic (C_{CP}) is plotted through two points, their coordinates $\mathcal{E}_{CP}$ and η_{CP} having the following expressions:

$$\mathcal{E}_{C.P.} = -\frac{0.25}{a} \cdot \frac{1-(1-c_T)(1-c_R)}{(1-c_R)} \cdot \eta_c + 0.5 \frac{1+(1-c_T)(1-c_R)}{(1-c_R)} \mathcal{E}_c$$

$$\eta_{C.P.} = 0.5 \frac{1+(1-c_T)(1-c_R)}{(1-c_R)} \eta_c - a \frac{1-(1-c_T)(1-c_R)}{(1-c_R)} \mathcal{E}_c \qquad (I)$$

where

ε_c and η_c - represent the coordinates of the homologues of these points on the thermal characteristic of the collectors under use (C_c).

(2) According to the value of the actual energy recovery rats (F), the value of energy recovery rate (F_o) is determined using curve ($F - F_o$) which presently is given in "Technical instruction for the design and dimensioning of solar installations used in preparing domestic warm water".

(3) By attempts using the diagram of the collection loop thermal characteristic (C_{CP}) (as presented in item 1), the calculus service point (P.F.C.) of the collection loop is determined by coordinates ε_{CP}^{PFC} and η_{CP}^{PFC} under condition

$$\frac{0.5}{a} \cdot \eta_{C.P.}^{P.F.C.} + \varepsilon_{C.P.}^{P.F.C} = \frac{F_o(t_c - t_o) + t_o - t_e + \Delta t}{I} \qquad \text{(II)}$$

where Δt_o represents the imposed value of temperature difference $t_{TP} - t_{TS}$ (e.g. 3,5 °C).

The calculus service point (P.F.C.) may also be obtained as follows:

- the line defined by relation (II) is plotted through two points and point P.F.C. results where it crosses characteristic C_{CP}.

(4) If the efficiency of the calculus service point (P.F.C.) is known, the specific flow rate on the heat exchanger secondary loop (b) is calculated using relation

$$b = \frac{\eta_{C.P.}^{P.F.C} \cdot I}{F_o(t_c - t_o)} \qquad \text{(III)}$$

(5) The resulting value of "b" is compared to "a" and if

$a \gtrless b$ - everything is correct

and if

$a < b$ - point 3) is reconsidered under the form 3^x:

3^x) By attempts using the diagram of characteristic (C_{CP}) point (P.F.C.) is determined so that its coordinates should check relation

$$\frac{0.5}{a} \eta_{C.P.}^{P.F.C} - \varepsilon_{C.P.}^{P.F.C} = \frac{t_e - t_o - \Delta t_o}{I} \qquad \text{(II)}$$

Point (4) is reconsidered; value "b" is recalculated using relation III which this time will surely satisfy the inequality $a < b$.

(6) The calculus temperatures of the heat exchanger are determined:

$$t_{RS} = t_o$$

$$t_{TS} = t_o + \frac{1}{b} \eta^{P.F.C.}_{C.P.} \cdot I$$

$$t_{TP} = \left(\varepsilon^{P.F.C.}_{C.P.} + \frac{0.5}{a} \eta^{P.F.C.}_{C.P.} \right) I + t_e$$

$$t_{RP} = \left(\varepsilon^{P.F.C.}_{C.P.} - \frac{0.5}{a} \eta^{P.F.C.}_{C.P.} \right) I + t_e \qquad \text{(IV)}$$

(7) The collecting area is determined using relation

$$S_P = \frac{G_T}{9\ b} \qquad \text{(V)}$$

and the number of collectors: $n=0.5\ S_p$

(8) The flow rate values of the primary and secondary heat carriers are calculated using relations

$$G_p = a\ Sp$$

$$Gs = b\ Sp \qquad \text{(VI)}$$

(9) Selection of pumps, heat exchanger and storage tanks is performed according to /2/.

B. Service analysis of solar installations under dynamic conditions

The solar installation service analysis under dynamic conditions means hour-by-hour control of the temperature values achieved and provided to the consumer by the solar installation. In order to make this possible, the working method needs to appeal to the third thermal characteristic, namely to the thermal characteristic of the solar installation (C_{IS}).

In order to plot the thermal characteristic of the solar installation (C_{IS}) when the collection loop thermal characteristic

(C_{CP}) is known, it is enough to determine the homologues of two points on characteristic C_{CP}. The following relations exist between the coordinates of a point M'' ($\mathcal{E}_{IS}$, η_{IS}) on characteristic C_{IS} and its homologue M' ($\mathcal{E}_{CP}$, η_{CP}):

$$\mathcal{E}_{I.S.} = -0.5\,\frac{a - b}{a \cdot b} \cdot \frac{V + 1}{V - 1}\,\eta_{C.P.} + \mathcal{E}_{C.P.} \tag{14}$$

$$\eta_{I.S.} = \eta_{C.P.}$$

where

$$V = \exp\left(R\,\frac{a - b}{ab}\right) \qquad \text{where} \qquad R = \frac{(KS)_{SCH}}{S_p}$$

(see Fig.5)

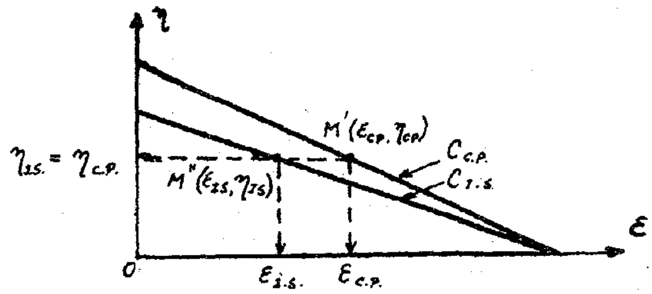


FIG.5

Relations (14) are obtained by the algebraic processing of the expressions defining:

(I) - the heat balance of a counterflow heat exchanger:

$$a\,(t_{TP}-t_{RP}) = b\,(t_{TS}-t_{RS}) = \frac{(KS)_{SCH}}{S_p}\,\Delta t_{ml} \tag{15}$$

(II) - coordinates of a service point (M') of the collection loop on characteristic C_{CP}:

$$\mathcal{E}_{C.P.} = \frac{0.5(t_{TP}+t_{RP}) - t_e}{I}$$

$$\eta_{C.P.} = \frac{a(t_{TP}-t_{RP})}{I} \tag{16}$$

(III) - coordinates of a homologue service point (M'') of the solar installation; this point is on its thermal characteristic C_{IS}, which is to be plotted

$$\varepsilon_{I.S.} = \frac{0.5(t_{TS} + t_{RS}) - t_e}{I}$$

$$\eta_{I.S.} = \frac{b\ (t_{TS} - t_{RS})}{I} \tag{17}$$

If the specific flow rate on the storage circuit (b) is equal to the specific flow rate on the collection loop (a) the following relations exist between the coordinates of a point M'' (ε_{IS}, η_{IS}) on characteristic C_{IS} and its homologue M' (ε_{CP}, η_{CP}) on the collection loop characteristic :

$$\varepsilon_{I.S.} = -\frac{1}{R}\,\eta_{C.P.} + \varepsilon_{C.P.}$$

$$\eta_{I.S.} = \eta_{C.P.} \tag{14'}$$

Therefore, in order to plot characteristic C_{IS}, the solar installation must be dimensioned and the dimensions of the collecting area and of the heat exchanger must be known. If the three thermal characteristic C_{IS}, C_{CP} and C_c are known (that is graphically plotted), the hour-by-hour temperature of the heat carriers under actual service conditions may be determined in different parts of the solar installation.

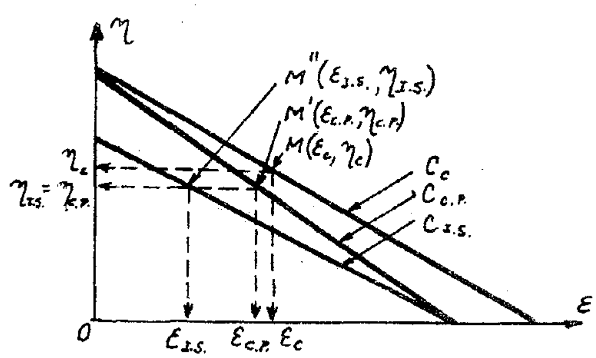


FIG.6

If

- the solar installation thermal characteristic (C_{IS})

- the instantaneous hourly three values of the solar radiation and of the outside temperature (I and t_e)

- the inlet temperature value in the heat exchanger of the secondary heat carrier (t_{RS})
are known, the outlet temperature value in the heat exchanger is determined by successive attempts, calculating ε_{IS} and η_{IS} with their definitional relations (17) until they represent the co-ordinates of a point on the solar installation characteristic C_{IS}. The working efficiency of the solar installation η_{IS} is determined as well. If point M'' (ε_{IS}, η_{IS}) is known, the respective service point of the collection loop M' (ε_{CP}, η_{CP}) is where ordinate η_{IS} crosses characteristic C_{Cp}.

The service point P.F. on characteristic C_{IS} may also be determined by crossing the equation line with characteristic C_{IS}.

The heat exchanger temperature values on the primary heat carrier is determined by relations (11). In order to determine the service point M (ε_c, η_c) of the solar collectors, the following relations are used:

$$\varepsilon_c = \frac{0.25}{a} \cdot \frac{1-(1-C_T)(1-C_R)}{(1-C_T)} \eta_{cp} + 0.5 \cdot \frac{1+(1-C_T)(1-C_R)}{(1-C_T)} \varepsilon_{cp}$$

$$\eta_c = 0.5 \cdot \frac{1+(1-C_T)(1-C_R)}{(1-C_T)} \eta_{cp} + a \frac{1-(1-C_T)(1-C_R)}{1-C_T} \varepsilon_{cp} \qquad (18)$$

these relations are obtained by processing relations (1).

The service efficiency values of the solar collectors, represent their behaviour indicator under dynamic conditions. The solar collector service temperature values (t'_{TP} and t'_{RP}) in the situation described above are calculated using expressions:

$$t'_{TP} = (\varepsilon_c + \frac{0.5}{a} \eta_c) I + t_e$$

$$t'_{Rp} = (\varepsilon_c - \frac{0.5}{a} \eta_c) I + t_e \qquad (19)$$

which are obtained by processing relations (3).

Considering the storage tank full of cold water (tempera - ture t_o), at the beginning of the solar day, the water temperature on the storage circuit at the heat exchanger inlet, t_{RS} is surely equal to t_o during the first morning hours.

Together with the determination of the solar installation service temperature values performed as described above (in the period when $t_{RS} = t_o$), a strict record of the warm water quantities introduced in the storage tank, as on a cloudless day it is possible that the storage tank fills at solar mid-day because the water supplied by the solar installation exceeds the temperature value required by the consumer. In this case, $t_{RS} \neq t_o$ and the heat balance of the mixed heat carriers gives:

$$t_{RS} = \left(1 - \frac{G_c}{G_s}\right) t_B + \frac{G_c}{G_s} t_o \tag{20}$$

representing one of the data required in determining the solar installation working temperature and the energy efficiency for several parts of the solar installations.

Under actual service conditions of the solar installations such situations as

- the temperature of the water delivered by the solar installation to the consumer exceeds the temperature value required by the consumer;
- the temperature of the secondary heat carrier at the heat exchanger inlet (t_{RS}) is higher than the cold water temperature (t_o) because of the recirculation of the water volume in the storage tank occur usually, and therefore it is rather difficult to control service under actual conditions.

The service points of the type M'' (ε_{IS}, η_{IS}), reflecting the behavior of the solar installation under dynamic conditions, are all on the same thermal characteristic C_{IS} of the solar installation plotted, considering the hypothesis of a constant value of the heat exchange overall coefficient of the heat exchanger (K_{SCH}) and with the value resulted from the dimensioning calculus (namely climatic conditions, average values for the solar installation service period).

The determination of the M'' type service points ($\varepsilon_{IS}, \eta_{IS}$) under dynamic working conditions, considering the variation of K_{SCH} according to the temperature values, is performed as follows:

- characteristic C_{IS} with value K_{SCH}, resulted from the dimensioning calculus is plotted;
- from this characteristic, t_{TS} and then t_{TP} and t_{RP} are determined by several attempts on this characteristic and value K_{SCH} is recalculated with this value for the selected heat exchanger;
- with this new value of K_{SCH}, characteristic C_{IS} is replotted until value K_{SCH} is established.

The same method is used for each service point of the solar installation (hour-by-hour). The tests performed considering a unique characteristic C_{IS} (resulted from the dimensioning calculus) leads to rather correct results; therefore they may be considered to represent the solar installations behavior under actual dynamic conditions.

The possibility of plotting the thermal characteristic of a solar installation may be used not only in dimensioning and analyzing the behavior of a solar installation under dynamic service conditions, but also in qualitatively comparing the solar installations in terms of their thermal characteristics.

The passing from the thermal characteristic of the solar collectors to the thermal characteristic of the collection loop and ultimately to the thermal characteristic of the solar installation facilitates the quantitative analysis of the influence performed by each element of this transformation.

C. Rapid method used in determining the average thermal performances for a random service period of the solar installation

The average service point ($P.F.^m$) in terms of its three aspects is determined:

$P.F.^m_{I.S.}$ - average service point of solar installation

$P.F.^m_{C.P.}$ - average service point of the collection loop

$P.F.^m_{C}$ - average service point of solar collectors

representing a synthetic illustration of the solar installation for the whole service period. The climatic parameters considered in this situation will be the average values of solar radiation intensity and of outside temperature values for the respective period (I_m, te_m).

The method to be described below is entirely based on the ideas stated above so that no further explanation is necessary:

I. Point (1) where line $\eta_C = M \cdot \mathcal{E}_C$ crosses the solar collectors characteristic ($C_C = AB$) is determined, where

$$M = 2a \frac{1 - (1-c_T)(1-c_R)}{1 + (1-c_T)(1-c_R)}$$

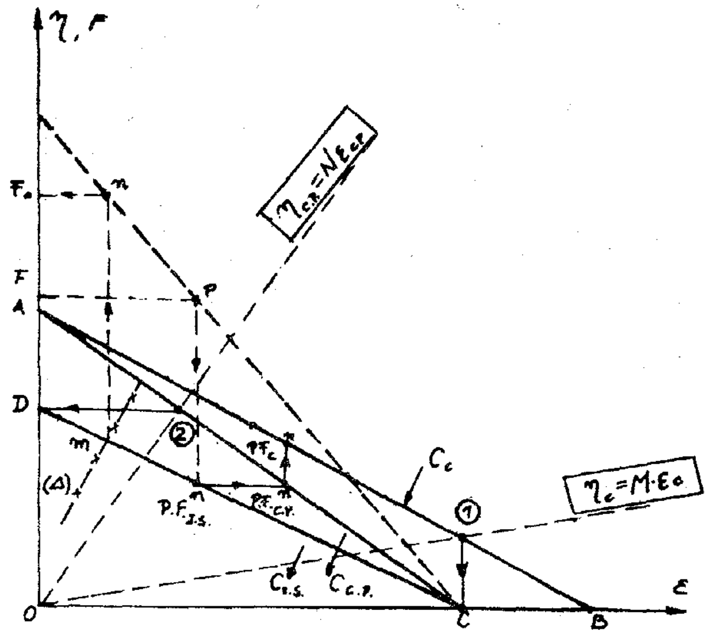


FIG.7

II. Point C is determined as being the perpendicular foot in point (1) on the abscissa. Line $\overline{AC}$ represents the collection loop characteristic (C_{CP}).

III. Point (2) where equation line $\eta_{CP} = N.\mathcal{E}_{CP}$ crosses the collection loop characteristic ($C_{CP} \equiv \overline{AC}^{CP}$) where:

$$N = 2.\ \frac{ab}{a-b}\ .\ \frac{V-1}{V+1} \qquad \text{if} \quad a \neq b \quad \text{and}$$

$$N = R \qquad \text{if} \quad a = b$$

IV. Point D is determined as being the perpendicular foot in point (2) on the ordinate. Line $\overline{DC}$ represents the solar installation characteristic (C_{IS}).

V. Point E on the ordinate is determined as follows:

$$OE = OD\ .\ \frac{1}{b}\ .\ \frac{Im}{t_c - t_o}$$

Line $\overline{EC}$ represents the dependence of the energy recovery rate (F) on the value of the abscissa ($\mathcal{E}$).

VI. Point m is determined where line (Δ) of equation

$$\eta_{IS} = 2\,b\,\left(\varepsilon_{IS} + \frac{tem - to}{I_m}\right)$$

crosses solar installation characteristic C_{IS} (line $\overline{DC}$).

VII. Point n is determined where the vertical through point m crosses the recovery rate line F (ε) (line $\overline{EC}$).

VIII. Value F corresponds to ordinate F_o of point n, according to Fig.8.

IX. Point p whose ordinate is F - value previously determined (see item VIII) - is determined on line $\overline{EC}$ of recovery rate (F).

X. Point PF^m_{IS} is determined where the vertical through point p crosses the solar installation characteristic (C_{IS} (line).

XI. Point $P.F.^m_{C.P}$ (ε^m_{CP}, η^m_{CP}) is obtained where the horizontal through-point $P.F.^m_{IS}$ (ε^m_{IS}, η^m_{IS}) crosses characteristic C_{CP} (line $\overline{AC}$); point $P.F.^m_c$ (ε^m_c, η^m_c) is obtained where the vertical through-point $P.F.^m_{CP}$ (ε^m_{CP}, η^m_{CP}) crosses the collector characteristic C_c (line $\overline{AB}$).

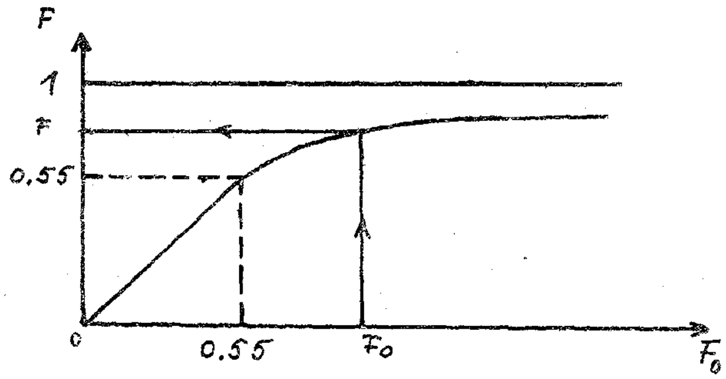


FIG.8

XII. In the case of this triple average service point (PF^m), the temperature values in different parts of the solar installation are calculated using the following relations:

$$\begin{cases} t_{TS}^{m} = \left(\mathcal{E}_{IS}^{m} + \frac{0{,}5}{b}\, \eta_{IS}^{m}\right) I_m + t_{em} \\ t_{RS}^{m} = \left(\mathcal{E}_{IS}^{m} - \frac{0{,}5}{b}\, \eta_{IS}^{m}\right) I_m + t_{em} \end{cases}$$

$$\begin{cases} t_{TP}^{m} = \left(\mathcal{E}_{cP}^{m} + \frac{0{,}5}{a}\, \eta_{cP}^{m}\right) I_m + t_{em} \\ t_{RP}^{m} = \left(\mathcal{E}_{cP}^{m} - \frac{0{,}5}{a}\, \eta_{cP}^{m}\right) I_m + t_{em} \end{cases}$$

$$\begin{cases} t_{TP}'^{m} = \left(\mathcal{E}_{c}^{m} + \frac{0{,}5}{a}\, \eta_{c}^{m}\right) I_m + t_{em} \\ t_{RP}'^{m} = \left(\mathcal{E}_{c}^{m} - \frac{0{,}5}{a}\, \eta_{c}^{m}\right) I_m + t_{em} \end{cases}$$

S Y M B O L S

t_o	- cold water temperature	$/^oC/$
t_{TP}	- primary heat carrier temperature	$/^oC/$
t'_{RP}	- primary heat carrier temperature when admitted in solar collectors	$/^oC/$
t_{TP}	- primary heat carrier temperature when admitted in heat exchanger	$/^oC/$
t_{RP}	- primary heat carrier temperature when exhausted from heat exchanger	$/^oC/$
t_{TS}	- secondary heat carrier temperature when exhausted from heat exchanger	$/^oC/$
t_{RS}	- secondary heat carrier temperature when admitted in heat exchanger	$/^oC/$
t_B	- water temperature in storage tank lower sheet	$/^oC/$
t_c	- warm water temperature required by consumer	$/^oC/$
t_e	- outside temperature	$/^oC/$
I	- overall solar radiation intensity	$/kcal/m^2h/$
c_T	- heat insulation degree of collection loop pipes from solar collectors to heat exchanger	

B I B L I O G R A P H Y

1. x x x - Analysis of behaviour under dynamic service conditions of solar installations for preparing warm water. INCERC (1986)

2. x x x - Design technical instructions for solar installations used in warm water preparation. INCERC (1981)

III.15 THERMAL PROCESSES SPECIFIC TO UNITS OF SHORT-TERM HEAT STORAGE IN PHASE-CHANGE SUBSTANCES (PCHSU) x)

Dan Constantinescu xx)

Anca Paponi xxx)

Florin Iordache xxxx)

The advantage of using phase change substances as a heat storage medium in passive and active solar installations is a reduced volume of the heat storage unit. When Glaüber salt is used to heat water at solar installations, the volume is reduced by about 60%, and if the salt is used to heat air, the volume is reduced by about 90%/1/.

The use of maleic anhydride as a heat storage medium specific to passive collecting walls leads to considerable reduction in wall dimensions and further to the simplification of building structure. Both substances were studied theoretically and experimentally in terms of thermal behavior . Calculus relations were drawn up according to the storage tank geometry; they may be used in determining the tank thermal loading/unloading time.

Numerical solutions to the Stephan problem /2/ as well as several approximate analytical solutions /3/, /4/ are known. All the solutions mentioned above refer to the problem in terms of Dirichlet or Neumann boundary conditions. In paper /5/ the Stephan problem was dealt with in terms of IIIrd type boundary conditions but with a constant heat carrier temperature. In active installations, the heat carrier circulates among the storage unit components and therefore its temperature changes between the inlet and outlet section. In this case the Stephan problem is completed with the energy equation written for the heat carrier /6/.

Our paper introduces the modelling of the heat transfer phenomenon specific to spherical and cylindrical geometry, both

---

x) PCHSU - phase change heat storage unit

xx) Senior Research Officer, INCERC

xxx) Mathematician, INCERC

xxxx) Research Officer, INCERC, Bucharest, Romania

for variable and constant temperature of the heat carrier. The calculus method is a variant of the perturbed parameter method and the final solution, which is analytical, is represented by the zero degree approximation sufficient for all engineering calculuses. The solution may be particularized for Dirichlet or Neumann boundary conditions. The analytical solution was controlled by the numerical solution worked out at INCERC /5/ and the resulting deviation of 1.5% proves the former valid.

Laboratory measurements were also performed in order to control the dimensioning method suggested. Glauber salt and maleic anhydride were used (Annex I) because their thermophysical characteristics had been tested at ICECHIM - Physical Chemistry Center. As the Glauber salt has to be prepared as a substance, additives were added to the active substance; this generates the decrease of the phase change latent heat from about 240 kJ/kg to about 220 kJ/kg. The Glauber salt is introduced in polyethylene spheres and the maleic anhydride in polypropylene cylinders.

1. Mathematical model specific to spherical PCHSU

The general model refers to a cylindrical PCHSU containing spheres filled with a phase change substance. The heat carrier circulates in the interspace between the spheres. The problem is formed of the Stephan problem associated with the energy equation for a heat carrier as well as IIIrd type boundary conditions for a heat carrier and Dirichlet boundary conditions for the position of the phase change front. The solution is based on the following approximations:

- the energy equation is represented by the integral equation of the boundary thermal level;
- the heat carrier heat balance does not consider the heat storage in the fluid mass;
- the solution of the conductive transfer parabolic equation has the from of a zero degree approximation;
- the phase change substance initial temperature is equal to the phase change temperature (inside energy variation is not taken into account);
- the value of the convective heat exchange coefficient does not vary with temperature;
- the thermophysical characteristics of the heat carrier and of the heat storing substance do not vary with temperature;
- the thermal processes inside the phase change substances are purely conductive.

The calculus scheme is presented in fig.1.

The energy equation is given by relation

$$\frac{\partial t}{\partial x} + \frac{\alpha S_{scH}}{I\, G_{sp}} \left(t - \theta\big|_{r=R} \right) = 0 \tag{1}$$

The associated boundary condition is

$$t\Big|_{x=0} = t_0 \tag{2}$$

The equation of the conductive heat transfer in phase change substances is

$$\frac{\partial \theta}{\partial \tau} = a_L \frac{1}{r} \cdot \frac{\partial^2 (r\theta)}{\partial r^2} \tag{3}$$

with the following boundary conditions:

$$\alpha \left(t - \theta\big|_{r=R} \right) = \lambda \frac{\partial \theta}{\partial r}\Big|_{r=R} \tag{4}$$

$$\theta\,(r=z, \tau) = t_F \tag{5}$$

The equation of the phase change front position variation is

$$\frac{dz}{d\tau} = - \frac{\lambda_L}{\rho_L L} \cdot \frac{\partial \theta}{\partial r}\Big|_{r=R} \tag{6}$$

with the following initial condition:

$$z\ (\tau = 0) = R \tag{7}$$

If dimensionless parameters are used:

$$\Theta = \frac{t-\theta}{t_0 - t_F}\ ;\quad T = \frac{t - t_F}{t_0 - t_F}\ ;\quad \beta_L = \frac{c_{pL}}{L}(t_0 - t_F)\ ;\quad \dot{r} = \frac{r}{R}$$

$$\dot{z} = \frac{z}{R}\ ;\quad \dot{x} = \frac{x}{R}\ ;\quad Bi_F = \frac{\alpha R}{\lambda_L}\ ;\quad Fo_F = \frac{a_L \tau}{R^2}\beta_L$$

equations (3) - (7) are written dimensionlessly: /6/

$$\beta_L \frac{\partial \Theta}{\partial \dot{z}} \cdot \frac{\partial \Theta}{\partial \dot{r}}\Big|_{\dot{r}=\dot{z}} = \frac{1}{\dot{r}} \cdot \frac{\partial^2 (\dot{r}\Theta)}{\partial \dot{r}^2} \tag{8}$$

$$Bi_F\, \Theta\Big|_{\dot{r}=1} + \frac{\partial \Theta}{\partial \dot{r}}\Big|_{\dot{r}=1} = 0 \tag{9}$$

$$\Theta\,(\dot{z}, Fo_F) = T \tag{10}$$

$$\frac{\partial T}{\partial \dot{x}} + A\Theta\Big|_{\dot{r}=1} = 0 \quad ; \quad A = \frac{\alpha\, S_{scH}}{G_{sp}} \tag{11}$$

$$T(\dot{x} = 1) = 1 \tag{12}$$

$$\frac{d\dot{z}}{dF_{oF}} = \frac{\partial \Theta}{\partial \dot{r}}\Big|_{\dot{r}=\dot{z}} \tag{13}$$

$$\dot{z}\left(F_{oF} = 0\right) = 1 \tag{14}$$

A solution of the form (15) is used in integrating equat - ion (8):

$$\Theta = \sum_{j=0}^{n} \beta_L^{j}\, \Theta_j \tag{15}$$

The zero degree solution, Θ_0 is obtained by identifying the zero powers of parameter β_L. The result is

$$\Theta_0 = \frac{\frac{1}{\dot{r}} - M}{\frac{1}{\dot{z}} - M} \cdot T \quad ; \quad M = \frac{1 - Bi_F}{Bi_F} \tag{16}$$

For $\dot{r} = 0$, $\Theta_0 = \infty$ so the solution is divergent. In order to avoid this mathematical disadvantage, new variables are suggested:

$$\dot{r} = u + \sum_{j=1}^{n} \beta_L^{j}\, \varphi_j(u,v) \tag{17}$$

$$\dot{z} = v + \sum_{j=1}^{n} \beta_L^{j}\, \varphi_j(v,v) \tag{18}$$

In order to observe values $\dot{r} = 1$, $\dot{z} = 1$, condition (19) is imposed:

$$\varphi_j\,(1,\, v) = \varphi_j\,(1,\, 1) = 0 \tag{19}$$

The zero degree solution in terms of the new variables u and v is

$$\Theta_0 = \frac{\frac{1}{u} - M}{\frac{1}{v} - M} \cdot T \tag{20}$$

By determining the one powers of coefficients β_L, the dif ferential equation of solution Θ_1 is obtained. Considering con dition $\Theta_1 \equiv 0$, the equation becomes an equation for obtaining function φ_1 (u,v):

$$u\frac{\partial \Theta}{\partial v}\cdot\frac{\partial \Theta}{\partial u}\Big|_{u=v} = \frac{\partial^2}{\partial u^2}\left(\varphi_1\Theta_0 - \frac{M}{M+\frac{1}{v}}\varphi_1\right) \qquad (21)$$

Taking into account solution (20) and condition (19)associated with the boundary condition (9) written for degree one approximation, (22) is obtained:

$$\varphi_1(u,v) = -(1-u)^2 u\ \frac{3(M+1)-M(1-u)}{6v^2(1-Mv)^2}\cdot T \qquad (22)$$

If solution Θ is limited to function Θ_0 and variables r, z to the zero degree development of parameter β_L, value V_0 for which Z = 0 may be determined using the following equation:

$$V_0 + \beta_L\varphi_1(V_0,V_0) = 0$$

or (23)

$$\beta_L(1-V_0)^2\ \frac{3(1+M)-M(1-V_0)}{6V_0^2(1+MV_0)^2}\ T = 1$$

Equation (11) for the heat carrier is written as

$$\frac{\partial T}{\partial x} + A(1+M)\frac{V(T,F_{oF})}{1+MV(T,F_{oF})}\ T = 0 \qquad (24)$$

The equation for phase change front position variation(13) is used in determining function $F_{OF} = f(v,T)$.

$$F_{oF} \cong \left[0.50 + 0.33M - V^2(0.50 + 0.33\,Mv)\right]\cdot\frac{1}{T} \qquad (25)$$

Relation (25) is used in determining function $V(T, F_{OF})$ which is included in equation (24). A differential equation is thus obtained whose solution is function $T(\dot{x},F_{OF})$.

Considering again solution $\varphi_1(u,v)$, its expression for the case of Dirichlet boundary condition (sphere wall constant temperature) may be determined. The condition results from the physical phenomenon attesting the equality between fluid temperature and wall temperature, the value being t_o. In these conditions $Bi_F = \infty$, therefore M = -1 and T = 1.

The result is

$$\varphi_1(u,v) = -\frac{(1-u)^3 u}{6v^2(1-v)}$$

and the relation used in determining value v_o:

$$V_o = 0.0834 \left(\sqrt{\beta_L^2 + 24\beta_L} - \beta_L \right)$$

The solution of equation (24) provides the air temperature value when exhausted from PCHSU:

$$T = T\ (\dot{x}=1,\ F_{oF}) \qquad (26)$$

Relation (25) where $V = V_o(T)$ (23) may be used in determining function $T = T(F_{oF})$ for which the phase change process is over. The temperature mean value in time of the air when exhausted from PCHSU must be equal to the one previously calculated, so as to consider the thermal loading/unloading process over Equation (27) is therefore generated:

$$\overline{T}(\dot{x}=1,\ F_{oF}) = T(F_{oF}) \qquad (27)$$

providing value F_{oF} and consequently the moment when the thermal loading/unloading process is over.

Values α and A are determined by relations

$$\alpha = 0.266\ (G_V/S)^{0.70} \qquad /7/$$
$$G_V/S \simeq C_1\ B_{iF}^{1.4285714}$$

C_1 = 791.05 - thermal loading

C_1 = 837.57 - thermal unloading

$$A = 4.429 \cdot 10^{-5}\ \frac{Q_{UTIL} / \bar{S}^{x)}}{B_{iF}^{0.4285714}}$$

The calculus example represents one of the experiments performed on a thermal load module Q_{UTIL} = 122.400 kJ. The fluid initial temperature is t_o = 45°C and S = 1.00 m^2, Bi_F = 2.00 Heat carrier temperature distribution along the PCHSU is presented in fig.2. The temperature variation of air when exhausted from the PCHSU is presented in fig.3. Finally, equation (27) is presented in fig.4 as the intersection of the two curves; the result proves that the substance stored the whole heat quantity after 6.10 h. The heat balance is controlled by recording the heat quantity delivered by air to the phase change substance:

$$Q = 6.10\ .\ 2{,}130\ .\ 1.296\ (45 - 37.70) = 122{,}905\ kJ$$

The calculus model described above may be used in dimensioning the heat storage units containing phase change substances

x) $\bar{S} = \pi D^2 / 4$ and $D > 20d$ /8/

in spherical modules.

II. Mathematical model specific to cylindrical PCHSU

The heat balance equations are practically the same as in the case of spherical geometry; the only difference occurs in the conduction equation written in cylindrical coordinates. The boundary condition is of Dirichlet type, therefore $Bi_F \to \infty$. Function (28) is obtained:

$$\varphi_1(u,v) = \frac{u^3(\ln u - 1) + u(\ln u - 1)}{4v^2 \ln^2 v} \tag{28}$$

The equation used in determining value v_o is given by relation

$$v_o + \beta_F \varphi_1(v_o, v_o) = 0$$

and value F_{oF} for which the phase change process is over is given by relation

$$F_{oF} \cong 0.465\left[v_o^2 \ln v_o + 0.50(1 - v_o^2)\right] \tag{29}$$

Fig.5 and 6 present the variation in time of the phase changefront position at thermal loading and unloading respectively for various values $\Delta t = t_o - t_F$. The cylinder under study has a 0.034 m diameter and contains maleic anhydride. Thermal loading is performed for $Bi_F = \infty$ and unloading for $Bi_F > 0$. Coefficient α_F has the value 12.10 W/m^2K.

III. Experiments on the passive heating system using storage in cylinders with maleic anhydride

The experimental system works in a solar cabin supplied with direct gain solar heating system. On the South façade the cabin has a triple-glazed window covering an area of 10 m^2 and with a specific heating volume of 3.4 m^3/m^2. 4m^2 of the window area is covered by solar collectors storing maleic anhydride.

The collectors are panels with reversible thermal behavior. The active area made of 90 cylindrical tubes filled with maleic anhydride collects and stores heat in the sunny hours; the storage capacity is of 21,000 kJ. In the sunless hours, the collectors exhaust heat to the dwelling space; the heat losses to outside are extremely low ($K_p \simeq 0.3$ W/m^2K) tanks to the collector heat insulation.

The experiments performed on the cabin were designed to determine the solar collector characteristic curve, which is presented in fig.7 with the collecting efficiency on the ordinate and a coefficient whose measurement unit is that of a thermal resistor on the abscissa:

$$\mathcal{E} = t_i - t_e/I$$

values t_i, t_e, I are daily mean values for sunny hours.

The melting and solidification time of the maleic anhydride were also determined by measuring the temperature values on the cylinder surface. The determinations agree with the calculated values and observe the values plotted in fig.5 and 6. The measurements and the calculuses coincide for low diameter horizontal cylinders. The measurements performed on 0.10 m diameter vertical cylinders prove the occurrence of strong convection currents in the liquid substance. The substance melting time obtained experimentally is about three times shorter thanks to natural convection as the process is not conductive.

IV. Conclusions

1. This study presents the mathematical modelling of the phase change thermal processes in spherical and cylindrical storage units.

2. The calculus relations may be used in dimensioning a PCHSU according to the temperature of the heat carrier circulated through the solar collector.

3. The measurements performed on the solar cabin attest the storage capacity of the maleic anhydride as storage element in a passive heating system.

Glauber Salt thermo-physical properties:

	Liquid	Solid
ρ	- 1,460 kg/m^3	1,460 kg/m^3
λ	- 0.57 w/mK	0.47 w/mK
C_p	- 1.74 kj/kgK	0.96 kj/kgK
L	- 250.8 kj/kg	250.8 kj/kg
t_F	- 32 ^oC	32 ^oC

NOMENCLATURE

t	- heat carrier temperature	/°C/
θ	- storage medium temperature	/°C/
S_{SCH}	- heat exchange surface	/m^2/
$\bar{L}$	- storage unit length	/m/
G	- heat carrier mass flow-rate	/kg/h/
R	- sphere radius	/m/
Z	- phase change front position	/m/
t_F	- phase change temperature	/°C/
L	- latent heat	/kJ/kg/
Bi	- Biot dimensionless number	
Fo	- Fourier dimensionless number	
β	- Stephan dimensionless number	

REFERENCES

/1/ Constantinescu, Dan - Mathematical Models Used in Dimensioning Solar Installations PCHSU Sinaia Conference, 1983, vol.I

/2/ Tao, L.C. - Generalized Numerical Solutions of Freezing a Saturated Liquid in Cylinders and Spheres, - A.I.Ch.E.J./13-1967

/3/ Kern, J. - A Simple and Apparently Safe Solution to the Generalized Stephan Problem, Int.J.Heat and Mass Transfer vol.20, 1977

/4/ Pedroso, R.I., - Inward Spherical Solidification, Int.J.Heat and Mass Transfer, vol.16, 1973

/5/ x x x - Heat Storage in Systems of Using Solar Energy in Building, Contr. 30/1981, 1982, 1983 INCERC

/6/ Constantinescu, Dan - Mathematical Model for Phase Change Processes - Spherical Geometry, "Installations", 3/1984

/7/ x x x - Rockbed Heat Storage, Contr. INCERC 552/1979

/8/ Mihăilă, C. Caluianu, V. Marinescu, M. Dănescu, Al. - Industrial Drying Processes and Installations, Ed.Tehnică, Bucureşti, 1982

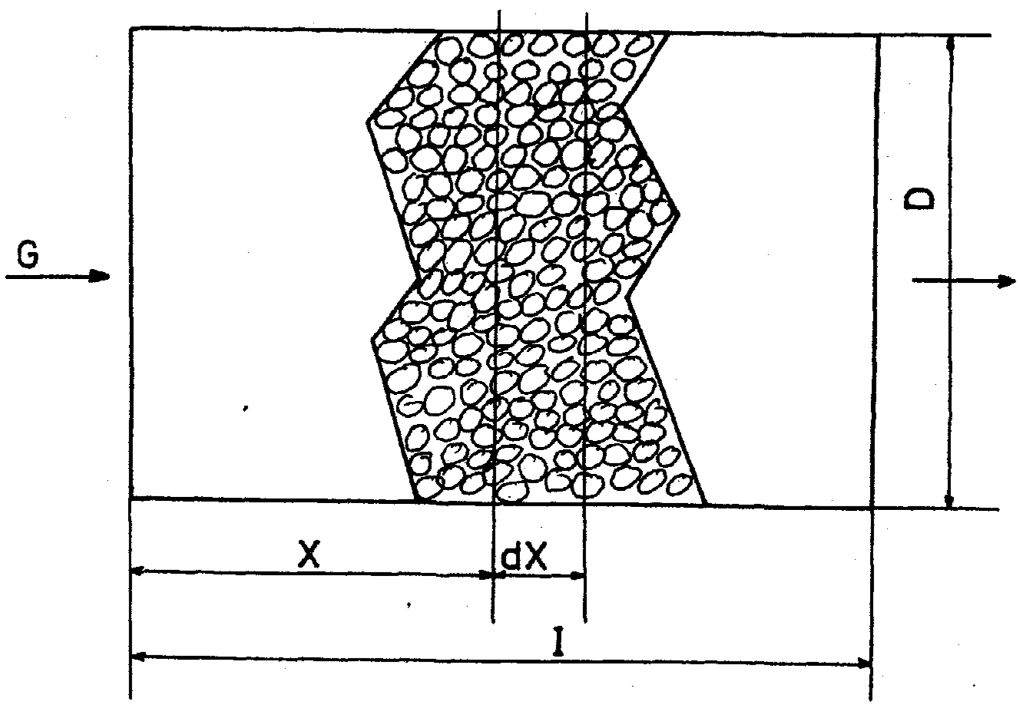


FIG.1 Calculation scheme for spherical geometry

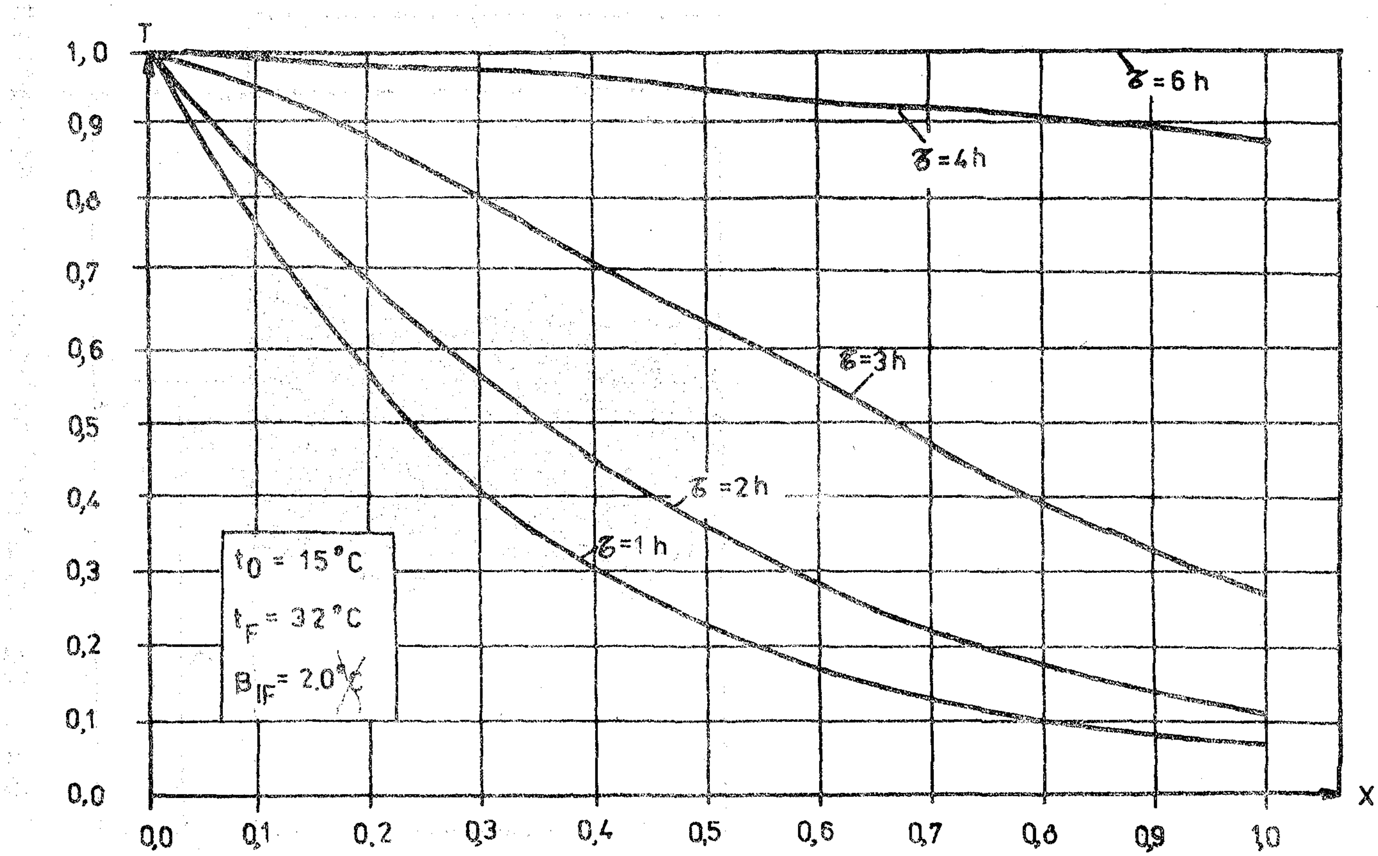


FIG. 2 Heat carrier space variation

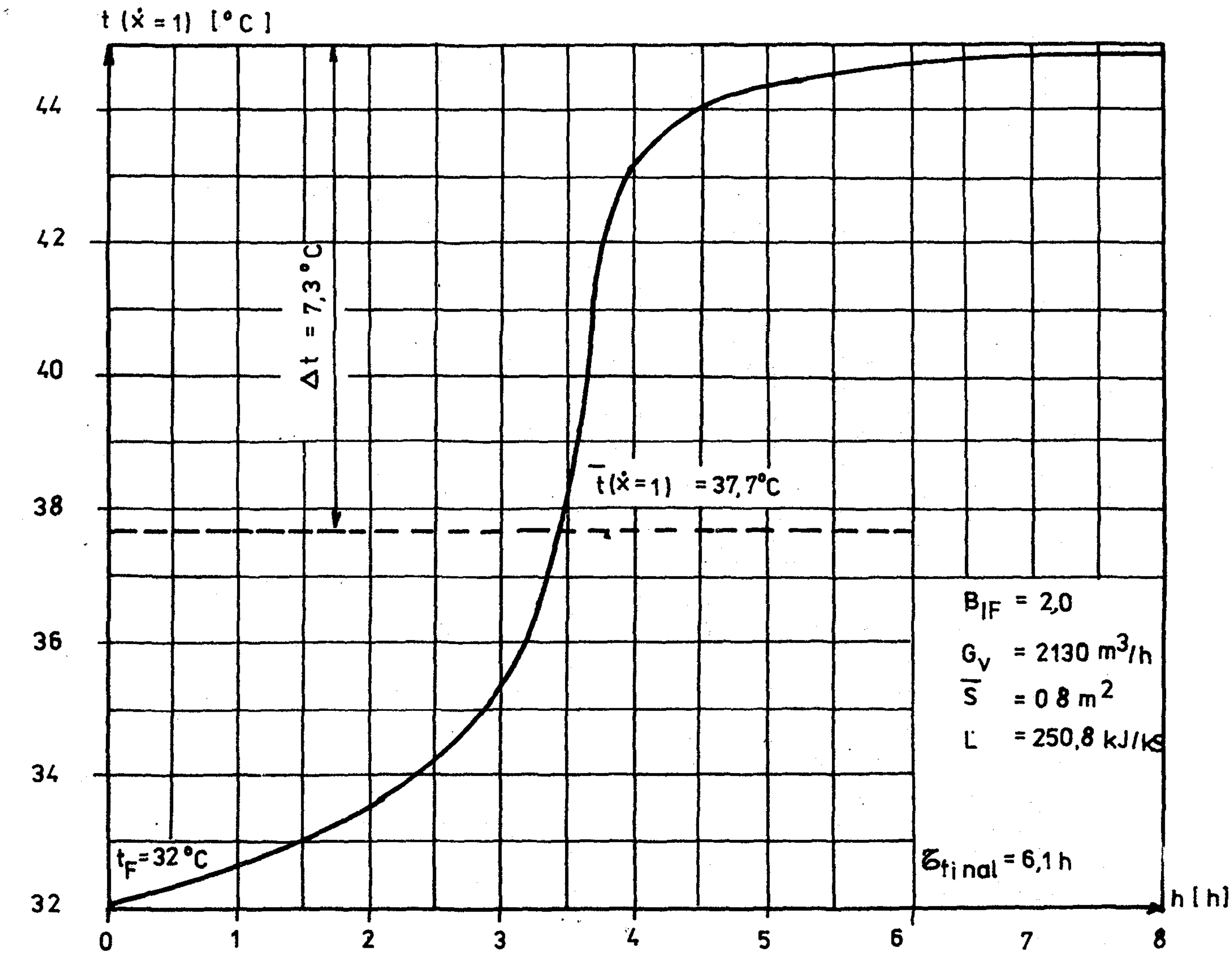


FIG.3 Oulet air temperature time variation

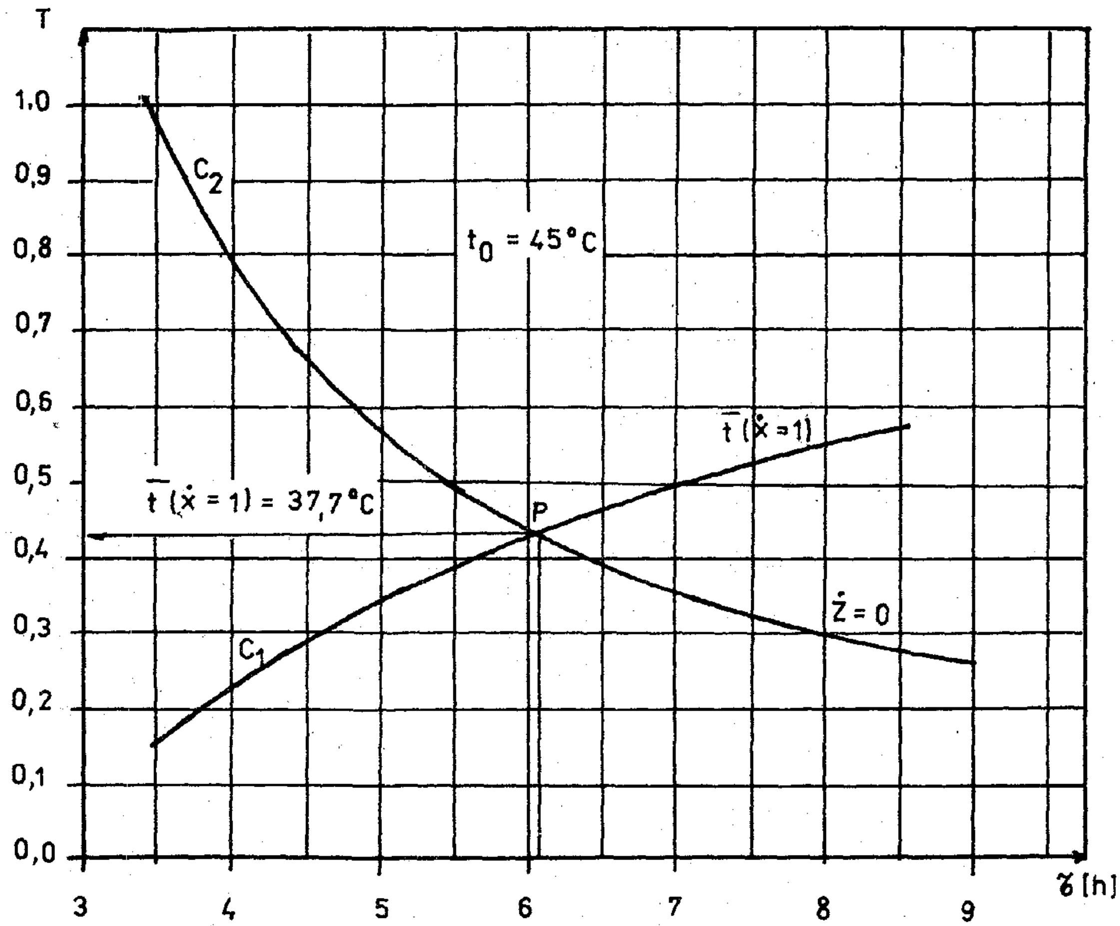


FIG.4 Melting time determination

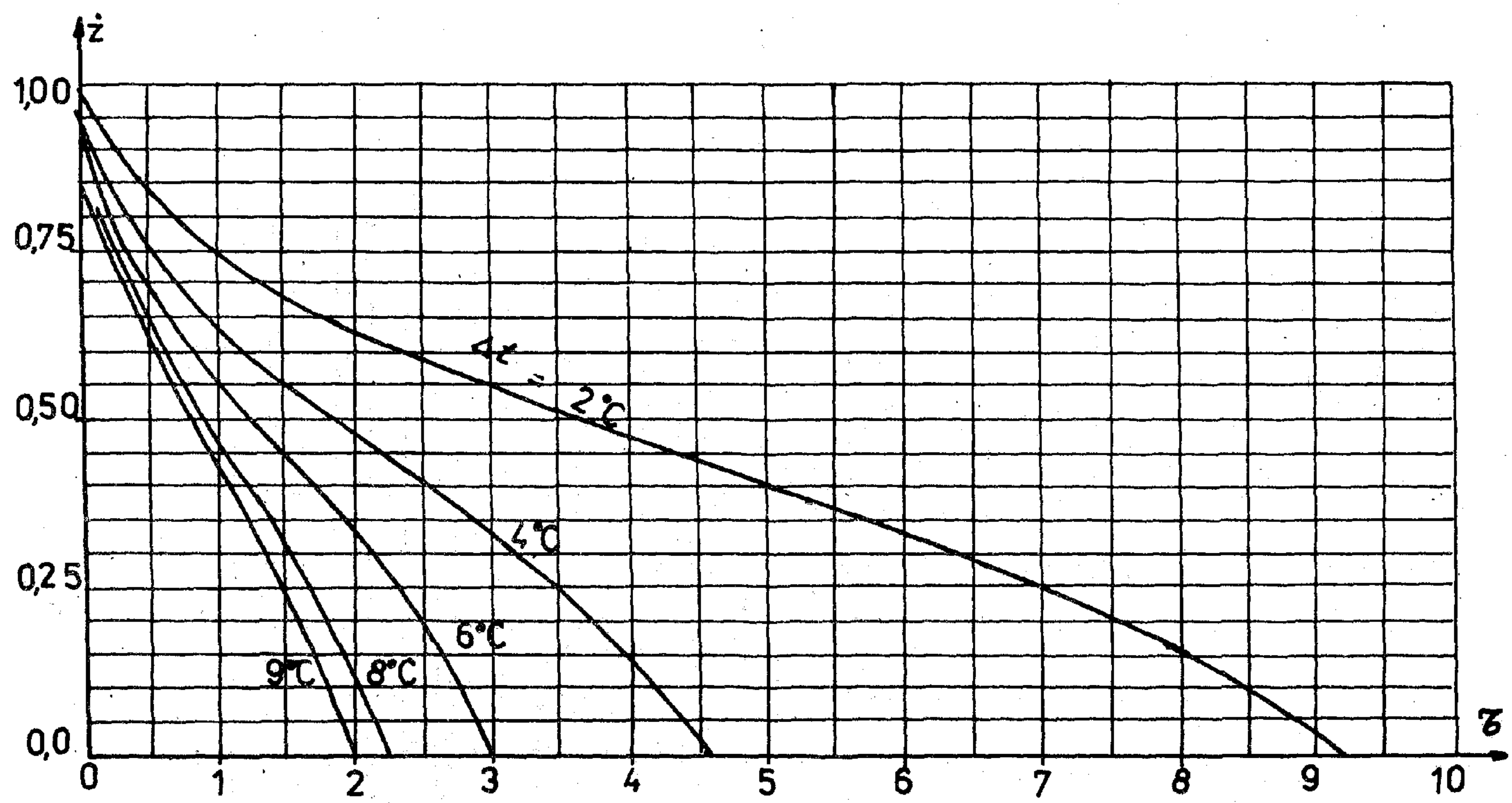


FIG.5 Phase change front position-loading period

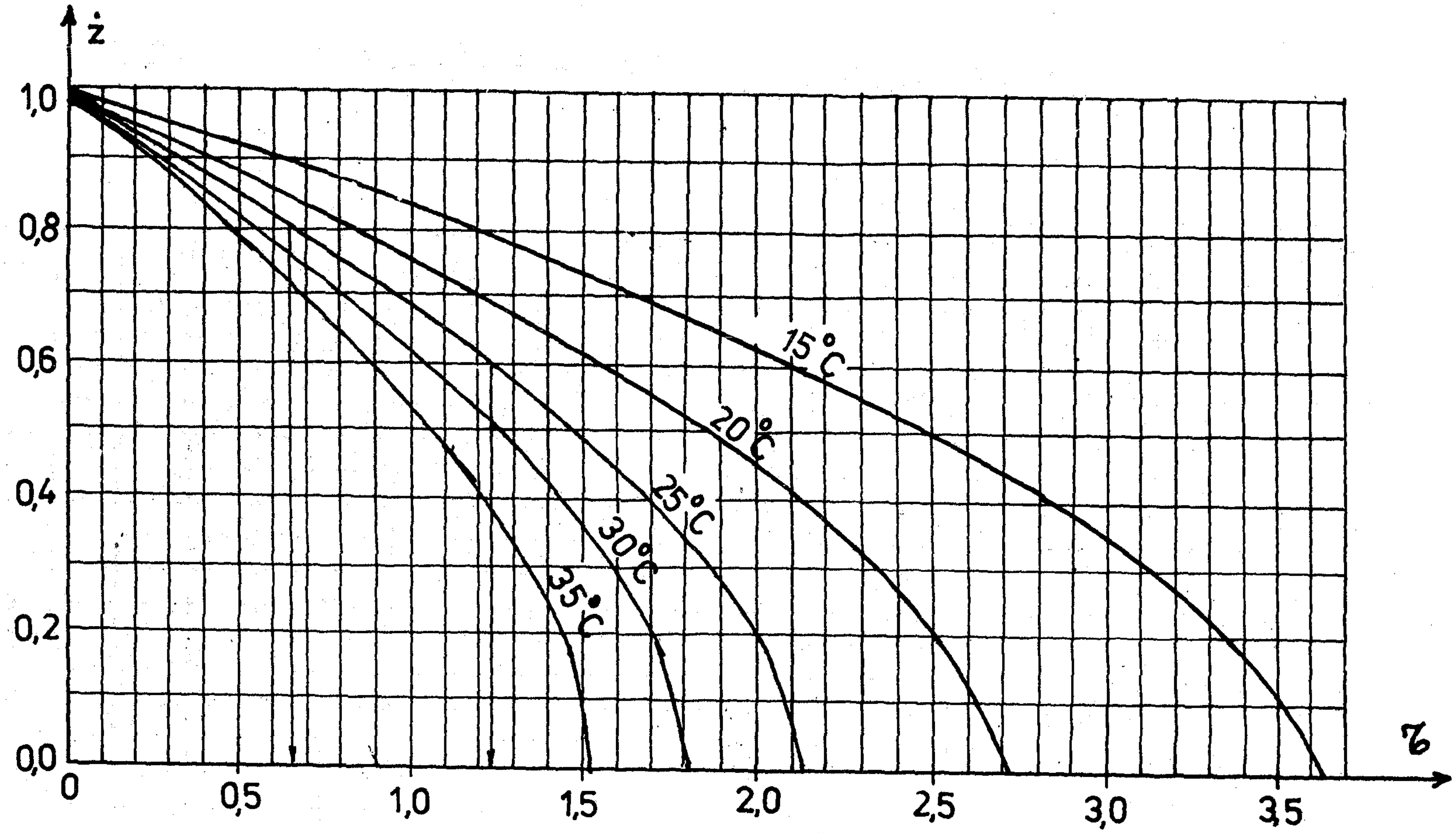


FIG.6 Phase change front position unloading period

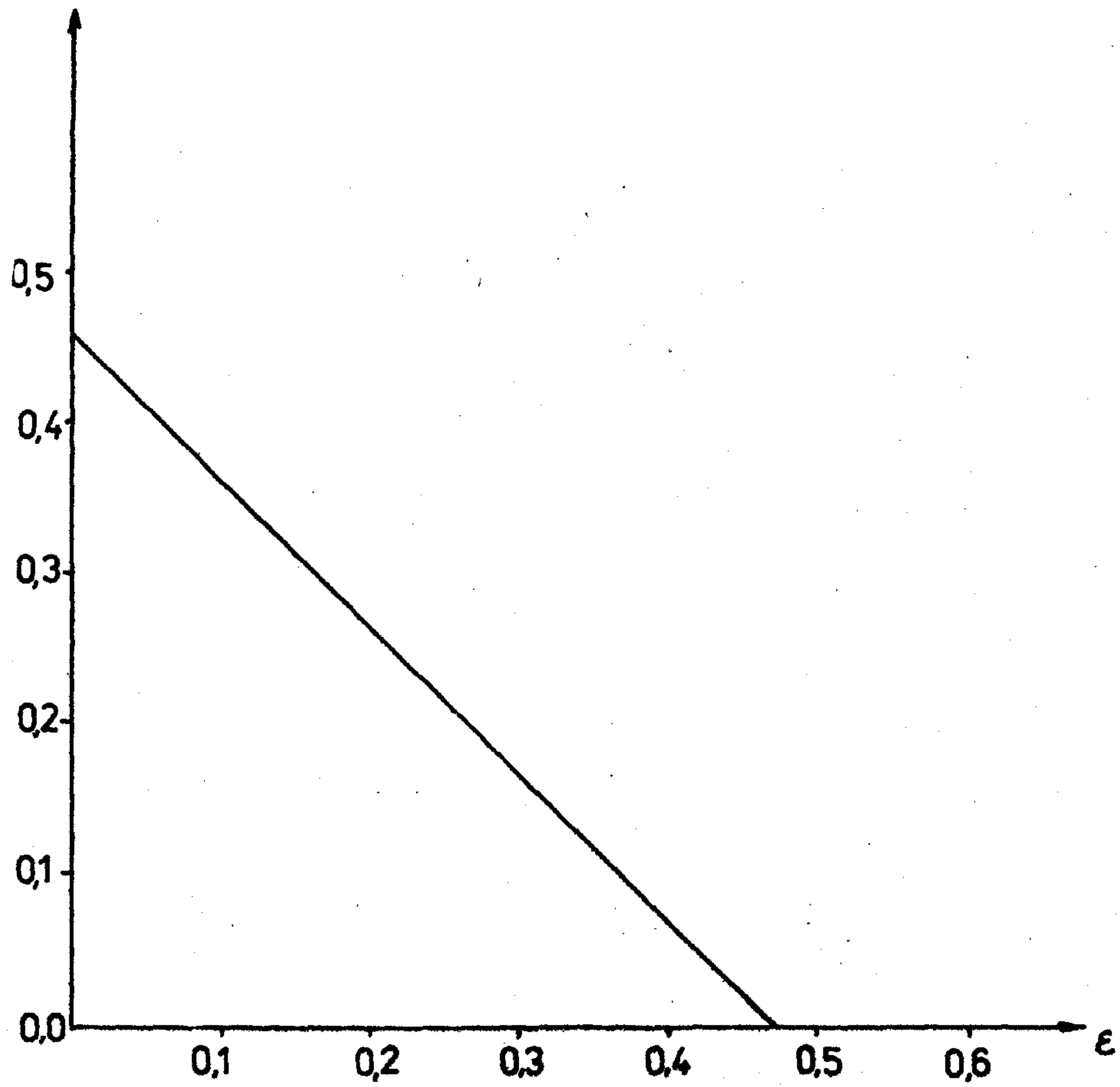


FIG 7 Thermal characteristic of the phase change pasive collector

III.16 ANALYSIS OF HEAT STORAGE IN EARTHEN TYPE SENSIBLE MEDIA - PLANE WAVE HEAT TRANSFER MODELLING

Dan Constantinescu x)

The fluctuation of the processes involved in heat production or/and consumption requires in many technological solutions the endowment of heat producing installations with heat storage units. In the warm period of the year, mainly in case of technological installations producing flue gases, a considerable heat quantity is lost; its exergy level is proper for space heating or/and warm water producing processes. Space heating in cold season requires long-time (summer - winter) heat storage. The use of water tanks as a heat storage medium involves expensive arrangements as well as ground areas whose subsequent use is seriously limited. Heat storage in latent media is not economical at all; besides the economic limitations , technical limitations are caused by substance instability as well as by rather sophisticated substance containerizing technologies. One of the solutions that may be applied consists of using soil as heat storage medium. Heat storage is based on the modification of medium inside energy; therefore this idea is sensible.

Dimensioning of soil seasonal heat storage units is one of the problems presently under study in Romania and all over the world. The study of thermal loading and unloading processes requires both the analysis of heat emission and taking over by the heat carrier and thermal wave propagation in soil during the loading and unloading period respectively. The process is unsteady; dimensioning consists of selecting the heat storage unit dimensions so as to meet the exergy level required by heat consumption by the unit loading in a pre-established period. Considering the difficulties by transfer, simplifying hypotheses leading to the solution of traditional problems of heat equation integration were used. One of them is to adopt the Dirichlet boundary condition on the heat carrier part (1). This condition may obviously be useful in the case of turbulent heat exchange from the heat carrier but it is not observed when flow is laminar, at least in the first loading period. An approximate solution of analytical integration of conductivity equation by segmenting the storage unit low capacity storage units was suggested; successive heat transfer is written under steady-state conditions (2). In this solution, the imposed boundary conditions are also Neumann or Dirichlet.

x) Building Research Institute - INCERC, Bucharest, Romania

It is important to determine the heat storage unit efficiency, that is, its value depending on the heat insulation rate-namely, on the heat losses of heated soil towards outside and ground water layers. This problem is more important in the case of using the heat generated by solar collectors as the exergy level specific to the source is rather low. Theoretical studies were performed considering either steady-state heat transfer or the semi-infinite medium as a heat dissipating element /1/. Numerical methods are of course the most adequate but they require considerable time and special work techniques in determining eigenvalues.

Considering the purely technical aspects of soil heat storage, we note that previous studies known to the author are focused on vertical drillings with heat sources from where the thermal wave propagates as concentric cylinders to the extremities or the storage units. In this case practical heat storage requires a sophisticated line of pipes for supplying each vertical drilling. Direct use of flue gases as a heat source is impossible, as the diameter of air ducts is considerable and aeraulic unbalancing of pipe lines occurs. The use of water as a heat carrier is therefore required with the following obvious limitations:

- temperature level up to 95°C;
- gas-water type intermediate heat transfer;
- danger of freezing in the cold season.

The use of compact technical solutions such as parallel-plane excavations leads to a shortening of pipelines and makes possible the direct use of flue gases as a heat carrier. Certain technological complications occur in each case because of the requirement to avoid condense (highly corrosive) but this paper is not focused on the solutions of these problems.

II. Description of the suggested system

Fig. 1 presents the scheme of the heat storage system in soil with thermal excitation of a plane wave type. In the thermal loading phase, the heat carrier is admitted on the exterior line (E) for heat emission and then circulated on the interior line (I); it returns afterwards to the heat source. The lines forming the heat source work in parallel generating a plane thermal wave propagating in the soil mass. It is recommended that on a D distance between the soil surface and the storage heat carrier, circulation pipes should not be placed, as this D-thick soil mass is a considerable thermal barrier. Because of this technical detail the mathematical model was thus conceived that the soil surface heat losses are null.

In the thermal unloading period the heat carrier circulates on reversed lines so as to have thermal contact with the soil wall supplying heat.

III. Presentation of mathematical model

This paper adopted an analytical solution to the problem of heat transfer from heat carrier to soil. The heat balance equations describe fluid temperature variations on the flow line and soil temperature variation according to the heat flow transmitted by the fluid. The heat losses of the active soil mass towards the outside or towards the neighboring layers were not considered in this phase of the mathematical modelling. Soil was considered an isotropic medium and the physical characteristics invariant as against temperature. The same was considered for the heat carrier. Further on, heat storage in fluid was not considered for the heat carrier, as its thermal capacity may be ignored when compared to soil (during the seasonal storage unit service). The heat balance equation for the heat carrier represents an approximation of the energy equation and was called by the authors overall heat transfer equation. By its general character the equation is not different from its form both when laminar flow and turbulent flow are analyzed. The effects of the two types of flow may be differentiated by specifying the α_F surface heat transfer coefficients determined by the traditional criterial equations specific to forced flow. As soil losses are ignored the Fourier equation considered only cross thermal gradient, the longitudinal one being the consequence of heat carrier temperature variation along the flow line. Heat exchange between (E) and (I) lines was not considered as the heat carrier inlet is at the top and its outlet at the bottom and this is the only zone subjected to inside energy modifications because of the contact with soil.

The calculus scheme is presented in fig.2. The balance equations are the following:

- for heat carrier:

$$\frac{\partial t}{\partial y} + B(t - \theta|_{x=\Delta}) = 0 \tag{1}$$

$$t|_{y=0} = \varphi(\tau) \tag{2}$$

- for soil:

$$\frac{\partial \theta}{\partial \tau} = a_s \frac{\partial^2 \theta}{\partial x^2} \tag{3}$$

with boundary conditions:

$$\frac{\partial \theta}{\partial x}\Big|_{x=\Delta} = K(t - \theta|_{x=\Delta}) \tag{4}$$

$$\frac{\partial \theta}{\partial x}\Big|_{x=0} = 0 \tag{5}$$

and initial condition:

$$\theta|_{\tau=0} = t_0 \tag{6}$$

Using the new variables:

$$\Theta = u - R \; ; \quad u = \theta - t_0 \; ; \quad R = t - t_0$$

$$\dot{x} = \frac{x}{\Delta} \; ; \quad F_0 = \frac{a_s \tau}{\Delta^2} \; ; \quad \dot{y} = \frac{y}{L}$$

the following new equations are obtained:

$$\frac{\partial \Theta}{\partial F_o} + \frac{\partial R}{\partial F_o} = \frac{\partial^2 \Theta}{\partial \dot{x}^2} \tag{7}$$

$$\frac{\partial \Theta}{\partial \dot{x}}\Big|_{\dot{x}=1} + B_i \, \Theta\Big|_{\dot{x}=1} = 0 \tag{8}$$

$$\frac{\partial \Theta}{\partial \dot{x}}\Big|_{\dot{x}=0} = 0 \tag{9}$$

$$\Theta\Big|_{F_o=0} = -R(0) \tag{IO}$$

for soil, and:

$$\frac{\partial R}{\partial \dot{y}} - 2\frac{1}{\delta} S_t \, \Theta\Big|_{\dot{x}=1} = 0 \tag{11}$$

$$R\Big|_{\dot{y}=0} = f(F_o) \tag{12}$$

for heat carrier.

The solution suggested for Θ $(\dot{x}, F_o)$ variable is:

$$\Theta(\dot{x}, F_o) = \sum_j A_j(F_o) \; c\,s\,(m_j \dot{x}) \tag{13}$$

If it is included in equation (7) it generates an ordinary equation with variable coefficients:

$$\frac{d A_j(F_o)}{d F_o} + m_j^2 A_j(F_o) + \frac{\partial R}{\partial F_o} \cdot \frac{2 \sin m_j}{m_j + \sin m_j \cos m_j} = 0$$

with the following solution:

$$A_j(F_o) = \frac{2 \sin m_j}{m_j + \sin m_j \cos m_j}\left\{ R(0) \exp(-m_j^2 F_o) + \int_0^{F_o} \frac{\partial R}{\partial S} \exp\left[-m_j^2 (F_o - S)\right] ds \right\} \tag{14}$$

mj eigenvalues are determined by equation (15):

$$\frac{m_j}{B_i} = \operatorname{ctg} m_j \tag{15}$$

Temperature variation function Θ (x, F_o) results:

$$\Theta(x, F_o) = -2 \sum \frac{\sin m_j \cos(m_j x)}{m_j + \sin m_j \cos m_j} \left\{ R(0) \exp(-m_j^2 F_o) + \int_0^{F_o} \frac{\partial R}{\partial s} \exp\left[-m_j^2 (F_o - s)\right] ds \right\} \quad (16)$$

Considering again the energy equation for heat carrier (11) the result is:

$$\frac{\partial R}{\partial y} + \left(4 \frac{1}{\delta} S_t\right) \sum \frac{\sin m_j \cos m_j}{m_j + \sin m_j \cos m_j} \left\{ R(0) \exp(-m_j^2 F_o) + \int_0^{F_o} \frac{\partial R}{\partial s} \exp\left[-m_j^2 (F_o - s)\right] ds \right\} \quad (17)$$

A new time function is defined:

$$\psi(F_o) = \left(4 \frac{1}{\delta} S_t\right) \sum \frac{\sin m_j \cos m_j}{m_j + \sin m_j \cos m_j} \exp(-m_j^2 F_o)$$

Equation (17) is reformulated:

$$\frac{\partial R}{\partial y} + \left\{ R(0) \psi(F_o) + \int_0^{F_o} \frac{\partial R}{\partial s} \psi(F_o - s) ds \right\} \quad (18)$$

The operational solution of equation (17) is given by relation (19):

$$\bar{R}(p, y) = \varphi(p) \exp\left[-p \bar{\psi}(p) y\right] \quad (19)$$

For the numerical example, the following dimensions of the soil heat storage unit are considered:

$L = 10.00\,m$; $\Delta = 0.50\,m$; $\delta = 0.05\,m$; $l = 10.00\,m$

The flow-rate values of the heat carrier (air) circulated through the air ducts are two:

$G_1 = 700$ kg/h ; $G_2 = 10{,}000$ kg/h

The two values correspond to laminar (G_1) and respectively to turbulent (G_2) flow through the air duct.

For the laminar flow the conditions are determined by value $Nu = 4.13 . \alpha_F \simeq 1.16$ W/m^{2}K results. Function $\psi(Fo)$ has the following form:

$$\psi(F_o) \simeq 0.9995\, exp(-0.362 F_o) + 0.0818\, exp(-10.68 F_o) + 0.0226\, exp(-40.31 F_o)$$

For values $F_o > 0.10$ expression $\psi(F_o)$ is reduced to the first term namely:

$$\psi(F_o) \simeq exp(-0.362\, F_o) \tag{20}$$

Value $F_o = 0.10$ corresponds to about 7.50 h which in a seasonal heat storage process may be ignored from the viewpoint of the contribution to the seasonal storage unit unloading.

Taking into account relation (19) the expression of temperature distribution specific to the heat carrier with laminar flow (see Appendix II) is:

$$R(\dot{y}, F_o) = exp(-\dot{y})\left[\delta(F_o) + \frac{0.602\,\dot{y}}{\sqrt{\dot{y} F_o}}\, exp(-0.362 F_o)\, I_1(1.20\sqrt{\dot{y} F_o})\right] \tag{21}$$

Function R $(\dot{y}, Fo)$ for turbulent flow is determined a similar way:

$$R(\dot{y}, F_o) = exp(-0.60\,\dot{y})\left[\delta(F_o) + \frac{0.982\,\dot{y}}{\sqrt{\dot{y} F_o}}\, exp(-1.607 F_o)\, I_1(1.964\sqrt{\dot{y} F_o})\right] \tag{22}$$

If the thermal excitation function is defined as F (Fo),the thermal response function is obtained by relation (23):

$$T(F_o, \dot{y}) = \int_0^{F_o} R(\dot{y}, s)\, F(F_o - s)\, ds \tag{23}$$

For the particular case $F_{Fo}(Fo) = t_c - t_o$, (24) is obtained:

$$T(F_o, \dot{y}) = (t_c - t_o)\int_0^{F_o} R(\dot{y}, s)\, ds \tag{24}$$

Considering the general expression (A.10) and the asymptotical development of modified Ist type and zero Bessel functions, the following expression is obtained:

$$T(\dot{y}, F_o) = (t_c - t_o)\, exp(-\gamma)\left[exp(-\beta F_o)\, I_0(2\sqrt{\gamma\beta F_o}) + \beta\int_0^{F_o} exp(-\beta s)\, I_0(2\sqrt{\gamma\beta s})\cdot ds\right] \tag{25}$$

For the heat carrier laminar flow, the following relation is obtained:

$$T_L(\dot{y},F_o) = (t_c - t_o)\exp(-y)\left[\exp(-0.362\,F_o)\,I_o(1.20\sqrt{\dot{y}F_o}) + 0.362\int_0^{F_o}\exp(-0.362\,s)\,I_o(1.20\sqrt{\dot{y}s})\,ds\right] \tag{26}$$

and for the turbulent flow:

$$T_T(\dot{y},F_o) = (t_c - t_o)\exp(-0.60\dot{y})\left[\exp(-1.607\,F_o)\,I_o(1.964\sqrt{\dot{y}F_o}) + 1.607\int_0^{F_o}\exp(-1.607\,s)\,I_o(1.964\sqrt{\dot{y}s})\,ds\right] \tag{27}$$

The relations above may be arranged as:

$$T_{L,T}(\dot{y},F_o) = C_{L,T}(\dot{y},F_o)(t_c - t_o) \tag{28}$$

For the calculus example, coefficients $C_{L,T}(y,Fo)$ may be determined by the diagram in fig.3.

The heat balance control relation, valid for complete thermal loading of the storage unit, is as follows:

$$B_i F_{of}\left[1 - \bar{C}_{L,T}(1,F_o)\right] = 2\,\frac{L}{\delta}\,St \tag{29}$$

where:

$$\bar{C}_{L,T}(1,F_o) = \frac{1}{F_{of}}\int_0^{F_{of}} C_{L,T}(1,F_o)\,dF_o$$

A study on temperature distribution in the soil mass may be performed using relation (16) where mj is reduced to the first eigenvalue m, with satisfactory accuracy of the final result. The calculus does not imply special difficulties and therefore will not be presented in this paper. The storage unit thermal loading may be controlled only by function T $(\dot{y},Fo)$ with relation (29) as control criterion (see Appendix III).

Considering further the calculus examples presented in this paper, thermal loading may be ensured in about 30 days for heat carrier laminar flow and in 9 days for turbulent flow.

The advantage of laminar heat carrier circulation and the necessity of increasing the thermal capacity of heat storage units ($\Delta^{x} \simeq 2.20$ m) is that its thermal loading could be performed within 6 months.

There are three ways of practically performing heat storage unit thermal unloading:

- a daytime storage unit works together with the seasonal heat storage unit; the heat carrier is circulated between the daytime unit and the seasonal one until the temperature level reached in the daytime unit meets the consumer's requirements. This system takes into account the fact that heat carrier heating is performed by means of the heat flow emitted by the soil mass at temperature levels variable in time according to daytime unit loading. The lowest limit of temperature level is determined by the temperature required by the consumer;

- the heat carrier is heated by stopping a short time inside the vertical drilling and then it is admitted in the daytime heat storage unit. The system service is similar to the service in the case described above but the carrier has an increased temperature in the seasonal unit and is stored in the daytime unit;
- the heat carrier is continuously circulated and heated up to the temperature level required by the consumer using an absorption heat pump.

The heat carrier circulated in the seasonal storage unit is the "cold source". The steam required by the heat pump service is also generated by the flue gases which supply the seasonal storage unit, as well.

The system works independently and may reach about 15-20°C ensuring a satisfactory efficiency of the heat storage unit (fig. 4).

The mathematical modelling of the system service is similar to the one described in the case of heat storage unit thermal loading.

IV. Overall thermal analysis model

Unlike the mathematical model described in chapter II (equations (1) - (6), the overall analysis model includes the temperature uniformity approximation on x coordinate. The equations describing the thermal loading process under these conditions are provided by the following relations:

$$\frac{\partial t}{\partial y} + 2\,\frac{1}{\delta}\, S_t\,(t-\theta) = 0 \qquad (30)$$

$$B_i(t-\theta) = \frac{\partial\theta}{\partial F_o} \tag{31}$$

with the boundary and initial conditions:

$$t\Big|_{y=0} = t_c \tag{32}$$

$$t\Big|_{F_o=0} = \theta\Big|_{F_o=0} = t_o \tag{33}$$

The solutions of system (30),(31) for laminar flow are represented by relations:

$$t(\dot{y}, F_o) = (t_c - t_o)\exp(-1.10\dot{y})\left[\exp(-0.41\,F_o)\,I_o(1.30\sqrt{\dot{y}F_o}) + 0.41\int_0^{F_o}\exp(-0.41s)\cdot I_o(1.30\sqrt{\dot{y}s})\,ds\right] + t_o \tag{34}$$

and

respectively:

$$\theta(\dot{y}, F_o) = t_o + 0.41(t_c - t_o)\exp(-1.10\dot{y})\int_0^{F_o}\exp(-0.41s)\,I_o(1.30\sqrt{\dot{y}s})\,ds \tag{35}$$

The calculus performed using relation (34) leads to the same result as the one provided by relation (26). This method may also be used in the thermal efficiency estimation calculus of a heat srorage unit; heat balance includes the heat losses towards environment.

In this case equation (31) changes as follows:

$$B_i(t-\theta) = \frac{\partial\theta}{\partial F_o} + B_{i1}\frac{\Delta}{L}(\theta - t_e) + B_{i2}\frac{\Delta}{L}(\theta - t_o) \tag{31_1}$$

and the integration of system (30) and (31_1) does not raise special problems.

The numerical tests performed on the unit under study in the calculus example proves that the variation in heat storage efficiency according to heat loss towards outside is significant while the heat carrier temperature is not significantly dependent (see Table I). The efficiency value was defined by relation:

$$\varepsilon = \frac{\theta(F_{of}) - t_o}{t_c - t_o} \tag{36}$$

Table I

$Bi_2 = 0.50$

t_c \ Bi_1	0.17	0.30	0.60	1.20
60	0.93	0.90	0.86	0.80
70	0.93	0.90	0.86	0.80
80	0.93	0.90	0.85	0.79
90	0.93	0.90	0.84	0.78
100	0.93	0.90	0.84	0.76

The practical performance of storage units with top inactive zone ensures a convenient thermal efficiency of about 85%, which is better than the values provided by water tank seasonal storage solutions.

V. Dimensional elements in practical performance of soil seasonal heat storage

The mathematical modelling presented in the previous chapters facilitates the determination of heat storage unit capacity and emphasizes a few important correlations between dimensionless Bi, St and Fo required by heat engineering calculuses. The calculuses performed on other cases reveal the fact that stored heat density is an important element in storage unit dimensioning. This value is given by the ratio between stored heat quantity and the area required by technological arrangements necessary to the thermal loading/unloading system.

If the heat carrier is warm water of about 85 - 90°C, the soil thermal capacity is about 55,000 kJ/m^3. If warm air (gas) of about 170°C is admitted, capacity reaches 135,000 kJ/m^3.

Considering a dwelling complex of 5,000 apartments with an annual heat consumption of 2.10^{5}GJ, the resulting storing volumes for the two variants under study are 0.35.10^{7}m^3 and 0.15.10^{7}m^3 respectively. If the heat carrier penetrates up to 10.00 m and 200.000 m respectively, the following areas result:

$q_1 = 55{,}000\ kJ/m^3 \qquad s_1 = 0.35.10^6 m^2; \qquad s_2 = 0.18.10^5 m^2$

$q_2 = 135{,}000\ kJ/m^3 \qquad s_1 = 0.15.10^6 m^2; \qquad s_2 = 0.70.10^4 m^2$

In this case the highest density of the stored heat quantity is of $3{,}00.10^7\ kJ/m^2$ which leads to 1.40/apartment used area index. For a complex of 5,000 apartments a square area with one side of about 85.00 m and 200.00 m heat carrier penetration depth may be used. For this geometry heat losses towards the adjoining soil are important as compared to the heat losses towards outside straight through the heat storage unit. For reduced depths, heat losses towards outside through horizontal area are important. It is therefore recommended in terms of thermal efficiency to adopt the high thermal density solution. The outside surface will no longer be equipped with special heat insulation, as an "inactive" soil layer is sufficient.

Fig.5 presents the correlation between soil surface temperature tsE and "inactive" layer thickness D for 150°C which is the highest thermal loading temperature in the warm season. For a 5.00 m thick inactive layer the influence of storage proves to be practically null and the ground may therefore be used for agriculture with only 2.5% storage density decrease.

V. Conclusions

1. This study is a theoretical contribution to the analysis of thermal loading and unloading processes of seasonal heat storage units using soil as storage medium.

2. The model of plane thermal wave propagation was analyzed. From the practical viewpoint this solution offers the possibility to use flue gases as heat carrier by simplifying duct line.

3. The study includes two mathematical models with distinct analytical solutions. The first model takes into account conductivity in soil; a uniform temperature distribution in soil is suggested in the overall model. Both variants offer solutions leading to close results.

4. The conclusion of the analysis on calculus examples is to select low heat carrier flow-rates and therefore laminar flow with low pressure drops as against turbulent flow.

5. The thermal efficiency studied on the overall thermal analysis model proves valid the possibility of reaching the value of 85% if an inactive part at the top of the heat storage unit works as heat insulator.

6. Practically, heat storage units with high thermal density are recommended as they have the highest thermal efficiency.

NOMENCLATURE

t_o	- storage mass initial temperature	/°C/
t_c	- heat carrier temperature at y=0 distance	/°C/
t	- heat carrier temperature	/°C/
ϑ	- soil temperature	/°C/
S_t	- Stanton dimensionless number	
Nu	- Nusselt dimensionless number	
F_o	- Fourier dimensionless number	

BIBLIOGRAPHY

/1/ Leonăchescu, N. - Heat Storage in Soil Using Tight Vertical Wells - Bulletin of Civil Engineering Institute, Bucharest, 1984

/2/ Skartredt, G. et al - Evaluation of Solar Collectors for Heat Pump Applications - Final Report to Albuquerque Operations Office. Contract No. DE - ACO4 - 78CS 35351 - 1980, August

/3/ Auer, F.; Ball, D.A.; Fischer, RD.;Hodgett,D.L. - Design Methods for Ground Source Heat Pumps Conf. "Subsurface Heat Storage in Theory and Practice" - Stockholm, 1983, June, 6-8.

/4/ Iordache, F.; Bergthaller, C. - Seasonal Heat Storage in Soil - Installations, (to issue)

/5/ x x x - Heat Storage in Sensible and Phase Change Substances - INCERC, Contract 30/1980

/6/ Constantinescu, D. - Approximate Analytical Solution for Heat Storage in Soil - Cylindrical Thermal Wave Model, Installations (to issue)

APPENDIX I

Solutions of mj (Bi) eigenvalue equations

Bi \ mj	m_1	m_2	m_3	Bi \ mj	m_1	m_2	m_3
0	0.0000	3.1416	6.2832	1.0	0.8603	3.4256	6.4373
0.001	0.0316	3.1419	6.2833	1.5	0.9882	3.5422	6.5097
0.002	0.0447	3.1422	6.2835	2.0	1.0769	3.6436	6.5783
0.004	0.0632	3.1429	6.2838	3.0	1.1925	3.8088	6.7040
0.006	0.0774	3.1435	6.2841	4.0	1.2646	3.9352	6.8140
0.008	0.0893	3.1441	6.2845	5.0	1.3138	4.0336	6.9096
0.01	0.0998	3.1448	6.2848	6.0	1.3496	4.1116	6.9924
0.02	0.1410	3.1497	6.2864	7.0	1.3766	4.1746	7.0640
0.04	0.1987	3.1543	6.2895	8.0	1.3978	4.2264	7.1263
0.06	0.2425	3.1606	6.2927	9.0	1.4149	4.2694	7.1806
0.08	0.2791	3.1668	6.2959	10.0	1.4289	4.3058	7.2281
0.1	0.3111	3.1731	6.2991	15.0	1.4729	4.4255	7.3959
0.2	0.4328	3.2039	6.3148	20.0	1.4961	4.4915	7.4954
0.3	0.5218	3.2341	6.3305	30.0	1.5202	4.5615	7.6057
0.4	0.5932	3.2636	6.3461	40.0	1.5325	4.5979	7.6647
0.5	0.6533	3.2923	6.3616	50.0	1.5400	4.6202	7.7012
0.6	0.7051	3.3204	6.3770	60.0	1.5451	4.6353	7.7259
0.7	0.7506	3.3477	6.3923	80.0	1.5514	4.6543	7.7573
0.8	0.7910	3.3744	6.4074	100.0	1.5552	4.6658	7.7764
0.9	0.8279	3.4003	6.4224	∞	1.5708	4.7124	7.8540

$$B_i = \frac{\alpha_F \Delta}{\lambda_s}$$

The general expression of function ψ (Fo) is:

$$\psi(F_o) = \alpha \exp(-\beta F_o) \tag{A.1}$$

Laplace transform is given by relation:

$$\mathcal{L}\left\{\psi(F_o)\right\} = \psi(p) = \frac{\alpha}{p+\beta} \tag{A.2}$$

Therefore:

$$\bar{R}(\dot{y}, p) = \varphi(p) \exp\left(-\frac{p\alpha y}{p+\beta}\right) \tag{A.3}$$

The following notations are used:

$$F(p) = \varphi(p)$$

$$G(p) = \exp\left(-\frac{p\alpha\dot{y}}{p+\beta}\right)$$

Consequently:

$$\bar{R}(\dot{y}, p) = F(p)\, G(p) \tag{A.4}$$

If the form of the excitation function has the form of Dirac function, A.5 results:

$$F(p) = \mathcal{L}\left\{\delta(F_o)\right\} = 1 \tag{A.5}$$

Therefore:

$$R(\dot{y}, F_o) = \mathcal{L}^{-1}\left\{\exp\left(-\frac{p\alpha\dot{y}}{p+\beta}\right)\right\} \tag{A.6}$$

Notation $\alpha\dot{y} = \gamma$ is used, so:

$$R(\dot{y}, F_o) = \mathcal{L}^{-1}\left\{\exp\left(-\frac{p\gamma}{p+\beta}\right)\right\} \tag{A.7}$$

$$\exp\left(-\frac{p\gamma}{p+\beta}\right) = \exp(-\gamma)\exp\left(\frac{\gamma\beta}{p+\beta}\right)$$

$$\mathcal{L}^{-1}\left\{\exp(-\gamma)\exp\left(\frac{\gamma\beta}{p+\beta}\right)\right\} = \exp(-\gamma)\,\mathcal{L}^{-1}\left\{\exp\left(\frac{\gamma\beta}{p+\beta}\right)\right\}$$

$$\exp\left(\frac{\gamma\beta}{p+\beta}\right) = \frac{p}{p+\beta}\exp\left(\frac{\gamma\beta}{p+\beta}\right) + \beta\frac{1}{p+\beta}\exp\left(\frac{\gamma\beta}{p+\beta}\right)$$

$$\mathcal{L}^{-1}\left\{\beta \frac{1}{p+\beta} \exp\left(\frac{\gamma\beta}{p+\beta}\right)\right\} = \beta \exp(-\beta F_o)\, I_o\left(2\sqrt{\gamma\beta F_o}\right) \qquad \text{A.8}$$

$$\mathcal{L}^{-1}\left\{\frac{p}{p+\beta} \exp\left(\frac{\gamma\beta}{p+\beta}\right)\right\} = -\beta \exp(-\beta F_o)\Big[I_o\left(2\sqrt{\gamma\beta F_o}\right) -$$

$$- \frac{\gamma}{\sqrt{\gamma\beta F_o}}\, I_1\left(2\sqrt{\gamma\beta F_o}\right)\Big] + \delta(F_o) \qquad \text{A.9}$$

The result is :

$$R(\dot{y}, F_o) = \delta(F_o)\exp(-\gamma) + \frac{\gamma\beta}{\sqrt{\gamma\beta F_o}} \exp(-\beta F_o)\exp(-\gamma)\, I_1\left(2\sqrt{\gamma\beta F_o}\right) \qquad \text{A.10}$$

DETERMINATION OF HEAT LOADING/UNLOADING PERIOD OF SOIL SEASONAL HEAT STORAGE UNIT - PLANE WAVE THERMAL WAVE

1. Function C(1,Fo) is determined:

$$C(1,F_o) = \exp(-\alpha)\left[\exp(-\beta F_o) I_o\left(2\sqrt{\alpha\beta F_o}\right) + \beta\int_0^{F_o}\exp(-\beta S)\cdot\right.$$
$$\left.\cdot I_o\left(2\sqrt{\alpha\beta S}\right)dS\right] \qquad \text{A.1}$$

where:

$$\alpha = 4\frac{L}{\delta}\,St\,\frac{\sin m_1\cos m_1}{m_1 + \sin m_1 \cos m_1}$$

$$\beta = m_1^2$$

2. Function $\bar{C}(1,Fo_F)$ is determined analytically or graphically

3, Equation A.2 is solved graphically or numerically:

$$1 - \bar{C}(1 - F_{of}) = \frac{2}{\xi}\cdot\frac{L}{\delta}\cdot\frac{St}{Bi}\cdot\frac{1}{F_{of}} \qquad \text{A.2}$$

providing value Fo_F where the heat storage unit is thermally loaded/unloaded. Coefficient represents the thermal loading accepting rate. ξ =1.12 may be accepted which means a thermal loading/unloading of about 90%.

Fig.6 presents the solving of equation A.2 for the calculus example specific to laminar flow. Fo_F = 9.00 and τ = 720 h result.

The same calculus model may be used in case of cylindrical wave loading /5/,/6/.

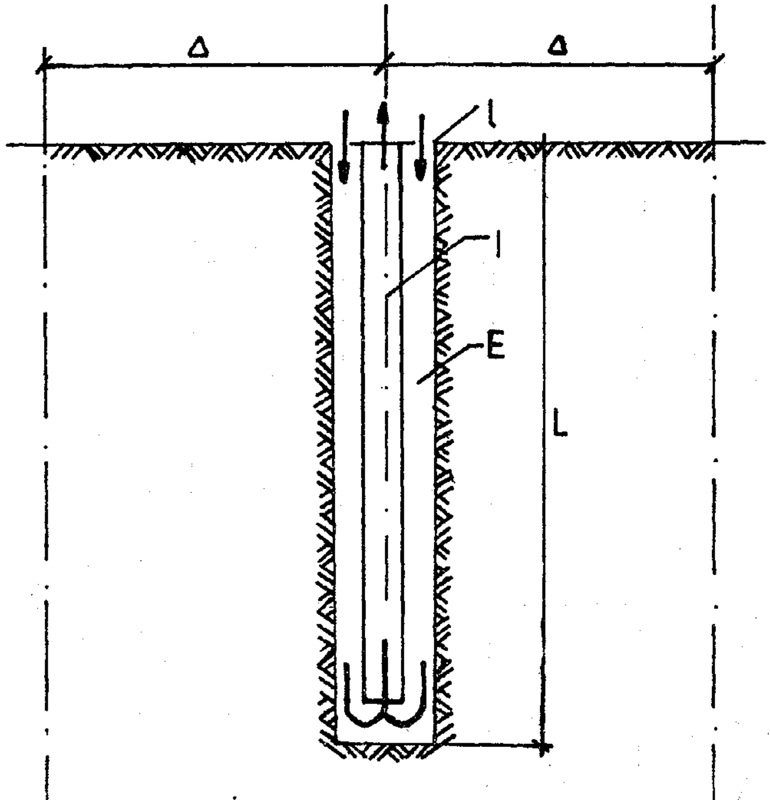


FIG.1 Functional scheme.

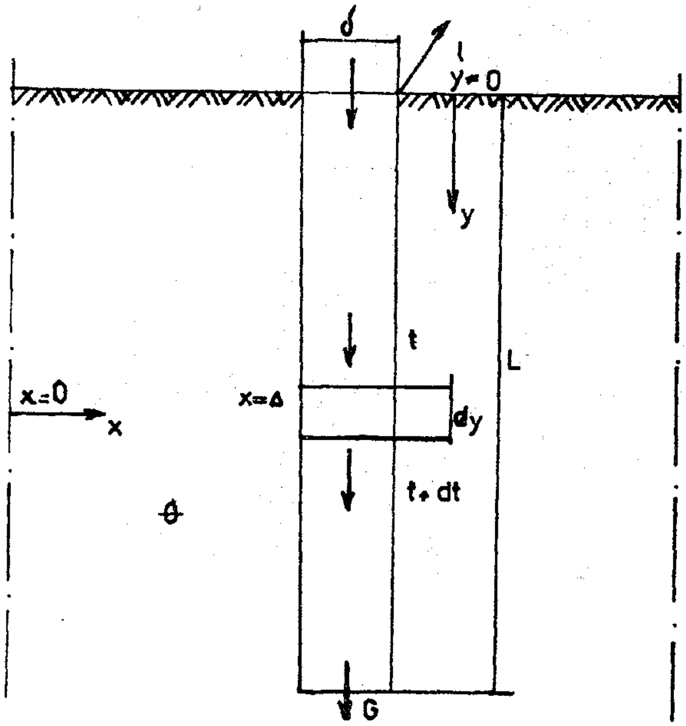
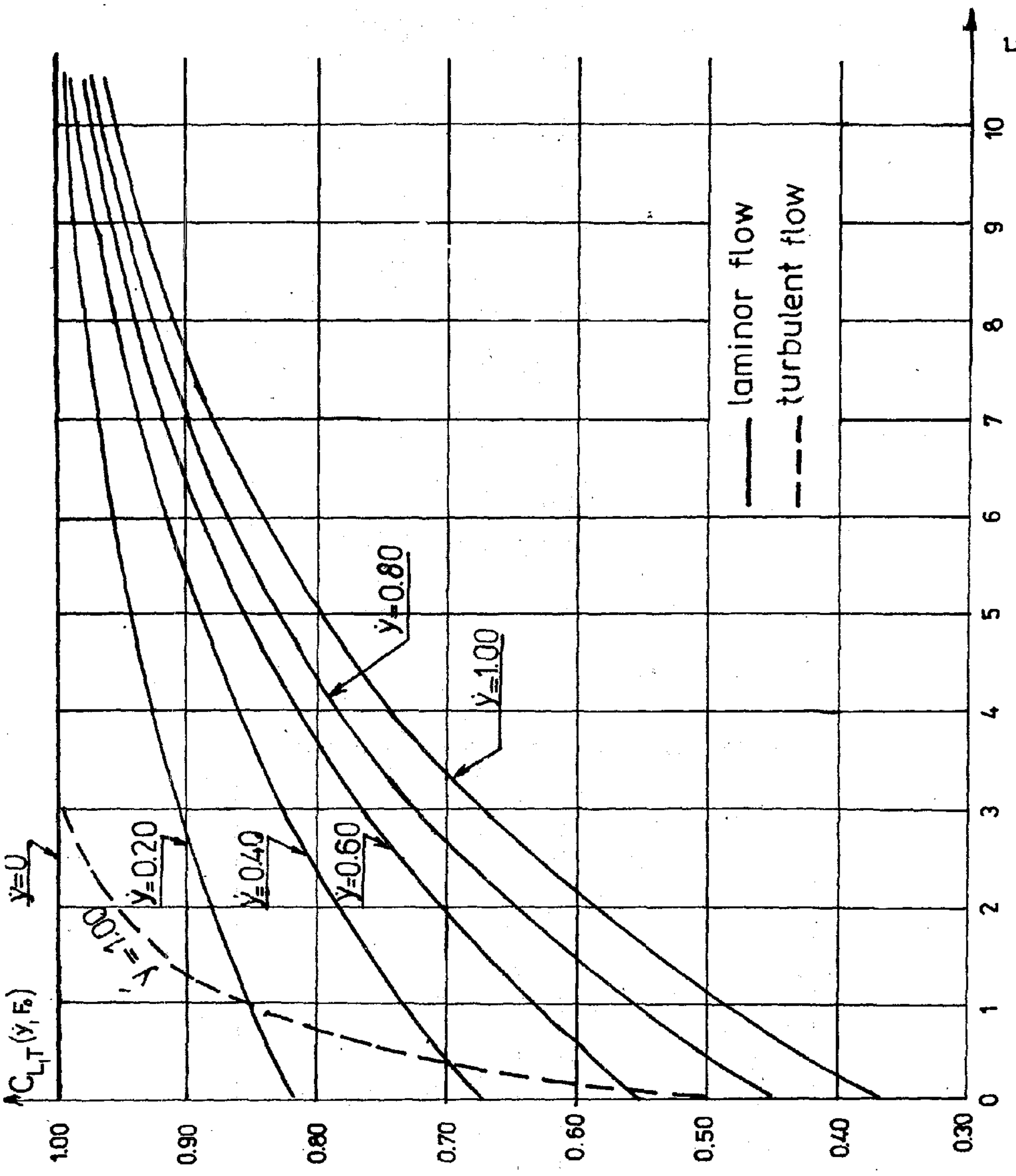


FIG.2 Calculation scheme.



$C_{L,T}(\dot{y}, F_o)$
F_o
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0
1
2
3
4
5
6
7
8
9
10
$\dot{y}=0$
$\dot{y}=0.20$
$\dot{y}=0.40$
$\dot{y}=0.60$
$\dot{y}=0.80$
$\dot{y}=1.00$
laminar flow
turbulent flow

FIG. 3

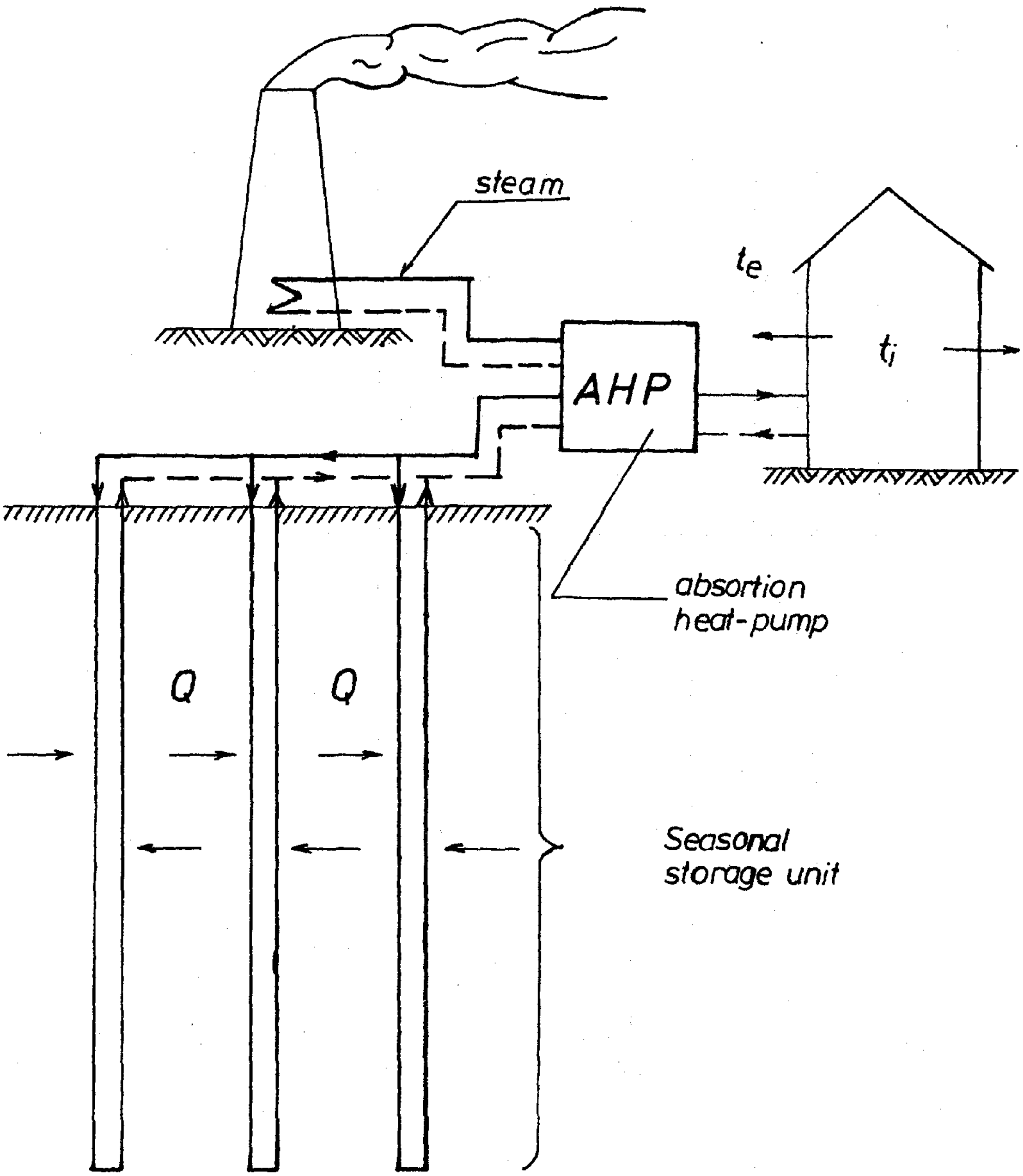
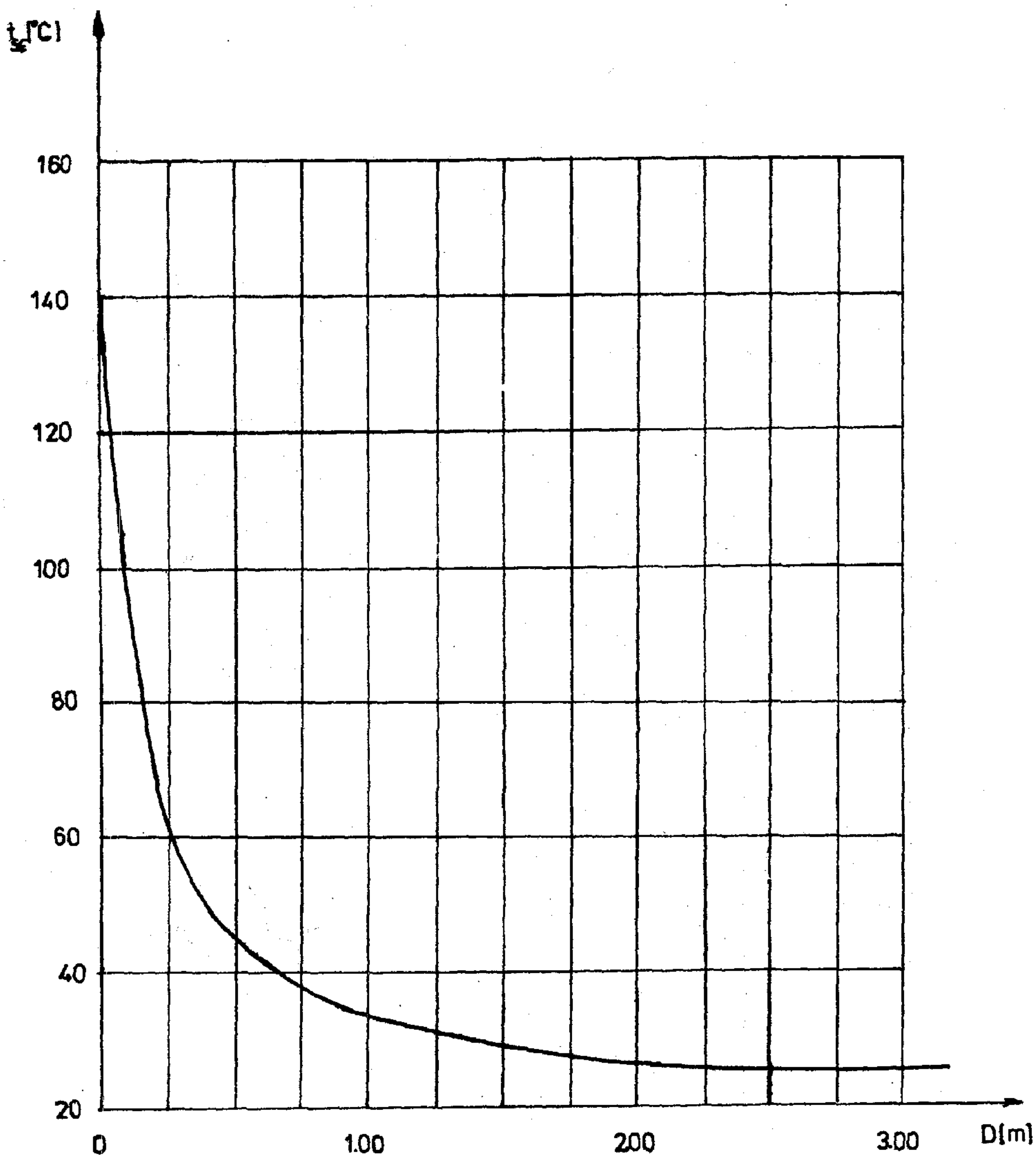
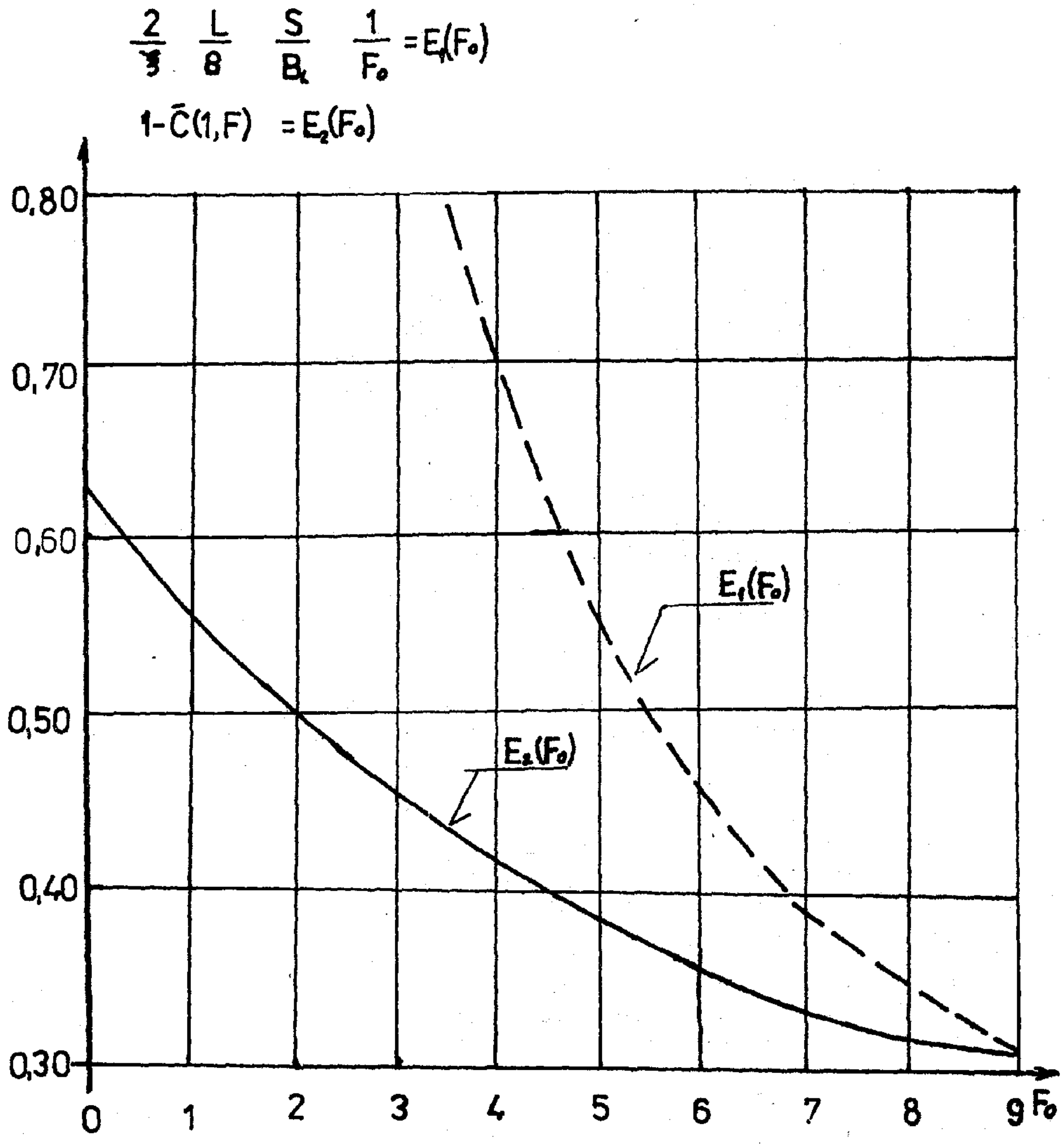


FIG 4. Functional scheme – unloading period.



FIG, 5 Variation of the soil supperficial temperature with D-passiv earth thickness.



$\frac{2}{3}\ \frac{L}{8}\ \frac{S}{B_L}\ \frac{1}{F_o} = E_1(F_o)$
$1-\bar{C}(1,F) = E_2(F_o)$
0,80
0,70
0,60
0,50
0,40
0,30
0
1
2
3
4
5
6
7
8
9
F_o
$E_1(F_o)$
$E_2(F_o)$

Fig. 6

III.17 MODELLING OF HEAT TRANSFER AND STORAGE IN GROUND SEASONAL HEAT STORAGE UNITS

Florin Iordache[x]
Cristian Bergthaller[xx]

I. INTRODUCTION

The heat storage unit, used for seasonal storage, is a main component in the framework of active solar systems and the use of nonconventional sources. The dimensioning and functioning of this component has important implications for the thermal performance of the system. Because of the unsteady character of heat transfer and storage processes, correct mathematical modelling of the heat transfer process is necessary for dimensioning and optimizing these systems.

As is well known, the efficiency of seasonal storage systems generally depends on their great volume, which permits the storage of heat in quantities so great that the heat losses are counteracted. Seasonal storage systems include water-bearing layers, lakes, and the ground. These systems can also profit from relatively low specific investments.

In this paper, the storage medium considered is the ground. This system presumes the presence of a hexagonal net verticalpipework that permits admission and exhaustion of the heat carrier.

The mathematical modelling of the unsteady processes of heat transfer and storage is necessary for compatibility between the functioning of the storage system and that of the heat source and the user. The respective results will finally permit the optimizing of the storage system.

The heat carrier used for loading and unloading the storage can be air or warm water; prepared either from a solar installation or by means of secondary industrial sources.

This last service may represent a potential heat source for the storage system regarding both heat quantity and its potential.

---

x Building Research Institute - INCERC, Bucharest
xx Center of Mathematical Statistics, Bucharest, Romania

II. SYSTEM DESCRIPTION: FUNCTIONING

As this problem is at its beginning (mathematical modelling) the system and functioning description will be carried on only at the level of a main scheme that must permit the use of a mathematical modelling.

As was mentioned above, the storage system presumes the existence of a hexagonal network of vertical pipes (fig.1), where the heat carrier can pass during loading and unloading of the storage. The coaxial pipe system permits the admission and exhaust of the heat carrier at the top so that the distribution and collection system can be practically placed at ground level.

The functioning of the storage system generally presumes two main phases:

a - the loading of heat storage

b - the unloading of heat storage

each of them developing over a period of several months. The first phase presumes a collaboration between the storage system and the source and the second one between the storage system and the user. In the framework of each phase, and between them, some interruption periods will appear when the circulation of heat carrier stops and a natural cooling occurs namely temperatures levelling into solid mass. From the mathematical modelling point of view the cooling phase is a functional one and it was presented as such. The functioning of the storage system consists of loading periods alternatively with cooling periods and unloading periods with cooling ones, the end of each period establishing the initial values for next period.

III. MATHEMATICAL MODELS. SOLVING METHODS.

As it was mentioned above and in the fig.1, the practical and functional performance of a vertical pipe network presumes the admission and exhaust of a heat carrier at the top. The two coaxial vertical pipes, through which the heat carrier circulates in opposite senses, behaving as a heat exchanger in counter current the fluid in the central pipe delivers heat to that one in the pipe of greater diameter and further to the ground.

In the present paper a simplified case is used for the mathematical modelling, namely: the admission of heat carrier at the superior side and its exhaust at the inferior one.

The temperature of the heat carrier at admission is a known function of time. The hexagonal network permits us the accepting of a new conclusion namely that the storage system can be considered as being composed of numerous storage modules of cylindrical shape independent from the thermal point of view. Each pipe within the network which heat carrier passes through, together with cylindrical earth volume around it, is a storage module which is filled by heat carrier of unknown temperature, varying in time and space.

Outside the pipe is considered without heat losses, this is perfectly insulated (being surrounded by similar modules with the same thermal behavior). According to the location of these storage modules we will also admit a simplification namely that there is no heat losses at the superior and inferior side of the storage modules. The relative great length of the storage module towards its thickness permits us the omission of the longitudinal conductibility towards the radial one. Another simplification is the omission of the temperature radial distribution of heat carrier. This simplification is generally validated by the turbulent flow of the heat carrier through the **pipe**.

In the framework of these simplifications, the mathematical formulation of the heat transfer and storage process results from the regulations of total heat at the level of some small fluid and earth elements. Thus the following problem that defines the temperature field in fluid and earth corresponding to storage way:

$$\frac{\partial t}{\partial \tau} + w\frac{\partial t}{\partial x} + \frac{\alpha S}{M_f \rho_f}\left(t - \theta\big|_{r=R_i}\right) = 0 \tag{1}$$

$$\frac{\partial \theta}{\partial \tau} = a\left(\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r}\cdot\frac{\partial \theta}{\partial r}\right) \tag{2}$$

with singularity conditions:

- boundary:

$$t(x,\tau)\big|_{x=0} = t_0(\tau) \tag{3}$$

$$\alpha\left(t - \theta\big|_{r=R_i}\right) = -\lambda \frac{\partial \theta}{\partial r}\Big|_{r=R_i} \tag{4}$$

$$\frac{\partial \theta}{\partial r}\Big|_{r=R_e} = 0 \tag{5}$$

- initial ones:

$$t(x,\tau)\big|_{\tau=0} = t^0(x) \tag{6}$$

$$\theta(x,r,\tau)\big|_{\tau=0} = \theta^0(x,r) \tag{7}$$

For solving this problem a method was used that consists in a combination of Crank-Nicholson method from parabolic equations and the method of characteristic from the hyperbole equations by which the transformation into the following system of linear differential equations is performed:

$$\left\{\begin{array}{l}
\dfrac{dt}{d\tau} = -\dfrac{\alpha S}{M_f C_f}(t-\theta_0) \\[2ex]
\dfrac{d\theta_0}{d\tau} = -2\dfrac{a}{\Delta^2}\cdot\dfrac{B_i(2m_i-1)+2m_i}{2m_i}\theta_0 + 2\dfrac{a}{\Delta^2}\dfrac{B_i(2m_i-1)}{2m_i}t + 2\cdot\dfrac{a}{\Delta^2}\theta_1 \\[2ex]
-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;- \\[1ex]
\dfrac{d\theta_K}{d\tau} = -2\dfrac{a}{\Delta^2}\theta_K + \dfrac{a}{\Delta^2}\left[1-\dfrac{1}{2(u_i+K)}\right]\theta_{K-1} + \dfrac{a}{\Delta^2}\left[1+\dfrac{1}{2(u_i+K)}\right]\theta_{K+1} \\[2ex]
\text{where } K = 1,2,\ldots,(m-1) \\[1ex]
-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;- \\[1ex]
\dfrac{d\theta_m}{d\tau} = -2\dfrac{a}{\Delta^2}\theta_m + 2\dfrac{a}{\Delta^2}\theta_{m-1}
\end{array}\right. \tag{8}$$

which will be integrated after:

$$\frac{dx}{d\tau} = w$$ - the first equation (9)

$$\frac{dx}{d\tau} = 0$$ - the rest of (m+1)equation(10)

After the intergation on short intervals $\Delta\tau$ of time the system (8) turns into the following linear algebric equations system:

$$\left\{\begin{array}{l}
t_{ij} + (F^{f^*}-1)\theta_{i,0,j} = E^{f^*}t_{i-1,j-1} + (F^{f^*}-E^{f^*})\theta_{i-1,0,j-1} \\[2ex]
\dfrac{B_i(2m_i-1)}{B_i(2u_i-1)+2u_i}(F^*-1)t_{i,j} + \theta_{i,0,j} + \dfrac{2u_i}{B_n(2u_i-1)+2u_i}(F^*-1)\theta_{i,1,j} = \\[2ex]
= \dfrac{B_i(2u_i-1)}{B_i(2u_i-1)+2u_i}(F^*-E^*)t_{i,j-1} + E^*\theta_{i,0,j-1} + \dfrac{2u_i}{B_i(2u_i-1)+2u_i}(F^*-E^*)\theta_{i,1,j-1} \\[2ex]
-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-\;-
\end{array}\right. \tag{11}$$

$$
\begin{cases}
\frac{1}{2}\left[1-\frac{1}{2(u_i+k)}\right](F-1)\,\theta_{i,k-1,j}+\theta_{i,k,j}+\frac{1}{2}\left[1+\frac{1}{2(u_i+k)}\right](F-1)\,\theta_{i,k+1,j}= \\
=\frac{1}{2}\left[1-\frac{1}{2(u_i+k)}\right](F-E)\,\theta_{i,k-1,j-1}+E\theta_{i,k,j-1}+\frac{1}{2}\left[1+\frac{1}{2(u_i+k)}\right](F-E)\,\theta_{i,k+1,j-1} \\
\text{where } \quad k=1,2,\ldots,(m-1) \\
\hline
(F-1)\,\theta_{i,m-1,j}+\theta_{i,m,j}=(F-E)\,\theta_{i,m-1,j-1}+E\theta_{i,m,j-1}
\end{cases}
$$

where

$$F^{f*}=\frac{1-E^{f*}}{2F_0^{f*}}\;;\quad E^{f*}=\exp\left(-2F_0^{f*}\right);\quad F_0^{f*}=\frac{\alpha\,\Delta\tau}{R_i\,\rho_f\,c_f} \tag{12}$$

$$F^{*}=\frac{1-E^{*}}{2F_0\,\frac{B_i(2u_i-1)+2u_i}{2u_i}}\;;\quad E^{*}=\exp\left[-2F_0\,\frac{B_i(2u_i-1)+2u_i}{2u_i}\right]$$

$$F=\frac{1-E}{2F_0}\;;\quad E=\exp(-2F_0)\;;\quad F_0=\frac{a\,\Delta\tau}{\Delta^2}\;;\quad B_i=\frac{\alpha\cdot\Delta}{\lambda_s}$$

$$a=\frac{\lambda_s}{\rho_s\,c_s}\;;\quad \Delta=\frac{1}{n_i}R_i\;;\quad \Delta\tau=\frac{\Delta x}{w}$$

For establishing convection heat transfer coefficient α, a criterial equation was used, characteristic to forced flow:

$$Nu = 0.023\;.\;Re^{0.8}\;.\;Pr^{0.4} \tag{13}$$

The practical solution of the system (11) was developed in connection with certain constant values of the factors, fact that led to the consideration of some unique values of the physical constants for the two fields, namely fluid and solid that are in thermal interaction. In this paper are presented the results obtained in the case where water is heat carrier. The values of physical constants were:

$$\lambda_f = 0.648 \left[\frac{W}{m \cdot K}\right]; \quad Pr_f = 3.56$$

$$\nu_f = 0.556 \cdot 10^{-6} \left[\frac{m^2}{s}\right]; \quad \rho_f = 1000 \left[\frac{Kg}{m^3}\right]$$

$$c_f = 4186 \left[\frac{J}{Kg\,K}\right]; \quad \rho_s = 1800 \left[\frac{Kg}{m^3}\right]$$

$$\lambda_s = 1.163 \left[\frac{W}{m \cdot K}\right]; \quad c_s = 837.2 \left[\frac{J}{Kg\,K}\right]$$

In the case of the heat cooling process mentioned above, which interferes with the circulation pauses of heat carrier, a conductive temperature uniformity within the storage takes place. The mathematical equation of this problem like that one of heat balance at the level of a small element is:

$$\frac{\partial \theta}{\partial \tau} = a \left(\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r} \frac{\partial \theta}{\partial r} \right) \tag{14}$$

with singularity conditions:

- boundary condition:

$$\left. \frac{\partial \theta}{\partial r} \right|_{r = R_i} = 0$$

$$\left. \frac{\partial \theta}{\partial r} \right|_{r = R_e} = 0 \tag{15}$$

- initial conditions:

$$\theta (x, r, \tau) \big|_{\tau = 0} = \theta^{0} (x, r) \tag{16}$$

By using the same solution method it can be obtained:

$$\begin{cases} \dfrac{d\theta_0}{d\tau} = -2\dfrac{a}{\Delta^2}\theta_0 + 2\dfrac{a}{\Delta^2}\theta_1 \\ \dfrac{d\theta_K}{d\tau} = -2\dfrac{a}{\Delta^2}\theta_K + \dfrac{a}{\Delta^2}\left[1 - \dfrac{1}{2(m_i+K)}\right]\theta_{K-1} + \dfrac{a}{\Delta^2}\left[1 + \dfrac{1}{2(m_i+K)}\right]\theta_{K+1} \\ \text{where} \quad K = 1, 2, \ldots, (m-1) \\ \dfrac{d\theta_m}{d\tau} = -2\dfrac{a}{\Delta^2}\theta_m + 2\dfrac{a}{\Delta^2}\theta_{m-1} \end{cases} \tag{17}$$

The system (17) being similarly integrated the algebraic equations system is obtained:

$$\begin{cases} \theta_{0,j} + (F-1)\theta_{1,j} = E\cdot\theta_{0,j-1} + (F-E)\theta_{1,j-1} \\ \dfrac{1}{2}\left[1 - \dfrac{1}{2(m_i+K)}\right](F-1)\theta_{K-1,j} + \theta_{K,j} + \dfrac{1}{2}\left[1 + \dfrac{1}{2(m_i+K)}\right](F-1)\theta_{K+1,j} = \\ = \dfrac{1}{2}\left[1 - \dfrac{1}{(2m_i+K)}\right](F-E)\theta_{K-1,j-1} + E\,\theta_{K,j-1} + \dfrac{1}{2}\left[1 + \dfrac{1}{(2m_i+K)}\right](F-E)\theta_{K+1,j-1} \\ \text{where} \quad K = 1, 2, \ldots, (m-1) \\ (F-1)\theta_{m-1,j} + \theta_{m,j} = (F-E)\theta_{m-1,j-1} + E\cdot\theta_{m,j-1}. \end{cases} \tag{18}$$

where:

$$F = \frac{1-E}{2F_0} \quad ; \quad E = \exp(-2F_0)$$

$$F_0 = \frac{a\cdot\Delta\tau}{\Delta^2} \quad ; \quad \Delta = \frac{1}{m_i}R$$

$\Delta\tau$ - is small time interval, which for this time can be arbitrarily selected.

System (18) is available duting the cooling period for each section i, as a result of the vertical storage segmentation and it must be separately solved for each of these sections. During this period among sections there is no heat interaction according to simplifying hypothesis accepted in the introduction.

The following lines will present the method of a numerical solution system (11) characteristic to heat storage loading and unloading periods.

Numerical solution

Because the time variable j in system (11) reaches very large values (if $\Delta\tau = 0.01$ and $\tau = 1000$ hours, which is about 40 days then $j = 100000$) is out of question to use a step-by-step direct solution, i.e. to solve the system for every i and j. Therefore we try to get an analytical formula which must be valid for every j. Unfortunately, the formulas we found are different for different sections (which means for different values of i), however there is no computational problem because usually i runs in a range from 20 to 40.

Let us write the system (11) in the matriceal form

$$A \cdot \theta_i(j) = B \cdot \theta_i(j-1) + P\, \theta_{i-1}(j-1) \tag{19}$$

where: $\theta_i(j)$ is the (m+2) - dimensional vector

$$\theta_i(j) = (t_{i,j}\ ;\ \theta_{i,0,j}\ ;\ \theta_{i,1,j}, \ldots, \theta_{i,m,j})$$

and A, B, P are the corresponding (m+2) x (m+2) matrices for example.

$a_{11} = 1,\ a_{12} = (F^{f^*} - 1),\ a_{13} = 0, \ldots,$

$b_{11} = 0,\ b_{12} = 0,\ \ldots,\ p_{11} = E^{f^*}$ and so on.

The matrix A is nonsingular therefore we can multiply by A^{-1} and get:

$$\theta_i(j) = C\, \theta_i(j-1) + (A^{-1} \cdot P)\, \theta_{i-1}(j-1) \tag{20}$$

where $C = A^{-1} B$

Now, let Δ be the diagonal matrix whose components are the eigenvalues of C and let V be a corresponding set of eigenvectors (we suppose all eigenvalues of C are real and C is not defective). Then:

$$C = V^{-1} \cdot \Delta \cdot V \tag{21}$$

and if we introduce the "canonical" variables $y_j(j)$ defined by

$$\theta_i(j) = V \cdot y_i(j) \tag{22}$$

the system (20) becomes:

$$y_i(j) = \Delta \cdot y_i(j-1) + S y_{i-1}(j-1) \tag{23}$$

where:

$$S = V^{-1}(A^{-1}P) \cdot V \tag{24}$$

It could be shown that for $i = 0$, $Y_o(j)$ the form

$$y_0(j) = Q_o \cdot R^j \tag{25}$$

where Q_o is a constant (m+2) x (m+2) matrix and R^j is a (m+2) vector

$$(R^j)^T = [1, \rho_0^j, \rho_1^j, \ldots, \rho_m^j]$$

where $\rho_0, \rho_1, \ldots, \rho_m$ are real constants between 0 and 1, and T means transposition.

We look for a solution of the "canonical" system (23) of the form

$$y_i(j) = B_i(j) L^j + Q_i R^j \tag{26}$$

with Q_i a constant (m+2) x (m+2) matrix, $B_i(j)$ a polynomial matrix and L a (m+2) - dimensional vector

$$(L^j)^T = [0, \lambda_0^j, \lambda_1^j, \ldots, \lambda_m^j]$$

here $\lambda_0, \lambda_1, \ldots, \lambda_m$ are non-zero eigenvalue of C is always zero).

By replacing (26) in (23) we get (m+2) equations like

$$\begin{aligned} \ldots &+ \lambda_k^j (b_0 + b_1 j + b_2 j^2 + \ldots) + \ldots = \\ = \ldots &+ \lambda_K \lambda_k^{j-1} (b_0 + b_1(j-1) + b_2(j-1)^2 + \ldots) + \ldots + \\ &+ \lambda_k^{j-1} (a_0 + a_1(j-1) + a_2(j-1)^2 + \ldots) + \ldots \end{aligned} \tag{27}$$

where $(b_0 + b_1 j + b_2 j^2 + \ldots)$ will be the (k,h) - th element of $B_i(j)$ and $a_0 + a_1(j-1) + a_2(j-1)^2 + \ldots$ is derived from $S y_{i-1}(j-1)$

From linearity of the system (23), it is enough to solve the "partial" problem

$$\lambda_h \left(b_0 + b_1 j + b_2 j^2 + \dots\right) = \lambda_K \left(b_0 + b_1 (j-1) + b_2 (j-1)^2 + \dots\right) + \\ + \left(a_0 + a_1 (j-1) + a_2 (j-1)^2 + \dots\right) \qquad (28)$$

where $a_0, a_1, a_2, \dots$ are given and $b_0, b_1, b_2, \dots$ are to be found.

When in the (n-1) th, (n-2) th,..., 1 at derivate of (28) (here n is for degree of the "a" s polynom j is replaced by i, we get

$$b_x = \frac{a_x}{\lambda_h - \lambda_K}, \quad b_s = \frac{1}{\lambda_h - \lambda_K}\left[a_s - \frac{s+1}{1} b_{s+1} - \frac{(s+1)(s+2)}{1\cdot 2} b_{s+2} + \dots\right.$$

$$s = n-1 \quad n-2, \dots, 1, 0$$

when $\lambda_h = \lambda_K$ and

$$b_{n+1} = \frac{a_n}{\lambda_K (n+1)}$$

$$b_{s+1} = \frac{a_s}{\lambda_K (s+1)} - \frac{s+2}{2} b_{s+1} - \frac{(s+2)(s+3)}{2\cdot 3} b_{s+2}$$

$$s = n-1 \quad n-2, \dots, 1, 0$$

when $\lambda_h = \lambda_K$. In the last case, bo will be determined from the initial conditions.

The new value Q_i are computed in a similar way,but is much simpler because n = 0.

After we have got the $B_j(j)$ and Q_j values, they can be used for getting $B_{i+1}(j)$ h and Q_{i+1} corresponding to the next value of i; on the other hand, by replacing $Y_i(j)$ from (26) in (22), it is an easy task to compute the temperature vector $\theta_i(j)$ in section i at every time j.

Sometimes, λ_h and λ_K are very close; this is why the computer program uses a trick in order to assure numerical accuracy. Also, a subroutine which outputs a high-precision eigenvalues of C matrice is provided.

The following lines will present the results obtained b y the application of the model and solution method for a constructive and functional situation thus defined:

- The pipe diameter which the heat carrier passes through: $d_i = 0.1$ m
- the length of the storage module : $h = 10$ m
- the diameter of the storage module : $d = 2.1$ m
- heat carrier water which circulates with a velocity of $w = 80$ m/h fact that leads to a value of $Re = 4{,}000$
- initial soil temperature and then $10^{o}C$
- inlet water temperature was considered constant in time and equal with $90^{o}C$.

The effective calculus was developed with $n_i = 1$ (namely, the thickness of the module was divided into 20 steps each one $\Delta r = 0.05$ m). Vertically the pipe height was considered as divided into 20 acctions each one having the length of 0.5 m.

The respective results are presented in figures 2 and 7. It is observed that under the specific service conditions, after a relatively short time of about 2 days, it can be concluded that the temperature along the whole length of the pipe is an approximately constant maximum value. This is due to the great value of the criterion $Bi = 8$ (rated to radial step) that physicaly leads to a rapid enough increase of temperature on the surface of the pipe. This heat convective flux rapidly decreases in order to be compatible with the migration possibilities of heat conductive flux. This fact leads to conclude that in this case the determination of the heat field under steady regime could be performed by means of a more simple model that neglects the differentiations among the various vertical sections caused by the gradient of the fluid temperature.

This more simple model is similar to that one presented in the case of the cooling process, the difference being present only concerning the first equation, that in the case of this process it results according to a limit condition of Neumann type (null flux) and in this case it must be according to a boundary condition of III type.

In the situation when the inlet function (the temperature of heat carrier at the addmission into the pipe) has a certain known oscillation the three phases: loading, unloading and cooling are replacing rapidly enough and have existence periods that depend on time variation of inlet function.

The results obtained in a storage module are given in figures 8 and 11 in order to present the thermal behavior at an inland function with a certain oscillation in time, and to show the importance of the numerical method. The characteristics are as follows:

- the pipe diameter which fluid passes through: $d_i = 0.1$ m

- the length of the storage module : h=5 m
- the diameter of the storage module: d_e = 1.0 m
- the heat carrier, water which circulates with velocity of w = 8 m/h leading to a value R_e = 400:
- initial soil and water temperature 10^oC
- inlet water temperature which varies according to the diagram in fig.8.

In 10 and 11 it is observed that cylindrical thermic ware is maintained. The oscillations of heat carrier temperature (fig.8) are dephased and damped according to the respective soil.layer.The relatively small oscillation of the heat carrier temperature on the height of storage module permits the usage of the simplified mathematical model, mentioned above (temperature is variable in time).

The same storage module was also tested to a value of Re = 4,000, namely a circulation water velocity of 80m/s, resulting an increase of temperatures level and this of addmited thermic flux caused by the increase of convective thermic transfer coefficient . The circulation rate value generally leads to an increase in the thermic oscillations amplitude. However more rapid results can be obtained by the convolution product between addmission function and the response one at unite impuls of the storage module. This solution is more rapid then program development but presumes a previous knowledge of the response function at unite impulse charac - teristic to the respective storage module. This function being known, we can easily obtain data on temperatures fields in the storage module, as a result of various inlet functions. Because of the numerical solution, the response function to unit thermic im - pulse is in fact a group of functions characteristic to every node of the respective network.

We can conclude that the mathematical model and numerical solution permit the practical determination of the storage module thermic field for any type of inlet function.

This is the reason why we can hope for the optimization of this system and its use.

At the same time we'll try to give up the numerous simpli - fying hypothesis mentioned above.

The possibility of omitting the following two simplifi - cations will be considered of great success:
- the neglecting of the longitudinal conduction.
- the constancy of physical parameters of heat carrier and soil.

The renounce at these two hypothesis has serious influence on the structure of mathematical model itself as well as on numerical.

The results thus obtained will permit the estimation of frontal heat losses of the storage module and thus of an efficiency which is very important for systems of seasonal storage.

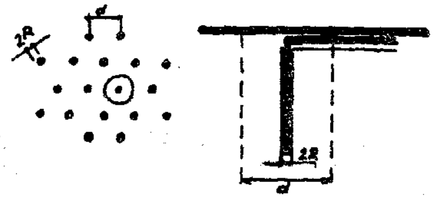


FIG 1- Calculation scheme-
seasonal storage.

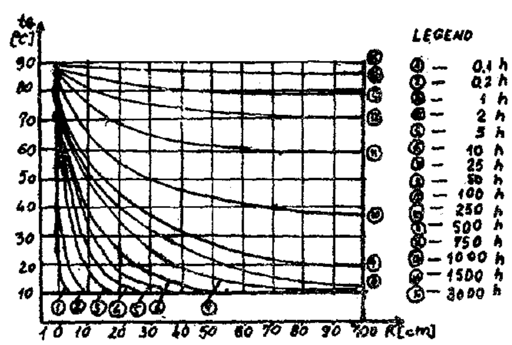


FIG. 2 -Temperature distribution
horizontal plan (-5.00 m).

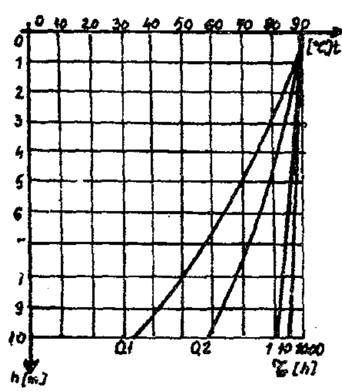


FIG. 3 Heat carrier
temperature

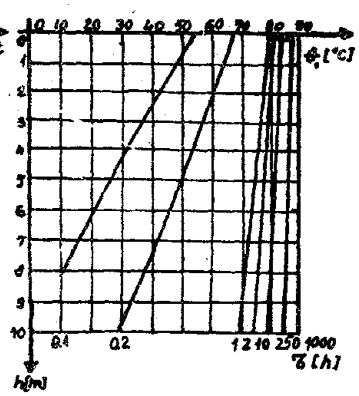


FIG. 4 Pipe surface
temperature

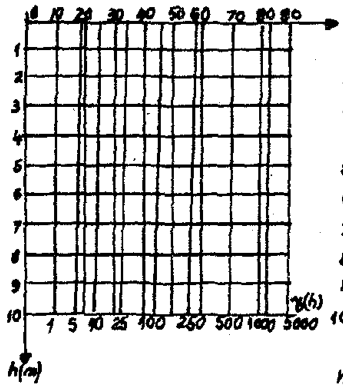


FIG.5–Earth temperature 20 m radius

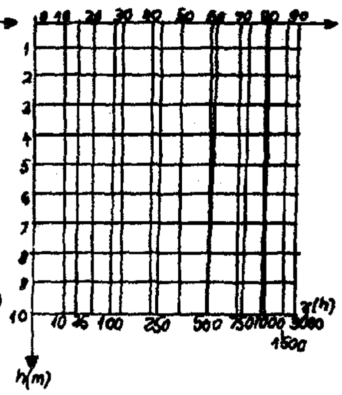


FIG. 6 – Earth temperature 50 m radius

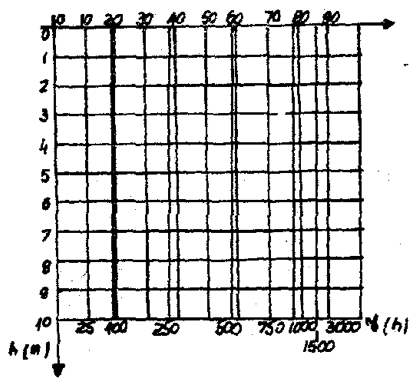


FIG. 7 Earth temperature – 1,00 m radius

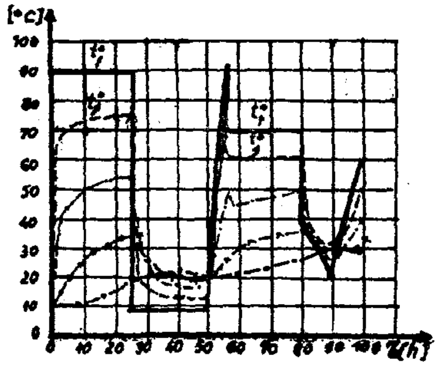


FIG. 8 Heat carrier inlet temperature plane (-5.00m) ; Earth temperature plane (-5.00m)

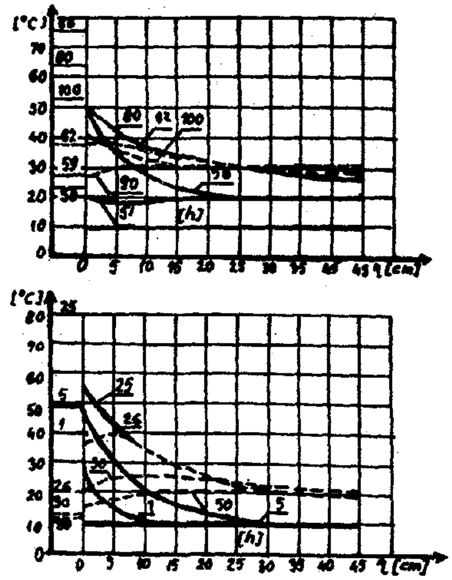


FIG. 9 - Earth temperature plane -3.50 m

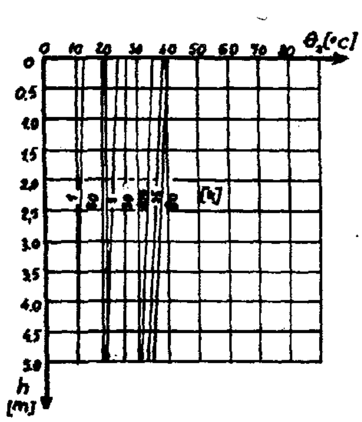


FIG. 10 - Earth temperature - . 10 m radius

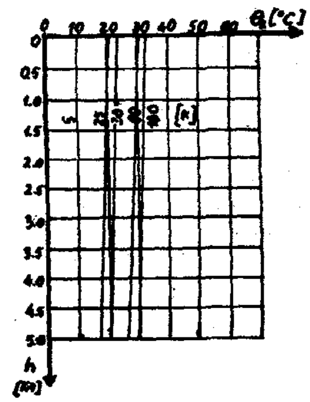


FIG. 11 - Earth temperature - . 45 m radius

NOMENCLATURE

t	-	heat carrier current temperature	(^{o}C)
ϑ	-	soil current temperature	(^{o}C)
W	-	circulation velocity of heat carrier	(m/h)
a	-	soil thermic diffusivity	(m^2/h)
α	-	factor of heat transfer by convection from heat carrier to the surface of the pipe	($W/m^{2o}K$)
λ_s	-	soil thermal conductibility	($W/m\ ^0K$)
λ_f	-	thermal conductibility of heat carrier	(W/m K)
ρ_s	-	soil density	(kg/m^3)
ρ_f	-	heat carrier density	(kg/m^2)
ν_f	-	kinematic viscousity of heat carrier	(m^2/s)
C_s	-	soil heat capacity	($J/kg^{o}K$)
C_f	-	heat capacity of heat carrier	($J/kg^{o}K$)
τ	-	current time	(h)
x	-	longitudinal current time	(m)
r	-	cross current space	(m)
R_i	-	pipe radius	(m)
Δ	-	step of radial network	(m)
Nu	-	dimensionless number Nusselt	-
Re	-	dimensionless number Reynolds	-
Pr	-	dimensionless number Prandtl	-
Fo	-	dimensionless number Fourier	-
Bi	-	dimensionless number Biot	-

Indices

i	-	net work index on x direction
k	-	net work index on r direction
j	-	time index

III.18 A TECHNICAL SOLUTION FOR HEATING ANIMAL HUSBANDRY HALLS USING A SEASONAL SYSTEM OF STORING THE HEAT SUPPLIED BY SOLAR RADIATION COLLECTORS

Dan Constantinescu x)

This paper introduces the theoretical analysis of solar radiation collecting processes as well as those of storing the heat that is obtained and its use during the cold season in order to heat two halls sheltering pigs; these halls belong to a large animal husbandry complex in Călăraşi. This analysis was used in drawing up the plans for an installation which opened in 1984.

Besides the economic value of the solution, this installation will be a pilot station as well, for the experimental control of the conclusions offered by the theoretical study.

The main requirements of the study of the physiological behavior of pigs are increased efficiency and reduced consumption of fodder, proving a direct correlation between the highest meat production and the factors of shelter inside microclimate. The factors with influence on the proper breeding of pigs are /1/:

- inside temperature level
- amplitude of inside temperature oscillation
- rate of fresh air admitted in animal breeding halls.

The correlation between the daily weight gain and the temperature is presented in Fig.1 and depends on the weight of the animals. The maximum value of the weight gain is obtained for a 18^0C-20^0 C inside temperature.

The inside temperature oscillation has negative effects on the above-mentioned factor, as is evident by the values in TableI.

---

x) Research Officer
Building Research Institute INCERC, Bucureşti, Sos.Pantelimon 266, Sector II
Romania, RO 73559

Table I

Inside temperature variation /^{o}C/	Daily average weight gain /kg/
Constant value 20^{0}C	0.80
16-27	0.60
10-32	0.48
4-36	0.31

The fresh air admitted will especially eliminate the carbon dioxide emissions, which endanger the life of the animals. The relation used in determining the fresh air rate is:

$$L = 1.3\, n \sqrt{g} \qquad /kg/h/ \qquad (1)$$

where:

n - number of animals /kg/

g - weight of an animal

L - fresh air massic flow-rate /kg/h/

The heat emissions generated by the metabolic processes, for 18^{0}C inside temperature, are determined using relation

$$Q_A = 0.016 n \sqrt{g} \qquad /KW/ \qquad (2)$$

When the world energy crisis started, important measures to reduce energy consumption and even halting space heating in animal shelters were adopted. Of course, negative consequences on animal breeding and on economic efficiency occurred. The only heat source in this situation is biological heat, which is insufficient to ensure proper conditions of inside microclimate.

In order to balance this situation, the first stage was devoted to the use of solar energy as a heat source. The installation project was based on the theoretical analysis which is described in this paper and will be performed in Călăraşi (44^{o} N latitude).

II. Description of technical solution.

The space to be heated shelters 1,000 pigs in a volume of 10,000 m^{3}. The buildings exist already and are characterized by

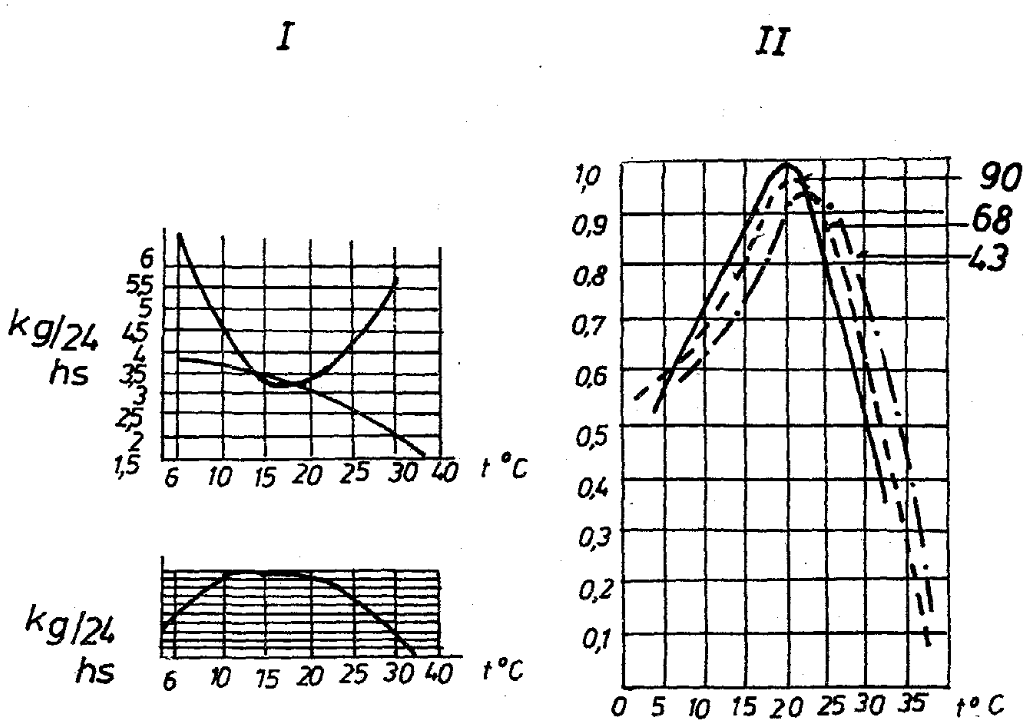


Fig. 1 Fodder specific consumption and daily weight gain according to inner temperature
H.P. R(I);U.S.A (II)

a 4,556W/K heat requirement index. The buildings thermal capacity is 627,000 KJ/K. The biological heat emissions are of 150 KW. The heating system uses warm air, covering both the heat requirement and the rate of fresh air. The overall massic flow-rate is 22,000 kg/h (12,800 kg/h represent the fresh air).

The air is heated in water-air heating batteries with 2,430 W/K thermal characteristic. The primary heat carrier is the warm water stored seasonly in a 6,000 m^3 tank. Water is heated by 2,800 water pellicle flat-plate collectors working in the period April-August. The inlet and outlet temperature values required in dimensioning the heating batteries are chosen by a thermal-economic optimum calculus. The parameters conditioning this decision are:

- building thermal capacity;
- building heat requirement;
- initial temperature of water in storage tank and its variation in time;
- heat insulation rate of heat storage tank;
- outside climate conditions.

t_{TO} and t_{RO} values have been determined by successive attempts, the inside heating thermal processes being modelled within a range of values between 75^{o} C and 40^{o}C. The solution that has been chosen is provided by the pair of values:

$$t_{TO} = 50^{o}C$$

$$t_{RO} = 30^{0}C$$

We should mention that the heating of animal shelters is performed only by using solar-heated water.

The calculuses performed on the mathematical model that was worked out prove that no auxiliary heating of halls is required beginning in March; the biological heat ensures the necessary microclimate. In March, the water temperature in the storage tank is of about 40^{o}C. Starting with March, the water will be used only to heat a greenhouse space used as hotbed and arranged on the solar collector support. The water in the seasonal storage tank is recirculated through the storage unit and heats the plant space. Additional economic gains are obtained by revaluating the plants and the installation service generates a maximum energy without using heat pumps or other exergy producing equipments.

Figs.2,3 and 4 introduce the main service schemes of the system. The initial and final temperature values of the water in the tank, which are provided by the theoretical calculus, are given in the figures.

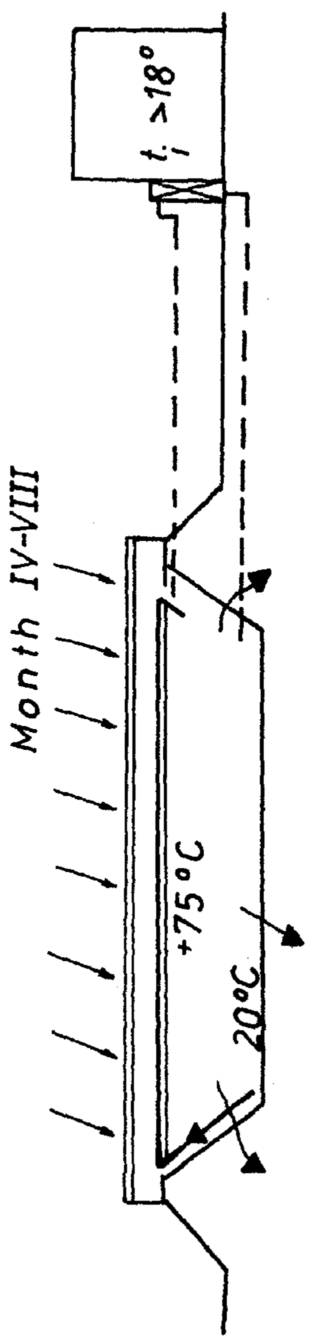


Fig.2

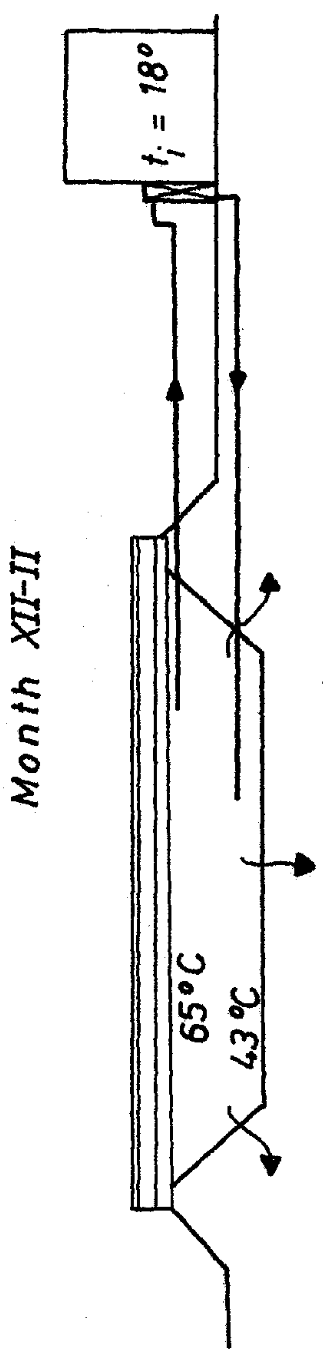


Fig.3

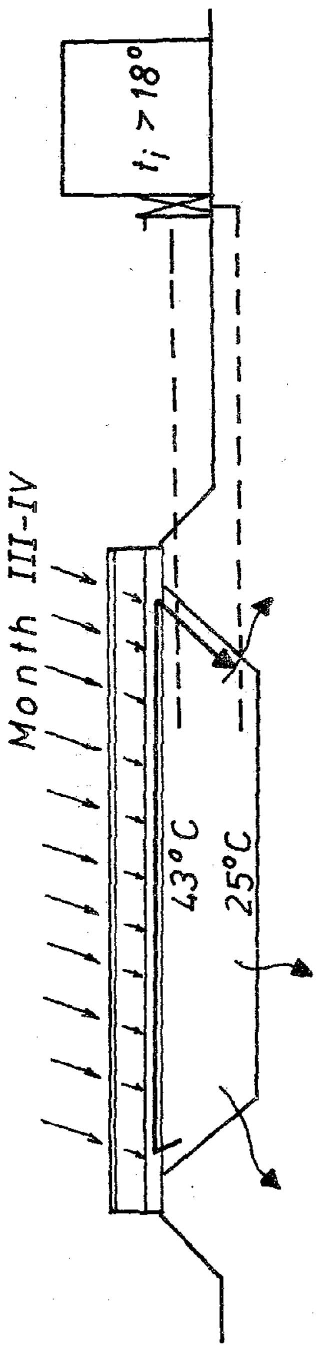


Fig.4

III. Thermal analysis mathematical models of system constituent parts.

This chapter presents the heat balance equations specific to the solar collectors as well as to the heat storage tank and to the heated space. The analytical solutions that are derived allow the system service analysis and the estimation of energy consumption and economic performances.

III.1. Water pellicle flat-plate collector

The solar radiation collecting unit is the water pellicle flat-plate solar collector made of high temperature ($\sim 80^{\circ}C$) and UV ray proofed plastics. The greenhouse effect is ensured by double glazing. The water that is taken over from the storage tank is admitted in the collector space, then heated in the sunny hours and again admitted in the tank. Water heating is therefore performed discontinuously and the collectors form a pasive heating system. Fig.5 introduces the calculus scheme. The calculus hypotheses are as follows:

- water heating is performed by thermodiffusion
- water thermophysical characteristics do not change according to temperature
- overall heat loss coefficient for $x = \delta$ area is constant
- (α_{τ}) coefficient is constant and equal to the daily average value
- solar radiation intensity and outside temperature values are considered in IIIrd type boundary conditions by daily average values.

The thermal response is represented by water temperature variation in sunny hours $\vartheta(x, \tau)$.

The problem is expressed as follows:

$$\frac{\partial \vartheta}{\partial \tau} = a \frac{\partial^2 \vartheta}{\partial x^2} \qquad (3)$$

with boundary conditions:

- Neumann type

$$\left.\frac{\partial \vartheta}{\partial x}\right|_{x=0} = 0 \qquad (4_1)$$

- IIIrd type

$$\left.\frac{\partial \vartheta}{\partial x}\right|_{x=\delta} = \frac{K_{\Sigma}}{\lambda}\left(t_{\varepsilon} - \vartheta_{/x=\delta}\right) \qquad (4_2)$$

Initial condition

$$\vartheta(x, 0) = \vartheta_0 \tag{5}$$

where

$$t_E = \frac{\alpha\tau}{K_\Sigma} I + t_e$$

The general solution is given by relation

$$\vartheta(x,\tau) = t_E - \sum_j \left[B_{1j} \cdot \cos(m_j x) + B_{2j} \cdot \sin(m_j x) \right] \exp(-m_j^2 a \tau) \tag{6}$$

For the actual case δ = 0.10 m and taking into account (4_1) and (4_2) boundary conditions, solution (7) is obtained,

$$\vartheta(\dot{x},\tau) \cong t_E - [1{,}095 \cos(0{,}763\,\dot{x}) \exp(-0{,}032\,\tau) - 0{,}119 \cdot \cos(3{,}36\,\dot{x}) \exp(-0{,}62\,\tau) + 0{,}35 \cos(6{,}40\,\dot{x}) \cdot \exp(-2{,}25\,\tau)](t_E - \vartheta_0) \tag{7}$$

where

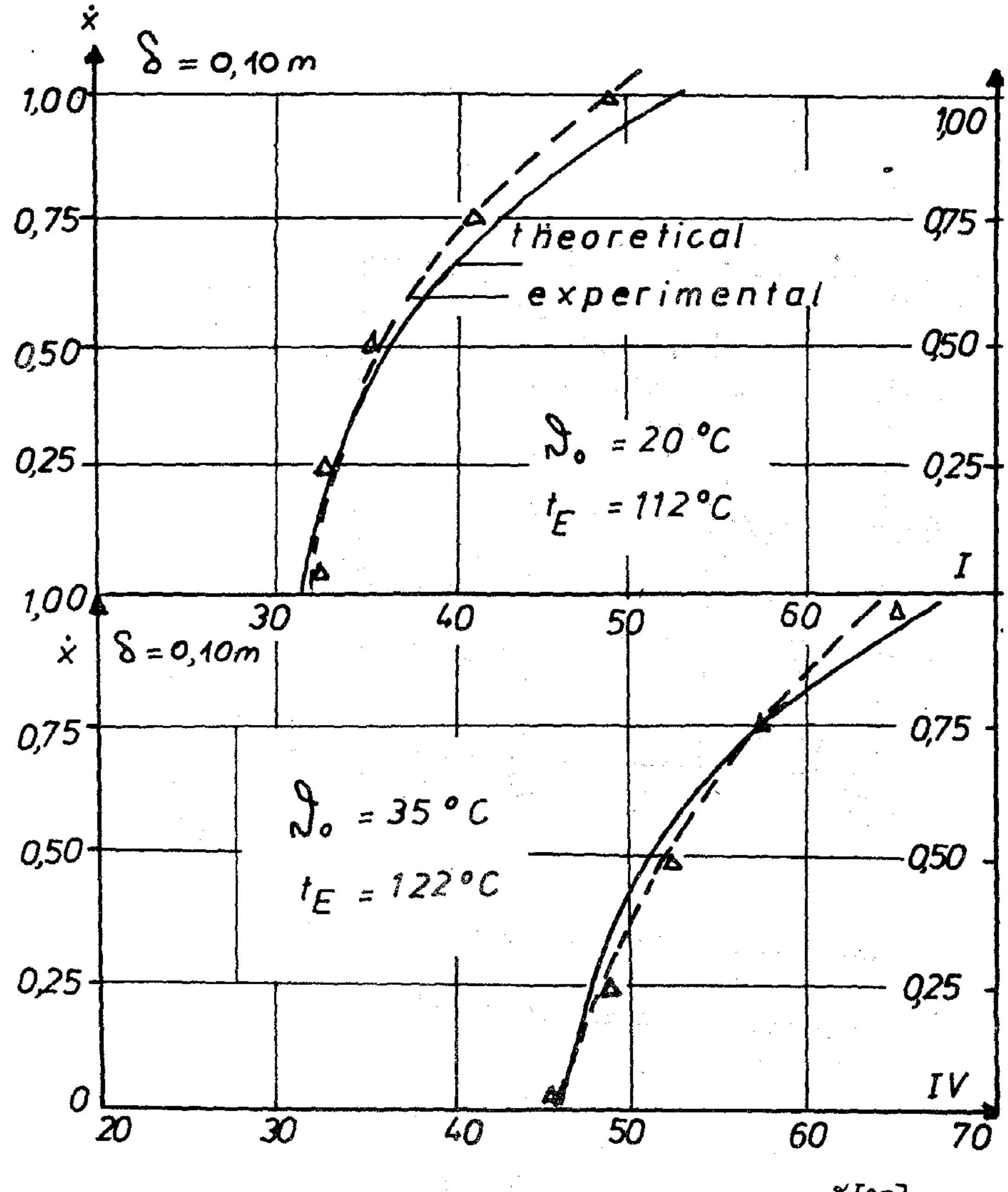
$$\dot{x} = x/\delta$$

According to the climatic data specific to the Southern part of Romania, the average daily sunny period in the warm season (IV-VIII) may be considered of 7 h/day. The final temperature value obtained in the solar collectors may be used by relation

$$\frac{t_E - \vartheta_f(\dot{x})}{t_E - \vartheta_0} \simeq 0{,}875 \cos(0{,}76\,\dot{x}) - 0{,}00155 \cos(3{,}36\,\dot{x}) \tag{8}$$

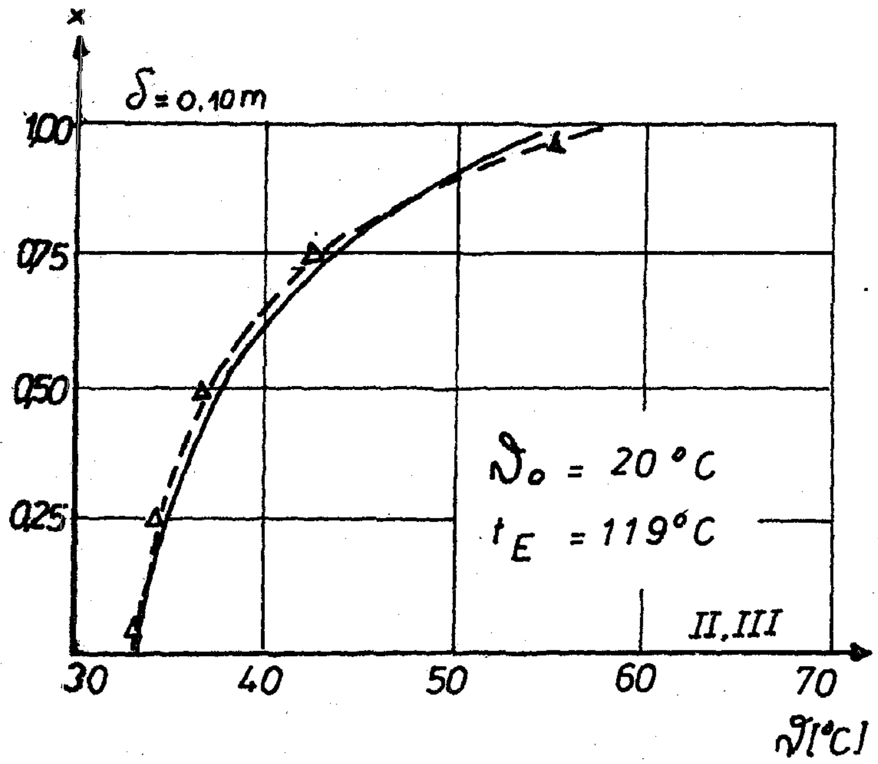
Fig.6 introduces the $\vartheta_f(\dot{x})$ experimental curves obtained in the following days: 28.04.1983; 04.05.1983; 05.05.1983 and 10.05.1983, when ϑ_0 = 20°C and ϑ_0 = 35°C. In these days, t_E ∈ /112°C, 122°C/. A satisfactory agreement between the measured values and the theoretical calculus is noticed. For measurements, a 2 x 1 modulated collector was used, supplied with a pressure drop tank and thermocouples placed at x = 0.00; 0.25; 0.50; 0.75; 1.00 coordinates. The average value $(\alpha\tau)$ = 0.68 and K_Σ = 4.64 W/m²K.

Fig.7 introduces - as histograms and average curves - the variation of the average final temperature of the heated water in the solar collectors and of the collection efficiency according to the number of water recirculations in the storage tank. The curves plotted in a continous line are determined according to the hypothesis of perfect temperature stratification



δ = 0,10 m
1,00
0,75
0,50
0,25
theoretical
experimental
ϑ₀ = 20 °C
t_E = 112 °C
I
1,00
30
40
50
60
δ = 0,10m
ϑ₀ = 35 °C
t_E = 122 °C
IV
0
20
70
ϑ [°C]

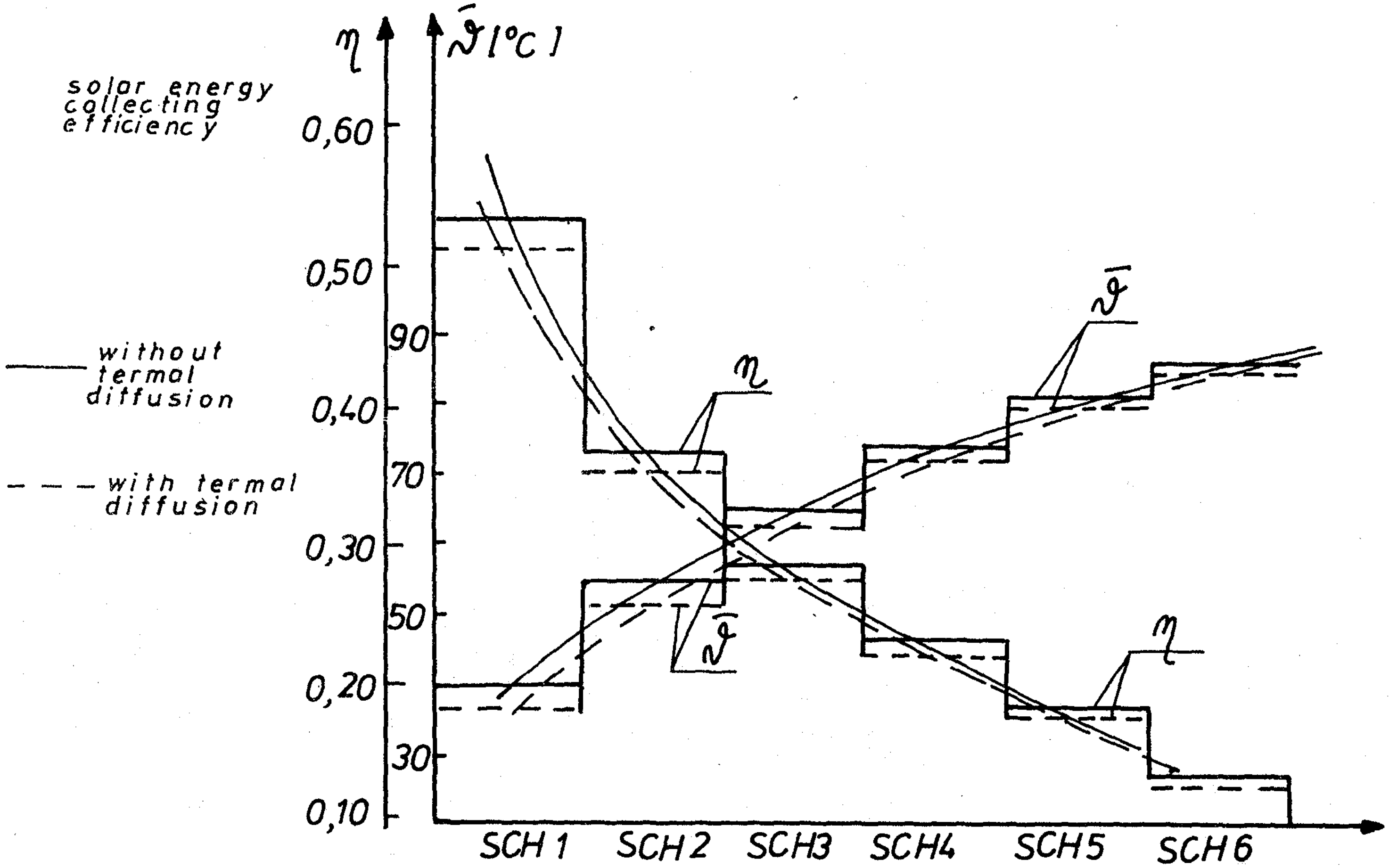
Fig. 6_1



—— theoretical

—△—△— experimental

Fig. 6_2



η
$\bar{\vartheta}$ [°C]
solar energy collecting efficiency
0,60
0,50
0,40
0,30
0,20
0,10
90
70
50
30
without termal diffusion
with termal diffusion
η
$\bar{\vartheta}$
$\bar{\vartheta}$
η
SCH1
SCH2
SCH3
SCH4
SCH5
SCH6

Fig.7

in tank and those plotted on a dotted line represent the consequence of the change in temperature distribution generated by the thermodiffusion in the seasonal heat storage tank.

The technical solution that has been analyzed ensures water recirculation in the tank for a period of 21 sunny days. The 21 days were included in the calculus in a period of 504 h (optimistic variant) up to 1,000 h (pessimistic variant).

At the end of the V^{th} exchange, the average temperature in the tank is of 80.7°C. For safety, a value of 75°C was considered in the design calculus.

III. 2. Analysis of heat diffusion phenomenon in the heat storage tank (charging period)

Temperature distribution in the seasonal storage tank depends on the heat diffusion phenomenon and has consequences on the solar radiation collecting efficiency. The analysis of this phenomenon is highly sophisticated; simplifying hypotheses are required. This phenomenon is mainly dynamic. In this paper, a discontinuous functioning of the system by successive settlings of water layers at different temperature values is admitted, in order to prove the thermal stratification hypothesis valid. The simplifying hypotheses are the following:

- the plane dimensions of the tank are very large as compared to its depth;
- the tank is considered an adiabatic space;
- neither uplifts not pumping water in and from solar collectors generate convective flows in tank.

If two water layers at t_c and t_R initial temperature values are in contact, the variation in time and space of the temperature of the two layers is studied.

The following solution (see Appendix 1) results:

$$\vartheta_c(x, \tau) = t_c - (t_c - t_R)\,\Phi(x, \tau) \qquad (9)$$

where

$$\Phi(x,\tau) = \frac{\Delta R}{H} + \sum_{k=1}^{\infty} \frac{(-1)^k}{k\pi} \exp\left(-\pi^2 k^2 \frac{a\tau}{H^2}\right)\left[\sin\frac{k\pi(\Delta_R - x)}{H} + \sin\frac{k\pi(\Delta R + x)}{H}\right]$$

and

$$\Delta_C + \Delta_R = H$$

The water is considered to be recirculated in 1,000 h as a practical application of the solution described above. The typical situation of the second exchange is $t_C = 54^{o}C$ and $t_R = 3.7^{o}C$. The following situations were analyzed: $\Delta_R/H = 0.75;\ 0.50;\ 0.25$ with $\tau = 1$ h and $\tau = 700$ h time units. The temperature variation curves are presented in Fig.$8_{1,2,3}$ ($\tau = 1$ h) and $9_{1,2,3}$ ($\tau = 700$ h). The conclusion is that in the end of the period, water temperature in the bottom zone is considerably different from the initial period. The direct consequence is the decrease of collection efficiency (see Fig.7).

Two parameters specific to the heat diffusion phenomenon were defined:

1. Diffusive heat transfer rate:

$$R_{TD} = \frac{\lambda}{\Delta_c} F_o^{-1}(\Delta_c)(t_c - \bar{\theta}_c) \qquad (10)$$

2. Heat diffusion equivalent distance:

$$\Delta_e = \Delta_c F_o(\Delta_c) \frac{t_c - t_R}{t_c - \bar{\theta}_c} \qquad (11)$$

According to the values in Fig.$8_{1,2,3}$ and $9_{1,2,3}$ the results will be:

Table II

CASE	I	II	III	IV	V	VI MU
R_{TD}	$2.18\ 10^{3}$	$5.80\ 10^{3}$	$13.05\ 10^{3}$	12.41	26.91	46.61W/ m^2
Δ_e	$5.00\ 10^{-3}$	$1.87\ 10^{-3}$	$0.83\ 10^{-3}$	0.87	0.40	0.23 m

The above mentioned values indicate a good thermal stratification in the tank. The calculus performed according to the hypothesis of uniform temperature in the storing mass leads to the conclusion that the average seasonal performance decreases by about 8%. The actual values are therefore expected to belong to this range of error. This working method is of course accepted in practical design calculuses, but this is not the purpose of this paper.

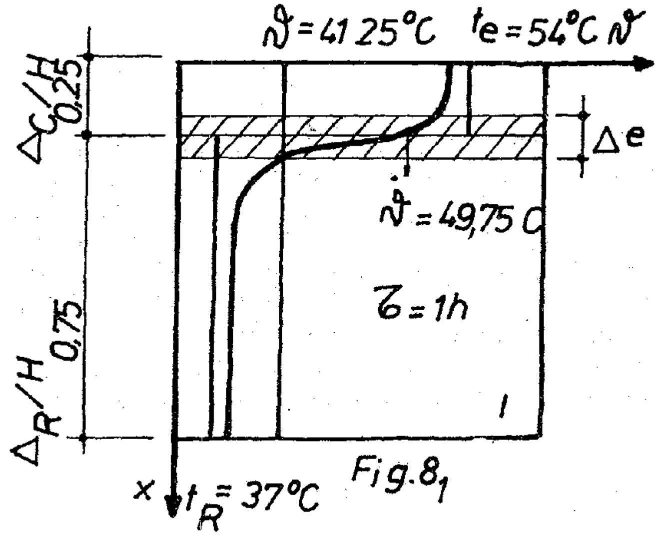


Fig. 8_1

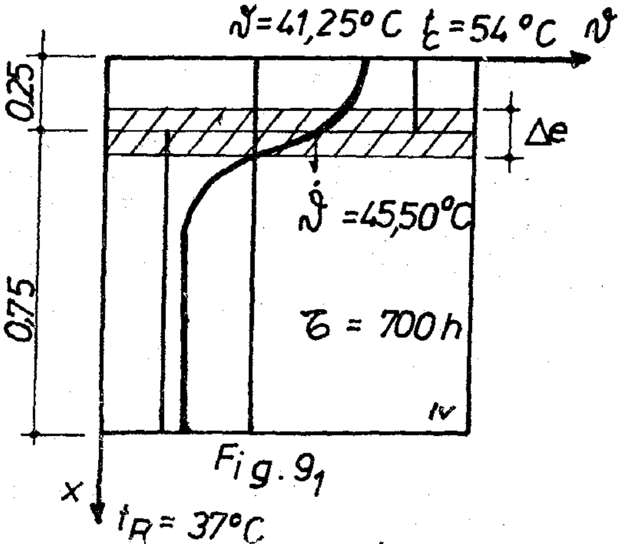


Fig. 9_1

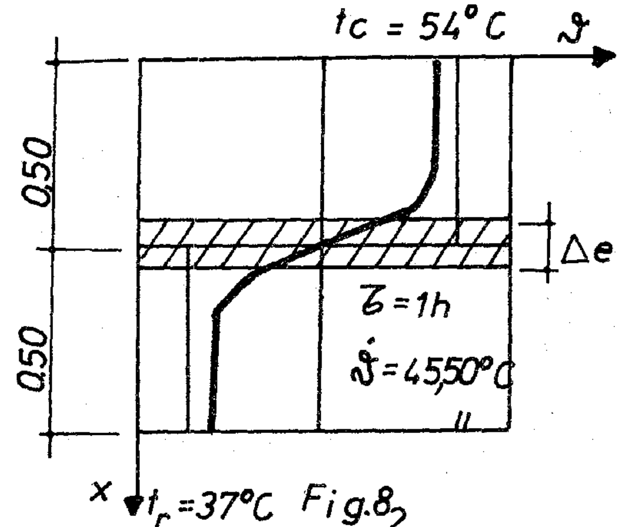


Fig. 8_2

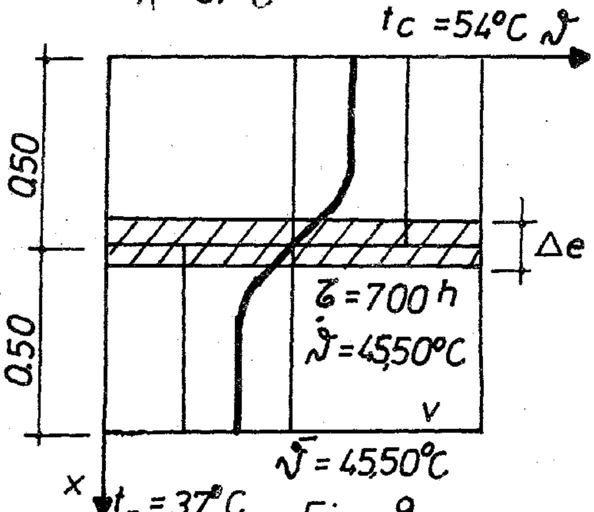


Fig. 9_2

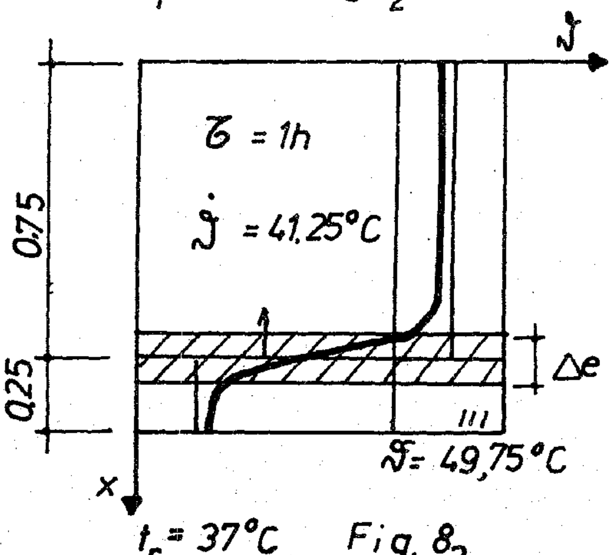


Fig. 8_3

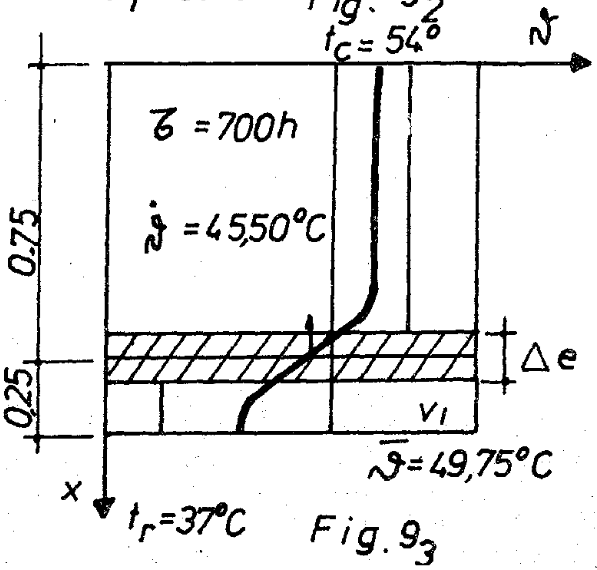


Fig. 9_3

III.3. Overall analysis model of storage tank thermal discharging and of space heating

The thermal discharging of the tank (for heating two halls and by heat losses to ground and to outside air) is studied by overall heat balance equations. This method is a simplified variant of the UTR method /2/ to be used in design calculuses (UTR = Unitary Thermal Response).

Calculation hypotheses:

- initial temperature of water in tank is uniform;
- the thermophysical parameters of water and of insulating materials do not vary with the temperature;
- while water is introduced from the hall heating circuit into the tank no drowned jets occur;
- heat transfer through soil is controlled by steady-state heat balance equations thanks to the good heat insulation of the tank;
- temperature and position of underground water are two constant values;
- The thermal response of the space is controlled according to the outside temperature values equal to the monthly daily average values in succession of identical diurnal cycles;
- the heat balance of the space is studied by steady-state equations; buildings massiveness represents the inertial element.

The calculus stages are briefly the following:

1. Determination of the zone where the heat flow lines disperse towards the outside air and the underground water (Fig.10).

For the two possible positions, P_a and P_b, values m_a and m_b are determined by relations /3/.

$$m_a = \frac{\lambda_{sol}}{\pi z_j}\left\{\left(\frac{2}{\alpha_i} + R_{iz}^{(1)} + \frac{H}{\lambda_{sol}}\right) - \left[\frac{1}{\alpha_i} + \frac{1}{\alpha_e} + (\pi - \dot{\alpha})\frac{L}{\lambda_{sol}} + R_{iz}^{(1)}\right] z_j\right\}$$

$$m_b = \frac{\lambda_{sol}}{(\pi - \dot{\alpha}) z_j + \dot{\alpha}}\left\{\left[\frac{1}{\alpha_i} + \frac{1}{\alpha_e} + (\pi - \dot{\alpha})\frac{L}{\lambda_{sol}} + R_{iz}^{(2)}\right] z_j - \left(\frac{2}{\alpha_i} + R_{iz}^{(2)} + \frac{H}{\lambda_{sol}}\right)\right\}$$

where

$$z_j = \frac{\theta(\tau) - t_f}{\theta(\tau) - t_e}$$

For the range $\theta(\tau) \in [35^\circ C, 75^\circ C] \cup t_e \in [-10^\circ C, 15^\circ C,]$ $m_a < 0$ results and therefore m_b is the only possible position.

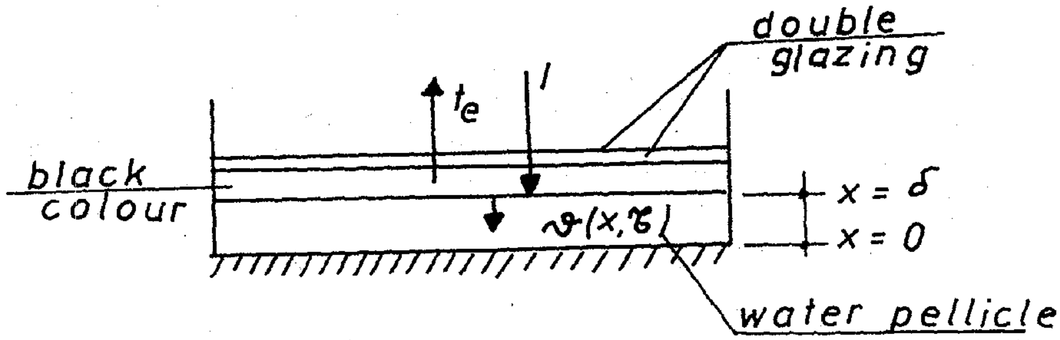

double glazing
black colour
water pellicle
x = δ
x = 0
ϑ(x,τ)

Fig. 5

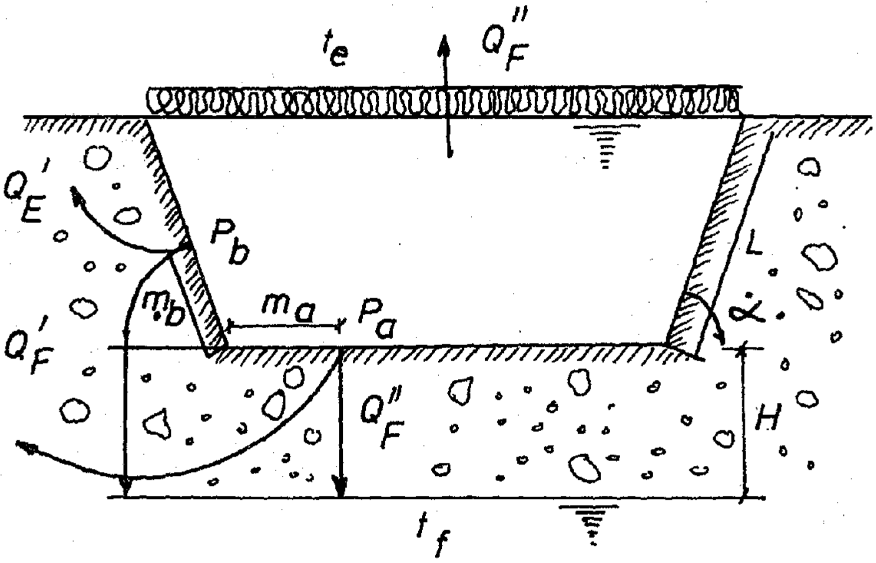

P_b
P_a
m_a
m_b
L
H
α

Fig. 10

$\frac{H}{P}$ = 0,174, in which sensible heat is stored, in water heated in a flat plate collector system, each collector being connected in parallel, with three recirculations per season of the water in the tank. They may be also applied to recuperators of heat resulted from residual energies.

The main problems dealt with in the paper refer to:
- the physical model of the processes in the storage tank;
- the mathematical model of temperature distribution along the tank vertical for "thermal storage-discharge";
- the adequate selection of heat-exchangers fed from the tank, in dynamic condition;
- establishing the period for an efficient utilization of the storage tank in order to supply the industrial consumer by means of heat exchangers with a view to subsequent coupling to a heat pump.

THE PHYSICAL MODEL

The thermal condition in the tank is non- steady, the analyzed system being forced circulation (fig.1). It depends mainly

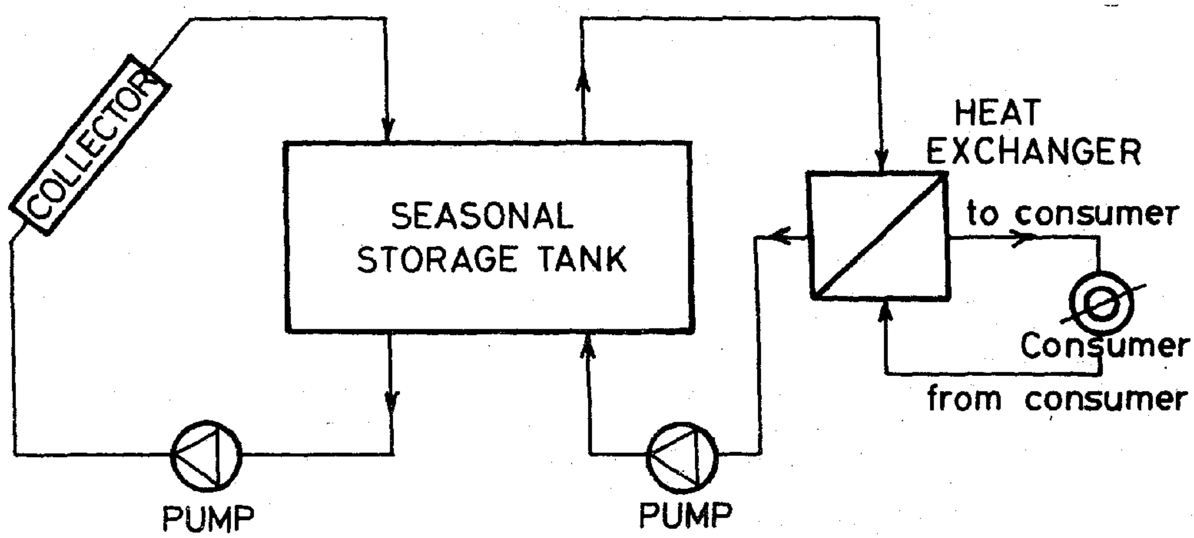


Figure 1

on: the thermal efficiency of the solar collector (or recuperator), parameter variable with time and dependent on solar radiation intensity and external climatic factors; the temperature of the water drawn off the tank, variable with time; duration of water circulation through the collectors in the sunny period; duration of water cooling in the tank or number of sunless days; optimum quality and thickness of heat insulation; tank geometry; tank location (outdoors, partially or wholly buried). The mere enumeration of these factors elonquently points to the complexity and difficulty of approaching a research of this kind.

The physical model drawn up by the authors is,briefly the following:

a. in the period of the heat storage:

- the hot water from the collectors (or the recuperator) is introduced as horizontal warm jets into the initially c o l d. steady water existing in the limited space of the tank /1/, /2/ , /3/.

The jets penetrate through the d_o = 20 mm diameter inlets of three distributing rings made of Ø 218 x 9 piping with respectively 20,35 and 45m diameters. They are submerced and buoyant, with cold water entrainment in density currents (of Archimedes type) under the influence of buoyancy. The great circulated water flow rates and the relatively great tank cross section determine low average jet velocities, of the 0.03-0.05 m/s order; consequently, the hypothesis of circulation with hydraulically steady and quasi-steady density inlet is justified. During the heat storage period (9 hours approxomately/day between April, 1 a n d October, 30-th, in Bucharest - Romania) heat transfer is due t o forced convection (molar) and to conductive thermal diffusion (molecular).

b. during the cooling or sunless day period, heat transfer is due both to the enthalpy flow rate in buoyance (Archime d e s) and to conductive thermal diffusion.

For example, the supply of water jets having a temperature lower than of the first water layers in the tank, a case that"can frequently occur towards the end of the thermal storage period" (in September-October), sets off an unstable stratification, with the occurance of buoyancy which is what, causes the transfer o f enthalpy from the hot zone to the cold zone and, by free convection, the redistribution of temperatures along the tank vertical. In the case of a drastic thermal insulation ($k_{iz} \leqslant$ 0.1 - 0.15 $W/m^2.^{o}C$) the effect of edge currents is neglijable, heat losses being, reduced and conductive thermal diffusion becomes the de - cisive transfer process in the thermal stratification along the vertical when buoyancy exists, edge density currents occur and thermal stratification is accompanied by mass and heat transfe r enthalpy).

THE MATHEMATICAL MODEL

Assumptions:

- the real discharge of the hot jets through the inlets of the distributing rings may be equated to a steady density circulation at low velocities, actually hydraulically steady;
- in each "characteristic" water layer in the tank, t h e

thermophysical parameters are considered mean and invariable with time. Their real variation with time and space is practically impossible to be expressed mathematically but for a reduced layer thickness, the variation of ρ, λ, c_p, μ with time is unessential;

- the radial temperature gradient are negligible
- the tank is located outdoors, at ground level;
- the initial cold water temperature is constant and uniform along the tank vertical.

1. The model of "Thermal Storage" (with Stable Stratification). According to the diagram in fig.2 the conservation balance may be written for any layer in the differential form /1/, /2/, /5/:

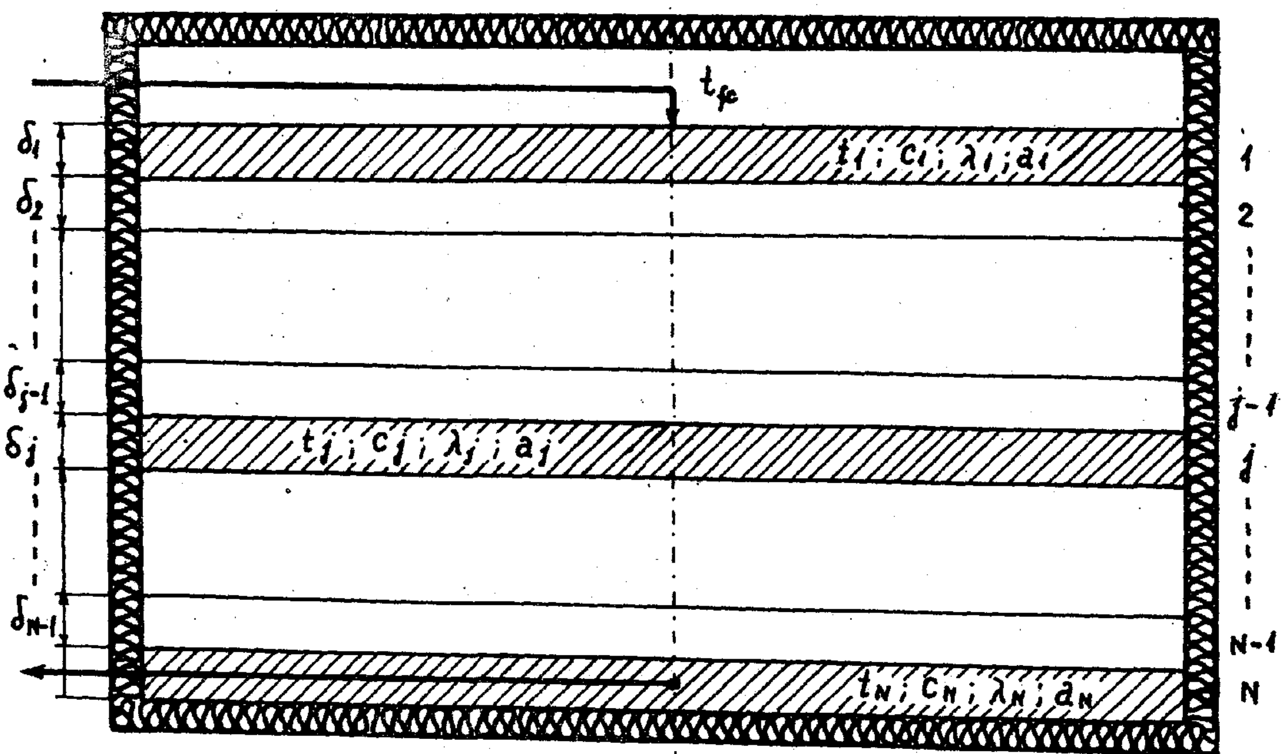


Figure 2

$$M\bar{c}_{p_s} \cdot \frac{dt_s}{d\tau} = m_c \bar{c}_{p_c} (t_{f.c} - t_s) - \bar{k}_{iz}\, S_R (t_s - t_e) \qquad (1)$$

By using the Euler method modified /5/, /7/, as approximate numerical method for the integration of type (1) equations, in finite differences, there results:

$$t_s^{\tau+1} = t_s^{\tau} + \frac{\Delta\tau}{M\bar{c}_{p_s}} \left[\dot{m}_c \bar{c}_{p_c} (t_{f.c} - t_s^{\tau}) - \bar{k}_{iz}\, S_R (t_j^{\tau} - t_e)\right] \qquad (2)$$

The unknown $t_{f,c}$ in relation (2) has been eliminated by coupling it to the Hottel-Whillier balance equation /4/, /5/, regarding flat solar collectors:

$$\dot{Q}_u = \dot{m}_c \bar{c}_{pc} (t_{f,c} - t_{i,c}) = S_p F_R' \left[\alpha \tau I_\beta - k_p \left(\frac{t_{f,c} + t_{ic}}{2} - t_e \right) \right] \tag{3}$$

having as result the final form:

$$t_{f,c} = \frac{1-\beta}{1+\beta} \cdot t_{i,c} + \frac{2\beta}{1+\beta} \cdot \left(t_e + \frac{\alpha \cdot \tau \cdot I_\beta}{k_p} \right) \tag{4}$$

in which,

$$\beta = \frac{k_p \cdot S_p \cdot F_R'}{2 \dot{m}_c \bar{c}_{pc}}$$

On the assumption of a complete mixing in each characteristic water layer (of Δy = 10 cm thickness and N = 100 layers) the general relations have been obtained:

a. In the storing period

- layer (1):

$$t_1^{\tau+1} = t_1^\tau + \frac{\Delta \tau}{m_1 \bar{c}_{p_1}} \cdot \left[\dot{m}_c \bar{c}_{pc} \cdot \left(t_{f,c} - t_1^\tau \right) - \left(t_1^\tau - t_e \right)\left(k_1 \cdot S_{lid} + k_{i2} \cdot S_{1,\ell} \right) \right] \tag{5}$$

- layer (j):

$$t_j^{\tau+1} = t_j^\tau + \frac{\Delta \tau}{m_j \bar{c}_{p_j}} \left[\dot{m}_c \bar{c}_{pc} \left(t_{j-1}^\tau - t_j^\tau \right) - \left(t_j^\tau - t_e \right) k_{i2} \cdot S_{j,\ell} \right] \tag{6}$$

- layer (N):

$$t_N^{\tau+1} = t_N^\tau + \frac{\Delta \tau}{m_N c_{p_N}} \left[\dot{m}_c \bar{c}_{pc} \left(t_{N-1}^\tau - t_N^\tau \right) - \left(t_N^\tau - t_e \right)\left(k_N S_{bottom} + k_{i2} S_{N,\ell} \right) \right] \tag{7}$$

b. In the cooling (or sunless day) period

$$t_1^{\tau+1} = t_1 - \frac{\Delta \tau}{m_1 \bar{c}_{p_1}} \left[\left(t_1^\tau - t_e \right)\left(k_1 \cdot S_{lid} + k_{i2} \cdot S_{1,\ell} \right) + \dot{Q}_1 \right] \tag{8}$$

where $\dot{Q}_1 = \frac{\lambda}{\delta_1} \left(t_1^\tau - t_2^\tau \right) \cdot S$, represents the conductive thermal flow rate (by diffusion) between layers 1 and 2;

$$S = \frac{\pi \cdot D_i^2}{4}$$ - contact area between layers.

- layer (j)

$$t_j^{\tau+1} = t_j^\tau - \frac{\Delta \tau}{m_j \bar{c}_{pj}} \left[k_{i2} \cdot S_{j,\ell} \left(t_j^\tau - t_e \right) + \dot{Q}_j \right] \tag{9}$$

- layer (N):

$$t_N^{\tau+1} = t_N^\tau - \frac{\Delta \tau}{m_N \bar{c}_{p_N}} \cdot \left[\left(\bar{k}_N \cdot S_{bottom} + k_{i2} \cdot S_{N,\ell} \right) \left(t_N^\tau - t_e \right) + \dot{Q}_N \right] \tag{10}$$

In these relations $\bar{c}_{p_c} = \bar{c}_{p_1} = \bar{c}_{p_2} = \dots \bar{c}_{p_N} = 4,19\ KJ/kg\,K$

$$\delta_1 = \delta_2 = \dots \delta_N = \frac{h_1}{N}$$

$$m_1 = m_2 = \dots m_N = M/N$$

The stability and convergence of the system of type (5-7) and (8-10) equations was assured by the time step $\Delta\tau = 1$ h for $\delta_j = 10$ cm; N = 100) the error being below 1% /1/, /2/, /5/,/6/, For the 20,000 m reinforced concrete cylindrical tank there have been considered V_R= 20,000 m; D_i = 50,5 m; h_1 = 10m; $k_1 = k_N = k_{lz}$= 0,16 W (m^2. C) ; $t_{i,c}$ = 15°C; S_p = 3774 m; V_c =37,74 m^3/h . (3 recirculations per season of the water volume in the tank) $\simeq$ 10 l/m^2.h; w_o= 0,077 m/s; type I.A.E.Alexandria flat solar collectors, having: m_1 = 10 l/m.h; S_p = 2 m; k_p = 907 W/(m^2. C) ; F'= 0,89; $\alpha\tau$ = 0,78 and being each connected in parallel. By running the program "SOLARIS-ICB-Heat Engineering Department" deawn up by the authors /1/, /2/, it has resulted that the cooling phenomenom occurs in the upper hot water layers as against the adjoining lower ones, hence an unstable stratification takes place.

This phenomenon is caused by the intake of water discharge from collectors with condition $t_{f,c} \leq t_1$, hence, by the occurance of buoyancy which, in October, operates intensely, leading to full quasi-mixing of the water in the tank.

For these reasons and also saving pumping energy during the heat storage period, the mathematical model of stratification (without buoyancy) is valid only with a control function of the type:

$$F \cdot \dot{m}_c\ , \quad with\ F = \begin{cases} 0, & t_{f,c} < t_1 \\ 1, & t_{f,c} \geq t_1 \end{cases}$$

Which may be obtained by the microprocessor automation of the storing system.

Thus, the model is confined only to the cases of stable stratification, where the influence of buoyancy is null.

2. The model of unstable stratification

The authors have extended this model for an unstable stratification of the type schematized in fig.3. The occurrence of free convection in the fluid in the presence of a temperature non-linear field (dependent on time or as a result of the intake of the hot jet into the tank) with the non-linear variation of density is set off by the buoyant force (Archimedes):

$$P_A = \gamma_0 - \gamma = -g(\rho - \rho_0)$$

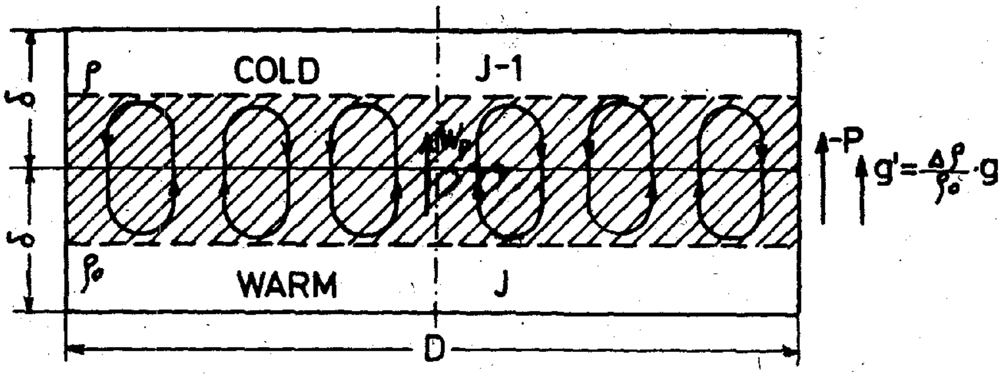


Figure 3

The time interval for the circulation on height Δy, is:

$$\Delta \tau = \sqrt{\frac{2y\rho_o}{g\Delta\rho}} \qquad (11)$$

and the "buoyancy" theoretical velocity:

$$w_p = \sqrt{\frac{g y \Delta\rho}{2\rho_o}} \qquad (12)$$

For liquide (water) $\frac{\rho-\rho_o}{\rho_o} \simeq \beta(T_o - T) = \beta\Delta T$ and the determinant similitude criterion, in the assumption of a linear variation $\rho = \rho(T)$ is Proude densimetric, $F_D = w^2/[g y\cdot(\Delta\rho/\rho_o)]$
With $\frac{T_o - T}{T} \simeq \beta\Delta T$, Grashof criterion is also obtained"

$$G_r = \frac{g y^3}{\nu^3}\beta\Delta T$$

For fluid layers heated in volume, Sparrow /8/, studying the analysis of linear stability, introduces Rayleigh criterion: Ra = $= Gr\cdot Pr = (g\cdot y^3\beta\Delta T\cdot\rho\cdot c_p)/(\nu\cdot\lambda)$

Theoretical and experimental research has demonstrated the existence of a Ra_{cr} which separates stable stratification from the unstable one, but thickness y (of the unsteady layer) cannot be mastered, being a parameter which cannot bring about progress in this problem. The critical Rayleigh number depends on hydrodynamic and thermal boundary conditions and on the non-linearity N, which represents a measure of the deviation of the real profile of densities as against the linear, classical one /8/.

Buoyancy velocity depends, too, on many factors such as: mixing length between the hot and cold particles, fluid layer friction, advancing resistance of the hot water mass into the cold one, the diffusion kinetic coefficient, etc.
Its mean value is, /1/ :

$$\bar{w}_p = \frac{1}{\delta}\int_0^{\delta} w_y(y)\,dy = \frac{2}{3}\sqrt{\frac{g\delta\Delta\rho}{2\rho_o}} \qquad (13)$$

and the effective mean velocity of the layer:

$$\bar{w}_{ef} = \bar{w}_y \pm \bar{w}_p \qquad (14)$$

(with sign + at the wall and - in the central zones).
The entalpy flow rate transferred by buoyancy is:

$$\dot{Q}_p = \dot{m}_p i_o = \pm \rho_o \bar{w}_p \varphi S c_{p_o} t_o \qquad (15)$$

where $\varphi = S_{ef}/S$, $(\varphi < 1)$. For two significant layers "j" and "j-1" in which buoyancy takes place, the adjusted conservation equations result:

$$m_j \bar{c}_{p_j} \cdot \frac{\Delta t_j}{\Delta \tau} = -\bar{k}_{iz} \cdot S_{j,l} \cdot (t_j^{\tau} - t_e) - \dot{Q}_j - \dot{Q}_p \qquad (16)$$

where

$$\dot{Q}_j = \frac{\lambda_i}{\delta_i} \cdot S \left[2 t_j^{\tau} - (t_{j-1}^{\tau} + t_{j+1}^{\tau}) \right] \qquad (17)$$

of

$$t_j^{\tau+1} = t_j^{\tau} - \frac{\Delta \tau}{m_j \bar{c}_{p_j}} \left[\bar{k}_{iz} S_{j,l} (t_j^{\tau} - t_e) + \dot{Q}_j + Q_p \right] \qquad (18)$$

The modified equations have been used to write a program for the simulation on computer of the model with stratification and buoyant force, when $t_j > t_{j-1}$. Figure 4 shows the temperature profiles traced on computer at the end of each significant

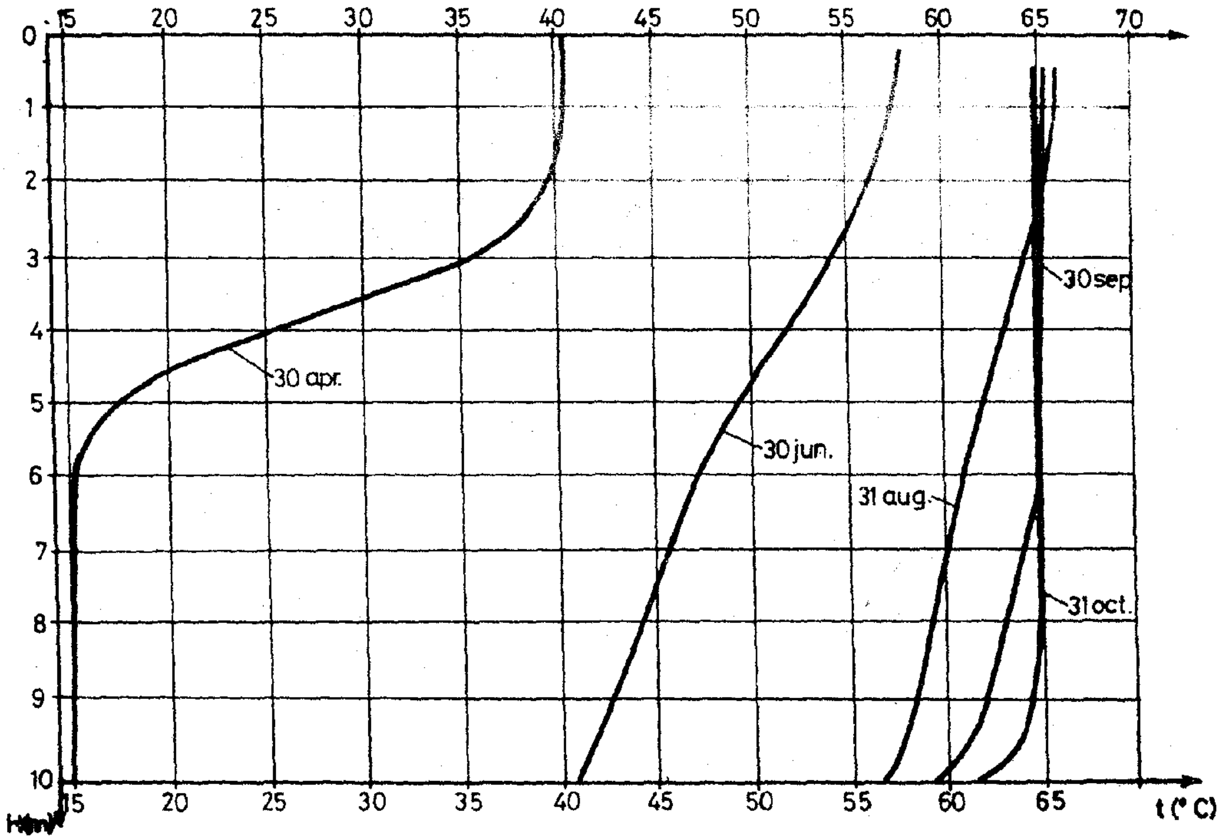


Figure 4

mouth during the"thermal storage " period of the tank.

3. The Model of "Thermal-Discharge" of the tank

According to the diagram in fig.1 and the assumptions:

- the tank supplies a low temperature industrial consumer by means of a surface heat-exchanger;
- the primary heat-carrier in the exchanger (the hot water in the tank) is taken over by the upper part of the tank through the same distributing rings used at the thermal "storage" stage;
- after being used in the exchanger, the primary heat carrier is again driven into the tank by a circulation pump; this readmission is performed by the concentric rings at the bottom of the tank;
- the heat exchanger operates in a dynamic, un-steady state: on the side of the secondary agent, the parameters (temperatur e , flow rate) remain constant with time, which implies the permanent modification of the temperature and flow rate of the primary agent taken over from the tank;
- thermal "discharge" begins from an initial thermal stratification corresponding to the end of the "thermal storage"(fig. 4, October).

The thermal condition in the tank has been simulated mathematicaly, using the equations type (5-7), (8-10), associated with the heat balance of the heat exchanger:

$$\dot{Q}_u = \dot{m}_1 \bar{c}_{P1}\left[t_1'(\tau) - t_1''(\tau)\right]\eta_s = \dot{m}_2 \bar{c}_{P2}\left(t_2'' - t_2'\right) = k(\tau)\cdot S_o \Delta t_m(\tau) \quad (19)$$

For the annual thermal requirements of an industrial consumer: $Q_i^{ann} = 1749\ Q_i^v$ $Q_i^v = 0.62893\ Gcal/h$ /2/ and a heat supply chart corresponding to table 1, the type ICMA B-55-OL/8 x 3,5m horizontal multi-tubular sectional heat exchanger, having the surface $S_o = 8427\ m^2$ has been tested.

TAB.1

Repartition of the thermal duty of the industrial consumer supplied from the storage tank

MONTH	XI.	XII.	I.	II.	III.
Q_i^{mon}/Q_i^{ann} %	12.5	22.1	26.6	22.1	16.7
t_e^{mean}, °C	6.1	0.9	-2.2	-0.1	4.6
t_d/t_i, °C	35/27	41/28	45/30	42/28	37/26

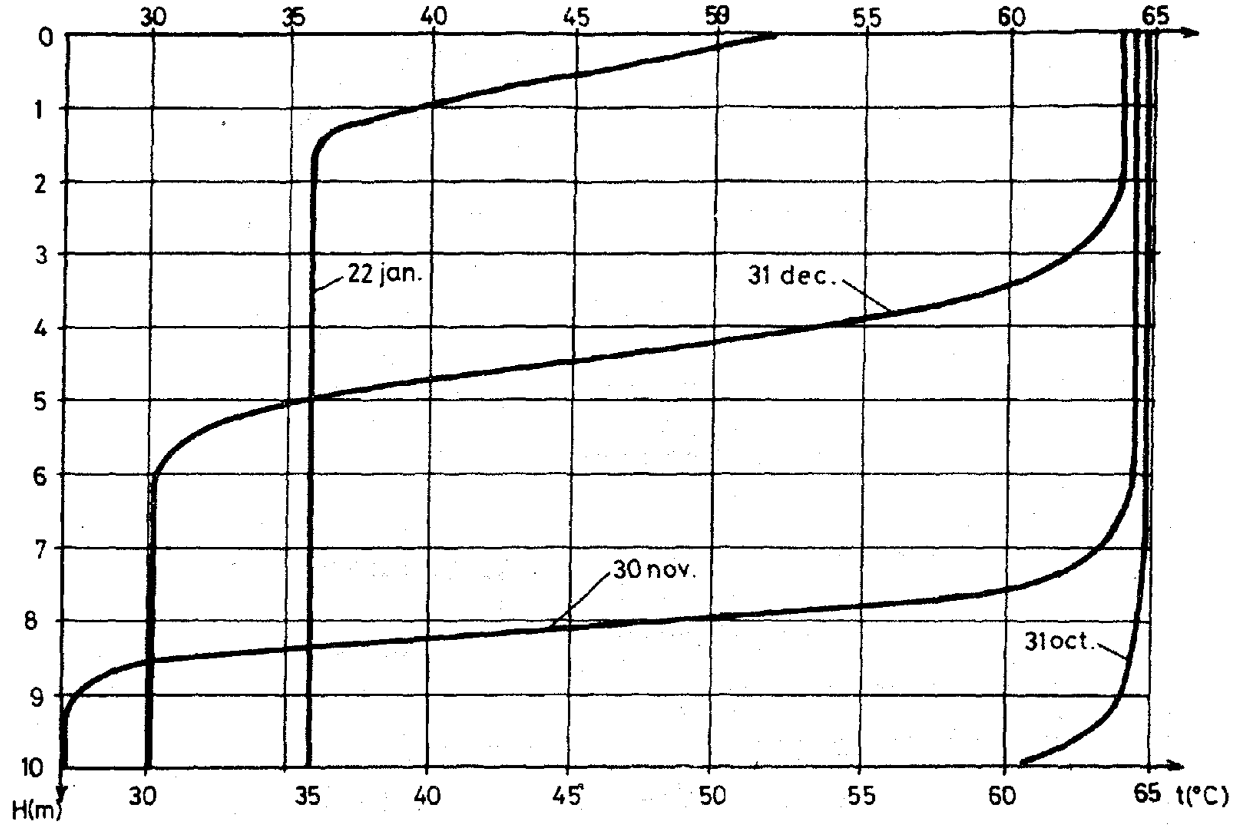


Figure 5

Figure 5 presents the evolution of thermal stratification at tank "discharge" by means of the heat exchanger, sized for peak conditions (January) and tested on computer in a dynamic regime. Figure 6 shows the curves of variation with time of water temperature when entering the tank, $t'(\tau)$ and respectively of the overall heat transfer coefficient $k(\tau)$. in figure 7.

CONCLUSIONS

- The authors' research has proved the necessity of simulating on computer the thermal processes in a tank for seasonal storage of the sensible heat in water heated by the sun (or by residual energies);
- During the "thermal" storage period, a thermal stratification occurs in the tank, especially during the first months April -July, which in the end evolves to a full quasi-mixing;
- The mathematical model with stratification and without buoyancy is restricted to the existence of a stable stratified temperature field, hence to a control function F, ($t_{f,c} \geqslant t$). If unstable stratification ($t_{f,c} < t$) occurs, the influence of buoyancy is decisive and the mathametical model worked out by the authors

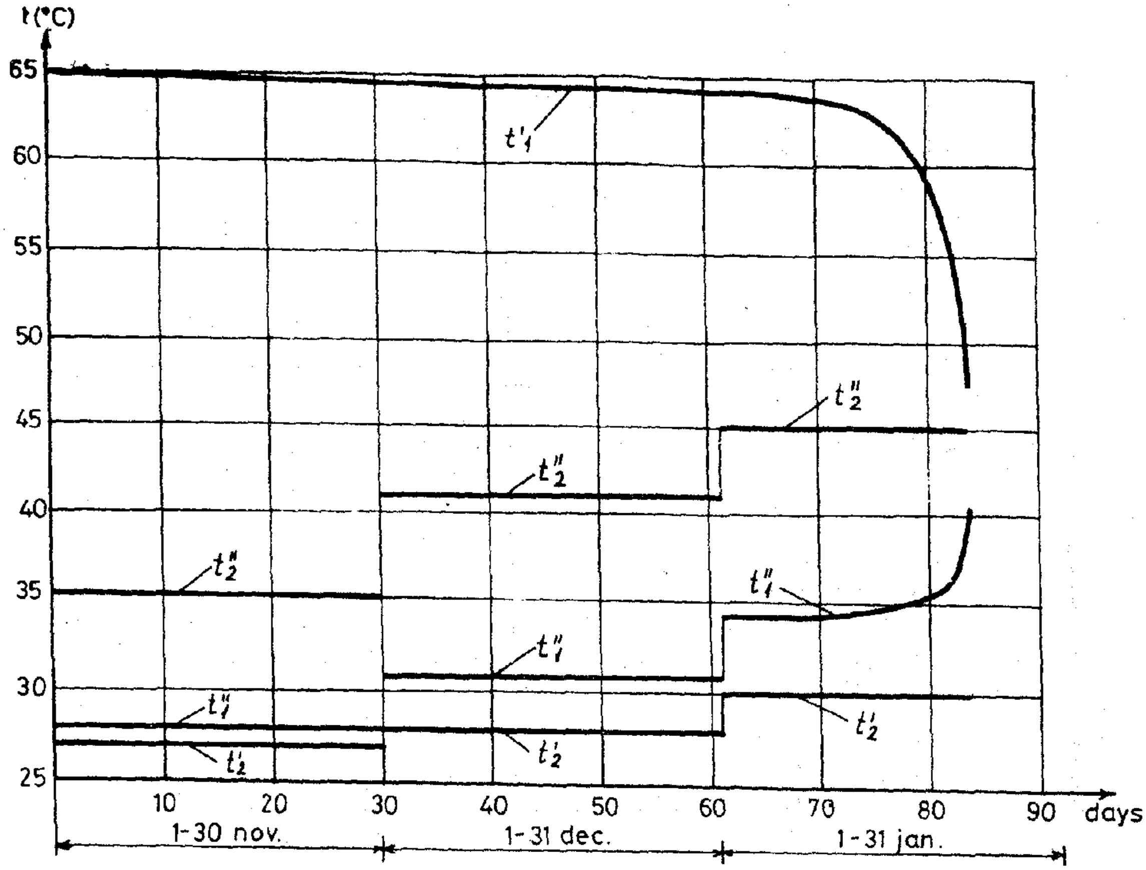


Figure 6

adequately answers the physical phenomena in the tank;

- The programs run on computer have proved that "thermal storage" is practically over in September, the heat losses during the month of October being non-significant at the 20,000m^3 tank . Therefore, interruption of circulation is advisable in October, a step that will save pumping energy. The mean temperature along the vertical tank at the end of thermal "charge" is approx.64.5°C in comparison with approx.57°C as results by applying a "fully mixed" calculus model /1/, /2/;

- The first stage of the thermal "discharge" by means of a heat exchanger has been considered completed when the temperature between the primary agent and the secondary one has decreased below 4°C. In this case, the program run on computer, according to the mathematical model of "discharge", with the initial stratification (fig.5), has proved that the system may operate, with the above mentioned heat exchanger, till January 23, or about 84 days. The second stage of "discharge" refers to coupling the storage system to a heat pump, thus obtaining total energy independence or to

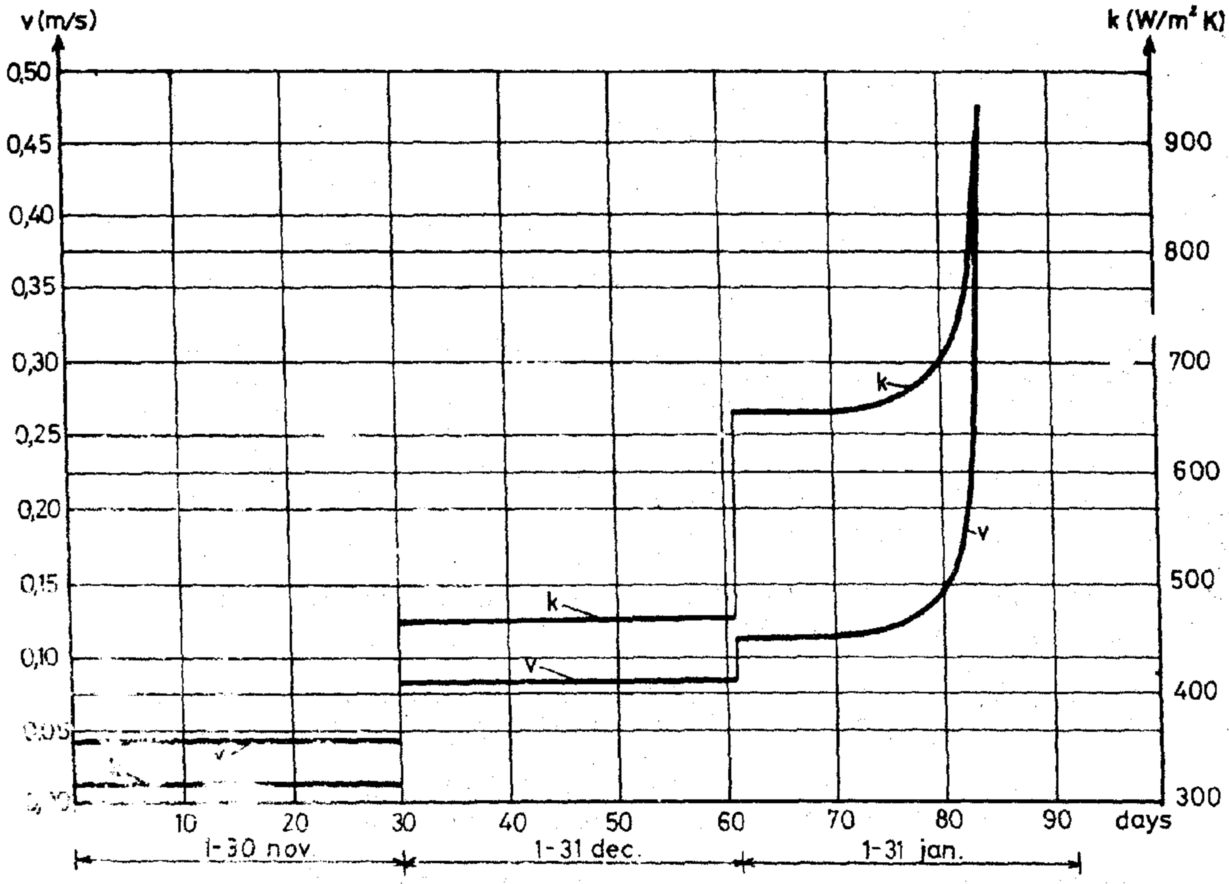


Figure 7

a classical addition source.

- At present, in co-operation with IPCT-Bucharest, INCERC - Bucharest and ICH-Bucharest, a pilot plant has been built for the heating of annex buildings on the ICH-platform, with the help of the heat stored in a 300 m^3 experimental storage tank, coupled to 40 flat plate solar collectors IAE-Alexandria (S=80 m^2) and a heat pump ICPIAF-Cluj (26,000 local/h). In this way 70-80% of the annual heat requirement is met for an approx.800 m^3 built volume. According to the recordings of flow rates, temperatures, circulation velocities of agents, the plant will enable the experimental testing of the mathematical models worked out and the drawing of final conclusions on these research problems.

Because of space limitations, it was not possible to include in the paper the results concerning the dynamic condition of the heat pump and the efficiency of the storage system but they point to the utility of seasonal storage systems in large capacity tanks.

BIBLIOGRAPHY

/1/ Mihăilă, C., Paraschivescu, Cr., Ghiauş, A.G.:"Contributions regarding simulation of Thermal Condition in Seasonal Storage Tanks" (I), Review of Buildings, no.9, Bucharest, 1984

/2/ Mihăilă, C., and Research-team: "Study regarding Thermal Condition in Seasonal Storage Tanks", Civil Engineering Institute, Bucharest, no.120 research contract, 1983.

/3/ Mihăilă, C., and research-team: "Measure plant for the Parameters of Water Thermal Condition in the 300 m^3 Solar Heat Storage Tank", no.192 research contract, Bucharest, 1984.

/4/ Hottel, H.C., Whillier, A.: "Evaluation of flatplate solar collector performance", Trans.Conf.on Use of Solar Energy, Arizona, Tucson 2, pp.74.1958.

/5/ Duffie J.A., Beckman,W.A.: "Solar Energy Thermal Processes", J.Willey, New York, 1974.

/6/ Welty,J.R., Wicks, Ch.E.Wilson, R.E.: "Fundamentals of Momentum, Heat and Mass Transfer", J.Wiley, New York, 1976.

/7/ Korn, G.A., Korn, Th.E.,: "Mathematical Handbook for Scientists and Engineers", Mc Graw-Hill Book Comp. New York, 1968.

/8/ Sparrow, E.M. Goldstain, R.J., Jonson V.K.: "Thermal Instability in a Horizontal Fluid Layer: Effect of Boundary Conditions and Non-linear Temperature Profile", J.Fluid Mech., vol.18, pp.513, 1963.

III.20 EXPERIMENTAL PILOT STATION FOR THE SEASONAL SOLAR ENERGY HEATING SYSTEM

– Rodica Grigore x)
Dan Berbecaru x)
Angela Costea x)
Cristina Hurduc x)
Valentin Boca x)

The possibilities of using solar energy during the whole year and especially in winter, when heating consumption in buildings grows, are conditioned first of all on the problem of solar energy storage.

Providing solar energy storage can eliminate the time impediment between the period of maximum solar contribution and the period of maximum consumption.

At the experimental pilot station in Bucharest scheduled to be built during 1985, the efficiency of the heating system will be checked with the help of seasonally stored solar energy in an above-ground 300 m^3 storage tank that is thermally insulated.

The installation is also provided with a heat pump in order to increase the efficiency of the system.

The experimental pilot station will be the subject of a large range of researches in order to check some theoretical hypotheses.

During the cold period of the year, solar energy may be used for heating buildings.

The most freqently used systems are the passive systems, which use collecting walls protected by glasshouses, and active systems that use solar collectors with air. These systems may reduce about 35-40% from the annual heating requirement of a building.

In order to increase the utilization of the solar energy for heating industrial buildings, it is possible to use seasonal storage of solar energy-produced heat, which will be used during the

x) Engineers Design Institute for Typified Buildings - IPCT - 21, T.Arghezi Street, sector 2, Bucharest, Romania

cold season of the year. This system may be used for a maximum of 80-100% from the annual heating requirements.

The system is applied in many countries (1, 2, 3) and has presented the desired results.

During 1982-1983, IPCT undertook documentary studies (4, 5) and economic efficiency analyses of different seasonal heat storage systems.

These systems are characterized by storage periods, thermal potential of the storage, and the storage medium.

Among these, in the present stage, the greatest practical possibility is represented by seasonal heat storage, using solar energy stored in the water from the thermal insulation tanks or reservoirs.

In order to demonstrate the practical efficiency of seasonal storage of solar energy, it has been decided to build an experimental pilot station at I.C.H.Bucharest (Hydrotechnical Research Institute) (6) that will be put to functional tests during this year.

IPCT will coordinate these research, which will be carried out by ICB (Construction Institute Bucharest) and INCERC (Building Research Institute) - Solar Energy Laboratory.

2. The principle elements of the experimental Pilot Stations

The heating system that uses seasonally stored solar energy for the experimental pilot station consists of:

- installation for solar energy collection;
- heat storage tank;
- heat consumer installation;
- solar district thermal station;
- auxiliary heating source;
- automatation, measure and control installation;
- measuring and registering equipment of the working systems of the experimental pilot station.

2.1. Solar energy collecting equipment is provided with an absorbing element and has a total collecting area of 80 m^2 (40 pieces).

Solar collectors are South directed and have a 30^o slope as against the horizontal line; the collecting period being April-October.

The panels are assembled into 4 groups of 20 m^2, (10 pieces)

that can be fed either in parallel or in series on groups.In this way can be tested the optimum method of connecting the solar collectors (in series or in parallel) so than function of the flow circulated through them is a maximum temperature of the stored water from the storage tank.

2.2. The storage tank is metallic, of a vertical cylinder shape, and has a volume of 300 m^3., with the ratio of the main dimensions $\frac{H}{D_R} \simeq 1$ and DR = 7.5 m.

This tank is placed aboveground due to the 4 m. depth which subsoil water. The storage tanks 60 m., deep excepting the bottom of the tank, which is placed on a sandwich type foundation with a 30 cm. polystyrene layer (fig.1).

Fig.2 and 3 do present specific aspects during the storage tank execution.

At the end of the storage period the maximum water temperature in the storage tank will be 70°C.

The stored heat at the end of the warm period of the year will be about 15 Gcal. Heat loses in the tank during the consumption period are about 35% from the stored heat.

The tank works with a free water level.

It is provided with two perforated ring pipelines, one at the top and the other one at the bottom, bothe of them used, a function of the working regime (storage or heat consumption), as repression or absorbtion equipment.

2.3. The heat consumer is represented by the new laboratory into the hydraulic testing hall of about 210 m^2.

The normal thermal load of the user is of 26,000 Kcal/h and the annual thermal load is of 15.5 Gcal. From the heat storage tank is taken over only 80% from the annual thermal load.

Nominal parameters of the heat carrier into the heating equipment are 60/40°C. The rooms are heated with pance convecto-radiators of CRP type.

The heating equipment is connected to the seasonal heat stored source in indirect circuit because of the possible apperance of the micro-organisms.

2.4. The district thermal station provides the heat loading of the storage tank during April-October period and the feedingof the heating consumer with the stored heat during November- March

period.

It consists of the following principale equipment:

- circulation pumps for the primary and secondary heat carrier;
- 2 heat exchangers with baffle block type B 7 - Am/6x3 m;
- compression heat pumps GPCF - 31,5.4.

ICH solution, the district thermal station, could not be provided with a heat auxiliary source working with a heat carrier for heating.

2.5. The auxiliary source is represented by electric radiators with oil, thermal insulated, placed into heated rooms. The systems represents 15-20% of the nominal heating load in the nominal calculus conditions (the temperature into the tank at the end of the heating period is of 15°C). The electric radiators can cover about 25% from the nominal heating load.

2.6. Automattion, measure and control installations for the experimental pilot station are presented in the third chapter.

2.7. The measure and registering installations for the working conditions of the experimental pilot station (10) were provided to allow a large range of experimental research according to those presented in chapter 5.

3. The working scheme of the heating system, using seasonal stored solar energy

The working scheme of the installation is presented into fig.4.

During the solar radiation period of the hot season (April October), when the automatic regulator SIRIS apprehends a temperature difference of minimum 15 degrees between the water temperature from the bottom tank and the solar collectors, the solar energy collecting installation is set in motion by the help of P 1 or P 2 pumps a function of the working conditions desired (see chap.5.1.).

The water heated in the solar energy collectors is introduced into the top of the tank with an extremly low speed in order not to disturb the thermal stratification. Thermal stratification ensures the working of the solar collector installation with a high pr uctivity degree.

At the end of the heating season, water from the tank reached the highest temperature degree.

The solar energy collecting equipment is emptied for the

cold period of the year in order to avoid its freezing.

During the heating season, when the heat stored in the storage tank is "consumped", the pumps will absorb water from the top of the tank and after the heat is extracted, it is driven back to the bottom tank, checking permanently the thermal stratification of the water.

In the first period (November-December) when water from the tank has a high temperature, the heat extraction is worked through the heat exchanger supplied with P 3 and P 4 pumps, a function of the heat requirement of the user.

After water yielded the heat to the heat carrier of the user (with nominal parameters of 60/40 ^{o}C), it has a temperature of about 40 ^{o}C and it is driven back into the tank.

When the whole tank has the same (40^{o}C) temperature by the gradual extraction of the higher temperature from the top, the heat pumps will start working, supplied by the pumps P 5.

The heat pump works when water from the tank reaches 15^{o}C, from this moment becoming inefficient. The heat pump increases the water thermal potential to about 60-70^{o}C. As the chosen heat pump has a greater capacity than necessary, it will work intermittently.

In order not to use a greater heat quantity that is necessary, an automatis regulator RPT was provided. It checks the heat carrier temperature in the installation.

The automatic set was also provided to work the electric radiators in order to obtain the proper inside temperatures.

The system is provided with a registering system for the produced heat by the help of solar energy and for the heat stored into a tank.

The system also registers the consumped heat from the tank and the electric energy consumed by the heat pump and the auxiliary heating system.

4. Specific calculus aspects

4.1. Determination of the storage volume

In order to establish the storage volume hypotheses are made that subsequently will be checked by an exact calculus in conformity with the directions given at chap.4.5. and 4.6.

The calculus relations are:

$$V = \frac{Q_R}{(\overline{tr}^{fin} - tr^{in})\ cp\ .\ 10^{-3}}\ m^3$$

$$Q_R = Q_R^{util} + Q_{PR}\ ;$$

where:

V = water volume of the tank (m^3);

Q_R= total heat quantity stored into the tank from the beginning of the heating season (Gcal);

Q_R^{util}= useful heat quantity from the tank (Gcal);

Q_{PR} = heat losses from the storage tank during the consumption perriod of the stored heat (Gcal);

t_R^{fin} = average final water temperature from -he storage tank at the end of the storage time period (0^oC);

t_R^{in} = initial water temperature into the storage tank (0^oC).

The useful stored heat will cover only a part of the annual heat requirement of the user, due to the practical necessity to have a spare auxiliary source that must cover the peak loads. The heat pump contribution (thermal equivalent of the electric energy for the compressor) also has to be considered.

- it follows the calculus

$$Q_R^{util} = 0.8\,Q_i^{an} - (Q_{PC}^{K} - Q_{PC}^{V}) = 0.8\,Q_i^{an} - Q_{PC}$$

$$QR_R^{util} = Q_{SC} + Q_{PC}^{V}$$

$$Q_R^{util} = Q_R^{util} + Q_{PC} = Q_R - Q_{PR} + Q_{PC}$$

where:

Q_i^{an} = annual heating load of the consumer (Gcal);

Q_{SC} = annual quantity of heat provided by the storage tank through the heat exchanger (Gcal);

Q_{SC}= (1 - x) % Q_R^{util}

Q_{Pc}^{V} = the heat quantity taken over from the storage tank through the heat pump vapourizer (Gcal);

Q_{Pc}^{V} = x % Q_R

Q_{Pc}^{K} = annual heat quantity provided by the condenser of the compression heat pump (Gcal); Q_{Pc}^{K} =130...150% Q_{Pc}^{V}

Q_{Pc} = annual thermal equivalent of the Q_{Pc}^{K} - Q_{Pc}^{V} electric energy used for the heat pump compressor;

x = quota of the heat from the tank that will be taken over by the help of the heat pump from a water temperature of 40°C to 15°C.

Q_{util} = total heat quantity provided from the heat storage tank considering also the heat pump contribution (Gcal).

For the nominal calculus conditions of the experimental pilot station:

$Q_i^{an} = 15.2$ Gcal

$t_R^{in} = 15^oC$

the following hypothesis was considered:

$t_R^{fin} = 65^oC$

$Q_{PR} = 33\%\ Q_R$

$Q_{FC}^K = 140\%\ Q_{FC}$

$x = 50\%$

Thus, it resulted:

$Q_R = 15$ Gcal; $Q_{PR} = 5.3$ Gcal; $Q_{util} = 12.4$ Gcal.

The volume of the storage tank:

$$V = \frac{15}{(65 - 10)\ 10^{-3}} = 300\ m^3$$

4.2. <u>Average heat transfer coefficient of the tank</u>

This coefficient was determined of the account of the Construction Institute Bucharest - Thermotechnical Department (7) studies and is assimilated with the cylindrical tank of 300 m^3 of Arhimede type with a cube placed on the ground.

In the thermal insulation conditions presented in chapter 2, it resulted an average heat transfer coefficient:

$K_R = 0.11\ W/m^2\ K\ (0.095\ Kcal/m^2h\ grd)$.

4.3. <u>Devices of driven back and absorption of water from the tank</u>.

The devices are identical, as they reciprocally change their part function of the working regime (storage - consumption). These devices are provided to the upper and lower parts of the tanks as

some ring shaped devices with repression spaces In order to have a uniform distribution the forebay principle was adopted:

$$\sum s_{orif} < 0,5\ s_{distr.}$$

It resulted a maximum driven back speed through apertures.

4.4. Determination of the solar energy collecting ares

There were taken into consideration the following nominal working conditions of the collection equipment. They were determined on the account of some previous studies (6,9).

Also taken into consideration was the four-time water circulation from the storage tank during the hot season and a specific flow on the primary circuit of 10 l/m^2 panel.

The solar collectors are supplied in parallel.

$$S_p = \frac{T \cdot V \cdot 10^3}{a \cdot \sum h\ s} = \frac{4 \cdot 300 \cdot 10^3}{10 \cdot 1589} = 76\ m^2 \simeq 80\ m^2$$

where:

$T = 4$ volums/season; $a = 10\ l/m^2$

hs = 1589 hours, the time period for solar energy collection during the hot season.

4.5. Calculus of the stored heat quantity into the storage tank.

During the heat loading, the main parameter that determines the stored heat quantity is the final temperature of the water from the tank.

$$Q_R = V\ (t_R^{fin} - t_R^{in})\ C_p \cdot 10^{-3}/\text{Gcal}.$$

The knowledge of the water temperature from the tank and its distribution on the vertical line represents a problem of great interest from our scientists.

The determination of the water temperature from the tank is achieved with the help of an equation system that has a mathematic pattern to operate the storage system. IPCT has carried out this mathematic model data program set (9).

There are two extreme limits of this phenomenon, also conditioned by the distribution method of water from the tank, the real situation may be somewhere between then:

- the homogenization of water temperature from the tank by

the mixing of hot water that comes from the solar panels with water from the tank, resulting an uniform temperature - STOMEX program;

- the perfect stratification of water temperature from the tank, through which it is supported no heat and mass exchange is happening, creates a delimiting surface between the hot water that comes from the solar panels and the cold water from the tank. This surface is acting from top to bottom as a piston - SOSTRA program.

The equations of the heat balance form the heat loading system of the tank in the homogenization variant, are:

$$S_P F_R' K_\Sigma \left[t_E - \frac{t_{TR} + t_R - (\Delta - \Delta_1)}{2} \right] = G_P \left[t_{TR} - t_R^{j-1} + (\Delta - \Delta_1) \right] \rho c_P$$

$$V \cdot t_R^{*j} = n\, G_P (t_{TP} - \Delta_1) + (V_R - n \cdot G_P)\, t_R^{j-1}$$

$$t_R^j = t_e + (t_R^{*j} - t_e) \cdot \exp\left(-\frac{24 K_R S}{\rho c_P}\right) ; \quad A = \frac{-24 K_R \cdot S}{\rho c_P}$$

$$\Delta = m \left[t_{TP} - t_R^{j-1} + (\Delta - \Delta_1) \right]$$

$$\Delta_1 = \frac{(t_{TP} - t_e)\Delta}{t_{TP} + t_R^{j-1} (\Delta - \Delta_1) - 2 t_e + 0.5 \Delta}$$

The used notations are:

S_p = solar panels surface;

F_R' = factor of the heat transport through solar panel;

K_T = heat global transmission coefficient, defining heat loses of the solar panel (kcal/m^{2}h grd);

t_E = exterior equivalent temperature ^oC, having the expression:

$$t_E = \frac{\alpha \tau}{K} I_\beta + t_e$$

$\alpha\tau$ = factor of the absorption transmission of the panel;

I_β = solar radiation intensity (kcal/m^{2}h);

t_e = outside temperature (^oC);

t_R^* = virtual average temperature of water from the tank without heat losses(perfect thermal insulation - ^oC);

t_R = average water temperature from the tank (^oC);

Δ = water temperature drop on the primary circuit (grd);

Δ_1 = the same, on the input solar circuit (panels storage tank) (grd);

G_p = the flow into the primary circuit (m^3/h);

m = ratio of the heat losses in the primary circuit to the collected heat by the solar panels;

A = time coefficient that includes the thermotechnical and geometrical characteristics of the tank;

$A = f(K_{R_1}\ V)$;

t_{TP}= temperature of the primary agent at the outlet from the solar panels (^oC);

n = number of hours per day of the solar collection installation service (hours).

The unknown elements that are determined (hour and day) are: t_R ; t_R^* ; t_{TP} ; Δ; Δ_1;

The equations of the heat balance - for the heating loading system for the tank in the stratification variant - are made for two areas: the hot area and the cold area.

$$S_p F_R' K_\Sigma \left[t_E - \frac{t_{TP} + t_{Rr}^{j-1} - (\Delta - \Delta_1)}{2} \right] = G_P \left[t_{TP} - t_{Rr}^{j-1} + (\Delta - \Delta_1) \right] \rho c_p$$

$$V_{RC}^j \cdot t_{RC}^{*j} = n G_P (t_{TP} - \Delta_1) + V_{RC}^{j-1} \cdot t_{RC}^{j-1}$$

$$V_R \cdot t_R^j = t_{RC}^j V_{RC}^j + t_{Rr}^j (V_R - V_{RC}^j)$$

$$t_{RC}^j = t_e + (t_{RC}^{*j} - t_e) e^{-Ac}$$

$$t_{Rr}^j = t_e - (-t_{Rr}^{j-1} + t_e) e^{-Ar}$$

$$\Delta = m \left[t_{TP} - t_{Rr}^{j-1} + (\Delta - \Delta_1) \right] ; \quad \Delta_1 = \frac{(t_{TP} - t_e)\Delta}{t_{TP} - t_{Rr}^{j-1} - (\Delta - \Delta_1) - 2t_e + 0.5\Delta}$$

The supplementary notations used are:

t_{RC}^* = the average virtual temperature of water from the hot past of the tank without heat losses (^oC);

t_{RC} = water average temperature from the hot past of the tank (^oC);

t_{Rr} = water temperature from the cold part of the tank (^{o}C);

$\dot{V}_{RC}$ = hot water volume from the tank (m^3).

$$Ac = f\ (K_R, V_{RC}\ )$$
$$Ar = f\ (K_R, V - V_{RC})$$

The unknown elements are:

t_{RC}^{*} ; t_{RC}; t_{Rr}; t_R; t_{TP}; Δ ; Δ_1;

The water temperature from the tank, t_R, has the significance of a normal average. For the hot areas the t_{RC} and t_{RC} temperatures are determined in the condition of a homogenization resulting from the temperatures mixture from the hot area.

The necessity of providing a safety degree for the experimental pilot installation made it possible to adopt the homogenization variant of water temperature from the tank during the loading period, in the normal conditions presented into chapter 4.4.

The final water temperature from the tank (at the 1st of Nov.) is - $t_R^{fin} = 65^{o}C$.

Adequately to this temperature, the stored heat quantity into the tank at the end of the warm period is:

$$Q_R = 300\ (65 - 15\ )\ 1\ .\ 10^3 = 15\ Gcal$$

For the monthly evolution of water temperature into the tank as well as the seasonal evolution of the heat quantity, there was drawn up the diagram (fig.5).

4.6. Heat quantity delivered from the tank to the consumer.

This heat is composed of the delivered heat through the heat exchanger when water from the tank has the temperature over 40^{o} C and through the heat pump when the water has the temperature under $40^{o}C$.

For the calculus the automatic data process a IPCT-CONRE was used.

The synthesis of the presented results as monthly evolution is showed by the diagram of fig.5.

- the heat quantity in the tank at the beginning of the heating season.

$$Q_R = 15\ Gcal$$

- the heat excess due to the thermal equivalent of the consumpted electric energy by the heat pump.

$Q_{PC} = 3$ Gcal

- heat losses of the tank during the cold season.

$Q_{PR} = 5.4$ Gcal (36% Q_R).

- the useful total heat delivered from the tank by the help of the heat pump:

$Q_{util} = Q_R - Q_{PR} + Q_{PC} = 12.6$ Gcal (82% Q_i^{an}).

- the degree of the annual heat requirement covered by the solar energy and the heat pumps.

$$an = \frac{Q_{util}}{Q^{un}} = \frac{12.6}{15,2} = 83\%$$

- heat provided by the auxiliary source:

$Q_{aux} = Q_i^{an} - Q_{util} = 2.6$ Gcal

- the equivalent of the yearly saved fuel by the help of solar energy seasonly stored:

$$G = \frac{Q_{util} - Q_{PC}}{\eta \cdot P_{ci}} \cdot 10^3 \text{ tcc} = \frac{12,6-3}{0.7.7000} \cdot 10^3 \text{ tcc} = 1.96 \text{ tcc}$$

5. Specific research aspects

5.1. The ascertainment of the optimum working conditions of the solar collectors-

Optimum working conditions must be established on the whole heat collection and storage system, taking into consideration:the productivity of the collection installation, the real conditions of stratification or homogenization of water from the tank which are also conditioning the heat losses of the tank. The final aim is to obtain the highest temperature of water in the storage tank and implicitly a more reduced storage volume.

The solar collectors may be supplied in series or in parallel, with a variable flow from 10 l/m^2 . to 30 l/m^2

The water from the tank may be carried through the solar panels and its circulation may vary for the experimental pilot equipment from 1 to 12 passings/season, which corresponds to a circulation pumps flow from 0,2 m^3/h to 2,4 m^3/h.

Applying the calculus programs mentioned in chapter 4.5.for the two specific cases of stratification-homogenization, it resulted the data presented on the diagrams from fig.6.

The most favorable situation is one with the water stratification into the tank, when the supply of the solar collectors is made in serie with a flow of 10 l/m^2h and with only one circulat-

ion of the water from the tank during a season.

Thus, at the end of the heating period an average temperature of 78,8 ^{o}C of the water in the tank will be achieved.

Fig.7 also presents the temperature variation for the water from the hot part and from the cold part of the tank during April-October.

During the summer of 1986 INCERC - the Solar Laboratory will make different measurements in order to test the optimal working conditions of the solar collecting device which is connected by the whole assembly of the installation.

Temperature will be registered in 12 characteristic places of the collection installation also registered will be the climatic data.

5.2. The experimental determination of the thermal regime of the water from the storage tank and the heat transfer coefficients.

According to the program proposed by ICB - Thermotechnical department (10), during 1986-1987, there will be carried out measurements on the experimental pilot station in order:

- to establish the evolution of the thermal stratification into the water from the tank in a dynamic state;
- to experimentally determine the limit layer respective the convection coefficient of the heat inside the tank;
- to determine the real heat losses of the seasonal storage tank.

On account of the obtained results it will be possible to check:

- the calculus hypothesis of the thermal transfer at the seasonal storage tanks overground placed;
- the mathematical models that were at the basis of data program made by IPCT and ICB for the heating installations using seasonal stored solar energy.

For this reason, during the thermal "loading" and "unloading" of the tank, there will be carried out measurements and recordings of the axial and radial temperature fields of the temperatures of the walls and on the bottom of the tank (inside and outside), in the ground and the air temperature over the free level of the water from the tank.

In order to achieve this, there will be mounted 34 thermistors and 22 thermoresistances for temperature measurement and 5 E L - 362A registering devices with 12 measuring points.

The establishement of the limit layer will be done due to the speeds and temperatures field determination, near to the water tank, by the help of a micro Pilot tube, respectively with a temperature detector.

During all this period there will be measured and registered the water flows circulated from the tank, as well as the stored or consumpted heat quantities from the tank.

5.3. The achievement of the chimical and biological steadiness of the water from the seasonal storage tank.

From the studied documentary papers (2), some microorganisms and worcks may appear due to longer period of hot water storage.

During 1986-1987, ICH intends to solve the problems of the chemical and bilogical steadiness of the water and of the micro-organisms and wracks appearence into the seasonal storage tanks.

6. Conclusions

The operation, during 1986, of the experimental pilot station at ICH, will allow us to appreciate the viability of the heating system by the help of solar energy.

Secondly, it will function as an experimental working base for clearing out some theoretical aspects concerning the heat storage itself.

Those two aspects being solved, and before the general application of the solution, it will be necessary to build another experimental pilot station, using this time a concrete tank or a covered one for the heat storage.

These solutions were taken into consideration by IPCT studies (4,5) but a series of aspects about the thermal hydroinsulation of the tanks and reservoirs must be studied.

Only after these aspects have been solved it will be possible to have decision as to the total cost of such a system with a share of about 50%.

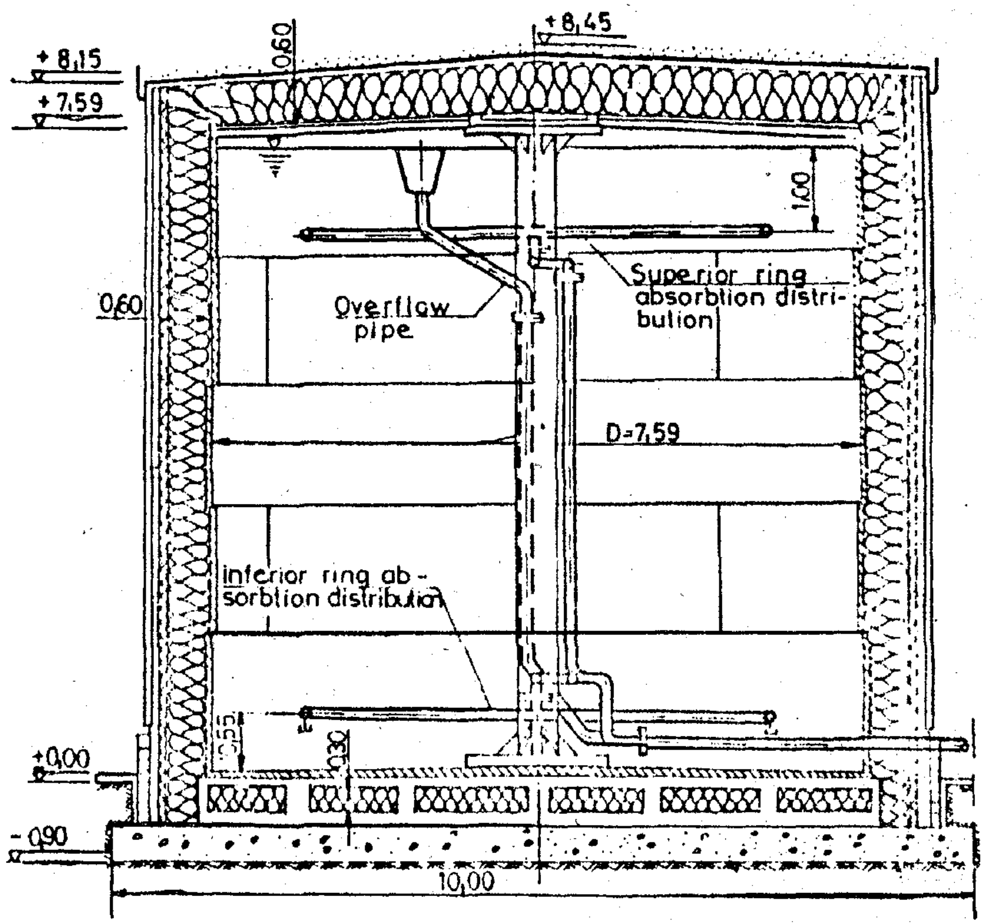


FIG I – METALLIC TANK OF 300 m^3 FOR HEAT SEASONAL STORAGE PRODUCED BY THE HELP OF THE SOLAR ENERGY AT ICH BUCHAREST

Foamed polystyren thermal insulation

Mineral wool thermal insulation

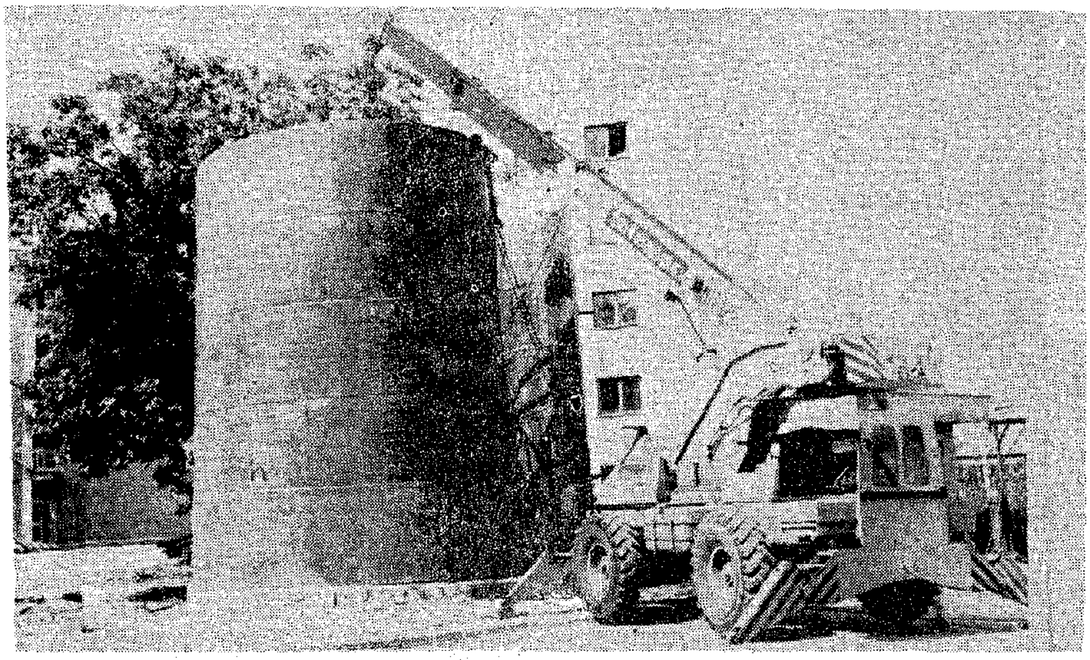


Fig. 2

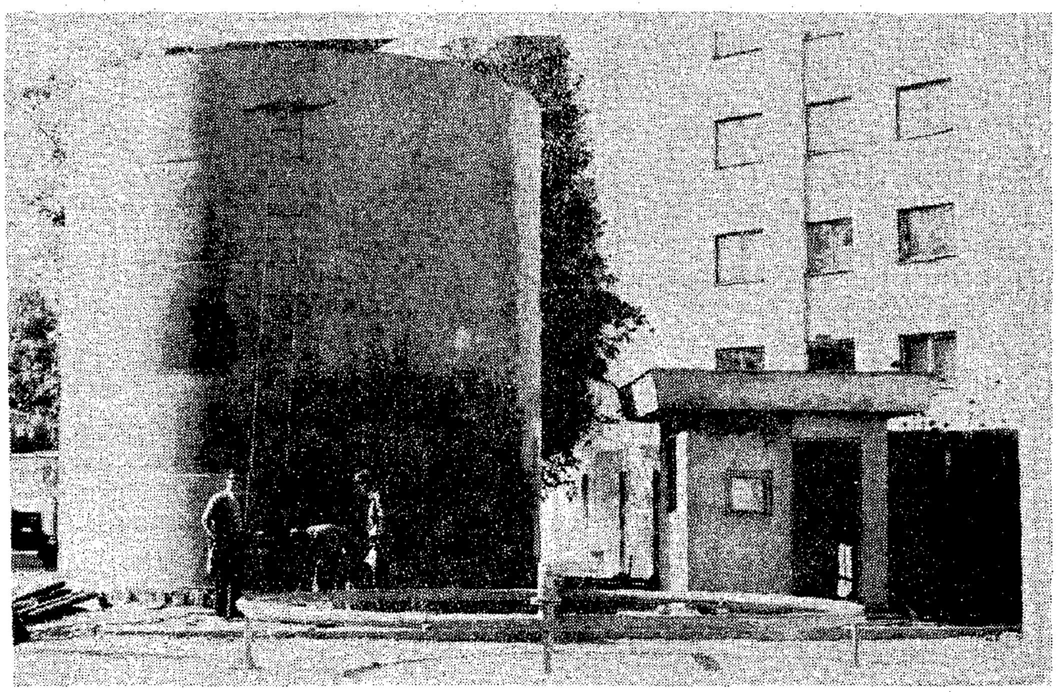


Fig.3

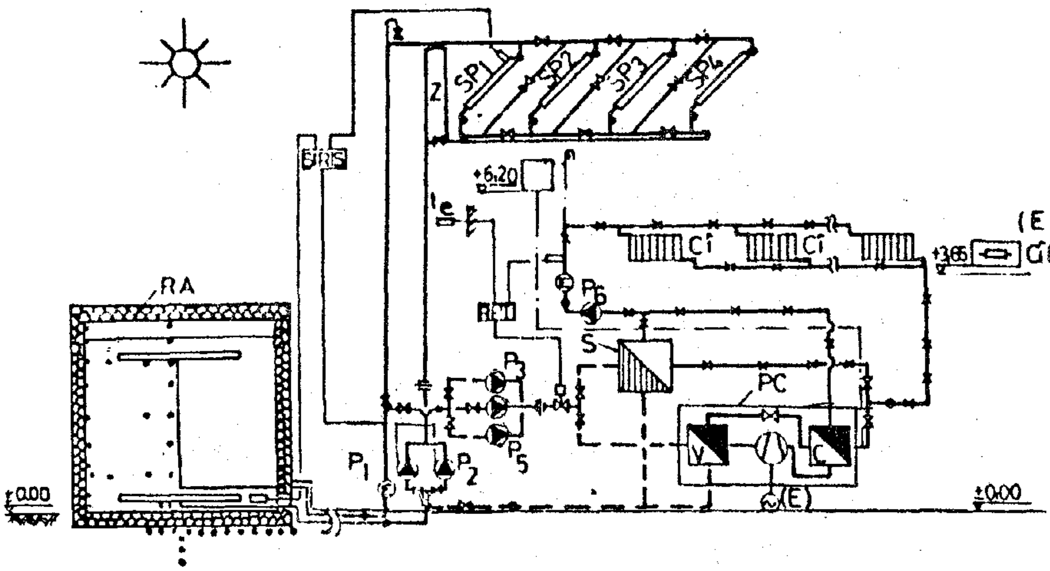


FIG 4 - WORKING SCHEME OF THE HEATING SYSTEM USING SOLAR ENERGY SEASONLY STORED FOR ICH - BUCHAREST

———— Solar circuit pipelines solar panels - storage tank
———— Heat feeding pipelines (primary circuit)
———— Heating pipelines 60/40°C (secondary circuit)
———— Safety pipelines - aeration
———— Automation circuit

RA	Hot water storage tank $V=300\ m^3$
SP_1 SP_4	Solar panels (IAA - ALEXANDRIA) 1...4 areas having each $20\ m^2$
Z	Hydraulic siphon
P_1, P_2	Circulation pumps for solar circuit MUA 16 type ($G=0{,}8\ m^3/h$ / $G=0{,}2\ m^3/h$)
P_3, P_4	Circulation pumps for feeding up the heat exchanger MUA 16 type ($G\ 0{,}3\ m^3/h$ / $G\ 1{,}2\ m^3/h$)
P_5	Circulation pump for feeding up the vaporizer (V); Cr50c type ($G=4\ m^3/h$; $H=3\ m\ H_2O$)
P_6	Circulation pump for feeding up the condenser (C), MUA 16 type ($G=1{,}25\ m^3/h$; $H=3\ mH_2O$)
S	Heat exchanger in counter flow with baffle plates B-7-Am type 6*3 (2 seried units)
PC	Heat pump with compressor GPCF type - 31.5.4
CI	Panel radiator convector CRP-1 type 777/25
CIE	Electric radiators "ELECTROMURES" (auxiliary heating)
VE	Open expansion vessel $V=0{,}25\ m^3$
•	Characteristic points for temperature measurement
-Ф-	Points for the heat flow measurement
⫲	Point for the flow measurement by the help of the rotameter (IAMC-OTOPENI)
(E)	Points for the electric energy consumption measurements (counter)
RPT	Regulator for thermal district point FEA type.
SIRIS	Automat regulation system of the solar installation "AUTOMATICA" type

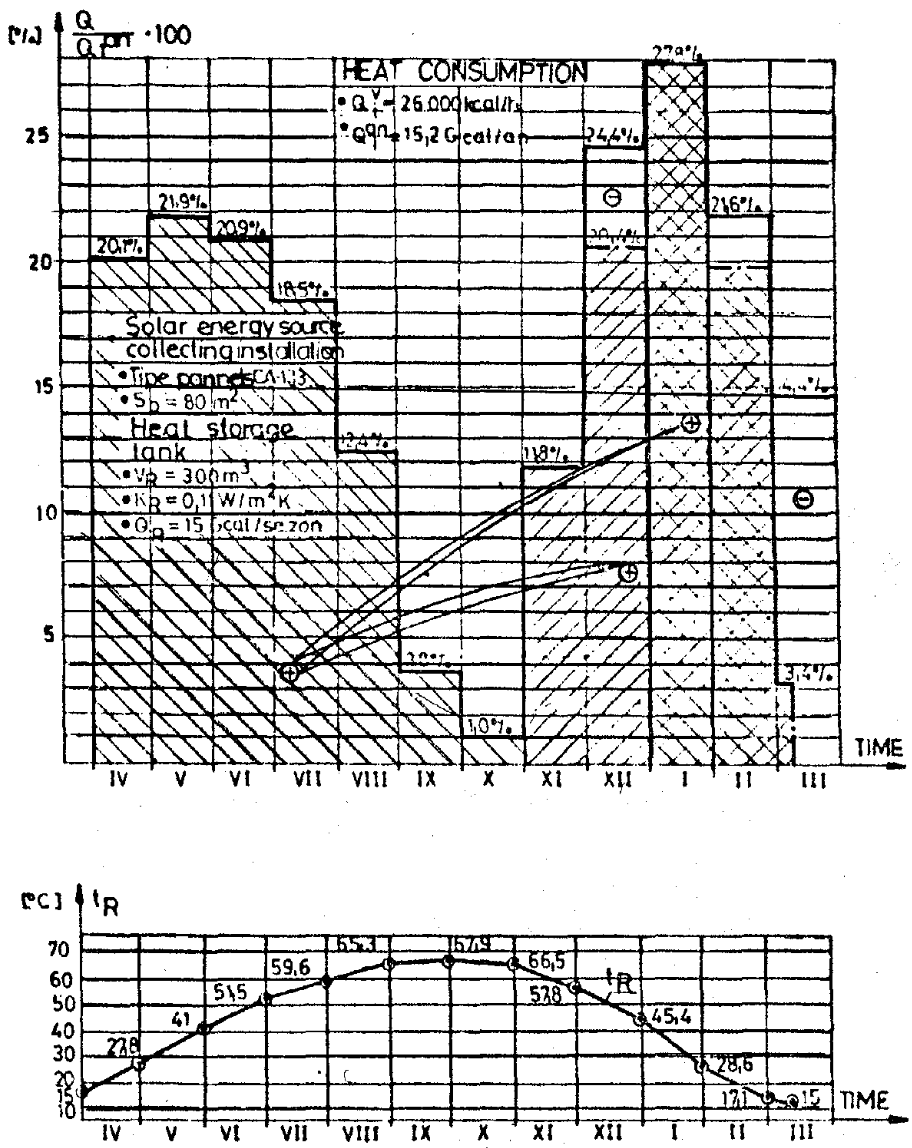


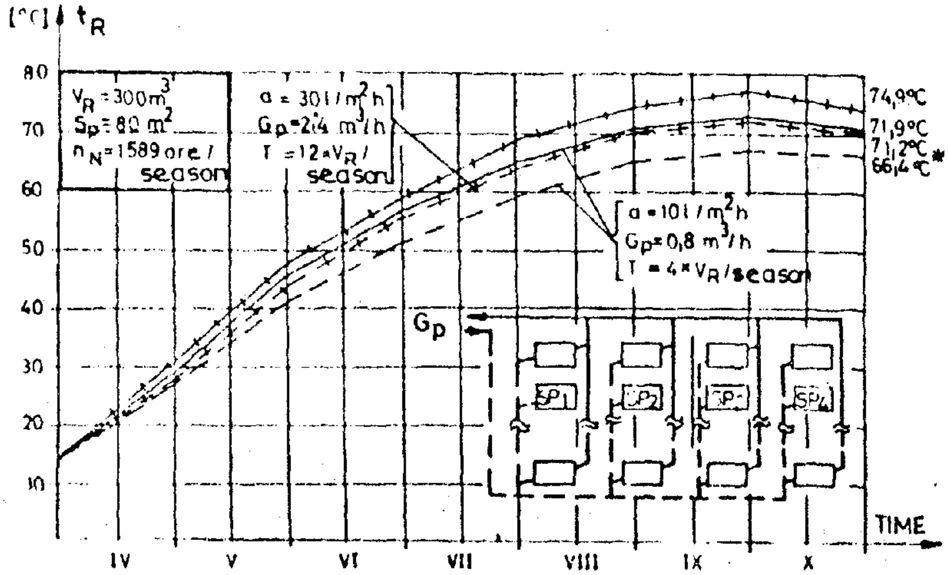
FIG5-DIAGRAM OF THE HEAT FEEDING OF THE SEASONARY STORAGE TANK AND OF THE HEAT YEARLY NECCESARY CONSUMPTION FOR HEATING.

- Heat consumption from the tank for healing with the heat exchanger
- Heat consumption from the tank for heating with the healpump
- Solar heat feeding quantity for the seasonary storage tank during the hot period

t_R Average temperature of the water from the tank

Q_f^{an} Early heat requirement for heating

Q Monthly requirement (−) or heat feeding (+)



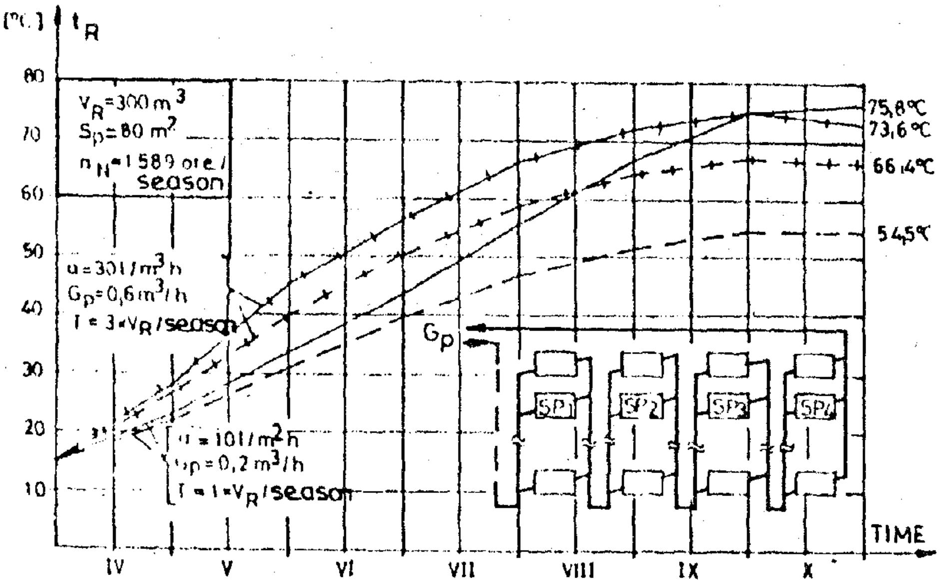


FIG 6 - THE VARIATION OF THE AVERAGE TEMPERATURE OF THE WATER IN THE TANK FEEDING UP IN PARALELOR IN SERIE THE SOLAR COLLECTORS, FUNCTION OF THE WATER FLORO CIRCULATED THROUGH SOLAR COLLECTORS

——— With the water stratification in the tank for $a = 10\ l/m^2$

-+-+- With the water atratification in the tank for $a=30\ l/m^2$

— — — With the homogenization of the water in the tank for $a=10\ l/m^2$

-+ -+ With the water homogenization in the tank for $a=30\ l/m^2$

* it is the hypothesis of dimensioning the installations of the experimental design

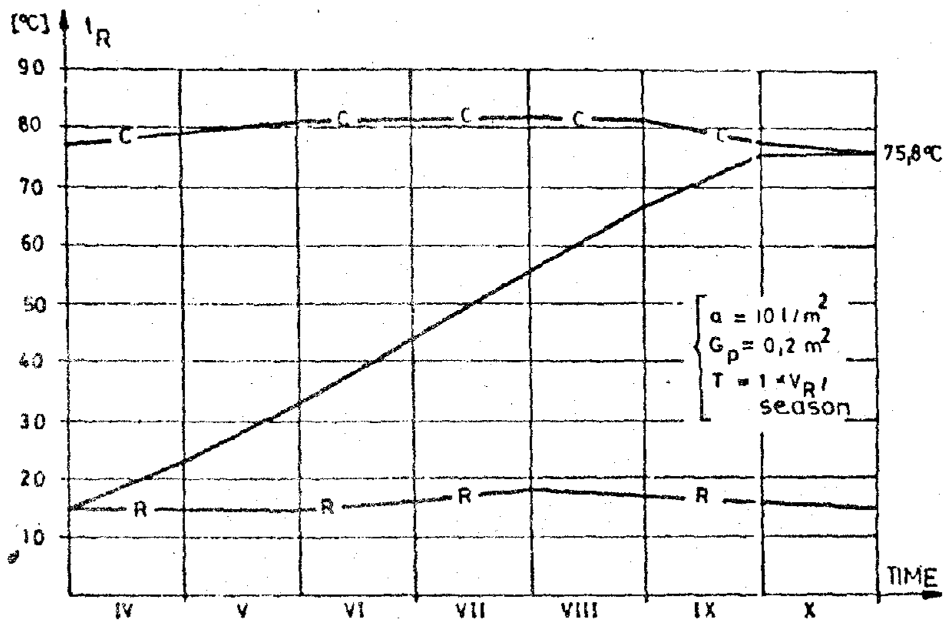


FIG 7 – TEMPERATURE VARIATION OF THE WATER INSIDE THE TANK WHEN A STRATIFICATION EXISTS AND THE FEEDING UP OF THE COLLECTORS IN SERIE

——— The average temperature of the water in the tank

—C— Water temperature in the hot area

—R— Water temperature in the cold area

UNITS OF MEASURE

1 Btu	=	252 calories
°C	=	(°F - 32) / 1.8
cf	=	conventional fuel
1 cm	=	0.394 in
°F	=	1.8 °C + 32
1 ft	=	0.3048 m
1 ft^2	=	0.0929 m^2
1 ft^3	=	0.0283 m^3
1 U.S. gallon	=	3.79 litres
1 HP	=	746 W
1 J/kg°K	=	2.39×10^{-4} Btu/lb.°F
°K	=	°C + 273.15
1 kcal/h	=	1.16 W
1 kcal/m^2h	=	0.37 Btu/hr.ft^2
1 kcal/m^2h°C	=	0.204 Btu/ft^2.hr.°F
1 kcal/mh°C	=	0.67 Btu/ft.hr.°F
1 kg	=	2.2 lb
1 kg/h	=	2.2 lb/hr
1 kg/m^2	=	0.2 lb/ft^2
1 kg/m^2h	=	0.2 lb/ft^2.hr
1 kg/m^3	=	0.0625 lb/ft^3
1 kg/ms	=	0.67 lb/ft.sec
1 kg/s	=	2.2 lb/sec
1 kgcf	=	20,380 Btu
1 kgcf/m^2	=	1,894 Btu/ft^2
1 kJ	=	0.948 Btu
1 kJ/kg	=	0.43 Btu/lb
1 kJ/kg°K	=	0.239 Btu/lb.°F
1 kJ/m^3	=	0.03 Btu/cu.ft
1 km	=	0.621 miles
1 kWh	=	3413 Btu
1 l	=	0.264 U.S. gallons
lei	=	Romanian currency
1 m	=	3.28 ft
1 m/s	=	3.28 ft/sec
1 m^2	=	10.76 ft^2
1 m^2/s	=	10.76 ft^2/sec
1 m^2h°C/kcal	=	4.9 ft^2.hr.°F/Btu
1 m^2°K/W	=	5.68 ft^2.hr.°F/Btu
1 m^2°C/W	=	" " " " "
1 m^3	=	35.3 ft^3
1 m^3/h	=	35.3 ft^3/hr
1 m^3/m^2h	=	3.28 ft^3/hr.ft^2
1 mm	=	0.039 in
1 mm H_2O	=	0.2 lb/ft^2
1 W	=	3.413 Btu/hr
1 W/°K	=	1.9 Btu/hr.°F
1 W/m°K	=	0.578 Btu/ft.hr.°F
1 W/m^2°K	=	0.176 Btu/ft^2.hr.°F
1 W/m^2	=	0.32 Btu/hr.ft^2
1 Wh/kg°C	=	0.86 Btu/lb.°F
1 Wh/m^3°C	=	0.05 Btu/ft^3.°F
1 Wh/°C	=	1.9 Btu/°F