THE SIMPLIFIED SIMULATION CODE 'LEGO' FOR HVAC-BUILDINGS SYSTEM DESIGN

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1- INTRODUCTION

The simplified thermal simulation of buildings is particularly useful for both bioclimatic design and the selection of the most suitable HVAC systems.
The LEGO computer program was prepared in order to simulate the conventional HVAC plant-building systems and the complex systems like seasonal storage tank and solar collector plants.
Therefore, it is possible with this kind of program to study the interaction among the various systems by means of combination of different simulation subroutines. In this way, a more accurate dimensioning of the systems can be achieved.
The computer code Is framed within simplif led programs and was conceived to realize simulations (for long period of time, too) on IBM compatible PC.
The computer program is entirely written in Fortran and is composed of several and different subroutines. The software structure has been done in a way so that it can be modified, Implemented or personalized by skilled users.
In order to make easier the introduction of data input and computer graphics output, it has been conceived a particular Interface in the EXCEL (Microsoft) frame which allows the use of LEGO in a piloted manner.
At the end of this report, two simulation results will respectively be presented for an air conditioning system design at ENEL building (with heat pump storage tank plus solar collectors), and for a direct gain seasonal storage tank bui lt in Catania.

2.VIDEO INTERFACE

The video interface system was prepared to facilitate the introduction of data input and computer graphics output. This system was placed in EXCEL (Microsoft) frame allowing the sequential input of data by filling in a "graphic board". This interface, allows also to choose the user level, adapting the requested data input.
Moreover, the system enables a direct dialogue with the user, through the on-line help an easily permitting the introduction of complex evaluation data.
In fact, it is possible to verify the introduced input values against the ones the processor considers as reasonable for the model in question. These latter values are recalculated moment by moment, on the basis of the already introduced data.
The interface looks after the output visualization through graphic constructions that can be personalized according to individual needs.

3.PROGRAM STRUCTURE AND ROUGH DESCRIPTION

The program is made of twenty-five sections all linked together to build a sole task with an overlay structure.
The code presents a modular structure specifically studied to receive future expansions and several component models (1).

The entire program has been conceived to also carry out long period simulations (one year or more) on IBM compatible P/C in reasonable time (some minutes to few hours, depending on the kind of plant and the chosen time step).
Simulation code operates within time domain. The phenomena of thermal and mass transfer are calculated with method of resolution of the finite differences, the first order explicit type (2).
Some physical phenomena, more specifically the convective exchange for air and fluids, are simulated by using simplified algorithms that bring to calculation times acceptable on PC.
The time step, so important for steadiness, precision and speed-calculation, may be chosen within a range included between one second up to twenty-four hours.
With some models such as parts of the building and the heat pump circuit, it might be necessary to operate on shorter time steps, due to the minor thermal inertia and/or to the major dynamics of transport phenomena in question.
In these particular cases, it is foreseen the possibility of operating on fractional time step, according to the one chosen for the remained parts of the system.
Several linked models are contained in LEGO program, and each of them can simulate the behavior of a specific component as mentioned above.
The LEGO handling approach for the several systems simulation is summarized below:

<u>BUILDING LAYOUT</u>

- Building divided into several floors separated by supporting slabs having equal characteristics. It is possible to simulate the under-roof and the underground floor.
- External walls (max 5) and roof are made of a certain number of layers of material with different thickness and thermophysical features.
Regardless the number of the chosen layers, the program considers every supporting slab of each floor and the roof composed of three longitudinal layers having the same thickness, but with thermophysical features calculated on the basis of the materials used for them.
- Glass surfaces characterized by the total thermal conductivity and the medium transparency to solar radiation.
- Possibility of simulating the external shading device for glass surfaces.
- The solar radiation effect in the surfaces (walls, windows, roof) is calculated for each time-step (3).
The model takes into consideration eventual obstacles that may inhibit the direct solar radiation (i.e. adjacent buildings, trees, small walls, etc.), and distinguishes them as medium-height shadings having their own distance with respect of each wall. The resultant effect is calculated for every storey and for the several inclinations of the direct solar radiation with respect to any external wall.
- Possibility to take into consideration thermal bridges.
- Internal masses characterization.
- Occupant's effect.
- Lighting effect.
- Other equipment thermal effects (computers, power machines, etc.).

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- Thermal dissipation due to HVAC system on the underground floor.
- Differentiate air changes for Summer, Winter, and mid-season.
- Differentiate heating and cooling systems on each storey with the choice among the several regulation systems.
- Humidification and de-humidification systems.
- Possible recover of heat on exhaust air ejection in HVAC plant.

HEAT PUMP MODEL

- There are three different models: air-water; water-water; water-water with evaporation tower.
- COP and power absorption variation concerning the several input-output operative conditions.

INERTIAL TANK

- Conductivity leakage effects in technological room.

BOILER

- Possibility of three choices: standard pressure boiler; high efficiency boiler; high efficiency boiler with heat exchanger.

BURIED CYLINDRICAL SEASONAL STORAGE TANK

- Bottom, side panels and cover are distinguished by numerical order and by the type of coating layers. Each layer is considered in terms of its thickness and thermophysical characteristics of the material used.
- Thermal stratification of water is obtained by dividing its whole volume into a certain number of horizontal layers. Convective motions are simulated by using simplified algorithms.
- Possibility of thermal insulation of the surface surrounding the seasonal tank.
- Outlet and inlet points of heating circuit which respectively are positioned in the upper and lower layer of the tank, in order to improve the fluid thermal stratification.
- Outlet and inlet points of solar panels circuit respectively positioned in the upper and lower layer of the tank, to improve the thermal stratification.

BURIED SEASONAL STORAGE TANK - DIRECT GAIN

- Tank shaped as an upside-down pyramid frustum, coated with transparent insulating material and wall inclination that can be modified (it may become a parallelepiped).
- The solar absorption in water is simulated according to a modified Beer's law (4).
- Bottom and side panels are numbered and characterized by the type of coating layers. Each layer is considered in terms of its thickness and thermophysical aspects of the material.
- Coating distinguished by a total transparency coefficient, thermal infra-red transparency and by its own global thermal conductivity (thermal mass is supposed to be negligible).
- Thermal exchange simulation in layers contour and soil, obtained by using node reticule all around the tank.
- Thermal insulation possibility for the surface surrounding the seasonal tank.
- Outlet and inlet points of heating circuit which respectively are positioned in the upper and lower layer of the tank, in order to improve the fluid thermal stratification.

SOLAR PANELS

- Characterized by thermal efficiency curve as a function of the parameter (Tp-Te)/Rad.

HEATING AND COOLING SYSTEM CONTROL

HVAC system simulation of LEGO program, as far as room temperature control is concerned, can operate as follows:

- 1 on-off switch for the whole building.
- 1 on-off switch on each storey.
- 1 PID switch for the all building.
- 1 PID switch on each storey.

4. ACHIEVABLE SIMULATIONS

LEGO program is capable to simulate the following plants:

- Building.
- Building having heat pump (heating & cooling).
- Building with heat pump (heating & cooling) operating at night to save energy costs.
- Building with boiler (heating only).
- Building with boiler for heating and with chiller for cooling.
- Building having seasonal storage tank and solar panels (heating only).
- Building having a direct gain seasonal storage tank (heating only).
- Building with heat pump, seasonal storage tank plus solar panels (heating & cooling).
- Building with heat pump and direct gain seasonal storage tank (heating & cooling).
- Seasonal storage tank plus solar panels. Users data are read by files (heating).
- Direct gain seasonal storage tank. Users data are read by files (heating).

Two typical configurations simulated by LEGO are shown:

1st example: air-conditioning at ENEL building by heat pump, seasonal storage tank, and solar panels.

The first example we're considering is the simulation of the energy behavior for a building-plant air treatment system for an ENEL building in Turin; it has been done within the ambit of researches having as objectives the use of renewable energy fonts, and the saving of primary energy.
Among the several hypotheses taken into consideration, we tried to find the most convenient solution regarding the plant configuration and the optimum saving of its major components.

A water-water heat pump system takes care of the building air treatment and it can be either connected to the underground water circuit or to the seasonal storage tank carrying 800 m^3, this latter one is heated by 120 m^2 solar panels.
The building has a rectangular layout of about 1.000 m^2 and two floors for a total height of seven meters.
A daily storage tank of 40 m^3 is installed among heat pumps and HVAC system and allows the functioning of heat pumps at night only, that is when electric energy is less valuable.
The seasonal storage tank (divided into two sections of 400 m^3 each) is collocated in the building frontyard and has the same characteristics of a buried cylindrical storage tank. It is completely coated with a polyurethane insulating layer of 20-30 cm thickness.

During the winter (fig.1) the plant is used as follows:
The outlet point is on the top of the tank (warmest zone). It draws water to heat the building. According to the fluid temperature we have three possibilities:
a) T> 40°C (40°C is the minimum temperature to heat directly the building)
b) 25°C<T<40°C (25°C is the maximum inlet temperature for heat pump evaporators.

c) 12°C<T<25°C (12°C is the underground water medium temperature in Turin)
d) T<12°C

Usually, at the beginning of heating period we are in a) condition, so the building is directly heated by the seasonal storage tank water.
After some times the water temperature decreases under 40°C, so it arrives in b) condition.
In that case we can't use the tank water to heat the building and neither we can't treat the water in the heat pump evaporators.
The problem is solved by a 3 way electro-valve that recycle in the evaporator circuit so to maintain the inlet evaporator water temperature less than 25°C.
When the temperature decreases below 25°C (case c)) it is not necessary to recycle the water.
The d) condition is an emergency solution because it is suitable to use directly the underground water without using the seasonal storage tank.

During the summer (fig. 2) the plant is used as follows:

The heat pumps always operate because we can cool the building. Nevertheless there are two possibilities:

e) T< 60°C (60°C is the maximum inlet temperature for the condensers.
f) T 60°C

In e) condition the circuit links directly both condesers and the seasonal storage tank. The outlet point is on the bottom of the tank (where the water temperature is lower). In this case the heat pumps heat the water tank.
In f) condition, instead, the tank is completely disconnected from the plant and the heat pumps use directly the underground water.

In fig. 3 the energetic flows of the plant are shown.
In fig 4-5 the temperatures and the powers exchange are shown from the seasonal storage tank during the year.
In fig.4 the nearest curves show the water temperature of each layer of water (so we can consider the stratification phenomena).

In fig. 6-7 we can see the internal building temperature for both storeys and for 2 day-type, when we choose an on-off regulation with one electro-valve per storey.

In fig 8-9 the same temperature is shown when we use two 3-way electro-valves (fig. 11) with PID regulator simulated by a particular software (5).

<u>2nd example: direct gain seasonal storage built in Catania</u>

This second simulation concerns the use of a tank with a transparent insulating cover for the heating of a building.
The sample, still to be finished, is just a 518 m^3 prototype installed at Conphoebus in Catania.
The cover is made of a transparent plastic honeycomb with cell-like structure.
The storage tank has the following characteristics:

Width above water level	13	m
Bottom width	5	m
Depth	6	m
Passing radiation	60	%
Cover conductivity	0.7	$W/m^2 °C$
T max functioning	80	°C

Tank walls and bottom are covered with insulating material.
As one can see from the diagrams, the tank must be put in the shading condition for some time in Summer, so that the operating temperature won't exceed the max level.

In addition, a small recycle pump behavior has been simulated (0.2 l/sec). Its purpose is to unify, as much as possible, the temperature of water-bearing stratum.
The tank steady state simulation lasts 365 days, with a load of 36.000 kWh (=129 10^9 J) distributed into December, January, February and March.

In fig. 12-13 are shown the temperature and power in the tank, while in fig. 10 there is the energy diagram.

REFERENCE

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(3) J. Duffie & W. Beckman: Solar Energy Thermal Processes
(4) Tennessee Valley Authority, Division of Water Control, Planning Engineering Lab.: Heat and Mass Transfer between a Water Surface and the Atmosphere, 1972
(5) G. Guardabassi: Elementi di Controllo Digitale, 1990

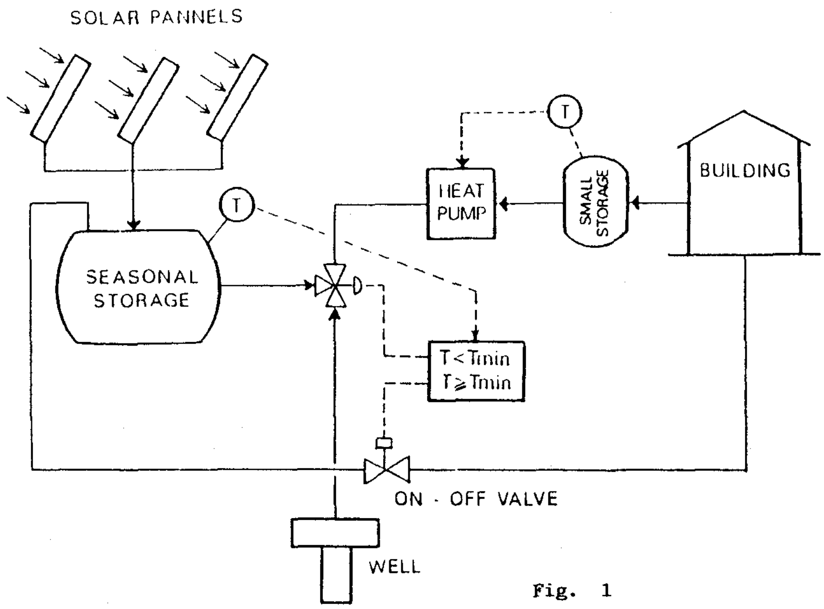

SOLAR PANNELS
BUILDING
HEAT PUMP
SMALL STORAGE
SEASONAL STORAGE
T<Tmin
T≥Tmin
ON - OFF VALVE
WELL

Fig. 1

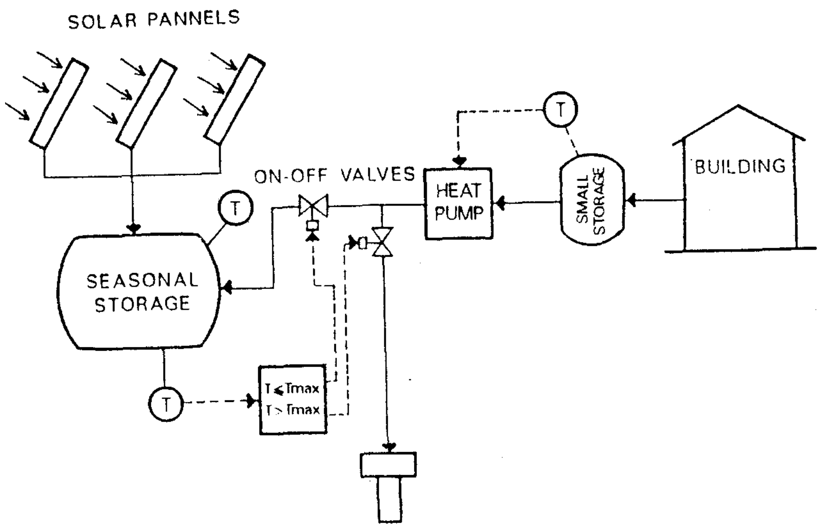
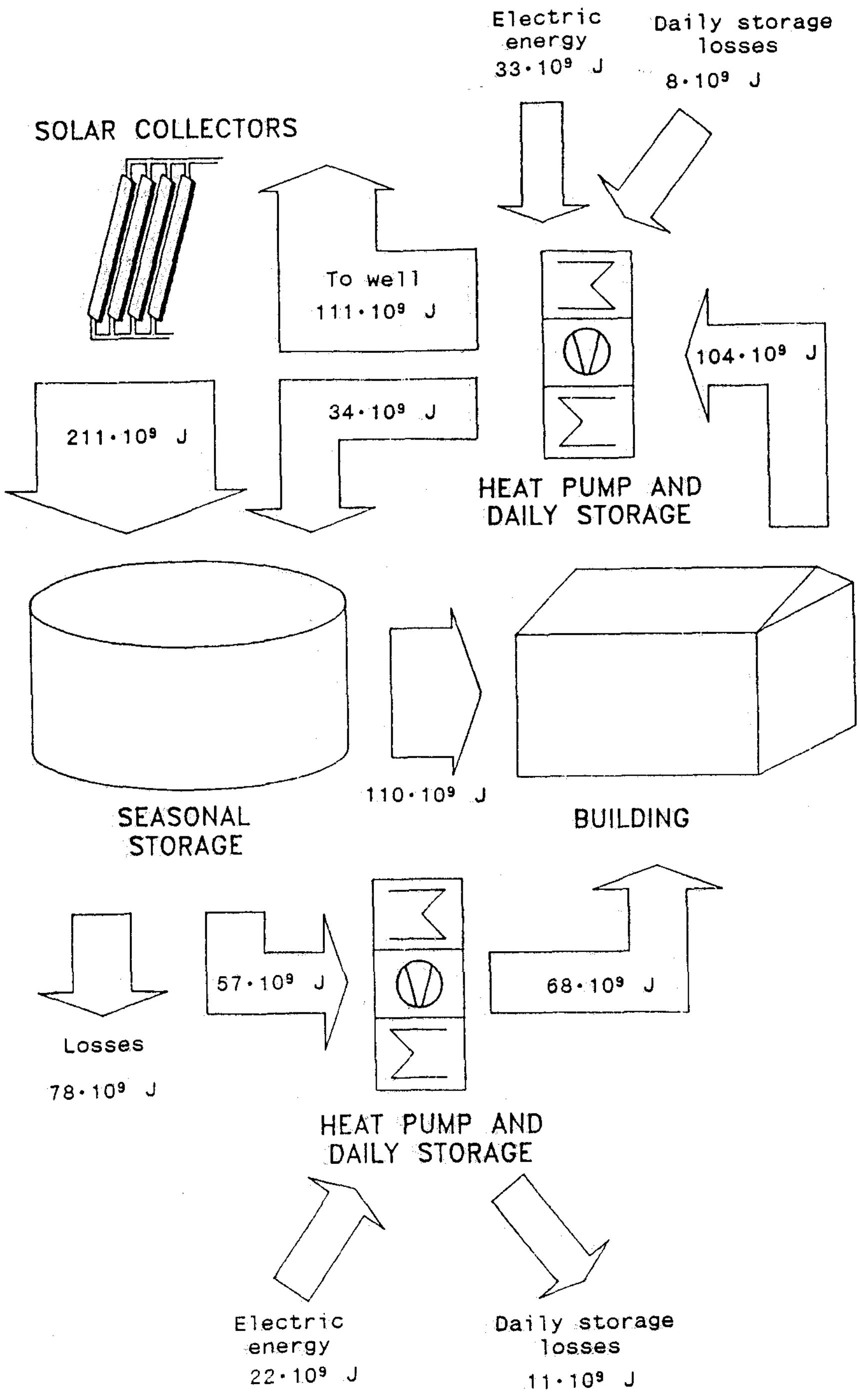

SOLAR PANNELS
ON-OFF VALVES
HEAT PUMP
SMALL STORAGE
BUILDING
SEASONAL STORAGE
T≤Tmax
T>Tmax

Fig. 2



Electric energy 33·10⁹ J
Daily storage losses 8·10⁹ J
SOLAR COLLECTORS
To well 111·10⁹ J
104·10⁹ J
211·10⁹ J
34·10⁹ J
HEAT PUMP AND DAILY STORAGE
110·10⁹ J
SEASONAL STORAGE
BUILDING
57·10⁹ J
68·10⁹ J
Losses
78·10⁹ J
HEAT PUMP AND DAILY STORAGE
Electric energy 22·10⁹ J
Daily storage losses 11·10⁹ J

Fig. 3

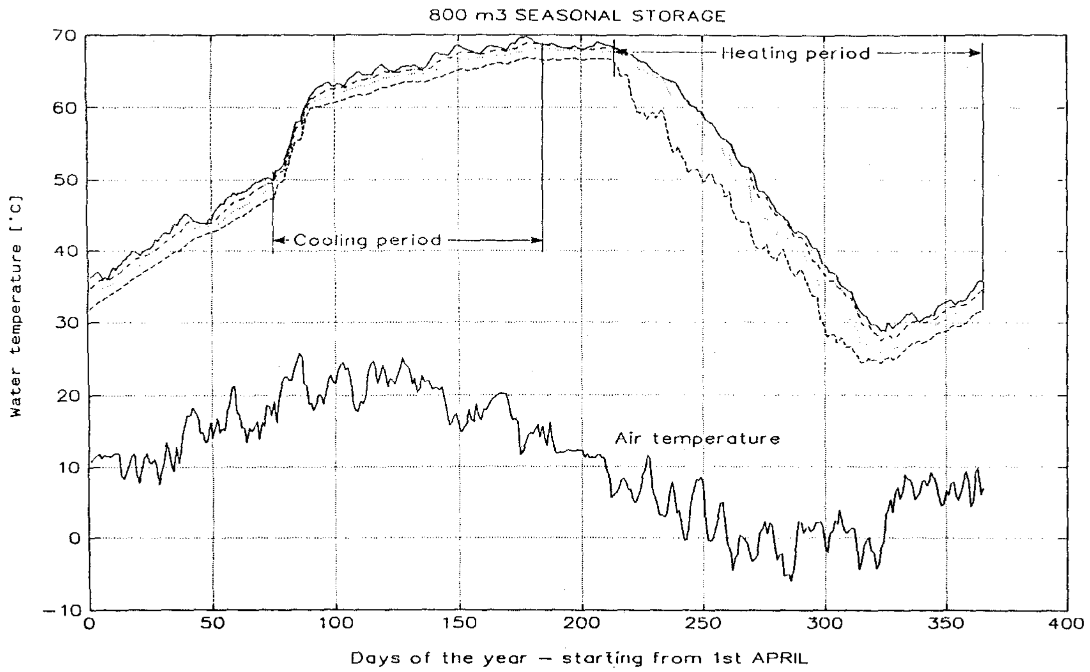

800 m3 SEASONAL STORAGE
Heating period
Cooling period
Air temperature
Water temperature [°C]
Days of the year — starting from 1st APRIL
70
60
50
40
30
20
10
0
-10
0
50
100
150
200
250
300
350
400

Fig. 4

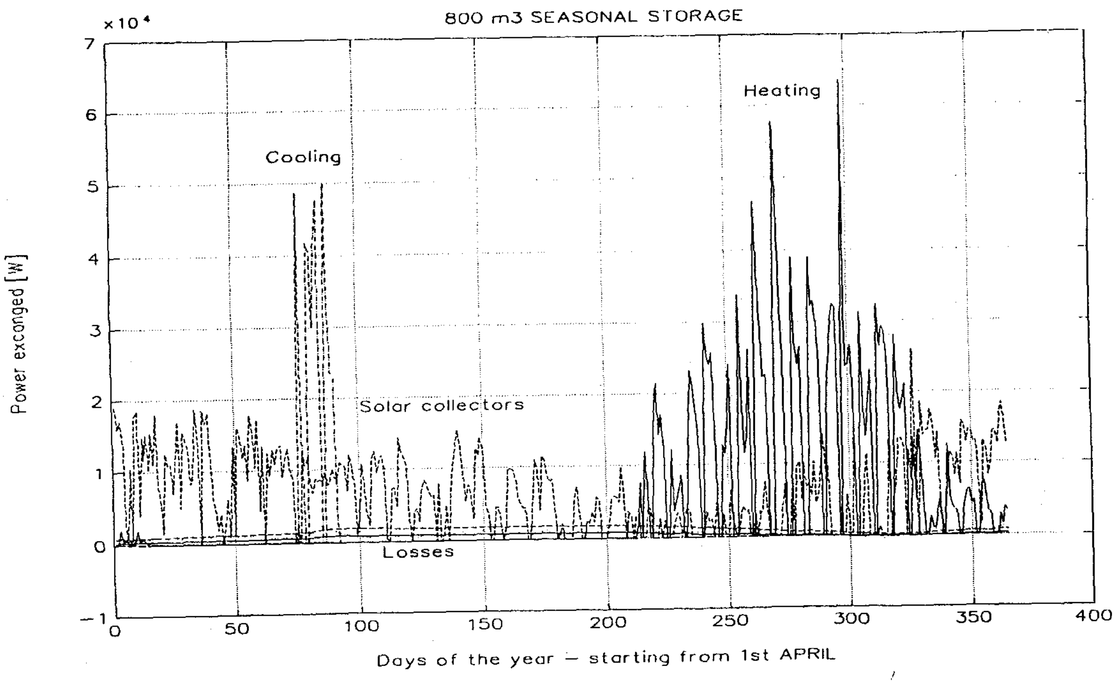

800 m3 SEASONAL STORAGE
x10⁴
Heating
Cooling
Solar collectors
Losses
Power excanged [W]
Days of the year — starting from 1st APRIL
7
6
5
4
3
2
1
0
-1
0
50
100
150
200
250
300
350
400

Fig. 5

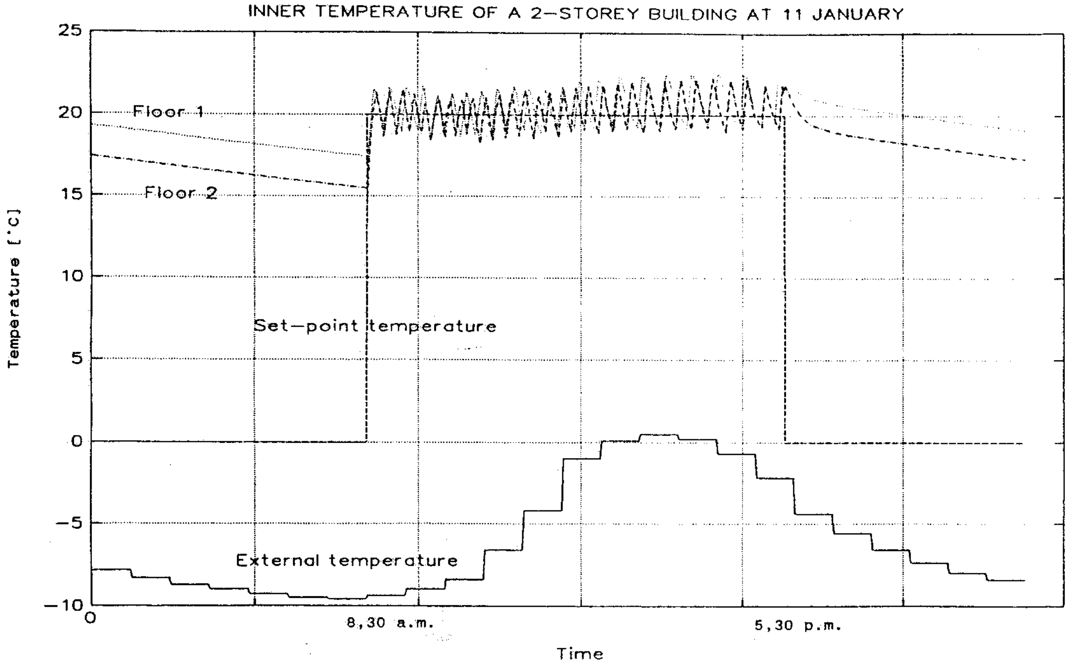

INNER TEMPERATURE OF A 2-STOREY BUILDING AT 11 JANUARY
Temperature [°C]
25
20
15
10
5
0
-5
-10
Floor 1
Floor 2
Set-point temperature
External temperature
0
8,30 a.m.
5,30 p.m.
Time

Fig. 6

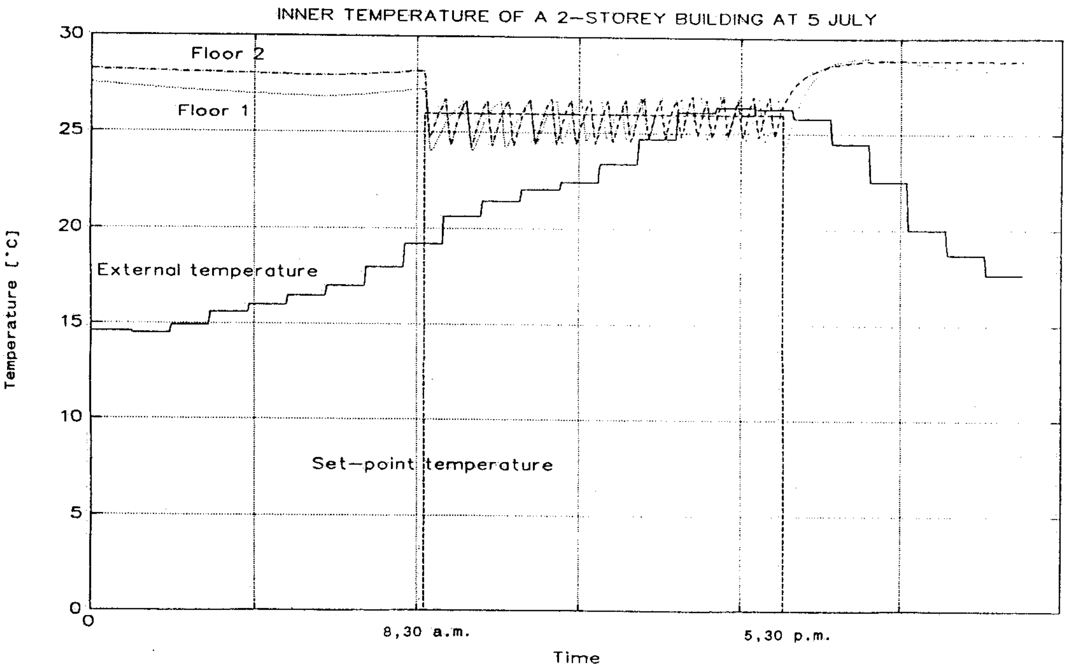

INNER TEMPERATURE OF A 2-STOREY BUILDING AT 5 JULY
Temperature [°C]
30
25
20
15
10
5
0
Floor 2
Floor 1
External temperature
Set-point temperature
0
8,30 a.m.
5,30 p.m.
Time

Fig. 7

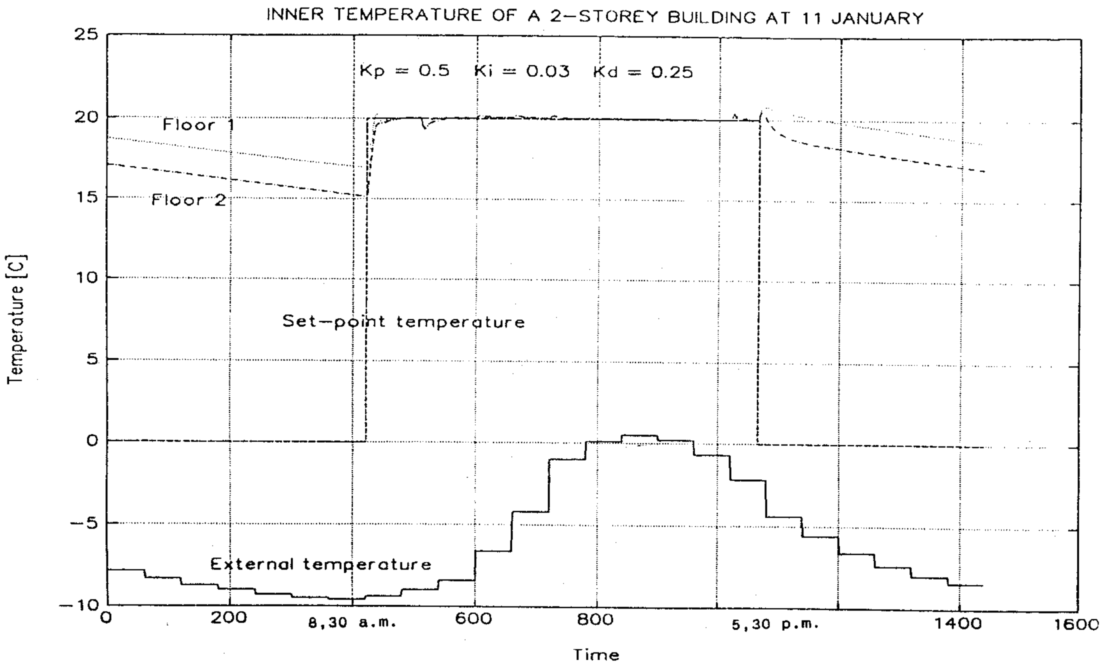

INNER TEMPERATURE OF A 2-STOREY BUILDING AT 11 JANUARY
Kp = 0.5 Ki = 0.03 Kd = 0.25
Floor 1
Floor 2
Set-point temperature
External temperature
Temperature [C]
25
20
15
10
5
0
-5
-10
0
200
8,30 a.m.
600
800
5,30 p.m.
1400
1600
Time

Fig. 8

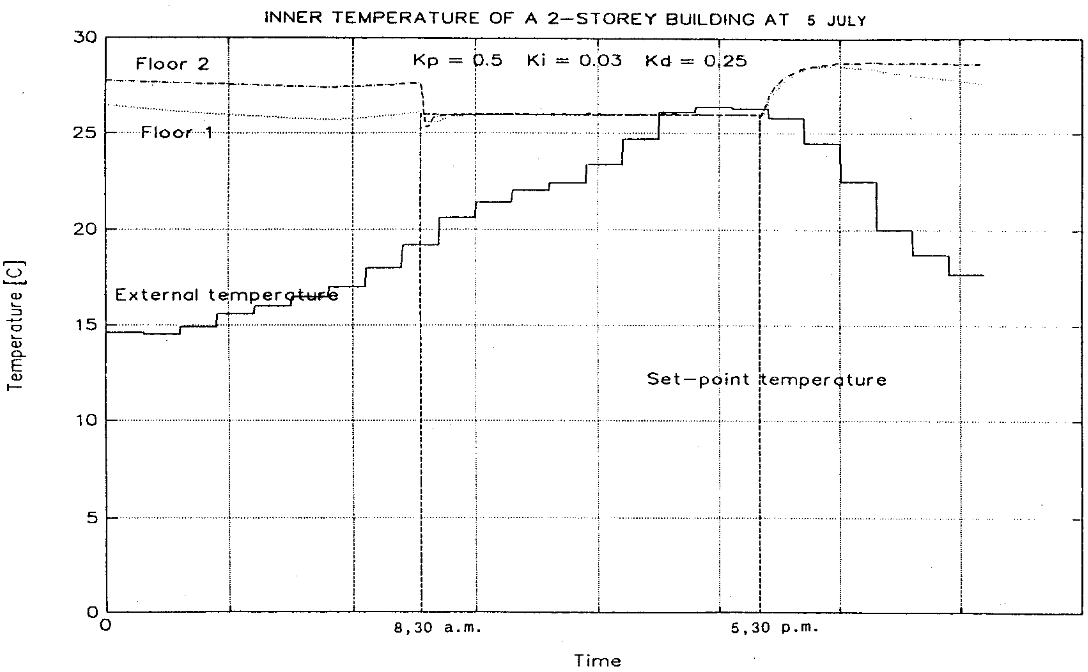

INNER TEMPERATURE OF A 2-STOREY BUILDING AT 5 JULY
Kp = 0.5 Ki = 0.03 Kd = 0.25
Floor 2
Floor 1
External temperature
Set-point temperature
Temperature [C]
30
25
20
15
10
5
0
0
8,30 a.m.
5,30 p.m.
Time

Fig. 9

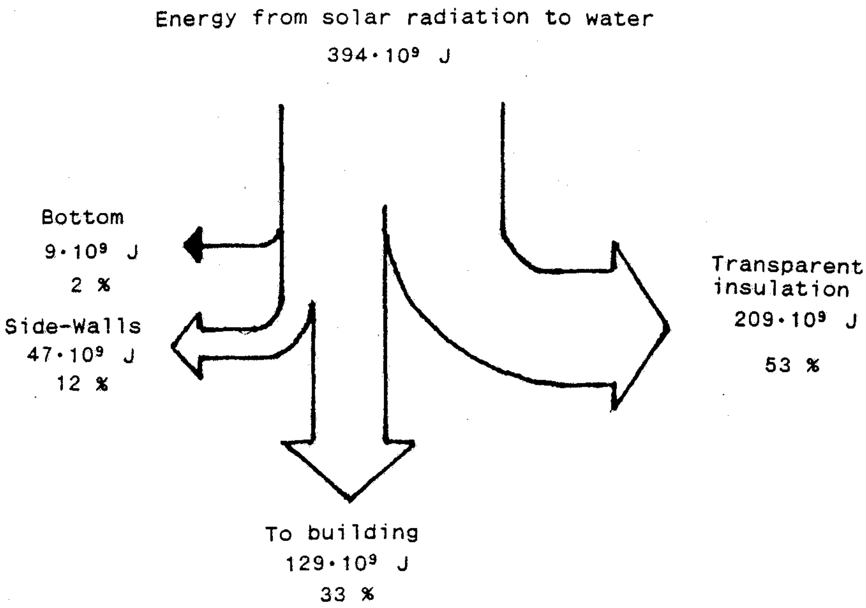

Energy from solar radiation to water
394·10⁹ J
Bottom
9·10⁹ J
2 %
Side-Walls
47·10⁹ J
12 %
Transparent insulation
209·10⁹ J
53 %
To building
129·10⁹ J
33 %

Fig. 10

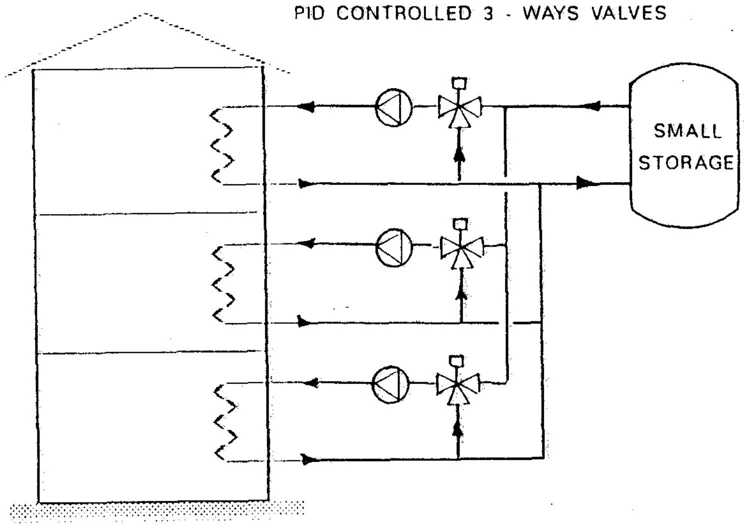

PID CONTROLLED 3 - WAYS VALVES
SMALL STORAGE

Fig. 11

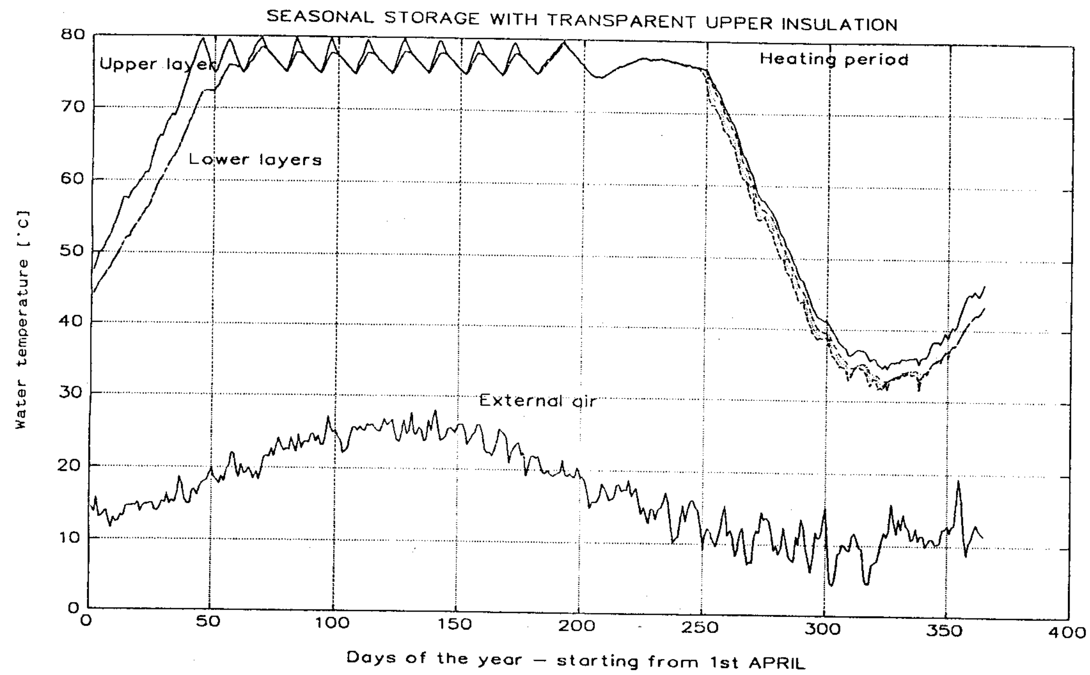

SEASONAL STORAGE WITH TRANSPARENT UPPER INSULATION
Upper layer
Lower layers
Heating period
External air
Water temperature [°C]
Days of the year – starting from 1st APRIL
0
10
20
30
40
50
60
70
80
50
100
150
200
250
300
350
400

Fig. 12

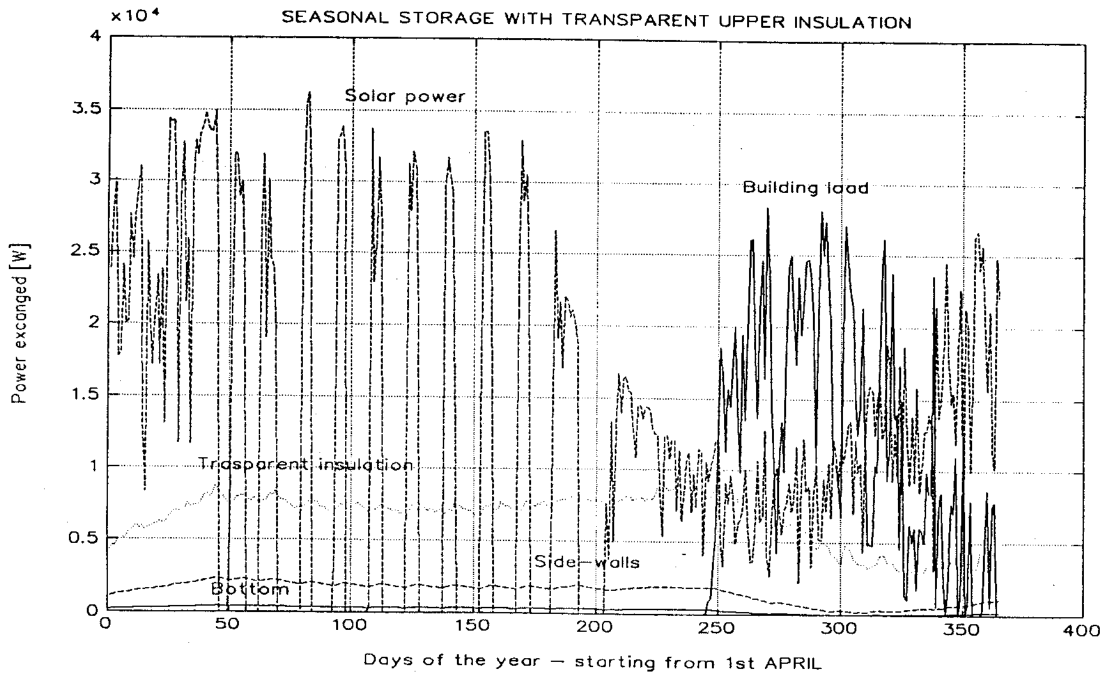

SEASONAL STORAGE WITH TRANSPARENT UPPER INSULATION
x10⁴
Solar power
Building load
Trasparent insulation
Side-walls
Bottom
Power excanged [W]
Days of the year – starting from 1st APRIL
0
0.5
1
1.5
2
2.5
3
3.5
4
50
100
150
200
250
300
350
400

Fig. 13