SIMULATION STUDY OF COUPLED ENERGY SAVING SYSTEMS INCLUDED IN REAL SITE BUILDING

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ABSTRACT

This study (*) has been developped in real site on gymnasium situated in the center of FRANCE which was experimented during two years. This building is equipped with two interconnected energy saving systems. In this first part of the paper the authors describe rapidly the two remarkable energy saving systems of the building. Then, they present theoretical and validation studies which were necessary to simulate correctly these two components. Finally, as these two thermal models have been implemented in TRNSYS simulation environment, they point out the relative importance of heat transfer relevant to each component of this gymnasium.

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NOMENCLATURE

Hla: heat exchange coefficient of air gap ($W/m^2.K$);

Hci: convective heat exchange coefficient of inside surfaces of rooms 1 an 2 ($W/m^2.K$);

Hce: outside convective heat exchange coefficient ($W/m^2.K$);

Hri: inside heat exchange radiative coefficient ($W/m^2.K$);[1]

Hre: outside heat exchange radiative coefficient ($W/m^2.K$);

ε: emisivity of glass wool and covering;

σ: STEFAN BOLTZMANN constant ($W/m^2.K^4$);

Ri: thermal resistance of glass wool ($m^2.K/W$);

Re: thermal resistance of iron covering ($m^2.K/W$);

Tela: inlet temperature of air gap (°C);

Tsla: outlet temperature of air gap (°C);

Tsext: outside surface temperature of iron covering (°C);

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Tsurlv: surface temperature of glass wool (°C);

Tsint: inside surface temperature of metal support called "alubac" (°C);

Tint and Text: respective values of inside (gymnasium) and outside ambient temperature (°C);

Φ: total solar radiation on covering (W/m^2);

Tm: mean temperature of air gap (°C);

$$Tm = (Tela + Tsla)/2$$

m : flow rate of air gap (kg/s);

Hrse: linearised infrared radiative coefficient of air gap from metal covering to glass wool (W/m4.°C);

Hrlv: linearised infrared radiative coefficient of air gap from glass wool to metal covering (W/m4.°C);

L: breadth of roof (m);

L(i): length of an element piece of roof (m);

Tsol: mean soil temperature over a month (°C);

Tspuits: outlet temperature of buried pipe system(°C);

Tepuits: inlet temperature of buried pipe system (°C);

Tse: inside surface temperature of covering (°C);

Cp: specific heat of air (J/kg.K);

α: solar absorption coefficient;

TT: time step of calculation (h);

1.INTRODUCTION

For ten years, our laboratory has been working on real site modelling, (FABRE 1982; TROMBE and Al 1985; TEPE 1984; BALEYNAUD 1987; GRENIER, JAVELAS and TROMBE 1989; MAVROULAKIS and Al 1991);

The aim of real site simulation is to know thermal behaviour (consumptions, comfort conditions, sensitivity parameters) of thermal systems by using predictive models on configurations which differ from experimental ones.

For such a kind of study we follow generally the different stages indicated further on.

It is first necessary to develop a simulation model as close as possible to physical reality.

Then, we must compare results from calculations to from experimentation results. It is called validation of models and it must be realized with a good accuracy on various parameters as temperature or thermal balances. Moreover, in real site we need to validate model on a long period of experimental results because climate is always changing. At the present case experimentation goes on over a two year period, 1991 and 1992.

At last, we develop parameter sensitivity studies which give more information and can lead sometimes to the elaboration of simplified models.

2.DESCRIPTION OF REMARKABLE SAVING ENERGY SYSTEMS

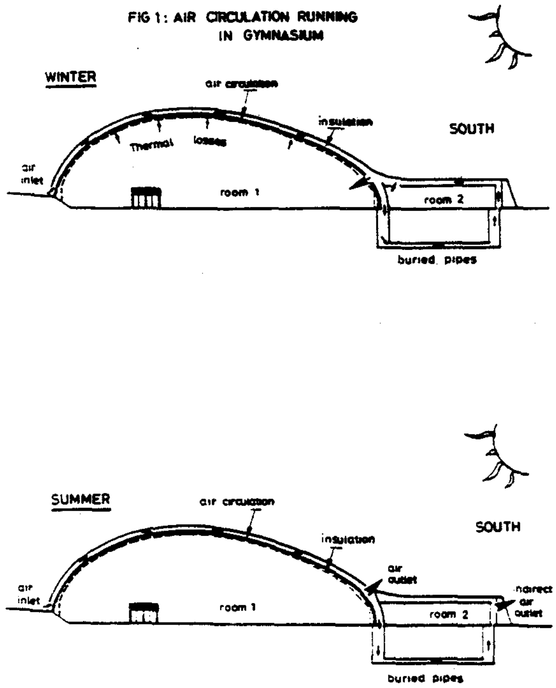
This gymnasium is equipped with two remarkable energy saving systems, Figure1.

The first one is a roof which is constituted of a metal covering, an air gap and insulation material.

The second is a buried air earth heat exchanger at two meters depth, beneath gymnasium. It is constituted of plastic tubes of different diameters.

In winter air coming from ventilated roof is led through air pipes to a buried pipe system before being sent into the building. In summer air is directly extracted from ventilated roof and thrown outdoors.

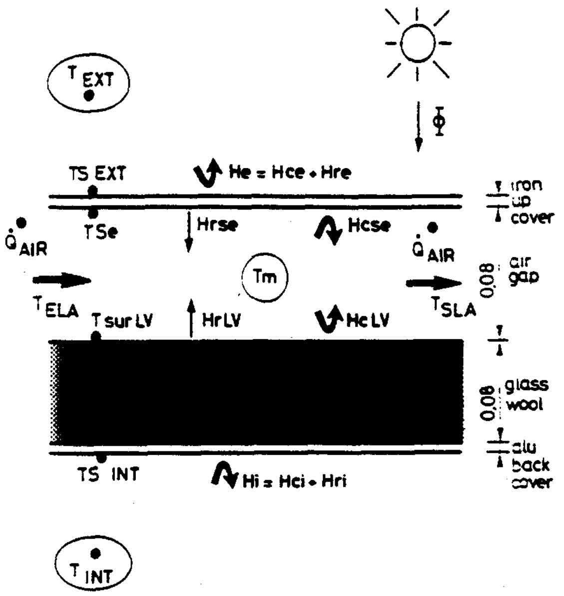
FIG 1: AIR CIRCULATION RUNNING IN GYMNASIUM



3.THEORETICAL STUDY

3.1 CASE OF AIR GAP

The ventilated roof has a very low thermal mass. It has been modelled in steady state using a three equations system.
Each of these equations represent the thermal balance of an air gap segment, Figure 2.



EQUATION 1

- (Hcse + Hrse + 1/ Re - 1 /Re * 1/ (Re*He+1)) * Tse + Hrse * Tsurlv + Hce * Tm = - 1/ (1+Re He) * ($\alpha\Phi$+ He * Text)

EQUATION 2

Hrlv * Tse - (Hrlv + Hclv + 1 / Ri) * Tsurlv + Hclv * Tm = - 1 / Ri * Tsint

EQUATION 3

Hcse * Tse + Hclv * Tsurlv - (Hcse + Hclv + 2 m * Cp / L / L (i) * Tela

With : Tm = (Tela + Tsla) / 2

REMARK

This set of equation is solved by GAUSS - SEIDEL method using an iterative process to take into account non linearity of radiative heat exchange coefficients.

3.2 CASE OF BURIED PIPE SYSTEM

In our study case, the following reasons led us to develop a simplified model:

- flow rates, compared to section of pipes, do not take great values;
- the buried pipe system is not insulated and ground temperature of soil follows, with a little dephasing, outside soil temperature at same depth;
- the depth of buried pipes under surface of gymnasium is roughly equal to 2 meters, so inside temperature of gymnasium has no influence on their thermal behaviour.

In consequence, we assumed that soil has a very high thermal mass and than keeps a constant temperature during the heat exchange. So, thermal balance of a pipe segment can be represented as indicated, Figure 3.

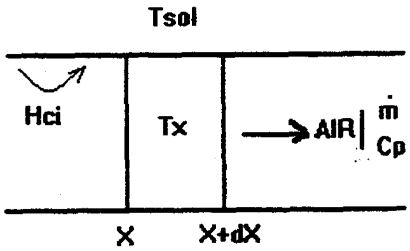


Figure 3: THERMAL BALANCE of a PIPE SEGMENT

$$T(x) = (To - Tsol) \times e^{-X/(mCpRth)} + Tsol$$

With : Rth = 1/ Hi *P
P= perimeter of pipes;
Hi = convective heat exchange coefficient of pipes calculated in turbulent flow from (BORY 1957).

$$Nu = 0.023 * Re^{0.8} * Pr^{0.33}$$

Nu = Nusselt number;
Re = Reynolds number;
Pr = Prandtl number;

4. VALIDATION of MODELS

4.1 Temperature validation

For validation of models we chose remarkable climatic sequences of ten days long. The first one was a cold winter period of March (from 1st till 10th) and the second a hot summer period of August (from 1st till 10th).

4.1.1 VALIDATION OF VENTILATED ROOF MODEL

We can see, Figures 4 and 5, that experimental and theoretical evolutions of roof air outlet temperature are in good agreement. Discrepancy between these two values is generally lower than 1 K, except for a few hours during sunny days. In this case, we think that error comes from our assumption of neglecting the roof thermal mass in our model.

FIG 4 : THEORETICAL and EXPERIMENTAL EVOLUTIONS OF ROOF AIR OUTLET TEMPERATURE for MARCH 1-10, 1991

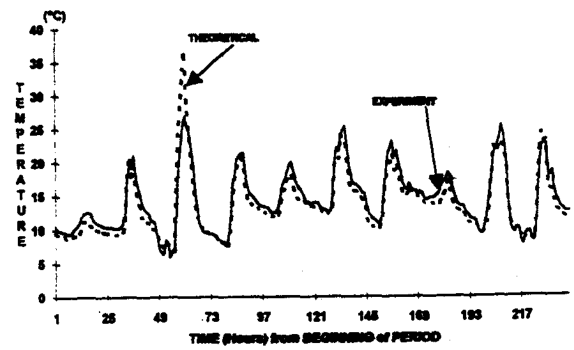
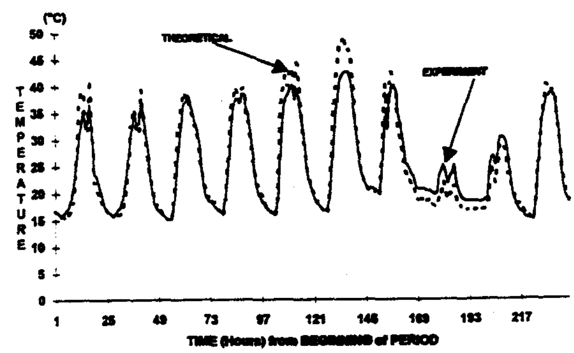


FIG 5 : THEORETICAL and EXPERIMENTAL EVOLUTIONS of ROOF AIR OUTLET TEMPERATURE for AUGUST 1-10, 1991



4.1.2 VALIDATION OF BURIED PIPE SYSTEM MODEL

There is again, Figures 6 and 7, a small discrepancy between theoretical and experimental air outlet temperature of buried pipe system. So, assumption of constant soil temperature during heat exchange is quite right.

FIG 6 :THEORETICAL and EXPERIMENTAL EVOLUTIONS of BURIED PIPE SYSTEM AIR OUTLET TEMPERATURE for MARCH 1-10, 1991

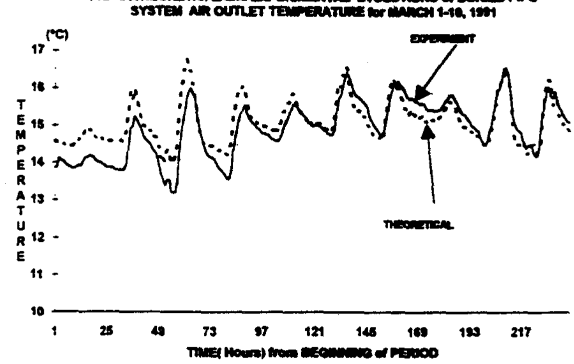
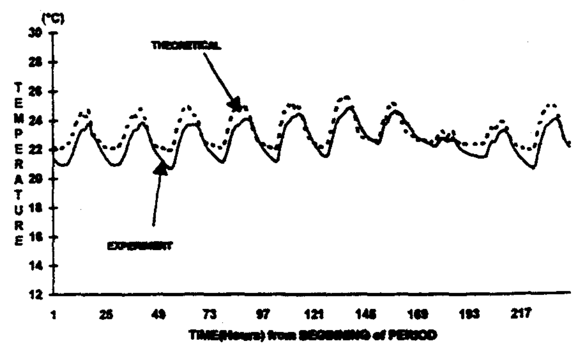


FIG 7: THEORETICAL and EXPERIMENTAL EVOLUTIONS of BURIED PIPE SYSTEM AIR OUTLET TEMPERATURE for AUGUST 1-10, 1991



4.2 TOTAL THERMAL BALANCE VALIDATION OF MODELS

For thermal balance validation of models on a long period we chose the whole first year of experimentation (1991).

4.2.1 CASE OF ROOF AND AIR PIPES

Results are presented for each month of year, (see table 1), and we can see that theoretical results are close to experimental ones. Relative error (column 4 of table 1) is generally lower than 10 %, but for August; (during this month,a breakdown occured in the acquisition measurement system.
Nevertheless, global relative error all over the year is very low.

1991	Theoretical Balance (kWh)	Experimental Balance (kWh)	Relative Error (ex-th)/ex
February	1906	1981	-3.9 %
March	1427	1371	3.9 %
April	1873	1868	0.3%
May	1848	1716	7.4%
June	1398	1352	3.3%
July	1299	1366	-5.2%
August	1471	1720	-16.9%
TOTAL	12222	11374	-1.3 %

TABLE 1 : THERMAL BALANCE VALIDATION OF ROOF an AIR PIPES

REMARK:

The results include two types of energy exchanges.
Energy gains from roof;
Energy gains from exchanges through pipes which are located in gymnasium.

So, we do not know exactly which is the part of energy coming from either roof or from gymnasium. Moreover, as these pipes are crossing different rooms, we need a multizone modelling of gymnasium.
We give the energy exchanges for each part (roof and gymnasium) in the fifth part of this paper.

4.2.2 CASE OF BURIED PIPE SYSTEM

We can see, Table 2, that monthly theoretical results yielded by model are not as close to experimental ones as for ventilated roof. Relative error (column 4 of table) can vary between from -1 %(February) to 44 % (April).
In April theoretical and experimental saved energies are very low. So, relative error can become very important.
At last, global relative errors on positive value (recovered energy of soil) and negative value (stored energy in soil) are lower than 13%.
Assumption of taking a monthly constant temperature for soil is again confirmed.

As a conclusion, we can say that the models are validated and it is possible to use them as predictive models. They have been implemented in (TRNSYS 1988) building simulation environment.

1991	Theoretical Balances (kWh)	Experimental Balance (kWh)	Relative Error (ex-th)/ex
February	1023	1012	-1 %
March	111	140	21 %
April	79	143	44 %
May	-276	-329	16.1%
June	-498	-582	14.4%
July	-1063	-1227	13.3%
August	-824	-904	8.8%
Addition of positive values	1213	1295	6.3 %
Addition of negative values	-2661	-3042	12.5 %

TABLE 2 : THERMAL BALANCE VALIDATION OF BURIED PIPE SYSTEM

5. RESULTS of SIMULATION WITH NEW MODELS IMPLEMENTED IN TRNSYS

5.1 Comparison of energy coming from roof and gymnasium

We note, that energy coming from ventilated roof is greater than 70 % for the two simulated years 1991 and 1992, (see table 3 and 4).
But we can also see that energy gains in air pipes are not negligible. Particularly, in winter when roof outlet air temperature is low and heating temperature of gymnasium is high. In this case recovered energy by pipes crossing gymnasium is relatively important.
Nevertheless, this energy is lost through the buried pipe system which is not insulated. To avoid this problem air pipes which cross different rooms of gymnasium should be insulated.

1991	Theoretical Balance (kWh)	Roof (kWh)	Air Pipes (kWh)
February	1981	1152	829
March	1371	924	447
April	1868	1360	508
May	1716	1270	447
June	1352	1120	232
July	1366	1266	100
August	1720	1638	82
TOTAL	11374 —	8730 (76.7%)	2645 (23.3%)

TABLE 3: SEPARATED THERMAL BALANCE of ROOF and AIR PIPES for YEAR 1991

1992	Theoretical Balance (kWh)	Roof (kWh)	Air Pipes (kWh)
November	2570	1065	948
December	3129	1821	1340
January	3334	2031	1393
February	3176	1822	955
March	3318	1618	858
April	2747	2099	648
May	3050	2726	324
June	1691	1418	273
July	1624	1530	94
TOTAL	22963 —	16130 (70.2%)	6833 (29.8%)

TABLE 4: SEPARATED THERMAL BALANCE of ROOF and AIR PIPEs in GYMNASIUM for YEAR 1992

5.2 Comparison of collected solar energy and gymnasium thermal losses

Ventilated roof can collect energy in two ways:

- the first one consists of the gymnasium thermal losses occurring mainly in winter, when inside ambiant temperature is greater then air gap temperature. It is generally the case when outside climatic conditions are bad and when there is no sun.

- the second one happens for sunny days when solar radiation on covering can reach a sufficient value.

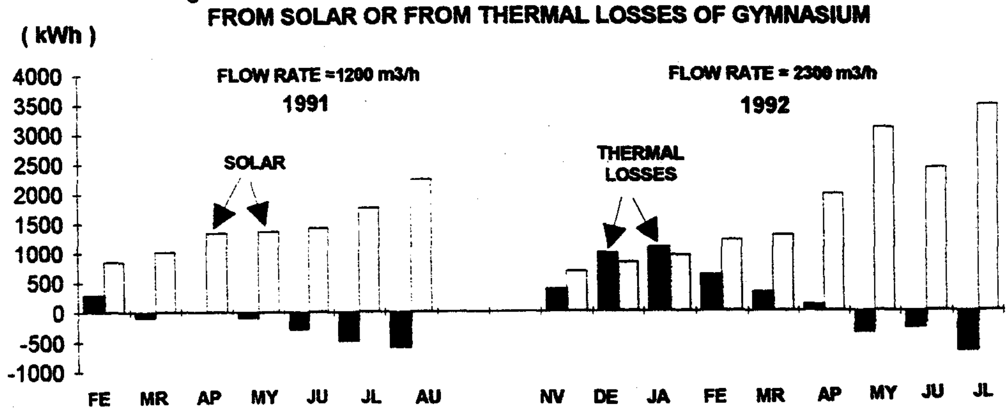
So, it will be interesting to know each part of energy coming either from thermal losses or from solar energy absorption on top cover.

Simulations results of this study are presented below, Figure 8, and we can see that these two phenomenas do not take the same importance.

Solar energy absorbed by covering during a whole year is greater than energy collected from from thermal losses of gymnasium but for two winter months. This result is quite normal because the internal side of the roof insulated and of course not the top cover.

Moreover, gymnasium heating temperature are lower than in dwellings. So thermal losses are lower too.

Figure 8: COMPARISON of COLLECTED ENERGY COMING EITHER FROM SOLAR OR FROM THERMAL LOSSES OF GYMNASIUM



CONCLUSION

This study points out the general interest of real site simulation with correctly validated models.

In this case, it can only be used as a tool to give more information about dynamic performance of systems or also to show out advantages or disadvantages of components in system design.

We have implemented these two models in TRNSYS simulation environment and there are available.

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