COMPARISON BETWEEN MONITORING AND SIMULATING. AN IMPORTANT STEP FORWARD FOR MODEL RELIABILITY

F. Stazi[1], C. Di Perna[2], L. Del Prete[1], A. Stazi[1]

[1]Department of Architecture Constructions and Structures, Polytechnic University of Marche,
Ancona 60131, Italy, e-mail: fstazi@yahoo.it
[2]Department of Energy, Polytechnic University of Marche,
Ancona 60131, Italia, e-mail: diperna@univpm.it

ABSTRACT

The new European regulations on energy saving were aimed at a reduction in consumption in the winter phase. This caused even warm countries such as Italy to use envelopes optimised for the winter phase only which are nevertheless unsuitable to the other seasons. The research was developed in order to understand the total yearly behaviour of different envelopes in Mediterranean climates. It started from a real case subject to: (i) monitoring; (ii) simulation of the as-built state for tuning up the software (ENERGYPLUS); (iii) parametric analysis. The research stressed the importance of the second step in calibrating the virtual model. The first simulation showed considerable differences between monitored and calculated values. Such differences were removed through gradual steps of input setting. The report shows said steps and how each input variation affected temperature values.

KEYWORDS

Model reliability, simulation and experiment, software Energyplus, building envelope.

INTRODUCTION

The research was developed in order to understand and optimise the behaviour of buildings in summer, winter and middle seasons in the temperate climates of the Mediterranean area.

The new regulations, calculation software and literature have focused on energy saving in the winter phase only. In warm-climate countries such as Italy this has resulted in the adoption of thoroughly unsuitable envelopes in the summer phase such as low thermal-inertia super-envelopes - i.e. actual thermos buildings - or passive systems designed for solar gain only.

Several researchers studied the importance of the calibration of the virtual models for high thermal inertia envelopes.

An interesting study about the models reliability was carried out from J. Kosny and E. Kossecka (2002). The researchers highlighted that the programs like BLAST, DOE2 and ENEGYPLUS, do not create errors in spite of the one-dimensional simplification of the flows if applied to low inertia structures, typical of the USA. The researchers demonstrated that applying such instruments to structures with high thermal conductivity determine errors of 44%, due to a three-dimensional "network" of thermal bridges (increased from elevated relationship between thermal conductivity of the structural part and the new super-insulating materials). The researchers proposed to simulate "equivalent walls" designed with one-dimensional structures multilayer with the same thermal property of the real wall.

A research group from the tropical climate of Reunion Island (F. Miranville et al. 2003) built up an experimental test-cell in order to study the behaviour of coverings. The study was carried out with a deep relationship between monitoring activities and simulation, including parametric sensitivity analysis and empirical validation in order to find any possible error in the modelling. The group introduced a method called "forcing" that consists in imposing some values obtained in the monitoring phase.

An interesting study about the models applied to solar walls was carried out from V. Hernandez et al. (2006). They realized a numerical and experimental study of a solar wall comparing the values of surface temperatures and the temperature in the external ventilation channel recorded during the monitoring activities with the same values calculated. They found a good approximation of the model.

To develop the research we carried out a series of monitoring activities, simulations and a parametric analysis of a residential-building case study.

THE CASE STUDY

The building consisted in a three-storied compact-shape volume oriented with its longitudinal axis inclined 14° clockwise with respect to the East-West direction in order to optimise sun exposure. Our study focused on the simplex flat (Fig.2), which is equipped with an external super-insulation in the east, west (shown in Fig. 1 with letter E) and north wall and which houses different passive solar systems in the south area: tree-shaded Trombe wall (shown in

Fig. 1 with letter B and Fig.3); unshaded Trombe wall (shown in Fig. 1 with letter A); Trombe wall with leaning greenhouse (shown in Fig. 1 with letters C and D and Fig.3), and greenhouse.

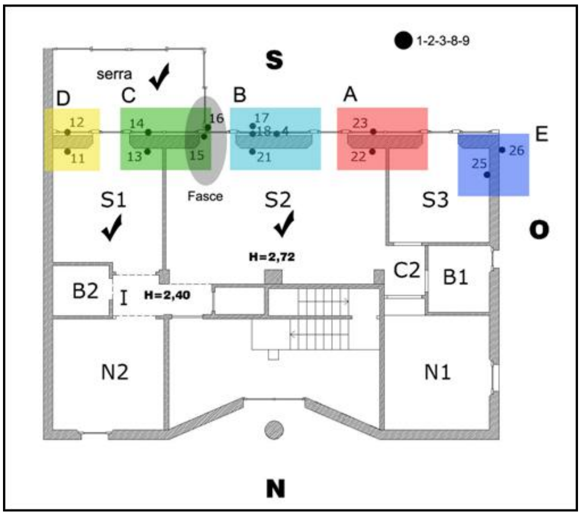

Fig. 1 - Schematic layout of the flat showing the different wall parts analysed and the locations of the probes for detecting surface temperatures.

Fig. 2- internal and external views of Trombe- wall

The Trombe walls are made up of a concrete wall 40 cm thick painted black on the outside and equipped with vents (2 at the bottom + 2 at the top). At a distance of 10cm on the external side a single glass surface (shaded by a roller-shutter) brings about the greenhouse effect.

Fig. 3- external view of the greenhouse

EXPERIMENT AND SIMULATION

Monitoring

The as-built situation was monitored in order to measure consumptions, ambient temperatures (internal and external) and surface temperatures in the external envelope.

In order to do this, a data logger was used (BACUC ABC), connected to an external climatic station (probes 1,2,3,8,9 in Fig.1 and Fig. 4) that included: hygro-thermal probe, wind speed and direction probe, solar radiation probe.

Two data logger ELOG were connected to a series of thermal resistances for surface temperatures (probes 11-26 in Fig.1).

A reader (BABUC A) was connected to a mobile point to read the internal parameters. (symbol √ in fig.1 and Fig.4). In particular we recorded the dry-bulb temperature (this probe was shaded for radiation heat flux), the wet-bulb temperature, the mean radiant temperature for the rooms S1, S2, S3 and for the greenhouse (Fig.1).

Fig. 4- external climatic station (BABUC ABC) and mobile internal station (BABUC A)

Finally a calorie counter for actual consumption values was used.

Simulation

Dynamic-state software ENERGYPLUS made it possible to reconstruct the same building in the as-built situation into a virtual model. The results showed that, although boundary conditions recorded during monitoring were introduced into the software (e.g. the values recorded by the external climatic station), the internal temperature values given by the software were far from the actual values.

We consequently had to tune up the software with gradual steps to vary the input values so that the output temperatures detected would coincide with the values measured during the monitoring phase. This made it possible to achieve a "correct", realistic and reliable virtual model of the as-built case in which parameters could be varied by changing the characteristics at every new level of investigation: climatic zone, orientation, shape of the building, type of opaque surface, glazed percentage, screening, materials, position of layers, thicknesses, use profile of the system etc. Such variations made it possible to make the case study more general and to estimate the effect resulting from incremental changes to the initial project.

This report shows the lack of correspondence between measured and simulated temperature values, especially as far as internal air temperatures are concerned. The steps taken to tune up the software used (ENERGYPLUS) are reported and highlighted, in particular the parameters to be set in the program in order for the model to be as close as possible to reality.

Definition of simulation inputs:

- Activity

Setting the activity template based on the type of zone; Occupancy: *0.04 people/m*^{2}; Environmental control: *heating 20 °C; cooling 26°C*

- Construction

External wall: traditional with external coating, transmittance U=0.224 W/m^{2}K, Thickness = 34cm;

Internal partition: air-brick wall with transmittance U=2 W/m^{2}K, Thickness = 10 cm;

Semi-exposed wall: air-brick wall with transmittance U=1.8 W/m^{2}K, Thickness = 14 cm;

External floor: traditional floor with transmittance U=1.4 W/m^{2}K;

Airtightness: 0.5 Vol/h

- Openings

Double glazing (openings): *4-12-4mm with transmittance U=2.77 W/m*^{2}*K;* solar heat gain factor=SHGC= 0,75 (according to UNI EN 410)

Single glazing (external side of the Trombe walls): *4mm with transmittance U=6.99 W/m*^{2}*K;* SHGC= 0,83 (according to UNI EN 410)

Frame and dividers: *aluminium shoulders with transmittance U=0.9 W/m*^{2}*K;*

Shadings: *blind with high reflectivity slab, external position and night/day operation for cooling.*

- HVAC

Type of system: central heating using water, radiators; temperature set point: 20°C; ignition profile: 2:00 a.m. - 3:00 a.m.; 6:00 a.m. -9:00 a.m.; 1:00 p.m. - 4:00 p.m.; 6:00 p.m. - 8:00 p.m.; 9:00 p.m. - 11:00 p.m.

- Thermal inertia

Concrete Trombe wall (south):

Conductivity= λ= 128 W/mk; Density= 2200Kg/m3; Specific heat=880J/kgK

Traditional wall (north, west, east):

Conductivity= λ= 128 W/mk; Density = 2200Kg/m3; Specific heat=880J/kgK

DISCUSSION AND RESULT ANALYSIS

Comparison between monitoring and first simulation

We compared the dry-bulb temperatures and the surface temperatures recorded during the monitoring activities with the same parameters calculated by the simulation software.The trend of air temperatures calculated by EnergyPlus shows very wide oscillations in comparison with the monitored trend, and it reaches peaks that are too high if compared to actual peaks (as shown in Fig. 5). On the contrary, the internal surface temperatures of Trombe walls as calculated by the software are very similar to monitored temperatures (as shown in Fig. 6). Consequently, the simulation of the passive system is carried out by the program in a correct way as concerns surface temperatures, while the differences between calculated and simulated air temperatures are due to excessive direct radiation which goes through the glazed surfaces and overheats the environments.

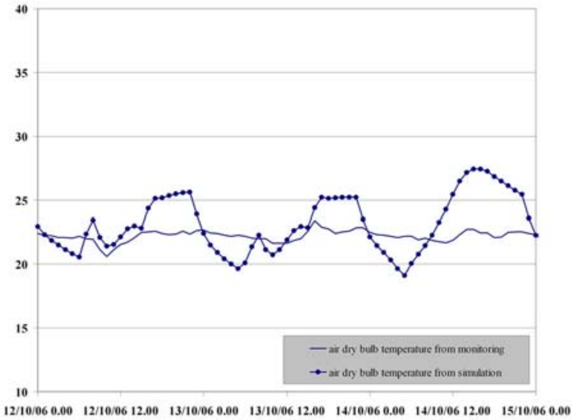

Fig. 5 - Air temperature in the living room according to monitoring activity and first simulation.

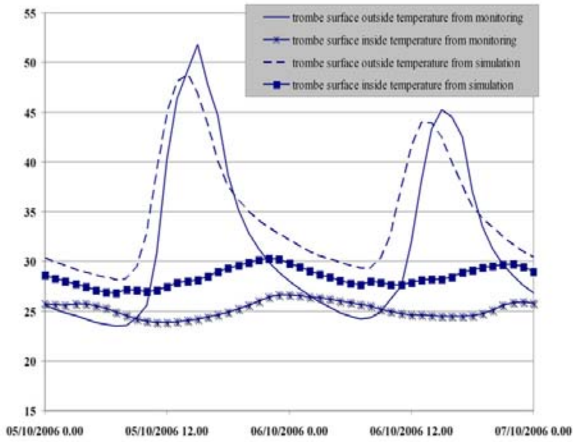

Fig. 6- Surface temperatures of Trombe wall according to simulation and monitoring activity.

The first step to optimise the virtual model consisted in introducing variations on the glazed surfaces (such as changing thermal transmittance and the solar heat gain coefficient), using a method to account for the presence of shading elements and changing the default values for air infiltrations. Further changes were subsequently made (such as the addition of an external film for the program to account for the blackened surface of the Trombe wall) so that the external surface temperature values of the Trombe wall would coincide with monitored values, since a lack of correspondence had be noticed in this case as well.

Step 1 – Changing the thermal transmittance of the glazed surfaces

The first attempt consisted in changing the thermal transmittance of the windows in the living room. This made it possible to decrease the influence of direct radiation on internal air temperature fluctuations. Eight different glass combinations were tested.

- Clear glass 4 mm; Air gap 10 mm; Thermal transmittance U = 3.13 m^2°K/W
- Clear glass 4 mm; Air gap 12 mm; Thermal transmittance U = 2.7 m^2°K/W
- Clear glass 4 mm; Air gap 16 mm; Thermal transmittance U = 2.5 m^2°K/W
- Clear glass 4 mm; Air gap 16 mm; Thermal transmittance U = 1.8 m^2°K/W
- Clear glass 4 mm; Air gap 16 mm; Thermal transmittance U = 1.8 m^2°K/W
- Clear glass 10 mm; Air gap 16 mm; Thermal transmittance U = 1.287 m^2°K/W
- Clear glass 10 mm; Air gap 16 mm; Thermal transmittance U = 0.418 m^2°K/W
- Clear glass 10 mm; Air gap 16 mm; Thermal transmittance U = 0.141 m^2°K/W

The diagrams of the surface temperature of the glazed surfaces and the temperature of internal air were derived in the output phase for all the combinations. The diagrams derived in the limit cases (high transmittance and low transmittance - Fig. 7) showed that the trend of the temperature stayed almost the same and small temperature translations upwards were seen as transmittance decreases. No flattening of the curves was seen. Therefore the variation in transmittance did not affect the improvement of the simulation model.

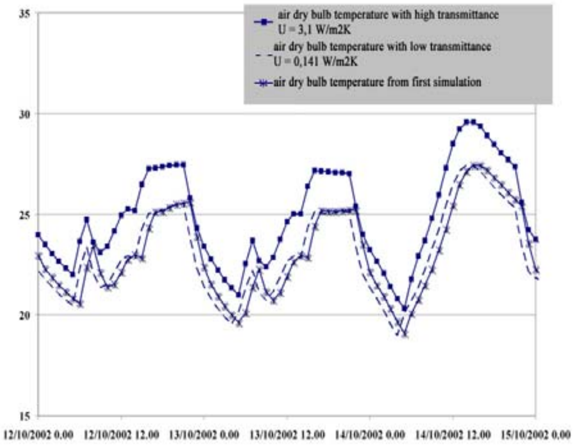

Fig. 7 – STEP1-Air temperature in the living room as thermal transmittance varies on the glazed surface.

Step 2 – Changing the SHGC in glazed surfaces

In the second step we changed the SHGC value, i.e. the solar heat gain coefficient, which considers the quantity of direct and diffused radiation entering internal environments through the glazed surfaces of the windows. Five tests were performed by changing the solar reflectance and solar transmittance of the glazed surfaces. The tests showed that an increase in the SHGC entailed such an upwards movement of the curve of the internal air temperature in the living room that temperatures close to 30°C were reached. On the contrary, as the SGCH decreased (lower value=0,43), the temperature curve went down. The tests made it possible to infer that the SHGC affects the entrance of solar radiation into internal environments and it reduces the surface temperature of the windows as well as the temperature of internal air, bringing it closer to more likely values. (Fig. 8.)

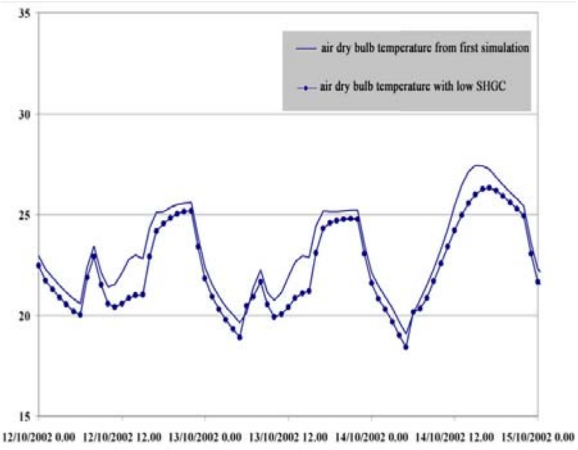

Fig. 8 - STEP 2 - Air temperature in the living room in the best SHCG case (SHGC=0,43)

Step 3 – Addition of balcony and tree

The previous steps having stressed the need to reduce the quantity of solar radiation coming in through glazed surfaces, we consequently had to introduce into the simulation the shading effect due to the presence of a balcony over the Trombe wall and a tree. Amongst the output reports the Window Heat Gain value was initially studied in connection with air temperature in the living room (Fig. 9).

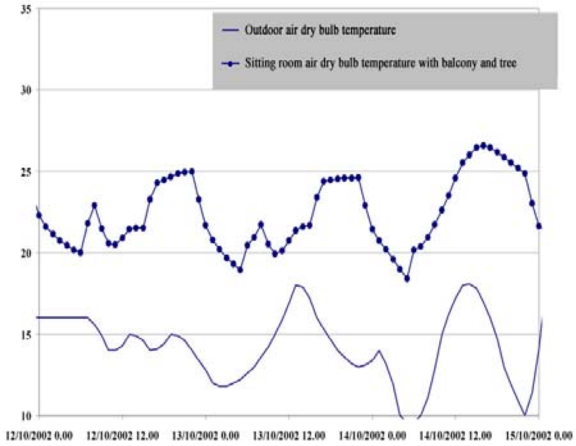

Fig. 9 - STEP 3 - Air temp. in the living room in the case with balcony and tree.

The balcony was simulated by means of a 1.5m overhang; the tree was simulated by means of a flat surface parallel to the building.

The results showed that a smaller quantity of solar radiation came in through the glazed surfaces. As a mater of fact, the Heat Gain value related to the simulation with the tree decreased to approximately 400 W/m2 from 800 W/m2 at the beginning, although it was still too high compared to a realistic value for the parameter. Besides that, although the Heat Gain value decreased, the temperature in the living room was not better than in the previous cases, as it reached 28°C and went below 20°C.

Step 4 – Changing meteorological data and the SHGC in double glazing only

In this step we changed the SHGC in the double glasses of the openings, on the front (external) side and on the back (internal) side so as to reduce their ability to absorb solar radiation. Together with this change, we also changed the EnergyPlus meteorological file in order to have a week when external temperatures were the same as the temperatures measured through monitoring, and consequently remove any differences deriving from external boundary conditions.

The results of the simulation (Fig. 10) showed that the trend of the temperature in the living room got satisfactorily closer to the actual trend of the temperature and was flatter than in the first case, although still too variable.

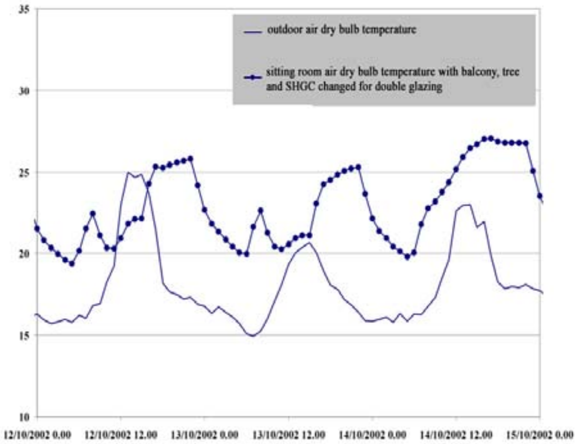

Fig. 10 - STEP 4 - Air temperature in the living room in the case with balcony and tree and SHGC changed for double glazing.

The Heat Gain value too was much smaller than in the first case - down to 100-200 W/m2 - and reflected the direct radiation values actually experienced inside a building. On the contrary, the external surface temperature of the Trombe walls was still too low in comparison with the temperature measured by the monitoring activity.

Step 5– Addition of black surface

The external surface temperature values were too low probably due to the fact that the black-painted surface was not simulated in the construction of the Trombe wall. In order to simulate this element we added a very thin surface of 0.001 mm with emissivity $\varepsilon = 0.05$.

The diagrams of the surface temperatures derived in the output phase (Fig. 11) show that internal surface temperatures follow the actual trend, while external surface temperatures have a smaller range. But this may be due to the fact that during the monitoring activity surface temperatures are detected through thermal resistances, which are directly irradiated and consequently overheated. So they might have measured values that were actually a little lower.

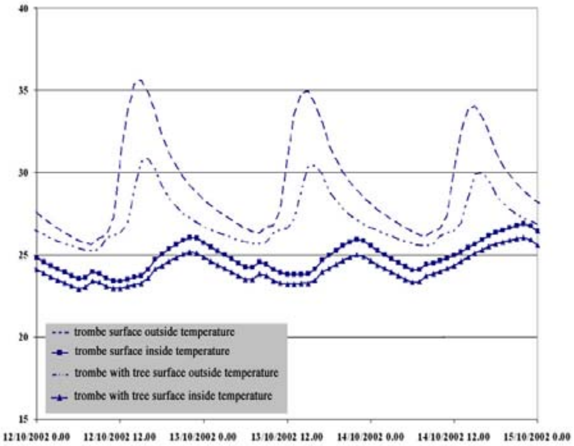

Fig. 11- STEP 5 - Surface temperature of the two types of Trombe wall (with and without tree) with black surface.

Step 6– Changing infiltrations

The analysis of the simulated internal surface temperatures in the living-room walls revealed to have too high thermal range and too low temperature values. These behaviours may be due to the fact that the infiltration was set at 0.6 Vol/h and steady throughout the whole day. In this phase a setting for opening and closing the windows was used so that the infiltration during the night was either zero or very low and 0.5 Vol/h during the day.

- Daytime infiltration in October
- Infiltration in December from 7 a.m. to 9 p.m.
- Infiltration in March from 7 a.m. to 9 p.m.
- Daytime infiltration in August + natural ventilation

Changing the infiltrations (Fig.12) into the internal environment entailed a considerable flattening of air temperature in the living room, which we deem similar to the temperature satisfactorily measured by the monitoring activity. The average temperature now is 23-24°C, 1 degree higher than monitored temperature (which is 22-23°C). Although we still see a thermal gradient between night and day, it is much smaller than in the initial case.

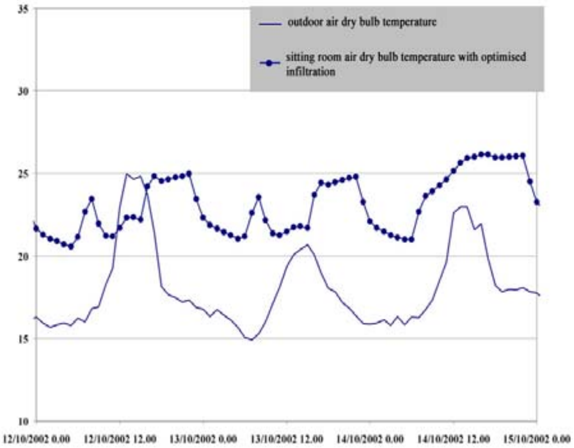

Fig. 12- STEP 6 - Air temperature in the living room with optimised infiltrations.

CONCLUSIONS

A comparison between the surface-temperature and internal-air values measured by the monitoring activity and the values derived from the simulation of the same case study shows that internal surface temperatures coincide in the two cases, external surface temperatures are slightly different, and internal air temperatures have considerably different values due to actual temperatures having a trend characterised by a smaller fluctuation. The gradual steps of adaptation of the model to reality shows the following:

About the internal air temperature:

- the transmittance variation in the glazed surfaces does not affect the fact of getting closer to the actual values;
- the introduction of obstructions simulating the presence of a tree or upper balcony does not have any effect;
- the decrease of the SHGC value brings the values closer to the actual values in that it causes the curve to be flattened;
- the change to double glazing and the subsequent decrease in the absorbance capacity of solar radiation causes the curve to be further flattened;
- the replacement of the default values related to external infiltration (0.5 Vol/h) with different values according to the time and seasons makes internal temperature values closer to the actual values (difference of just 1°C).

About the external surface temperature:

- the introduction of an external layer simulating the blackened surface of the Trombe wall brings external surface temperature values closer to actual values.

REFERENCES

Stazi F., Di Perna C., Stazi A. and Ricci E. 2006. "Solar architecture and Italian climate: the summer behaviour and the suitable passive solar systems", Proceedings of World Renewable Energy Congress 2006 Florence, Italy.

Kosny J., Kossecka E. 2002. "Multi-dimensional heat transfer through complex building envelope assemblies in hourly energy simulation programs.", Energy and Buildings 34 pp.445-454. Elsevier Ltd.

Miranville F., Boyer H., Mara T., Garde F. 2003. "On the thermal behaviour of roof-mounted radiant barriers under tropical and humid climate conditions: modelling and empirical validation", Energy and Buildings 35 pp. 997-1008. Elsevier Ltd.

Hernàndez V., Morillòn D., Best R., Fernàndez J., Almanza R., Chargoy N. 2006. "Experimental and numerical model of wall like solar heat discharge passive system" Applied Thermal Engineering 26 pp. 2464-2469. Elsevier Ltd.