THE USE OF A SIMULATION TOOL IN ORDER TO OBTAIN THE THERMAL PERFORMANCE OF PASSIVE SOLAR HOUSES IN PORTUGAL

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ABSTRACT

This paper describes the methodology used in a simulation process that pretend to compare predicted and measured values. This process corresponds to one of the main task in a project denominated "*Thermal Characterization of Passive Solar Construction in Portugal*". The aims of this two year project are to identify and quantify the thermal performance of those buildings. This study was carried out combining short measurements with a simulation tool. The present paper analyses the use of a simulation tool (ESP_r) [1] in modelling the building and calibrating the model by comparing it with the measured data. The methodology is discussed in detail for two passive solar houses and the discrepancies obtained in the process are analysed and correlated with the input parameters of the model.

INTRODUCTION

The experimental studies in buildings, in order to get its thermal performance in an annual basis is a long and difficult task. There are many important parameters that are difficult to measure and to control. The results need to be correlated with the climatic conditions and therefore the experimental period turns out to be too long and expensive and finally the results are very restricted to the conditions or parameters that occurred during the monitoring campaign.

Although a simulation tool can be used to achieve the thermal performance of a real building, the difficulties are also enormous, mainly if the goal is to reproduce the real indoors conditions. For instance, it is extremely difficult to model the real behaviour of the occupants, which has a major influence in the thermal behaviour of the building. Consequently important uncertainties are expected in both processes.

METHODOLOGY

The main idea of the methodology used in this work, is to combine a short period of experimental work (two weeks) with simulation for that period, in order to get a "consistent" model which can be used to get the thermal behaviour of the building and to perform sensitivity studies, that will allow to identify the parameters mostly affecting the thermal behaviour of the building.

In order to proceed with this strategy the following steps are necessary:

- **Model**: to create a model that describes the building and the users behaviour.
- **Measurements and Predictions Comparison**: compare the results obtained by simulation **(blind simulation**) with this model, with the experimental results obtained during the measurements campaign.
- **Calibration**: analyze the uncertainties, identify the causes and if possible improve the model.
- **Sensitivity Studies**: to use the improved model in order to perform parametric studies that will quantify its influence in the building.

The creation of the model needs information that is mainly obtained from the designer and also by a visit or survey. These elements are very important in order to describe and characterize the building. The translation of this information from the building to the model **-** "descriptive abstraction" **-** requires from the modeller a good knowledge of the overall heat transfer process in presence in order to simplify the geometry. The most important is to characterise the main driven phenomenons in presence, (solar gains, internal gains, infiltrations, mass transfer). This will permit the modeller to make the necessary simplifications, without loosing information and produce a "consistent" model with the reality.

It is necessary to check carefully site and layout, obstructions and interference in terms of solar gains.

The construction materials and elements (external and internal) need to be well known. It would be helpful to identify not only the area, but also the thickness of each layer, the material and its position and the thermophysical properties of each element (conductivity, density, and specific heat). For the external and internal surfaces, define at least the colour and, if possible, the *surface properties* (emissivity and solar absorsptivity) or characterise the surface in terms of brightness.

The glazing materials and the shading devices should be carefully characterised. This includes the glazing *type* (single, double, etc.), transmission properties (average total transmittance at least) and *U* value. For the windows and shading devices it is necessary to identify, for the particular period, the operation hours, openings and closings. The characterisation of the shading devices, should be as exhaustive as possible, regarding its type, position transmission properties and any other particular information. Other information, regarding operation of systems (heating and cooling), schedule operation, set points or power needs to be obtained. The same for lighting and domestic equipment

All this information is obtained in the projects and by visiting the buildings. It is quite important to understand the way the occupants actuate with the building. This information is obtained through out the inhabitants.

<u>The Model</u>

Having all the previous information, and knowing quite well which are the final goals of the each case under study, the modeller can produce a preliminary model which could consistently represent the building or part of it in terms of geometry (site, orientation, opening areas, monozone, multizone, obstructions) construction (type of envelope, walls, glazing, insulation, color, shading devices), and the building energy flow paths (plant, occupancy) .

This “preliminary model “ represents the essence of the building or as said before part of it, being more or less complex in definition, according the complexity of the building and the thermal processes.

The final ‘product’, the model, will be used by a simulation tool, which will inter-connect all the building input parameters and energy flows, and solve the correspondent mathematical equations.

<u>Measurements and Predictions Comparison</u>

The simulation results obtained from this “preliminary model “ are considered “blind”, by the fact, that they have not been yet compared with any experimental results from the building. So the modeller does not know if they are good or bad results. Those results are quite important, in order to check how far the predictions are from the measured results. It gives an idea of the errors, if they are quite obvious, or the possibilities of improvements that can be achieved by the model.

In most cases, this improvement process consists in checking the input data of the model, for example, the thermophysical properties, the geometric definitions of the building. These improvements may sometimes increase the complexity of the model, which in the early stage has suffered simplifications, that are not so obviously after all.

The process of redefining a model, performing the simulation and comparing the predictions with the measured values has a final goal: to create a model, that reproduces “<u>reasonable well</u>” the measured results. This is not a “validation” process, which is something more complex. The final result of this process could be defined as the “<u>calibration model</u>”, which corresponds to the one, that under the same particular conditions of the experimental stage, predicts quite well those results.

The main problem is to define what we mean by “quite well”, because this concept is ambiguous and it depends of each particular case. In some cases, the uncertainties of a particular parameter are so big, that it is impossible to improve the results.

There are no specific answers for the previous questions, but they mostly depend on the information available regarding the building, its quality and about what happened during the measurement campaign.

<u>Sensitivity Analysis</u>

With an improved model it is possible to carry out sensitivity studies. This analysis has the main purpose to check the influence of distinct operative and construction parameters on the thermal performance of the building. Depending on the case, the main parameters under study usually are: <u>*Shading devices*</u>, is one of the parameters that must influence the air temperature inside the building, mainly in summer time. It is important to study the existence and influence of the relative position of the devices (external, internal, none) and the time schedule of operation. <u>*Ventilation rate*</u> is other important parameter in summer. The main question is to quantify the influence of the night ventilation in the thermal behaviour of each building. The <u>*Occupation*</u>, and schedules can be a considerable internal gain, difficult to match with the reality. Some other parameters related with construction and geometry can be studied, namely the use of insulation in the envelope, <u>*Glazing* type</u> and <u>*Colour*</u> of the external facades and then quantify the improvement in the comfort conditions.

«VALE ROSAL»
SOLAR PASSIVE HOUSE

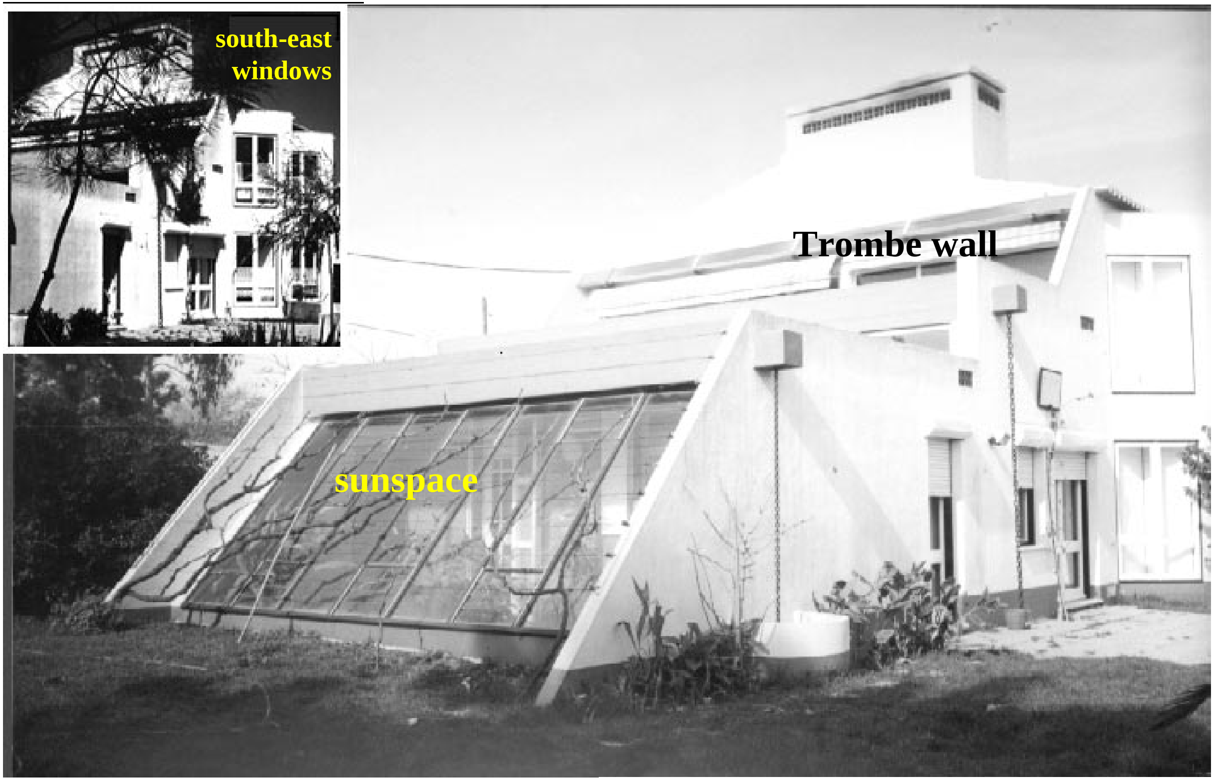


Photo 1: «Vale Rosal» - Solar Passive House

This house (photo 1) was monitored during nine summer days, 3 - 11 July (Julian date: 184-192), in order to measure air temperatures inside a bedroom, the living-room and its attached sunspace. Some site outdoor conditions, like the global solar radiation and air temperature, were also measured.

Thermal Model

Firstly two separeted models were created: **bedroom/trombe wall** and **living room/sunspace** (fig.1). Simulation results revealed that these models are very simplistic and do not describe accurately indoors conditions.

As can be seen in graph 1 and 2, simulated temperatures have higher swings than those measured. Inadequate roof description and insufficient thermal mass could be the main reasons of this performance.

A **global house model** was implemented to better characterise the physical reality: north buffer zone and other bedrooms, which consequently increases the thermal mass, and ventilated roof zones.

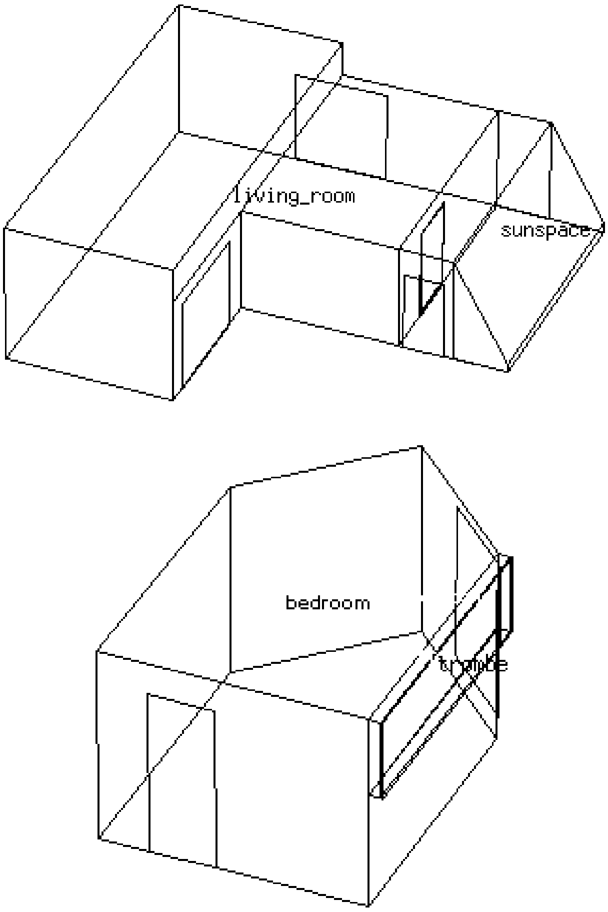


Fig. 1: Two independent model zones

Blind Simulation Conditions

- The first simulations applied to the described models assumed the following conditions: **Without internal gains**: its influence is very variable depending on occupation behaviour and we could know how do this house perform only with 'external conditions'.
- **Infiltration:** 0.2 ACH in bedrooms and living room and 1 ACH in sunspace and roof.
- **Solar protection:** during the monotorization campaign the external roller shutters in the living were closed except upper south windows that had not any solar protection. Bedroom window had internal shutters closed during all days.
- **Shading devices:** in summer Trombe Wall is shaded with an overhang and external roller blinds. These devices were simulated as an obstruction that considers diffuse radiation only.
- **Vegetation solar protection**: the attached greenhouse is shaded with wired deciduous vine that produces reductions in the single glass transmission, reflection and absorption coefficient values [2].

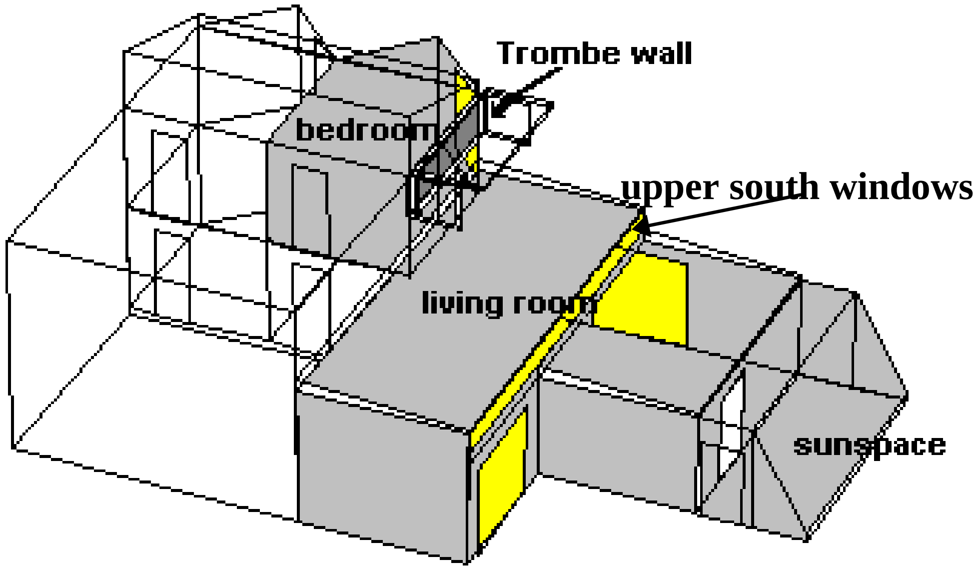
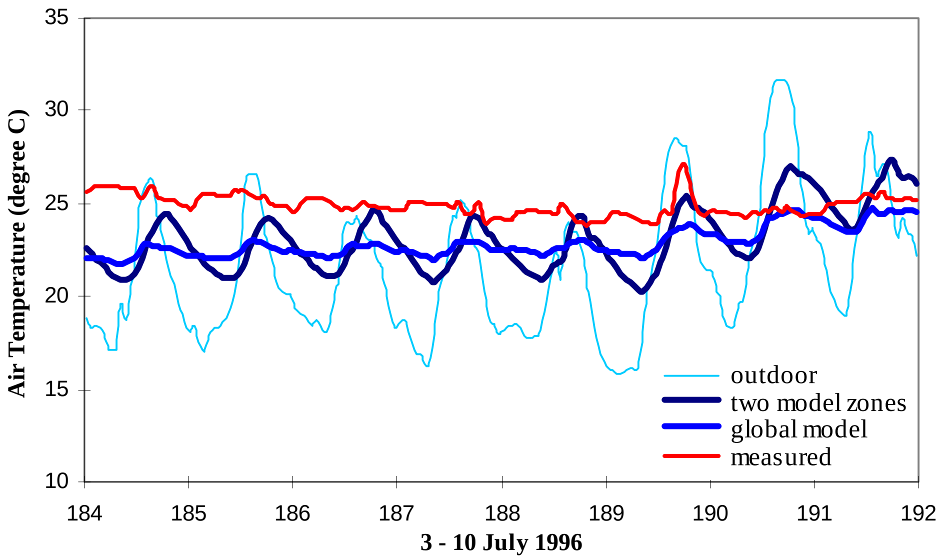
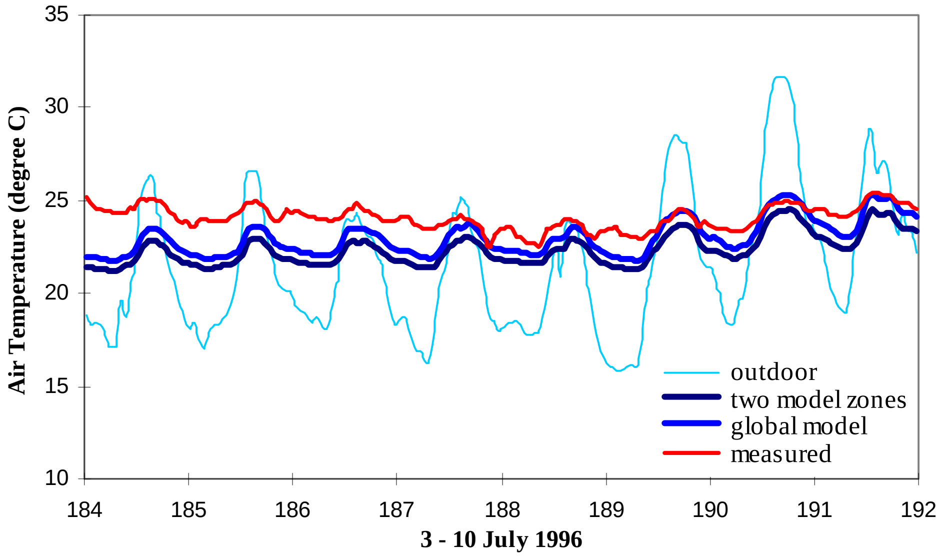


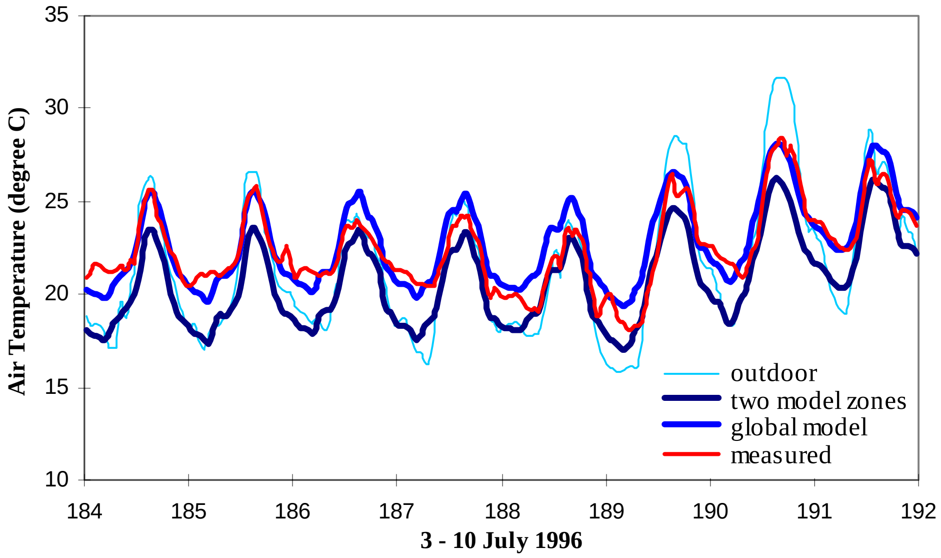
Fig. 2: Global model with eleven thermal zones.



Graph 1: Simple and global model (bedroom).



Graph 2: Simple and global model (living room).

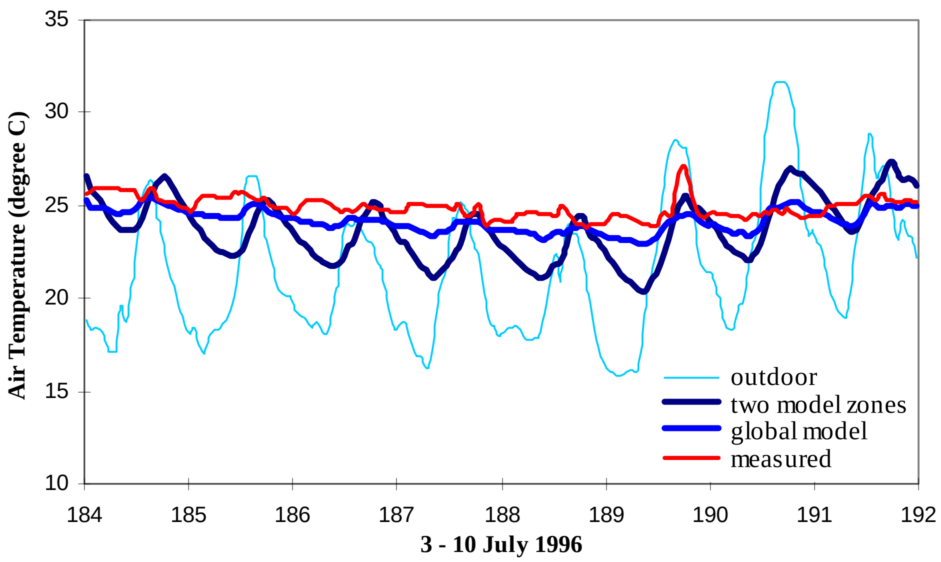


Graph 3: Simple and global model (sunspace).

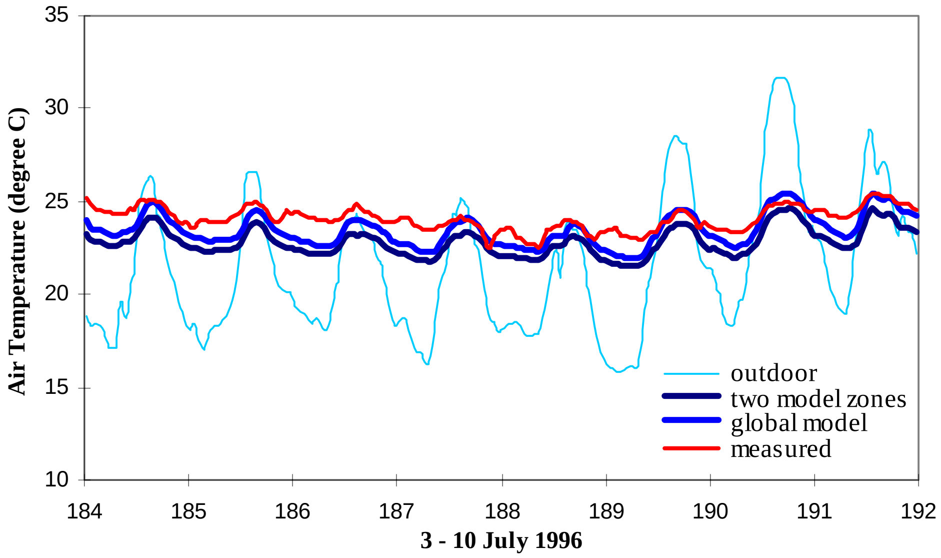
Start-up Conditions

The first simulation period (day 184 - 188) shows a notorious discrepancy between the measured and predicted values in terms of main tendencies. In the rest of the period (day 189 - 192), beside the differences, the model tends to match the measured values. The main reason for this behaviour is certainly the influence of the start up conditions, related with the climatic conditions. In the days before the measurements in the house, there were no climatic data available for this site. Then it was used a fictitious period that reproduces the first measured day (17.1 to 26.3 ºC). If we used realistic climatic data to start-up days, obtained at nearest meteorological station, the results will change considerably (graphs 4, 5 and 6).

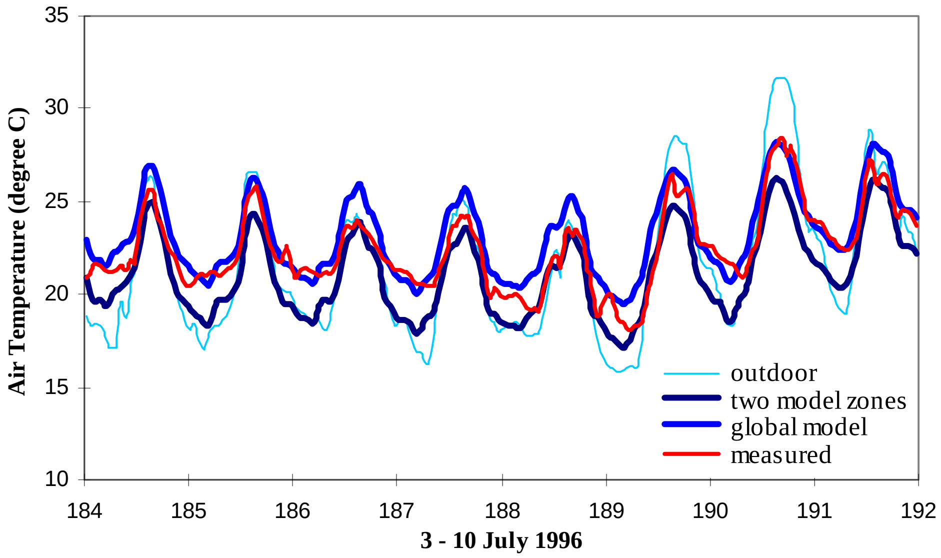
Global model results show, for the sunspace, a reasonable consistence with the measured values. In the next step, we have investigated how the occupation influences the results in the model, for the bedroom and living room.



Graph 4: Start-up conditions (bedroom).



Graph 5: Start-up conditions (living-room).



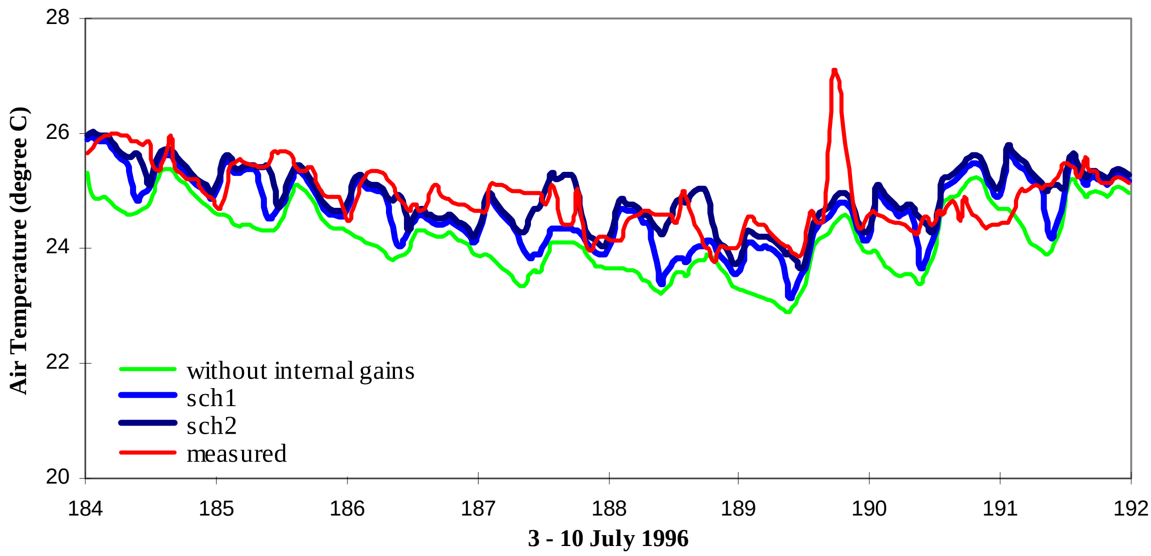
Graph 6: Start-up conditions (sunspace).

Internal Gains

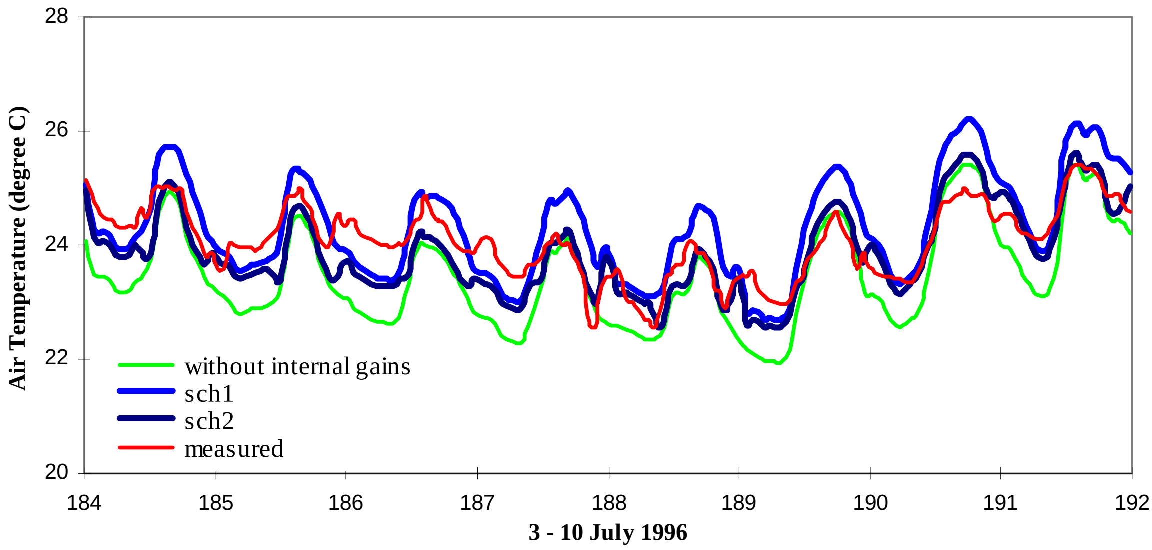
Sensitivity studies concerning internal gains were performed with different occupation modes (table 1). Simulation results profiles were very influenced by the occupation mode and, as can be seen in graphs 7 and 8, a different schedule could increase air temperatures considerably. We conclude that in spite of difficulty in matching schedules to reality we can obtain main tendencies for the use of distinct occupation modes.

TABLE 1: Internal gains

Schedules	Period (hours)	I. Gains (W)
Bedroom		
Sch1: all days	0 - 8	100
Sch2: weekdays	0 - 10	100
weekend	0 - 18	100
Living room		
Sch1: all days	0 - 24	150
Sch2: weekdays	22 - 10	150
weekend	0 - 10	150
	22 - 24	300



Graph 7: Bedroom occupation study.



Graph 8: Living room occupation study.

Conclusions

This calibration process reveals the importance of a right selection of the model and climatic start-up conditions which could produce large differences in temperature swing or profile results. For example, the use of a simple model has many limitations in describing thermal mass storing or ventilated roof effect.

Simulations without internal gains, beside its influence in inside temperature level, show the correctly main tendencies of the thermal house performance.

NAFARROS SOLAR HOUSE

Photo 2: Nafarros Passive Solar House (Sintra)

Thermal Model

This house is quite unusual, with large glazing areas, massive walls and the big floor to ceiling height (photo 2). This complexity leads to a 20 zone model. For instance, the living room has a significant stratification and was therefore modelled by a 3 zone model.

At the Solar House, a 2 week monitoring (17-27 June 1996) took place. The collected data were used to perform a calibration process for a bedroom and the living room.

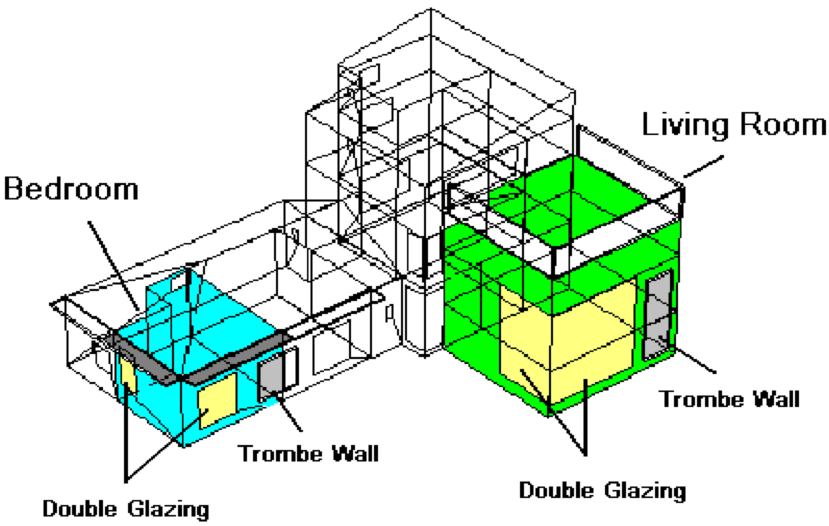


Fig. 3: Esp-r model

The first blind results for the living room, show important discrepancies between predictions and measured values. The measured values show (graph 9) a random behaviour in the daily peaks temperatures, which probably reflects different control for the solar gains and windows and doors opened by the occupants. Under these conditions it is very difficult to predict the thermal behaviour of the living room with accuracy.

In some days, there is a difference of about 3 °C between predicted and measured temperature profiles. This situation can result from different reasons, but the big difference in the first five days of the simulation period denote seriouly wrong in the preditect behaviour. The climatic date used in the simulation was then investigated. Although the indoor monitoring was performed from the 17 to the 27 of June 1996 (days 168-179, Julian date), the site outdoor temperature was measured correctly only from 24 to 27 of June (graph 10). For the rest of the monitoring period the outdoor temperature data from the nearest meteorological station (Lisbon) was used to create the Esp_r climatic file. Comparing the temperature data for the two sites, in Lisbon the values are higher than in Sintra (graph 10), and this could be a justification for the big differences in the first days, so, it seems reasonable to analyse only the last four days.

In order to improve the model, several simulations were carried out with enphasis in:

Air flow Simulation

Three different kinds of air flow inside the living room were simulated, in order to understand the previous differences between predicted and measured results.

- **Increase of the infiltration rate** inside the living room (assuming the previous blind control). The previous assumption of 1 ACH does not seem to be very realistic in this case. The temperature profile that is closer to the measured is the one with 3 ACH from 8 to 24h (graph 11). Nevertheless, during daytime there are some considerable gains, which is probably, the reason for the discrepancies, that are not able to be explained just by controlling the infiltration rate.
- **Air exchange among the 3 stratifications** There is almost no influence of the air exchange among the living room stratification on the indoor temperature (graph 11).
- **Mass flow network**
  A mass flow network was introduced within the thermal model (fig. 4).

In order to perform a consistent mass flow network, several windows opening controllers were introduced, as well as flow nodes at different heights. Thus, air will flow through the south window of the living room only if three conditions are satisfied simultaneously. Indoor temperature should be greater than 18°C and greater than outdoor temperature. Wind velocity should be less than 4 m/s, because a big wind velocity can lead to unpleasant draughts and therefore to a considerable local discomfort.

The inclusion of a mass flow network to the whole building model has an important thermal effect. It leads to lower indoor temperature swings and mean indoor temperatures closer to those suggested by the comfort standards (22°C). Unfortunately this is an ideal summer strategy and does not describe what really happened during the monitoring period (graph 11).

Solar Control

None of the previous simulations during the calibration process showed by itself to be responsible for the obtained discrepancies. The effect of different solar blinds was therefore analysed (graph 12 and 13).Two kinds of solar controls were studied:

- **External obstrutions,** that cut only direct radiation, and leads to higher diurnal temperatures
- **External blinds** cutting direct and diffuse radiation

Two types of blinds and solar controls were simulated. The first one is an attempt to outline an external blind, that should be closed whenever the radiation intensity reaches 300 W/m^2. The optical properties of these blinds were simulated to be the same as for external roller shutters. The second type of blinds (venetian blinds) were simulated operating all day, and in order to reduce the double glazing direct normal radiation for about 81,7% when compared with the previous shutters.

The blinds that produce temperature profiles closer to the ones measured are the external venetian blinds (always closed) with 3 ACH (graph 13). However comparing with the measured values, there are some unexplained internal temperature peaks; it seems that occupants have let the blinds open during some important period of the day. The sudden increase in the temperature might also have happened due to a permanent opening of windows, which gave rise to an indoor flow of warm outdoor air.

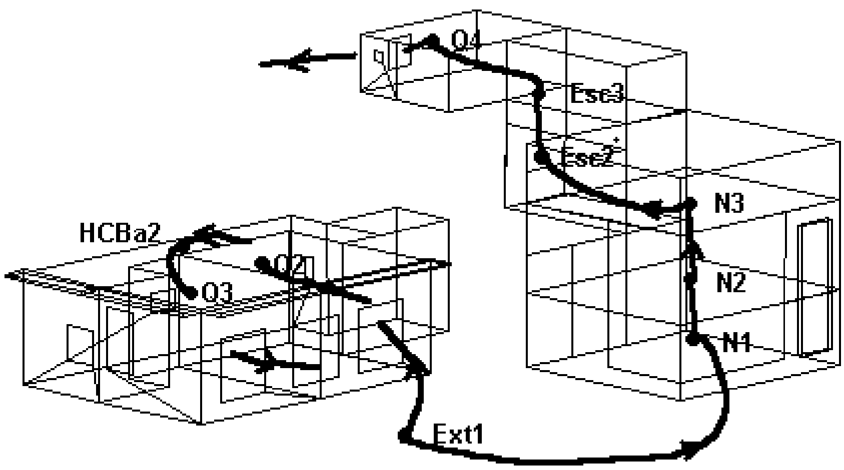
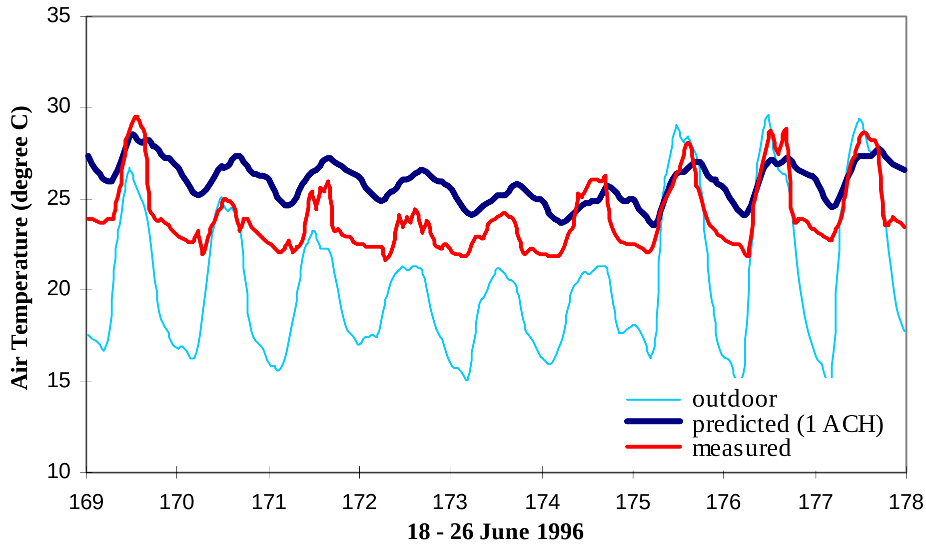
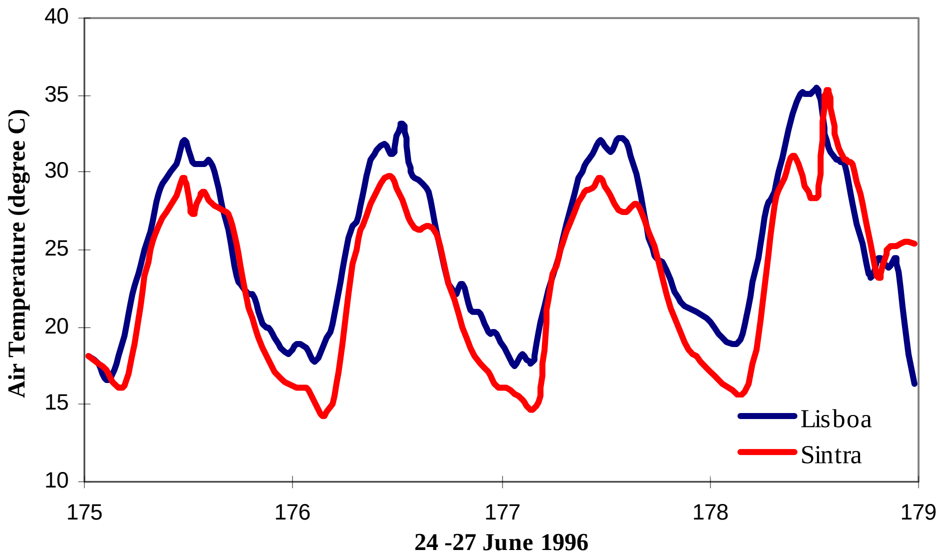


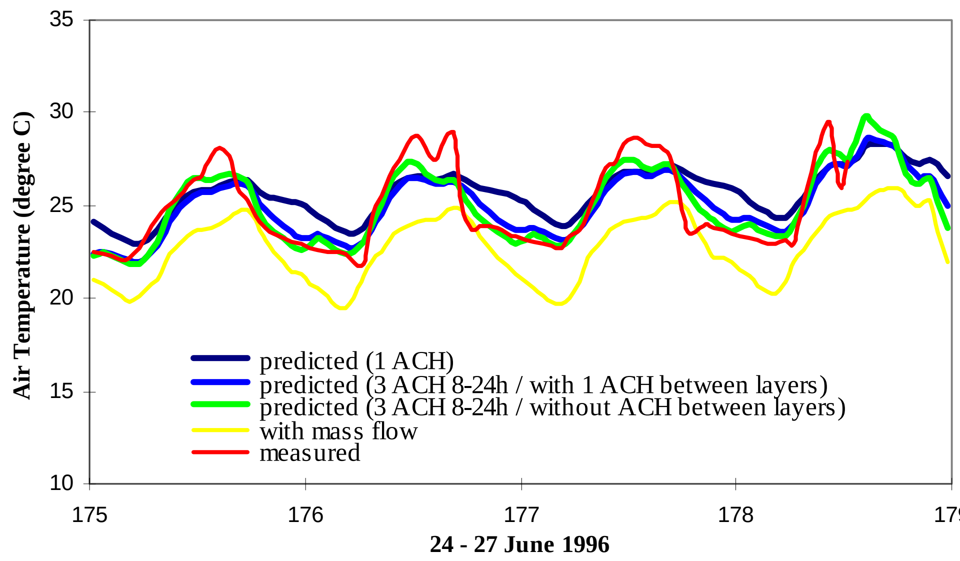
Fig. 4 : Mass Flow Network



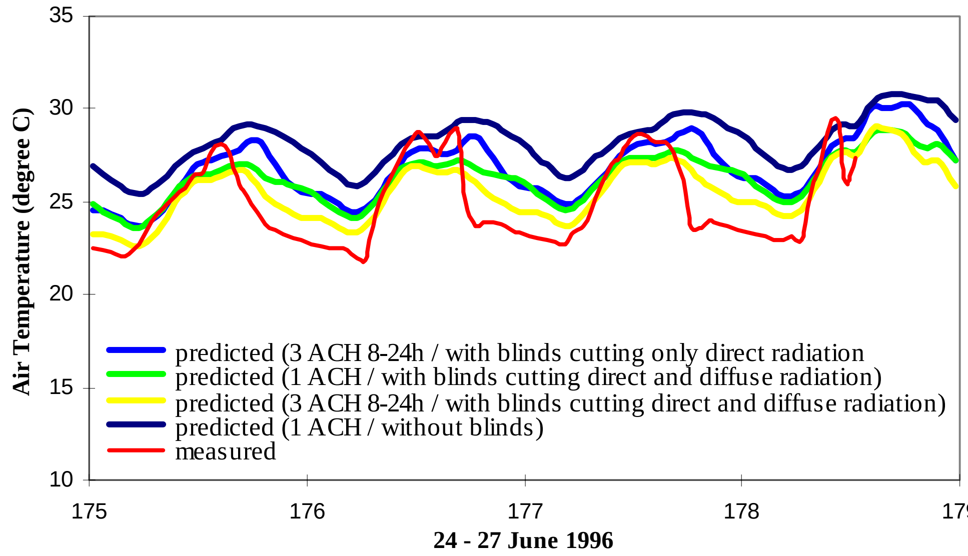
Graph 9: Blind calibration for the living room



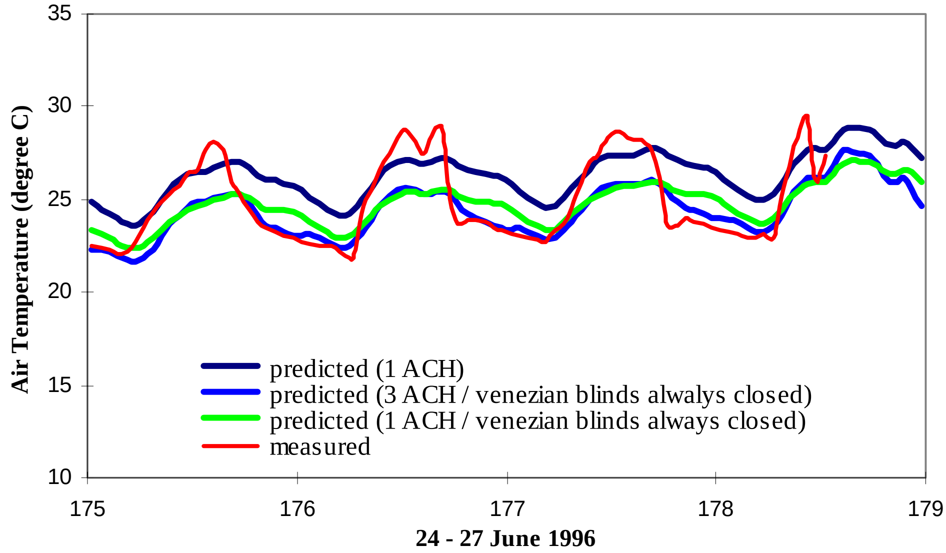
Graph 10: Comparison between the outdoor temperature profiles for Lisbon and Sintra



Graph 11: Air exchange among layers and mass flow network (living room)



Graph 12: Sensitivity study concerning external blind types



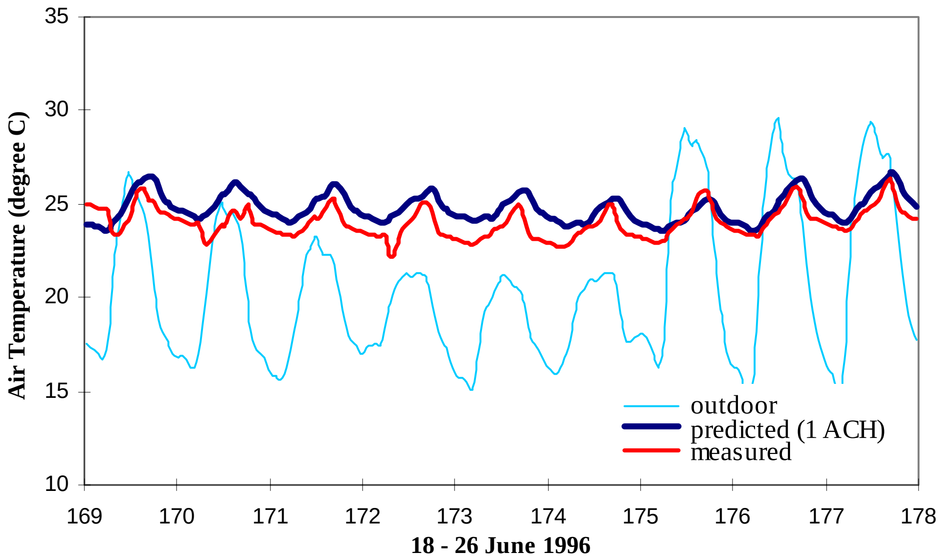
Graph 13: The effect of using external venetian blinds

Unlike in the living room, the blind simulation temperature profile inside the bedroom is very close to the measured one (graph 14). There are two main reasons for this to happen. First there are not so many ventilation possibilities for the bedroom as for the living room, which has many more openings. On the other hand, the occupation (and therefore the interaction occupant-room) is meaningless for the bedroom, but not for the living room.

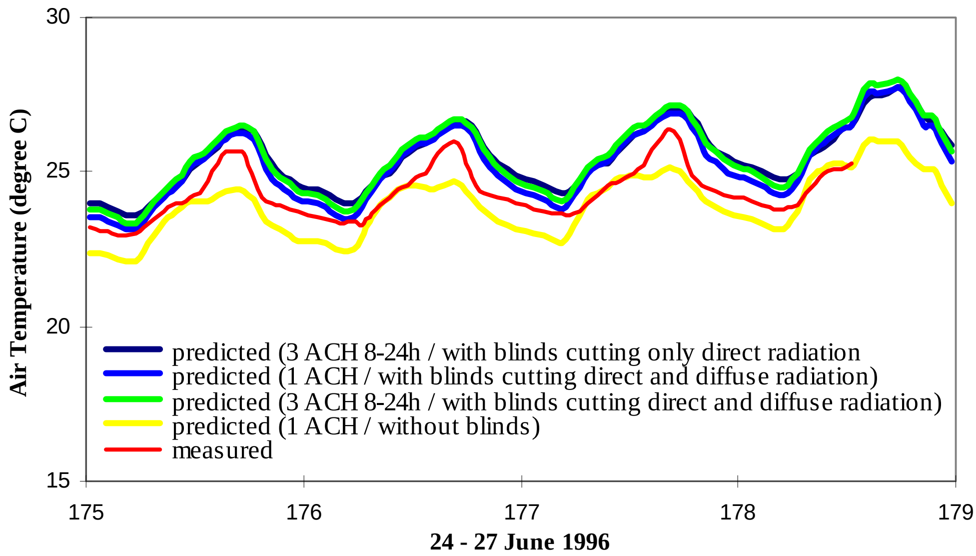
Sensitivity studies

In spite of having a good initial approach (with 0.5 ACH, without shutters and with shading), further studies were carried out: higher infiltration rate (1ACH) and a near approach to the shadings and blind controls. The influence of the shading devices (fig. 3 and photo 2) were analysed, as well as two different blind controls: without blinds for the whole day and with blinds cutting direct radiation above 300 W/m^2 (graph 15).

The solution that reproduces closer the measured air temperatures inside the bedroom is the one with 1.0 ACH, without shutters and with shading.



Graph 14: Blind calibration for the bedroom



Graph 15: Sensitivity study concerning the bedroom

Conclusions

The presented building allowed us to study two zones with extreme thermal behaviours: the living room and bedroom. The living room exhibits a quite random thermal behaviour due to the many openings and also due to the lack of information concerning the interaction occupant-building. Therefore it was difficult to calibrate the model based on logical supposings. In spite of the above mentioned difficulties, it was possible to draw a main conclusion for this case. The infiltration rate is much more important than the air exchange among the stratifications. The solar control has an enormous influence in the indoor temperature. Therefore, a good knowledge of the optical properties of blinds is essential to the success of the calibration process.

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CONCLUSIONS

The case studies presented in this work, showed the difficulties and the possibility of that may occur during the simulation process. The following conclusions can be drawn:

The input parameters related with the operative conditions of the buildings have a major influence in the overall process. Namely: the solar control and the opening of windows, which gave rise to an indoor flow. It is essential during the monitoring campaign to get the information related to these parameters; if not it will be very difficult or impossible to get "reasonable" model that will permit further simulation studies.

The climatic data have a major role, and local values should be obtained a few days before the monitoring campaign.

REFERENCES

[1] Clarke, J. et al, ESP-r ESRU Manual U93/1, 1993.

[2] Barroso-Krause, C., "Vegetal shelter: is it a good thermal option as a passive cooling strategy?", 3rd European conference on architecture, Florence, Italy, May, 1993.