IMPACT AND SOURCE OF UNCERTAINTIES IN HIGH EFFICIENCY BUILDING SIMULATION: SOME EXAMPLES

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ABSTRACT

This paper deals with two examples of sources for uncertainties in the simulation of high efficiency buildings. The two sources deal with solar shading and the value of simulation parameters like albedo and initial state. To assess the two sources of uncertainties, simulation results and real measured data of an experimental passive house were used, and the two parameters, often not considered with care during simulation, were varied.

The results indicate that a wrong hypothesis on the geometrical model, such as the kind of the shading used, and in the same way an inaccurate estimation of an entry parameter, such as the albedo, may considerably increase the hours of overheating. This demonstrates the large effect that the uncertainties have on the simulation and can create the differences between simulation results and real cases.

INTRODUCTION

This article proposes the study of two cases. The first underlines the impact of a bad assumption in the design of the geometrical model. The second case raises the problem of bad knowledge in the entry parameters which can lead to wrong conclusions on an example of the thermal models calibration. The article emphasizes that it is necessary to estimate the uncertainties on the entry parameters to obtain not only a value of the building energy performance, but also an error range resulting from the estimated uncertainty.

Recent experience feedback (Cellura, 2010) reveals significant differences between simulation and real consumption of high energy efficiency buildings. These differences may be due to the consequences of bad simulation hypotheses in the design phase of buildings.

In order to understand the impact of simulation hypotheses, simulation tools can be simplified in two parts:

- The physical models; and
- The entry parameters.

In the entry parameters the geometrical model is separate from the other parameters. For the three aspects (physical model, geometrical model, and other entry parameters) there are two kinds of uncertainties:

- The quantifiable uncertainties; and
- The subjective uncertainties.

Data is always associated with some uncertainty, and it is necessary to quantify these uncertainties in order to evaluate the quality of the simulation result. For example, the uncertainty bound to equipment in the method to the experimenter, is an estimation of the difference between the results and the reference value. For example, in experimental physics the uncertainty in results arises from the measurements and the reference value from the metrology laboratory. In the case of building energy performance, the reference value is difficult to obtain; a building is a complex object and the estimation of the uncertainties on simulation results is delicate.

The quantifiable uncertainties are related to the entry parameters and being determined by measured data or by a data builder. The subjective uncertainties result from hypotheses used in the simulation, the misunderstanding of one physical phenomenon. Consequently, these result in a bad model and are less recognizable than the quantifiable uncertainties. This kind of uncertainty (subjective) concerns the three aspects of the simulation tools named above (physical model, geometrical model, and other entry parameters). Indeed, assumptions need to be made in order to design a building in reality. But, the estimation of certain entry parameters can introduce subjective uncertainties. These uncertainties may be significant. However, it can be observed in scientific lecture that it is rare that the results of energy performances take the uncertainties into account. In the best case when dealing with experimental results, the value of uncertainty corresponds to the precision of the measuring instrument.

Today the conception phase of a building cannot be made without simulation. It conditions many of the choices in terms of the equipment and thermal strategy. Certain assumptions of simulations, which are sometimes commonly accepted, may involve uncertainties and even error. Thus, investigation into the reliability of the simulation uncertainties needs to be undertaken.

SIMULATION AND EXPERIMENT

The experimental device

The INCAS platform was introduced by the National Institute of Solar Energy in Le Bourget-du-Lac, France. It consists of single-detached houses with low energy consumption, even an annual positive energy balance. These houses have the same geometry but have different construction techniques, materials and internal loads levels.

Figure 1 House INCAS-DM

Each house contains more than 100 sensors to quantify the thermal and air behaviour in the houses. This study concerns one of the single-detached houses in the experimental platform at INCAS. The house is named DM (Double Mur in French that means: double wall) and is a heavy construction. The thickness of the walls is 50 cm, it is made up of 15 cm of perpend, 20 cm of insulating material, and 15 cm of perpend. The house contains 4 thermal zones: the under floor space; the ground floor; the first floor; and the attic. The rate of infiltration is very low and is 0.6 vol/h at 50 Pa. Its strategy of energy saving is of the passive type. The solar gains are maximized in winter and minimized in summer, as can be seen in by the glazed surfaces distribution and solar shading in Figure 2.

Figure 2 INCAS North façade and south façade

Geometrical model

The geometrical model is the first stage in the factors that can impact on the simulation results. The choices made at this stage influence the results obtained from the simulation. The features offered by modelling software force these hypotheses. For instance, the windows in the INCAS – house DM are set back by 35 cm internally. Consequently, the good modelling process is to simulate shades provoked by this sinking. Such as a simple overhang and rectangular side fins of 35 cm. This kind of detail is normally forgotten. In order to understand their importance, a comparison between simulation results undertaken, in Energy Plus, of the building with just the overhang modelled ((Case A) : Figure 3.a), against the results for a model with the overhang and the side fins modelled ((Case B) : Figure 3.b).

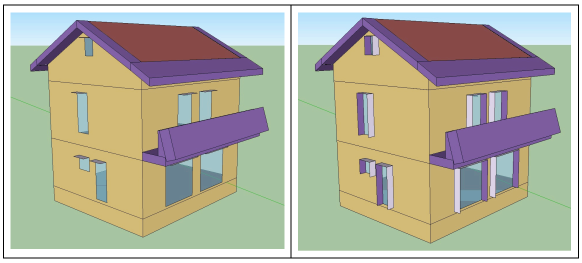

Figure 3.a. Case A *Figure 3.b. Case B*

The simulation is performed on an annual basis and does not take into account the internal equipment and the occupants. In the simulation the albedo is equal to 0.2. The building is in free evolution (no heating, opened shutter, no cooling, no internal load). The reason of this simplification (free running) is to minimise the sources for uncertainties. For example, HVAC appliances in this house are complex to simulate and not installed in the house at the time of this study. That's the reasons why free evolution is considered in this article. Temperatures are compared in Table 1.

Table 1 shows the average, maximum and minimum interior air temperatures of the two cases ground floor zones.

Table 1
Air Temperature for simulation Case A and Case B

	EXT. TEMP.	CASE A (WITHOUT)	CASE B (WITH)	RELATIVE DISTANCE (%)
T_{moy}	10.3°C	19.7°C	18.4°C	7.1
T_{max}	30.3°C	31.2°C	29.7°C	5.1
T_{min}	-8.9°C	8.6°C	7.7°C	11.7

Case A predicted the temperatures to be 5-10% higher when compared to the Case B values.

One of the problems of the INCAS houses concerns the summer comfort and is because of their construction (thick wall, very good airtightness). Figure 4 illustrates the distribution of the temperatures of the higher temperatures during the summer months (July and August). With the side fins, it is observed that there is a sharp decrease in the number of hours there are high temperatures occurring. This demonstrates the impact the extra shading has on the results.

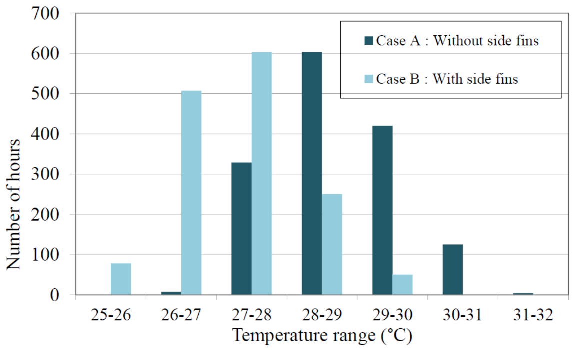

Figure 4 Number of hours by temperature range during July and August for different case.

A comfort indicator to compare the modelling with or without side fins can be introduced to further assess the impact the geometry differences have. The indicator uses 27°C as a good estimate of the upper limit of thermal comfort. The number of hours when this temperature is to warm can be counted. There is 962 hours of overheating throughout the year with the side fins, and 2050 hours without the side fins. The difference is considerable: it is almost 40 days compared to 85 days of overheating in a year. It is greater than a factor of 2, and a percentage difference of 113%.
It is understandable that there is a significant impact in results as the house uses passive strategies and is very sensitive to the solar contributions. Besides, there is no ventilation in the house. For such buildings, it is necessary to take certain aspects of the building into account with more or less accuracy. For houses using passive strategies, the important aspects are: the solar contributions, the solar shading, the orientation and the glazed surfaces. Thus, the geometrical model must be made with detail.

This first example highlights one of the sources that can create errors: the geometrical model. It establishes an important aspect of the parameter entries. The following example shows how bad knowledge of parameters can give wrong results in a comparison of simulation results against measured data. All further simulations are undertaken with the side fins as solar shading (case B).

Comparison simulation/experiment

To establish whether the relevance of the simulations and the monitoring can be controlled, a comparison was made with the first experiments results of the INCAS-DM house. The real mean interior air temperature measurements taken in the ground floor is compared with the ground floor simulation temperatures results. The sensor used is a PT100. The data acquisition is calibrated and the measurements uncertainties for the ground floor mean air temperature is ± 0.35°C. The used weather file is obtained from the measurements taken at the INCAS experiment platform and covers a period of a week with a time step of one minute. Two parameters are tested in the comparison: the albedo; and the initial state. Albedo is the ratio of reflected solar radiation from the surface to incident solar radiation upon it. The initial state is the state that is recorded in the house before the beginning of the experiment and the simulation. In this study, this state is represented by the initial air mean temperature.
The construction of the DM house is thick and heavy and results in a high thermal inertia. The study is of a one week period, but the previous week's temperatures and solar gains impacts on the experiment week's results. This is due to the thermal inertia of the building. The previous week's measurements are provided, and to try to stabilize the building the shutters were closed and the ventilation was turned on during that previous week. These measures were taken to try and make the initial state of the measurements correspond with the initial state used in simulation. That's the reason why, in the simulation, the interior air temperature was forced (by means of a heating and of a cooling system) to a certain value $T_{ini,}$ which corresponds to the initial state that was wished for the simulation. Figures 5 and 6 display Albedo and Initial State simulation and measurement results. The experimental protocol of the trial phase is the following, on the date of 5th July;

- the shutters are opened and the ventilation is switched off;
- the house is left in free evolution;
- in the simulation, the heating and the cooling which maintains an initial temperature (T_{ini}) was stopped;
- the free evolution at the same moment as in the experimental protocol was started; and
- several T_{ini} tests for the initial state close to the experimental temperature were simulated.

The evolution of the interior air temperature of the ground floor between the measured data and simulations results with different initial state is compared in Figure 5. The best possible result is observed when there is a coherency in the temperature evolution and when the order of magnitude between the simulation and the experiments for T_{ini} are close to those reached on average in the experiments.

In order to understand what the impact of the initial temperature choice is and to find what the best value is, the technique of the Least squares can be used (Equation 1), (Protassov, 2008).

$$X^2 = \sum_{\text{number of points}} \frac{(Val_{exp} - Val_{theo})^2}{(2\sigma)^2}$$

Equation 1 Least squares equation

This equation allows for the quantification of the residual difference (difference between the simulation and measured results). σ corresponds to the uncertainty of the measurements (0.35°C). The more the X^2/number of points value is closer to 1, the smaller is the residual difference and the better the theoretical model describes the real case. If the X^2/number of points value is smaller than 1, this implies two possibilities:

- the uncertainties are undervalued; and/or
- the theoretical model is wrong

It is unlikely that the average value of the difference between the theoretical value and the experimental value is smaller than the uncertainties of the experiment.

The results were most similar when the T_{ini} was between 26°C and 26.5°C. In Table 2, we observe a X^2/number of points close to 1. These values (nearly 1.4) are unexpected here because of the complexity of the simulation models (i.e. non-linear).

Table 2 shows the X^2/number of points for different T_{ini}.

Table 2
X^2 value for different T_{ini}

INITIAL STATE	X²/NUMBERS OF POINT
25°C	2.66
25.5°C	1.81
26°C	1.41
26.5°C	1.48
27°C	2.66

If the variation and the influence of only one parameter are considered, the model can be validated using the Least squares method in the modelling approach: the theoretical model seems to be good. However, this kind of approach, which is deliberately exaggerated here, is not rigorous, (the evolution of the temperature is influenced by more than one parameter: for example the albedo). The initial state is not the only influential parameter in the simulation. An example below handles the case of the albedo which is commonly taken as being equal to 0.2 in simulation for urban zones. An Albedo of 0.2 was used in the “geometrical model” part but an albedo 0.4 was used previous simulations in this part of the paper (initial state comparison). A comparison is made between 0.2 and 0.4 which is a coherent albedo for white cement (the case as in the INCAS houses). The comparison of evolution of air interior temperature of the ground floor between measured data and simulation results with different albedo value is displayed in Figure 6. The trend is modified and is more coherent with the evolution of the experiments temperatures, as can be seen in Figure 6. The effect of the modification is outstanding because it is in summer, the house is very sensitive to the solar contributions and there is no ventilation in the house.

In the case of an annual simulation in free evolution with an overhang and side fins, the value for overheating is 2377 hours for an albedo of 0.4 and 962 hours for an albedo of 0.2. The relative difference is 147%. It is 40 days compared to 99 days of overheating which is almost a factor of 2.5. Figure 7 illustrates the distribution of the temperatures of the higher temperatures during the summer months (July and August) for different albedo. This distribution underlines the impact of the albedo.

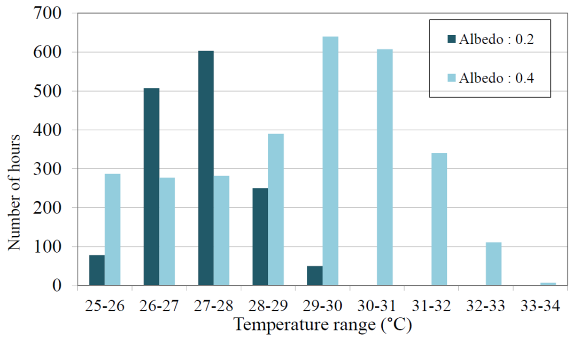

Figure 7 Number of hours by temperature range during July and August for different albedo.

In the range of coherent albedo for a building, the variation of this has a sharp impact on results, knowing that the building is sensitive to the solar gains. For this reason, a precise measure of this parameter should be done as well of its uncertainty in order to obtain an accurate simulation.

DISCUSSION AND RESULT ANALYSIS

The model could be validated with the calibration of adjusting both parameters – Albedo and Initial State. But it is clear that a simulation does not limit itself to two influential parameters. It is known that the building involves several physical phenomena and consequently a large number of parameters. The geometrical models shading, albedo, and the characterization of the initial state are only some examples among the entry parameters that establish a simulation of thermal dynamics. An estimation of an assumption and\or bad knowledge of these parameters can entail errors in the simulation results. One could think that models are validated because they show a trend which is coherent with the experiments, but actually it could also have many errors which compensate for each other.

The impact on the simulation results depends on the influence and on the uncertainty of the entry parameters. To be able to determine the influential parameters and especially the interactions between them, an analysis of global sensibility (Saltelli et al, 2008) is required. However, the study presented in this article does not take into account the aspect of "living" in the building. The appliances and the occupants are not simulated (experimentally or numerically). The purpose is to limit the simulations to at the most, the known and controllable parameters. This study on the albedo and initial state is made about a house without consideration for the occupant. The behaviour of the occupant is difficult to simulate, in particular the opening and closing of windows for their comfort. Models were determined (Haldi et al., 2009), but they remain of difficult application to normal thermal simulation. So the wrong consideration of the occupants can be regarded as a hypothesis of simulation which impacts strongly on the differences with the real cases.

CONCLUSION

The approach of this article is to emphasize some sources of uncertainty that may involve errors. The goal is to visualize the significant impact of certain hypotheses or even the misunderstanding of the parameters of a model on a thermal energy balance. It tries to give suggestions to search the parameters that are likely to cause important differences between simulation and real cases. It shows that wrong hypotheses related to the occupants (occupation and activities) are not the only source of uncertainty which can be responsible for observed differences. These sources must be identified and their impact has to be estimated.

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NOMENCLATURE

T: Air mean temperature
T_{max}: Maximal air mean temperature
T_{min}: Minimal air mean temperature
T_{ini}: Temperature fixed of the initial state
Val_{exp}: Experimental value
Val_{theo}: Theoretical value (simulation result)
σ: Uncertainty value of the air temperature measure

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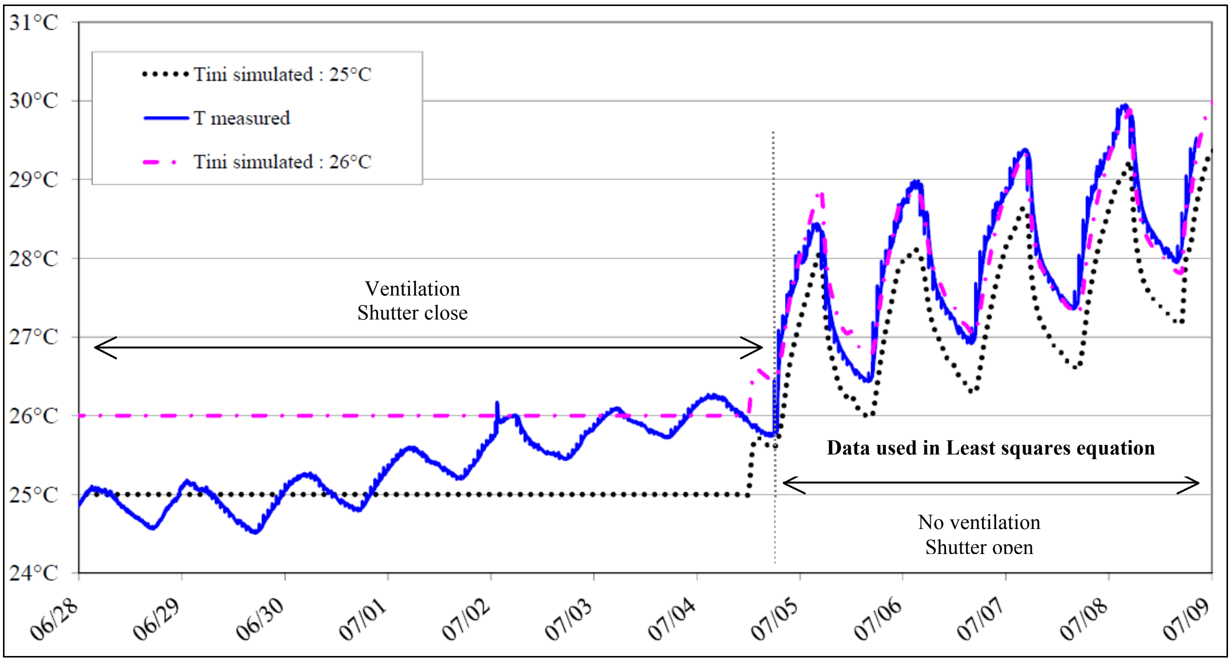

Figure 5 Comparison evolution of air interior temperature of the ground floor between measured data and simulation results with different initial state with an albedo at 0.4.

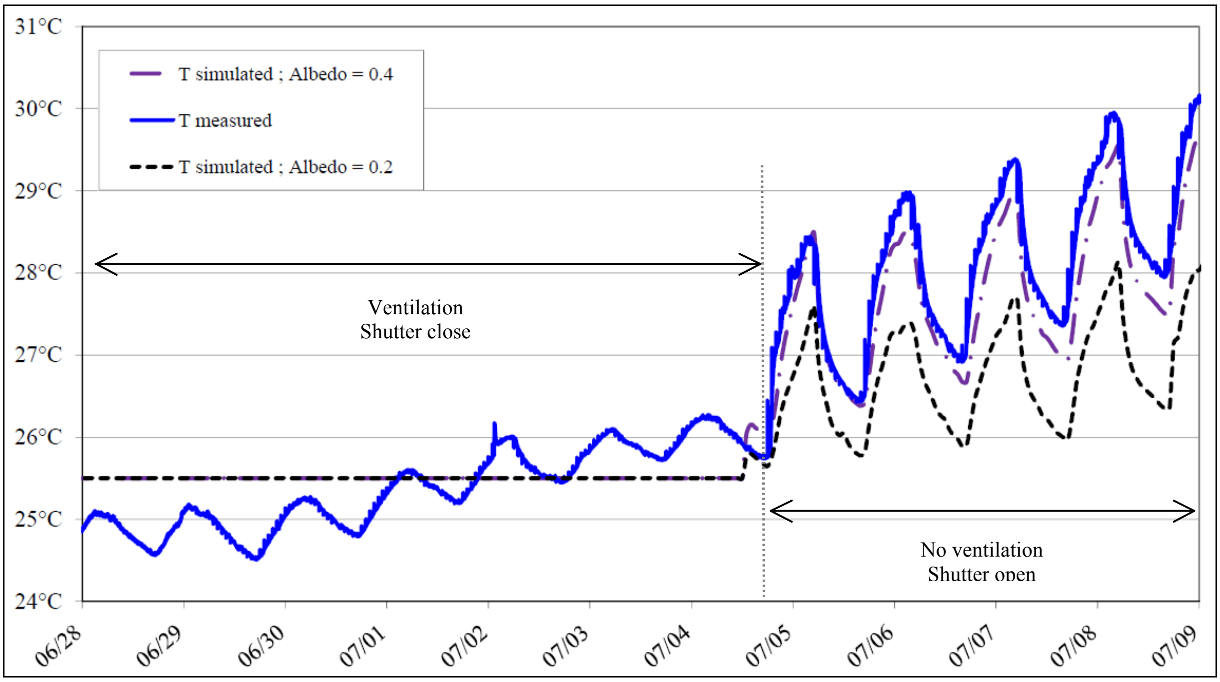

Figure 6 Comparison of evolution of air interior temperature of the ground floor between measured data and simulation results with different albedo value with initial state at 25.5°C.