Should solar irradiance be included in inverse modeling?

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1 Introduction

Within the European project Climate for Culture, researchers are seeking to find the influence of the changing climate on the built cultural heritage. The Building Physics and Systems group at the University of Technology of Eindhoven participate in this project (van Schijndel et al. 2010). Currently they are able to simulate the indoor climate of several monumental buildings for the next hundred years (for results see (Kramer 2011)) using the model HAMLab (van Schijndel 2007) with artificial climate data for the years 2000 until 2100.

Due to the long simulation period (hundred years with time step 1h), combined with detailed physical models, the simulation run time is long. Furthermore, the detailed modelling of the buildings itself requires much effort: the monumental buildings are old and protected. Therefore, blueprints are hard to find and destructive methods to obtain building material properties are not allowed.

A simplified model with physical meaning is desired which is capable of simulating both temperature and moisture. The parameters of the model will be derived by an inverse modelling technique which fits the output of the model to measured values of respectively temperature and relative humidity.

During the development of the model, the following question was invoked: should the sun irradiation be included as an input or not?
2 Model

The developed models are shown in Figure 1. The thermal model is a 3rd order model with 9 parameters. The hygric model is a 2nd order model with 5 parameters.

Because this paper deals with the question of including or excluding the solar irradiation as an input, the thermal model is further specified:

Thermal model inputs:

i) Temperature outdoor;
ii) Solar irradiation on vertical plane oriented on NORTH;
iii) Solar irradiation on vertical plane oriented on EAST;
iv) Solar irradiation on vertical plane oriented on SOUTH;
v) Solar irradiation on vertical plane oriented on WEST;
vi) Fixed temperature node.

The reason for splitting up the solar irradiation is that the used model is represented in State Space form. The huge advantage of the State Space form is the very small calculation time. A State Space model belongs to the family of LTI-models (Linear Time Invariant), therefore the identified parameter \( f_I \) (factor for solar gain) is time-invariant. Because the azimuth and elevation of the sun are not time-invariant, it is impossible to derive a good State Space model with only one input signal of the solar irradiation: nevertheless, the solar gain into the building is not a constant factor \( f_I \) times Global Irradiation On Horizontal Plane.

\[
SG \neq f_I \cdot Global\_Irrad\_Hor 
\] (1)

Therefore, the Global Irradiation on the horizontal plane is converted into four signals, as mentioned above, which include the sun irradiation on a vertical wall for the orientations North, East, South and West. Hence, the SG is calculated according to:

\[
SG = f_I \cdot Irrad
\] (2)

Equation (2) describes the inproduct between the factor \( f_I \), which is a vector of four factors (one per orientation), and the irradiation (which is a matrix of \( n \times 4 \), an input signal per orientation).
3 The used building: St. Baafs cathedral

The building which is used to demonstrate the influence of the solar irradiation as an input signal, is the St. Baafs cathedral in Gent (Belgium). Figure 2 shows the exterior, the location of the sensor in the south transept and the glazing in the façade of the south transept. Because of the large area of the glazing, which is oriented to the south, the St. Baafs cathedral is an appropriate building to test the influence of including the solar irradiance.

![Figure 2: the St. Baafs cathedral in Gent (Belgium), exterior (left), sensor indicated by arrow in south transept (middle) and church window in south transept (right).](image)

4 Results

The performance of the models (i) thermal with solar input, (ii) thermal without solar input and (iii) the hygric model, is assessed by the criteria Mean Squared Error, Mean Absolute Error and Goodness of Fit, see Table 1.

<table>
<thead>
<tr>
<th></th>
<th>MSE</th>
<th>MAE</th>
<th>FIT [%]</th>
</tr>
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<tbody>
<tr>
<td>THERMAL with solar input</td>
<td>0.17</td>
<td>0.32</td>
<td>91</td>
</tr>
<tr>
<td>THERMAL no solar input</td>
<td>0.74</td>
<td>0.69</td>
<td>81</td>
</tr>
<tr>
<td>HYGRIC</td>
<td>1870</td>
<td>32</td>
<td>86</td>
</tr>
</tbody>
</table>

The time plots of the fits are shown on the following page in Figure 3 and Figure 4. Obviously the solar irradiation has no influence on the hygric model output. However, the performance deviation of the thermal models indicated by the criteria in Table 1, can be seen clearly in these time plots.
The model without solar irradiation as input cannot reproduce the measured signal accurately: solar irradiation is a temporary heat input, hence the model without solar irradiation included lags this heat input and therefore the simulated temperature lies below the measured temperature.

Figure 3: Resulting fit of models (thermal above, hygric below) if solar irradiation is not included.

Figure 4: Resulting fit of models (thermal above, hygric below) if solar irradiation is included.
5 Conclusion

When reproducing a measured temperature signal with a model, i.e. inverse modelling, the solar irradiation is an important input signal which should be included.

Furthermore, when using LTI-models (Linear Time Invariant) such as a State Space model, the proposed method of including the solar irradiation works well.