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Testing the model matches reality: a review and investigation of model calibration techniques for dynamic thermal simulation of buildings.

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Abstract

This study aims to calibrate dynamic thermal simulation (DTS) models of an existing domestic building to 'real–world' measurements of internal room temperatures. The work includes definition of the error between real-world measurements and predicted values from the thermal simulation and identification of which input parameters most significantly affect the predicted values and increase the gap between real and modeled energy performance. A manual calibration approach was selected to fine tune the thermal model of the case study house in IES-VE DTS for a two week period of June. The required data for the creation of the energy model were collected during a site survey. Temperature sensors were used to record the temperatures in each room and weather data corresponding to the calibration period were collected from local weather stations. Various parameters were changed iteratively to evaluate the impact of each parameter on the internal temperatures and a combination of the significant parameters resulted in a model with an average CV(RMSE) of 5.5% which was accepted as calibrated

Keywords: Calibration; dynamic thermal simulation; performance gap; domestic buildings

Introduction

There is a significant gap between predictions of building energy use at the building design and engineering stage, and measurement results once buildings are operational. This 'energy performance gap' erodes the credibility of the design and engineering sectors of the building industry, and leads to general public scepticism of new high performance building concepts. Bridging the gap between predicted and measured performance is crucial if the design/engineering stage is to provide serious input to the delivery of buildings that meet their (quantified) ambitions. Bridging the gap is also crucial if the industry wants to deliver buildings that are robust, for instance in terms of 'occupant proofing' or 'climate change proofing', and which are engineered to adapt to changing use conditions. http://www.plymouth.ac.uk/pages/dynamic.asp ?page=events&eventID=7881&showEvent=1 [assessed 20/8/2013]).

Calibrated simulation according to Cervantes J.(2006)is the process of using a building simulation program for an existing building and "tuning" or calibrating the various inputs to the program so that predictions match closely with measured data.
Calibration methods can be categorized in the following 3 major categories (Bertangolio S.,2012).

- Manual iterative calibration methods
- Graphical and statistical methods
- automated and semi-automated calibration methods

To date, there has been limited work on model calibration of real-world buildings with the predictions from building simulation tools. Where research has been carried out this is limited and appears to only take a rudimentary approach to matching predicted vs actual building performance indicators. However to have building simulation models which match with the performance of the building they are simulating is crucial, particularly for real-time performance feedback which is one of the long-term goals of the building simulation community.

This study aims to calibrate the dynamic thermal simulation (DTS) model of an existing domestic building to 'real–world' measurements of room internal temperatures. The focus of the work includes the definition of the error between real-world measurements and predicted values from the thermal simulation and the Identification of input parameters of the simulation that affect more the predicted values and increase the gap between real and modeled energy performance.

Methodology

The proposed calibration methodology is deeply related to on-field inspection and data collection issues and is developed to fit with the audit/inspection process.

A manual calibration approach was selected to fine tune the the predicted indoor air temperatures of the DTS model against the measured values for the period of 1-14 June. An energy consumption calibration was out of the scope of this study.

The case study house was selected because of the sub-hourly step monitoring of internal temperatures with temperature sensors and energy consumption of major appliances with smart meter devices.

A site survey that follows the guidelines of RdSAP was performed for the collection of the required input data for the thermal modelling such as construction components properties and dimensions, site surroundings and orientation. Detailed measurements of the spaces were needed for the creation of the architectural plans and the geometry of the model in lack of documentation. An interview with the occupant was conducted during the site visit regarding the occupancy schedules, window opening patterns and lights and equipment operation schedules.

Temperature measurements were taken in each room of the house using
Onset HOBO miniature temperature pendant data loggers set to record at 15 and 30 minute intervals. After the temperature data were collected they were converted to average hourly temperatures in Excel for the comparison with the hourly reported data from the simulation. They were also plotted daily to identify any outliers such as high peaks and remove any errors. The electricity consumption data of the boiler were also plotted and analyzed to ensure that the heating was off for the selected period.

Weather data of two local weather stations inside Loughborough University and WeatherAnalytics (http://wxaglobal.com/IES.html?id=760&cid=1419) that corresponded to the calibration period were collected due to the different weather variables provided by each weather station. An epw weather file for the simulation was then created by EPW Creator Excel spreadsheet which is available for download from IES.
All the rest data required for the simulation were taken from technical guides or were based in engineering judgment.

A base case simulation was run in IES-VE DTS for the Birmingham standard simulation weather file. As a first refinement the model was run with the epw file created by the collected local weather data to evaluate the importance of using historical weather data and the effect of the outdoor conditions to the indoor air temperatures.

The next steps included iterative changes of input parameters that remained unknown after the site visit or were considered important for the thermal behavior of the house. These parameters were changed manually one at a time against a base case scenario.

The parameters under study were the infiltration rate, additional ventilation rates from fireplace open chimneys, the construction material properties of the kitchen space which was an extension to the initial construction, external wall insulation, glazing properties, internal heat gains from people, heat transfer between thermal zones through open internal doors, window opening schedule.

The Mean Bias Error (MBE) and the Coefficient of Variation of the Root Mean Squared Error (CV(RMSE)) statistical metrics were used to check the accuracy of the calibrated model. A CV(RMSE) of 5% was selected as an accepted level of error between the predicted and measured mean hourly indoor air temperatures.

Model Description

A 3 bedroom end terrace house built in the 1940's was modelled in IES-VE. The house is located in Loughborough, UK in a residential suburban environment and accommodates 3 people and consists of three bedrooms and bathroom on the first floor, a hallway, kitchen, living room and dining room on the ground floor. The total floor area of the house is 79 m^2. The house front façade has a South-West orientation and it is not shaded by any trees or surrounding buildings.

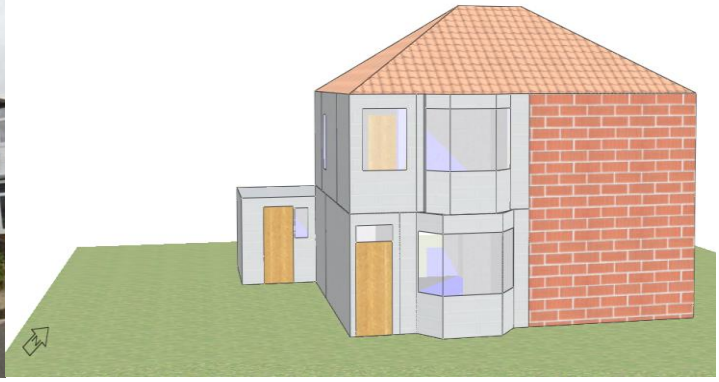

Figure 1. Left: photo of the front of the house, Right: Model in IES-VE

Initial Results

The simulation of the base case that was run with the Birmingham EWY.fwt weather file predicted internal room temperatures that had a percentage difference from the measured of 0 -25%. Although the simple percentage difference was in accordance with the measured values, the CV(RMSE) revealed an error of 14-37%, As a first refinement the Birmingham weather file was replaced by the created Loughborough epw. The simulation results showed a percentage difference of -2 – 16 % from the mean hourly measured temperatures, while the CV(RMSE) was reduced to 4 -17 %. The rest of the fine tuning simulations were based in the Loughborough epw simulation case.

Fine tuning steps

The following parameters were found to have the greatest impact on the internal temperatures:

- The default infiltration rate of 0.25 ach was increased to 0.5 and 1.0 ach. The 0.5 ach infiltration rate resulted on a reduction of the CV(RMSE) by 2-3% on the ground floor spaces and an increase of 2% for the upper floor rooms. Accordingly, the 1.0 ach infiltration rate resulted on a reduction of 5-7% for the ground floor and 5-6 % increase of the CV(RMSE) for the upper floor.
- An additional ventilation rate of 40 m3/h ,from the open fireplace chimneys of the living room and dining room spaces resulted in a reduction of the CV(RMSE) of those spaces by 2% for the living room and 5% for the dining room and an increase of 2-3% for the upper floor spaces.
- The kitchen space is an extension to the main construction but approximate year of built was unknown. Because of the 30 cm width of external wall, it was initially assumed that it followed the 2002 UK building regulations (wall Uvalue= 0.27 W/m2K). This resulted to high internal temperatures compared to the measured. In this step the construction components of the kitchen were changed to 1995 UK regulations (wall Uvalue= 0.36 W/m2K). The impact on the CV(RMSE) was a reduction of 8%.
- The shading coefficient of the double glazing was changed from 0.7 for the base case to 0.3 and 0.5. Low shading coefficient (SC) values mean that the solar heat gain from the glass is reduced. From the statistical metrics analysis it was found that the shading coefficient of 0.3 resulted that the CV(RMSE) was reduced by 2/3 for the dining room and living room, 1/2 for the kitchen, while for the first floor was increased. For SC 0.5, the CV(RMSE) was decreased by approximately 5% for the living room, dining room and kitchen. For the upper floor rooms there was no change except of a 4% of the storage room.
- The initial ventilation rate of 0.4 ach for fresh air requirements as suggested from approved document F, was changed in MacroFlo with a 30% opening area and different schedule of opening the windows. This resulted in 4% increase of the CV(RMSE) error for the upper floor and a 3% decrease of the CV(RMSE) for the ground floor.

From the above fine tuning steps the parameters that resulted to a higher decrease in the CV(RMSE) were selected and a final calibration model was prepared. The combination contained the following parameters: infiltration 0.5 ach, no cavity insulation, additional ventilation rate due to chimneys, kitchen construction of 1995 regulation standards, 0.4 ach ventilation, 0.3 SC for the kitchen and 0.5 SC for the rest of the house. The above combination resulted in a CV(RMSE) close to 5% for most of the spaces and it was accepted as calibrated (table 1).

Table 1. Results of the calibration scenario

	Predicted	**Actual**	**MBE Calibration scenario**	**RMSE Calibration scenario**	**CV(RMSE) Calibration scenario**
Room					
Hallway	18.73	18.78	-6%	0.85	4.5%
Living room	18.65	18.81	-1%	0.83	4.4%
Dining room	18.77	18.33	2%	1.02	5.5%
Kitchen	18.81	18.4	5%	1.25	6.8%
Bathroom	18.81	19.71	-5%	1.54	7.8%
Master bedroom	19.83	20.35	-5%	1.13	5.5%
Bedroom	20.08	20.34	-5%	1.17	5.8%
Storage room	18.80	20.27	-7%	1.66	8.2%

Conclusions

The basic conclusions that derived during the research project is summarized to the following:

The most important findings from the analysis of the simulations are:

- The use of local weather data that correspond to the calibration period had a great impact on the CV(RMSE) error of the predicted values compared to the use of standard simulation weather data. In this study, the CV(RMSE) after the use of the Loughborough epw that consisted of local data against the BirminghamEWT.fwt weather file was reduced by 10 to 20%. This revealed the uncertainty of the results of dynamic simulations that are performed with standard simulation weather data from nearest available sites.
- The simple percentage difference between predicted and measured data was found to be unsuited for calibration purposes and a combination of the MBE,RMSE and especially CV(RMSE) was more reliable.
- Infiltration and ventilation flow rates were found to have the greatest impact on the predicted indoor air temperatures and they should be taken under careful consideration when modeling a domestic building. This underlines the need for blower-door test to measure the exact infiltration rates. The additional ventilation due to open chimneys affected the internal temperatures of the ground floor spaces and should be taken into account into the modeling.

- Another parameter with high influence on the predicted values was the Shading Coefficient of glazing. Low values of shading coefficient (0.3) decreased the indoor air temperature in all spaces.

Limitations of methodology

- The sample of this study was very small and no attempt should be made to extrapolate the results of this study to the whole housing stock.
- Uncertainties arise over the quality of the monitored data due to sensor limitations and wrong positioning within the rooms/thermal zones.
- The lack of occupancy data and windows opening schedules led to an interview–based collection of data that were simplified.
- The collection and analysis of the weather data required for the epw weather file which was essential for the simulation was proven difficult and with high level of uncertainty. The epw creation itself presented compatibility problems with the IES, which in the end was resolved by the company's support center.
- No systematic sensitivity analysis was used to identify the importance of each parameter under a logical range of values.

References

Approved Document F-Ventilation (2010 edition),

Bertagnolio, S., 2012,"Evidence-based model calibration for efficient building energy services". PhD Thesis, Energy systems Research unit. Aerospace and Mechanical Engineering Department Faculty of Applied Sciences, University of Liege

Cervantes, J.C.B., 2006. Development of an Automated Methodology for Calibration of Simplified Air-Side Hvac System Models and Estimation of Potential Savings From Retrofit / Commissioning Measures. *Engineering*, (December,2006).

CIBSE Guide A (2006) Environmental design, the Chartered Institution of Building Services Engineers, London. ISBN-10: 1-903287-66-9

IES 2012, Integrated Environmental Solutions ltd, http://www.iesve.com/ (accessed 27 May 2012).

Sap, R.D. et al., 2007. Appendix S : Reduced Data SAP for existing dwellings. , (March), pp.1–18

WeatherAnalytics (http://wxaglobal.com/IES.html?id=760&cid=1419[assesed 04/05/2013])