FORENSIC WHOLE-BUILDING SIMULATION

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ABSTRACT

A homicide investigation required a whole-building simulation to determine the temperature and humidity profiles for a period of interest, to test the alibi of a known suspect. This paper describes the project from calibration through to delivery of information in court. Conclusions are provided about requirements of such models, the calibration process, and the reliability and accuracy of predictive models.

Specific details about the case cannot be revealed, to maintain the integrity of the Young Offenders Act as it existed at the time of the incident. For the purposes of this presentation, however, those specific details are not really that important. The objective of this discussion is to present a methodology for calibrating and using a computer model to predict building performance. The end use of the information – while interesting and unusual – is secondary to the objective of the paper, although it does perhaps serve to broaden the scope of understanding of what whole-building computer models can do.

PRIMARY WORK REQUEST

Background

In 1992, York Regional Police Department (YRPD) contacted our office to request a whole-building energy simulation that incorporated local temperature and relative humidity information. They informed us that victims of a multiple homicide were discovered in a residence, but the time of death was not known. The YRPD had engaged a specialist who could fix the time of death, extrapolating backward from the discovery and condition of the victims, but only with accurate estimates of temperature and relative humidity for the time interval of interest. The investigating officer explained that it was critical to determine the time of death, as the YRPD had a probable suspect in custody, but the suspect had an alibi for part of the time in question. If it could be established that the event did not occur during that time, the suspect's alibi would be invalid.

At that time, we had developed software to simulation whole-building energy consumption. As it happened, the software calculation engine was based on a direct solver; it did not use transfer functions, correlations, bin methods, or other translational calculation methods. As a consequence, besides determining zone and whole-building energy usage, the software also provided hourly values of temperature and relative humidity in up to seven zones, and so was well-suited for the YRPD's request.

A model can be characterized as using inputs (building dimensions, climatic data, building characteristics,

operating conditions) and a solution engine (direct solver for heat/mass/air transfer between zones, including the outdoors) to produce outputs (interior temperature and relative humidity, in this case). The exercise, therefore, involved calibrating a model for a period during which many parameters are known or measured, and then using the calibrated model to predict the building's response during the period of interest.

Calibration

Figure 1 shows a graphical representation of the modelling process. The objective of the calibration exercise is to determine those dependent aspects of the building response that can vary in the model, as a response to external parameters. In this case, hourly values of zone temperatures and relative humidity for a specific time period were of interest, so these parameters were measured for a different time period, with all non-variable building parameters (e.g., dimensions and operating conditions) and climatic inputs known. Then, the variable building parameters (in particular, infiltration/exfiltration characteristics) were adjusted so that the outputs form the model matched the measured temperature and relative humidity. In other calibration exercises, different variable parameters might require calibration (e.g., occupant behavior or lighting schedule), but in this case these parameters were known and constant. So, for a given set of known climatic data and manual input data, the model is adjusted until the output matches known results, and the model is then said to be calibrated.

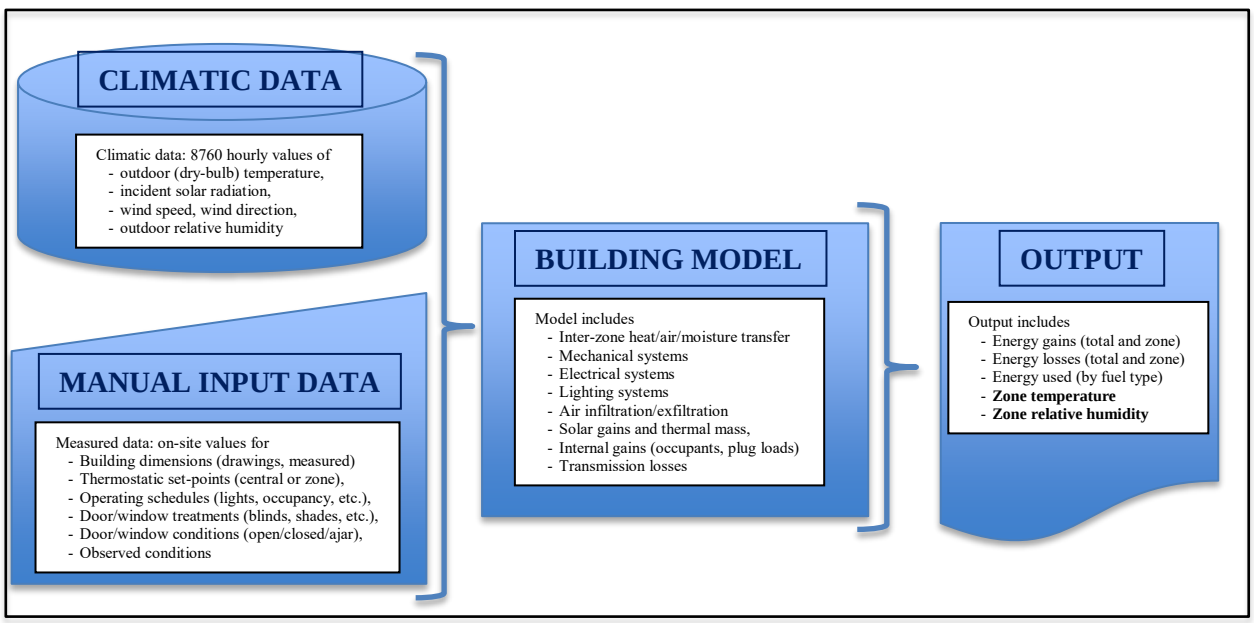

Figure 1: Process flowchart of Whole-building Model

If the calibration exercise was successful, the calibrated model could then be used to predict the building's response to climatic conditions for the period of interest. In that exercise, the calibrated model is used in concert with the climatic data for the period of interest and the manual input data (which are constant for both periods), to produce the output.

A brief note about appropriate climatic data: the values should be representative of the location and the time interval of interest, and be obtained from a reputable source. Environment Canada publishes Climate

Normals, which are average values and therefore were not suitable for this purpose, which required actual measured data for a specific location. Similarly, the typical .TMY and .TRY data could not be used. We contacted local meteorological stations located at nearby airports to obtain the desired information. In our case, Toronto Harbour (YTZ – now called Billy Bishop Toronto City Airport), Toronto Airport (YYZ), Toronto Downsview (YZD), Buttonville (YTZ), and Hamilton Regional Airport (YHM – now called John C. Munro Hamilton International Airport) were the only available stations, but there has been significant expansion in available sources since then.

Figure 2: Analog Hygro-thermometer for Recording Temperature and Relative Humidity

We chose temperature, humidity, and windspeed data from the nearest stations that recorded that information, and solar radiation data from the nearest station whose latitude was closest to the site of interest.

Figure 2 shows a typical device used to measure and record time-varying temperature and relative humidity in a specific location. The device shown is an analog instrument, so it directly measures the parameter of interest rather than relying on calibrated electronic circuitry. Devices similar to the one shown in Figure 2 were placed in the building at the specific locations of interest, and the model was configured to produce results for those same locations.

The predicted output from the model was compared against the measured parameters for the calibration period. The variable characterizing the relative air-tightness of the building envelope was adjusted to provide the closest match to the measured data: the model then varies that parameter to account for wind and stack effects. We observed good agreement between measurement and model, except for an interval at the start of the calibration period. Several possible reasons for the poor fidelity were investigated, but eventually we interviewed the YRPD for further information. They reported that, because the building was not secured, they installed an officer on site to protect the integrity of the crime scene until they collected all the pertinent evidence, and then released that officer to other work. Adding the internal gains associated with an occupant improved, and properly characterizing the officer's activities, resulted in quite good agreement.

Application of the Calibrated Model

Given this agreement, and the path taken to achieve the agreement (i.e., because we could account for the reasons for the initial lack of agreement, and because the changes required to achieve agreement were discreet and provided a predictable and justifiable response), we considered the model to be calibrated, and proceeded to predict the required results.

As it happened, the results suggested that the crime occurred at a different time from the period for which the suspect had an alibi. Naturally, defence counsel was interested in discrediting the model during the trial, and attempted to do so, but apparently without success. During one particularly memorable exchange during cross-examination (which is also illustrative of the need for rigorous and thorough measurement while on site), defence counsel noted that the initial investigating officer on the scene had recorded the temperature on the main floor, and then proceeded up the stairs to discover the victims. Defence counsel suggested that the recorded temperature was higher than the predicted value, which he felt invalidated the results. He suggested that the upstairs temperatures would be even higher (because "heat rises"), which seemed to be confirmed by the investigating officer's notes), so the model's predicted result for those locations (i.e., where the victims were found) would be even more inaccurate. In response, I noted that:

- a thermostatic setpoint is not an accurate measure of temperature, as a thermostat is not a thermometer (it is merely an on/off switch for the mechanical systems)
- although we had only reported the temperature on the second floor, the model actually predicted values for all zones, and the downstairs temperature was reasonably close to the thermostat reading)
- while it is generally true that "heat rises", in this case the upstairs was cooler than the downstairs, because the blinds were partially drawn in the upstairs bedrooms, thus reducing solar gains relative to the ground floor (thus, the important of noting the treatments and condition of windows and doors)
- while the investigating officer would be a trained professional – and certainly had the presence of mind to note the thermostat reading in the first place – any assessment of the upstairs temperature, where there was not even a thermostat to provide a rough estimate, would be a subjective observation. The upstairs was not well vented, and would have been stuffy. Odours would indicate what the officer could expect to find. The officer was a larger individual, who was wearing a suit and overcoat, and who had just climbed a flight of stairs. He might easily have sensed that the upstairs area was warmer than downstairs, even if that were not the case. In this situation, even an

individual trained to be an objective observer might make a subjective observation.

Defence counsel had to admit that the model appeared to provide a reasonable representation of the actual conditions, and the results were admitted as evidence. Ultimately, the suspect was convicted.

CONCLUSION

Whole-building energy models can provide a wide range of useful results. Calibrating the model is a necessary step if the results are to be reliable, and this presentation provides some guidelines on how such reliability can be achieved.