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VALIDATION OF A NEW INTEGRATED DESIGN TOOL FOR NATURALLY VENTILATED BUILDINGS

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ABSTRACT

In many cases natural ventilation is used to ensure an acceptable indoor environment. However it is difficult to design a building for acceptable ventilation rates and indoor comfort without the proper tools or guidelines. The passive building simulation tool *Building Toolbox* (Web-site: http://www.newquick.com) was extended with natural ventilation models for the design of natural ventilated buildings. The simulation tool was verified with actual measurements during three case studies to ensure its integrity and to illustrate its applicability in this field. The predicted indoor air temperatures of all the studies were within 1°C for 80% of the time.

KEYWORDS

Passive buildings, building simulation, natural ventilation, indoor comfort, thermal performance of buildings, building design tool, stack effect, wind effect.

INTRODUCTION

The principle elements, in order to provide an acceptable indoor environment in most applications, are dry bulb temperature, relative humidity, outdoor air ventilation rate and air movement (ASHRAE Fundamentals Handbook 1997 and CIBSE Guide Volume A 1986). The problem however is to predict these conditions in the design of new building facilities to ensure a healthy indoor environment.

Natural ventilation is a very common method to create acceptable conditions in building facilities but also the most difficult to design for. Most available calculation methods do not integrate the performance of the building envelope with ventilation in a dynamic fashion (Rousseau and Mathews 1994). These methods can therefore result in a very poorly designed building.

The best way to go about this will be to use a thermal simulation program, which integrates all the elements having an influence on the indoor air conditions and ventilation rates. With such a simulation tool, it would be possible to investigate the effect, the building envelope and ventilation openings will have on the outdoor air ventilation rate and the indoor air conditions.

It is always important for the user that a simulation tool predicts "real life", for confident use in practice. Therefore a verification study was performed to validate the integrity and accuracy of the models and to illustrate the value and applicability of simulation in the design of building facilities. The study was performed empirically by comparing the predicted values to measurements.

SIMULATION MODELS

An electrical analogy introduced by Van Heerden and Mathews (1996) is used to model the heat transfer processes in the building for the accurate prediction of the thermal performance of the building zones. The model makes use of a six-node electric circuit to simulate the different heat flow paths. The ventilation model makes provision for deliberate flow through purpose provided openings such as open windows and ventilators caused by natural driving forces. These ventilation rates are directly influenced by the pressure distribution on the building envelope and the characteristics of the different openings.

The pressures on the building envelope consist of wind induced pressures and pressures arising from the difference in temperature between the indoor and outdoor air. A ventilation model introduced by Mathews and Rousseau (1996) where the building may be represented by a flow network of pressure nodes coupled by non-linear flow resistances is used to predict the ventilation rates. The air flow rate through an opening can be calculated by employing the energy conservation equation in the following way:

$$Q = C_d A \left[\frac{2}{\rho} \Delta p \right]^{\frac{1}{n}} \tag{1}$$

where Q is the flow rate (m^3/s), C_d the discharge coefficient, A the area of the opening (m^2), ρ the density of the air (kg/m^3) and Δp the pressure difference across the opening (Pa). Wind pressure is calculated as follows:

$$C_p = \frac{p_{wind} - p_{ref}}{\frac{1}{2}\rho V_h^2} \tag{2}$$

where p_{ref} is the reference pressure (Pa), which equals the static pressure of the undisturbed airflow and may be taken as equal to the barometric pressure, and V_h the free stream velocity at roof height (m/s). The free stream velocity at roof height is given as:

$$V_h = V_{ref}\left[\frac{h}{h_{ref}}\right]^{\alpha} \tag{3}$$

where h is the roof height (m), V_{ref} velocity at a specific reference height (m/s), h_{ref} the reference height (m) and α the velocity profile exponent. The orientation of the building with respect to the wind direction is taken into account by the C_p values (Rousseau and Mathews 1996). The pressure (Pa) due to thermal forces is given as:

$$p_{therm} = 0.0342\frac{y p_{ref}}{T_i T_o}(T_o - T_i) \tag{4}$$

where y is the height (m) of the opening above ground level and T_i and T_o the indoor and outdoor temperatures (° C) respectively.

VALIDATION OF MODELS

The facilities of the Equine Research Centre of the faculty of Veterinary Science of the University of Pretoria at Onderstepoort were used for this study. The models were verified by comparing the simulated predictions to measured conditions.

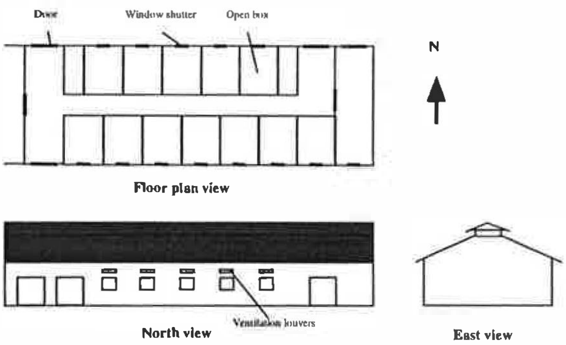

Figure 1: Schematic drawing of the stable

Building description

The stable used, provided mechanical ventilation facilities. The building had a double layer brick construction and a 27° angle pitched corrugated iron roof with a plaster board ceiling. Figure 1 displays a schematic drawing of the stable. The facility has 12 sliding window shutters and ventilation louvers for ventilation purposes.

Procedure

The following three studies were conducted for 24 hour cycles on the same stable to obtain the validity and integrity of all the models in an integrated fashion. The first study was done to verify the thermal performance of the building envelope on its own (building model). The best way to achieve this was to ventilate the building with a known rate of outside air (forced mechanical ventilation). By doing this we simultaneously pressurised the building space to eliminate any natural ventilation or infiltration. For this study all the window shutters were closed.

The second study was performed to obtain the accuracy of the building model integrated with the ventilation model (wind and thermal effects). In the third study we investigated the integration of the building, ventilation and internal heat models. An internal heat load was present in the form of horses. The window shutters were open during study 2 and 3 to allow for natural ventilation.

Measurements

Measurements were taken over a period of one week during June 1998. The measurements included indoor air temperatures, outdoor air temperatures, the radiation of the sun, wind speed and wind direction and mechanical driven air flow rates. From this data a single representative day for each study was extracted to be compared with the 24-hour day predictions provided by the simulation tool. The building was left in its passive state with the window shutters open for 24-hours to stabilise after the first study, which involved mechanical ventilation.

Results

Only the indoor air temperatures were used for evaluating the accuracy of the simulation tool. Figure 2 to Figure 4 display the predicted and actual measured indoor air temperatures for each study, as well as the outdoor air conditions for the applicable period.

It is clear from the results of case study 1 that the dynamic modelling of the building envelope is satisfying with the ventilation rate known. Good comparison between the measured and predicted indoor air temperatures in study 2 and 3 will therefore point to the accurate prediction of natural ventilation.

A moderate average wind of 1.6 m/s from a north west direction was measured during the 24 hours of case study 2. Therefore the dominant force behind the natural ventilation was wind and not temperature. This study's results reflect therefore on the accurate modelling of natural ventilation driven by wind through vertical openings.

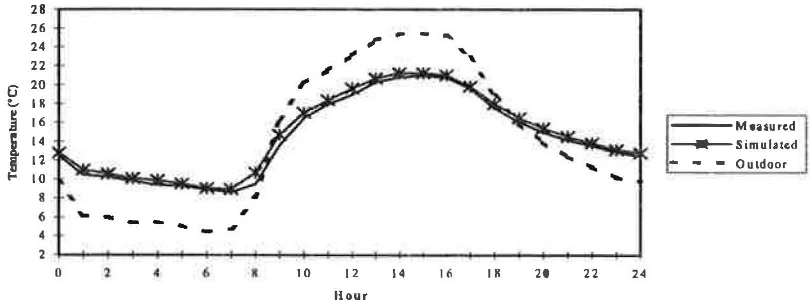

Figure 2: Indoor air, case study 1

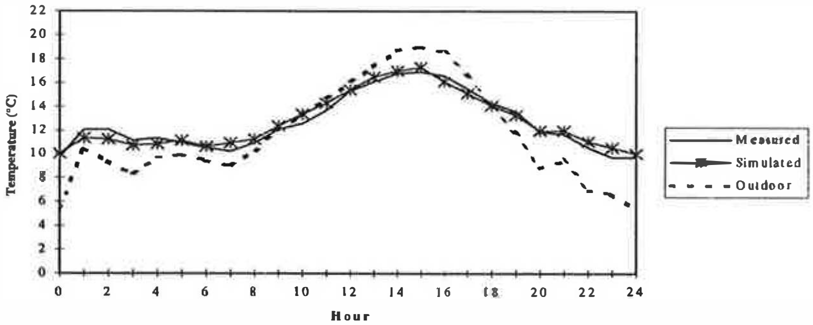

Figure 3: Indoor air, case study 2

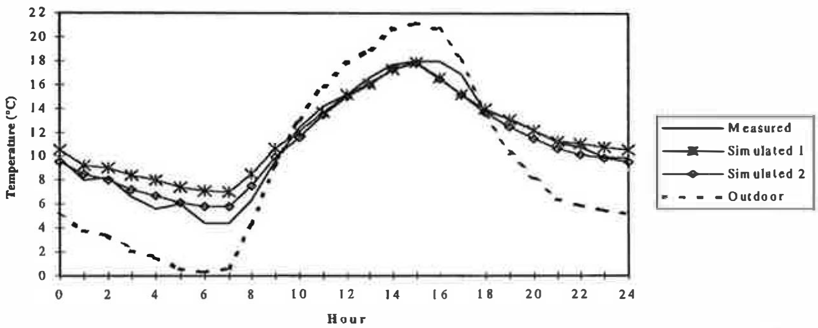

Figure 4: Indoor air, case study 3

The results of study 1, 2 and 3 are summarised in Table 1.

TABLE 1
SUMMARY OF VERIFICATION RESULTS

Study	Case study 1		Case study 2		Case study 3	
Type	Measured	Predicted	Measured	Predicted	Measured	Predicted
T_{ave} (°C)	14.4	14.8	12.6	12.7	11	11.1
Swing (°C)	12.4	12.3	7.2	7.2	13.6	12
Max. error (°C)	1.2		0.8		1.6	
Within 1°C (%)	92		100		80	
Within 2°C (%)	100		100		100	

The results obtained from the first simulation (simulation 1, figure 4) during case study 3 showed large discrepancies during the morning and late night. This result can be attributed to the inaccurate prediction of temperature induced ventilation since windless conditions existed during the time. Each window opening was treated as one opening at one specific stack height (at geometric area centre). This only made provision for one directional flow driven by the ventilation louvers at a higher vertical location.

If an opening's vertical dimension is large enough to create a temperature difference due to the stack effect, two directional flow can occur through the same opening (ASHRAE Fundamentals Handbook 1997). To make provision for this effect, each window opening was treated as two openings (simulation 2) directly above each other, each with its respective relative geometric area centre height. The results from this simulation 2 (figure 4) are a big improvement on the first one with acceptable accuracy.

No natural ventilation air changes were measured for verification purposes. But we know that the thermal performance of the building envelope is correct for a given ventilation rate. Therefore the predicted air changes calculated for natural ventilation must be correct since the comparison between the predicted temperatures is more than satisfying.

CONCLUSIONS

Three case studies were conducted to verify the simulation models' predictions. The simulated indoor air temperatures of all the case studies were within 1°C for 80% of the time. The case studies have shown that the stack effect, the driving force behind temperature induced ventilation, can be better accounted for if all the vertical openings are treated as two separate openings directly above one another. The height difference between the openings is the distance between the geometric centres of the two divided areas.

The verification results reflect on the accurate modelling of the building envelope and ventilation models (wind and temperature induced) in an integrated fashion. The results were further sufficiently accurate for the simulation models to be used with confidence in the design of forced or natural ventilated (through vertical openings) buildings.

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