Energy Impact of Ventilation and Air Infiltration
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The Energy Impact of Ventilation on Industrial Buildings

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Synopsis

A combined thermal and ventilation model has been used to investigate the seasonal variation of air infiltration rates and ventilation heat losses in modern industrial buildings. The model was initially compared to measurements of ventilation rates, temperatures and heating loads in such a building, and was found to agree well. The model was then used to predict infiltration rates, temperatures, ventilation heat losses and space heating loads for a standard heating season for that building. The effects of variation in the building air-tightness, and of the intermittent use of the loading door were also investigated. The results indicated that modern design and construction practices could significantly reduce infiltration, and so reduce energy use.

1. Introduction

The energy impact of ventilation on heating industrial buildings can be significant, and is often considered by design calculations to contribute up to 50% of total heating load. Measurements of ventilation rates over a wide range of industrial building types [1,2] have indicated that considerable variations in ventilation rate and therefore in ventilation heat loss, can occur. These variations occur both between building types, and over time, under the influences of wind and temperature differences. Mis-judging these variations at the design stage can lead to under- or over-sized heating systems and result in poorly performing inefficient buildings.

Previous work by the authors [3] has demonstrated the use of ventilation models to predict the variation of ventilation rates in industrial buildings over time. In this paper a zonal ventilation model has been combined with a building energy model, HTB2 [4], in order to predict the impact of ventilation on space heating energy use for a modern industrial building.

The paper first introduces the measured air leakage and ventilation data collected during recent experiments in a modern factory. This data was used to set-up and check the operation of the zonal ventilation model. The zonal model has been combined with the building energy model, HTB2, so that the ventilation heat loss can be explicitly modelled during an energy simulation. The results from HTB2 simulations were compared with measured data on internal temperatures and energy use for the same factory. The model HTB2 was then used to predict the seasonal ventilation performance and energy use of the factory. Finally, variations of air leakage and door opening were assessed.

2. Ventilation and Air Leakage Measurements

Ventilation and air leakage measurements have been carried out on 3 industrial buildings in

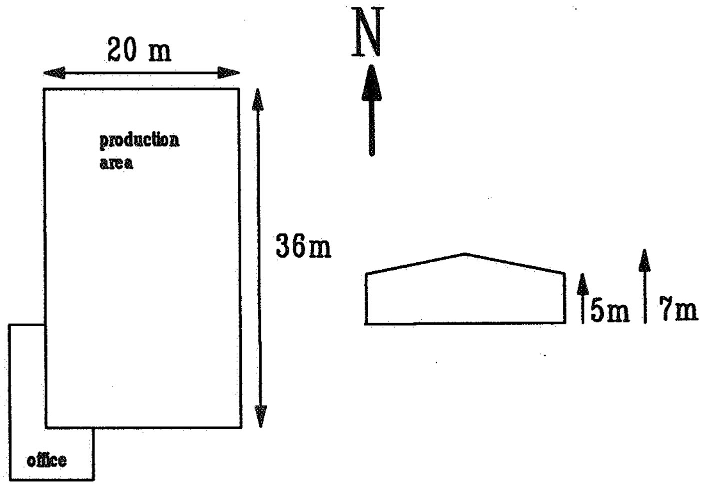

Figure 1 Unit 42, Factory Plan and Section

Aberaman, South Wales, as part of a project to investigate the design and construction of modern 'low energy' factories [1]. The factories involved were designed within the current building regulation requirements, with a design U-value of 0.45 W/m²/°C. They were also specifically designed to achieve a low air infiltration rate. Attention was given to the detailing of the building to ensure that the thermal insulation was properly installed and that air leakage was minimised. The design and construction processes were monitored to determine and correct any problems.

The factory monitored (Figure 1) was of 720m² production floor area, with a composite cladding construction. The heating system comprised of two wall-mounted warm air heaters, with destratification fans in operation. The factory had an insulated loading door and 2 roof ventilators.

Air leakage and ventilation measurements were carried out in February and August 1992, respectively. The air leakage measurements were carried out by pressurisation fans installed in the fire doors. Internal/external pressure differences of up to 60 Pa were achieved for air flow rates of 7 m³/s. Ventilation measurements were carried out using constant concentration and tracer decay methods with N_2O as the tracer gas. Continuous constant concentration measurements were carried out over a 14 day period. Tracer decay tests were also performed to assess the ventilation rates occurring during the use of the loading door. The results are summarised in Table 1.

Air leakage at 50Pa		6.1 m³/s
Average ventilation rate		0.16 ac/h
Typical ventilation rate with loading door open		1.5 ac/h
Average temperature during ventilation measurements;	Internal	21.5 °C
	External	16.2 °C
Average wind speed		3.2 m/s
Predominant direction		SW (45° off major axis)

Table 1 : Summary of air leakage and ventilation measurements

3. Preparation of Zonal Ventilation Model

The data required for the zonal ventilation model was derived as follows, using the same procedures as developed in an earlier investigation [3] :

i) the measured air leakage curves, as shown in Figure 2, for background (doors and roof ventilators sealed) and total (doors and roof ventilators unsealed - but not open) situations were used to estimate the equivalent crack opening parameters for the envelope. The resultant open areas are summarised below :

background leakage area	- 1.21m²
loading door (closed) leakage area	- negligible
roof vents (closed) leakage area	- 0.1m²

ii) through visual inspection, and application of the simple rule developed in the earlier work, these open areas were located on the envelope. Apart from the location of the ventilators and door, there were no obvious sites for anomalous background leakage. Accordingly, the background was apportioned equally (by wall length) to locations where there were changes in construction or junction of major components, i.e. at eaves level, or at rooflights. This

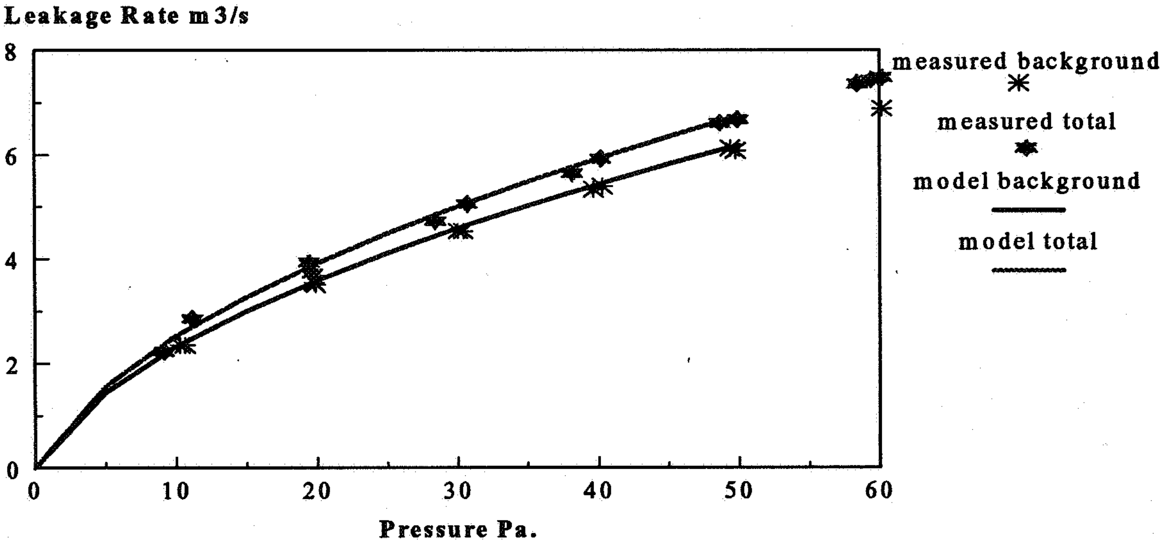

Figure 2 Measured and Best Fit Leakage Data

provided the following simple background opening distribution;

facade	height	open area at each height
south wall	1m & 5m	$0.0755m^2$
west wall	1m & 5m	$0.1510m^2$
north wall	1m & 5m	$0.0755m^2$
east wall	1m & 5m	$0.1510m^2$
west roof	6m	$0.1510m^2$
east roof	6m	$0.1510m^2$

This initial distribution of background areas was not altered further. It is worth noting that thermographic experiments with and without building pressurisation indicated considerable leakage at the eaves levels, as assumed in the above.

iii) surface average wind pressure coefficients were calculated using standard algorithms, as previously used [3].

The zonal ventilation model was applied to this data to predict the variation of air infiltration rate over time for a two week period in July/August 1992, for which measured ventilation data was available for comparison. These ventilation measurements were obtained from constant concentration experiments [1]. Internal and external air temperature data was collected on site and wind velocity data was obtained from a nearby meteorological station. The predictions for this comparison were made using the recorded internal temperatures.

The predicted and measured infiltration rates are plotted for the 10 day period in Figure 3. Hourly values for predicted and measured infiltration rates are compared in Figure 4. There was a reasonable agreement between the two data sets. A major contribution to the differences was considered to be due to the use of off-site wind velocity data. It was not possible to permanently monitor wind velocity directly on-site, due to a high risk of vandalism.

4. Test Simulation Using HTB2

As part of on-going developmental work within the WSA research group, the building thermal model HTB2 has been modified to include the zonal ventilation model within its' dynamic calculation procedure. The modular nature of HTB2 [4] enables such additional sub-models to be incorporated with relative ease.

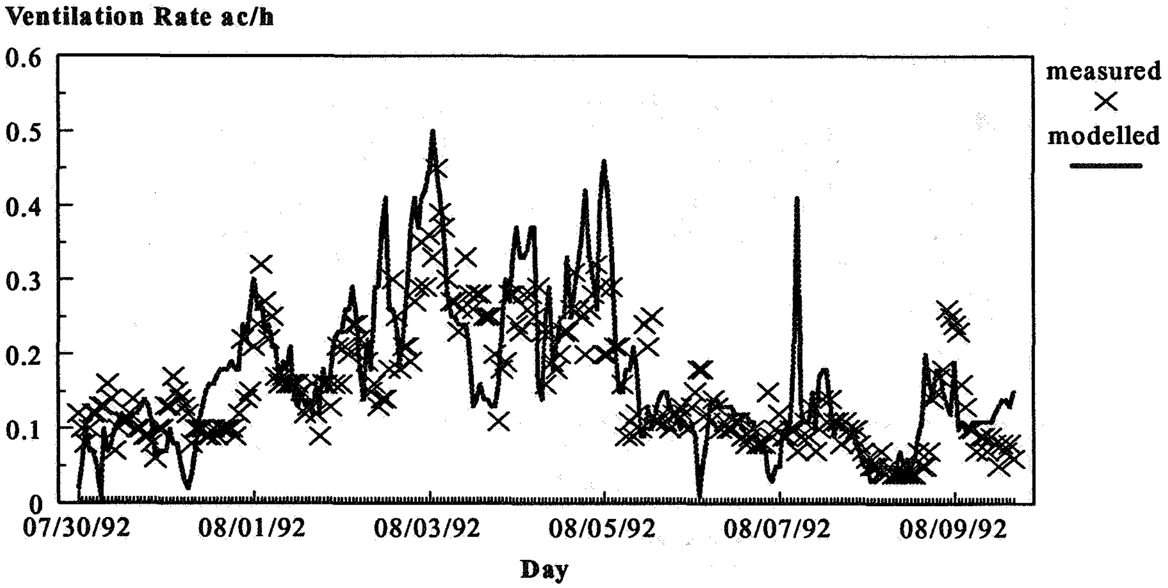

Figure 3 Measured and Predicted Infiltration Rates

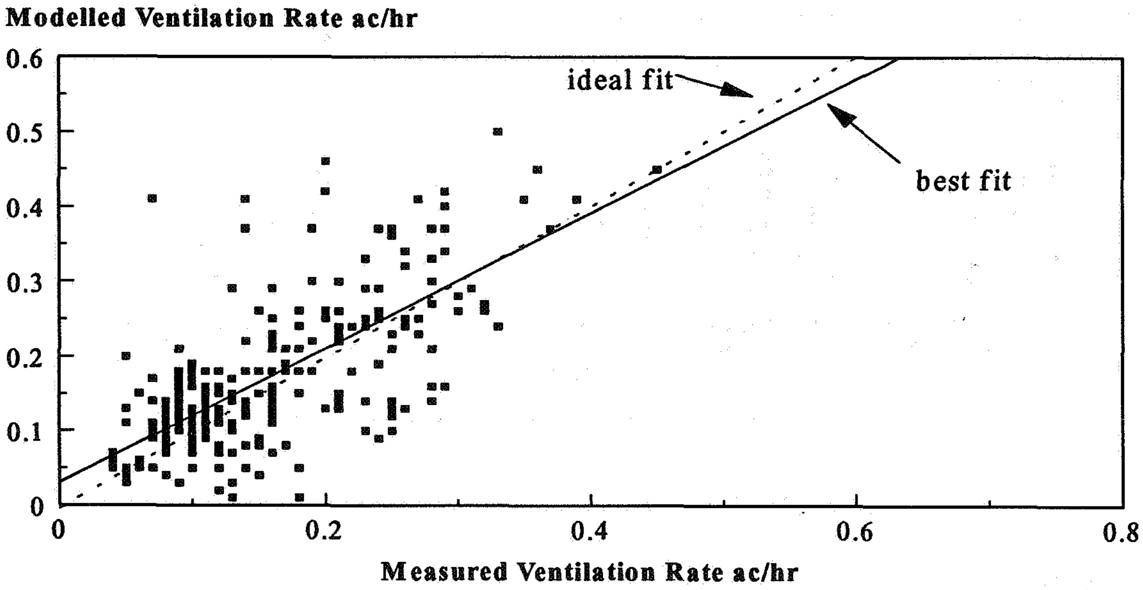

Figure 4 Measured and Predicted Infiltration Rates Comparison

The combined model was set-up to simulate the thermal performance of the factory over the period February-March 1992, using a straight-forward representation of the building fabric and heating system derived from design details and the ventilation model as developed above. The warm-air heating system, in particular, was not treated as an "ideal" system, but was described as having time constants and deadbands as appropriate for such an industrial system.

Measured ventilation data were not available for this period, but measurements were made of internal and external air temperatures and space heating fuel use, on a half-hourly basis [1]. These were converted to hourly records for the comparison with the modelled results.

The results of the building simulation are given in Figure 5a and 5b for an example period of 16 days. Figure 5a compares measured and predicted internal air temperatures. The comparison

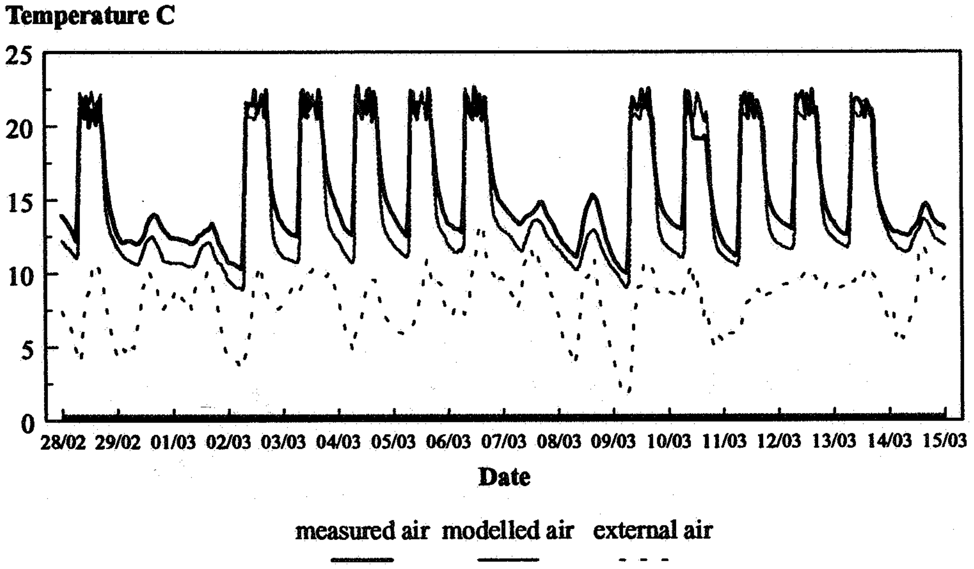

Figure 5a Measured and Predicted Space Temperature

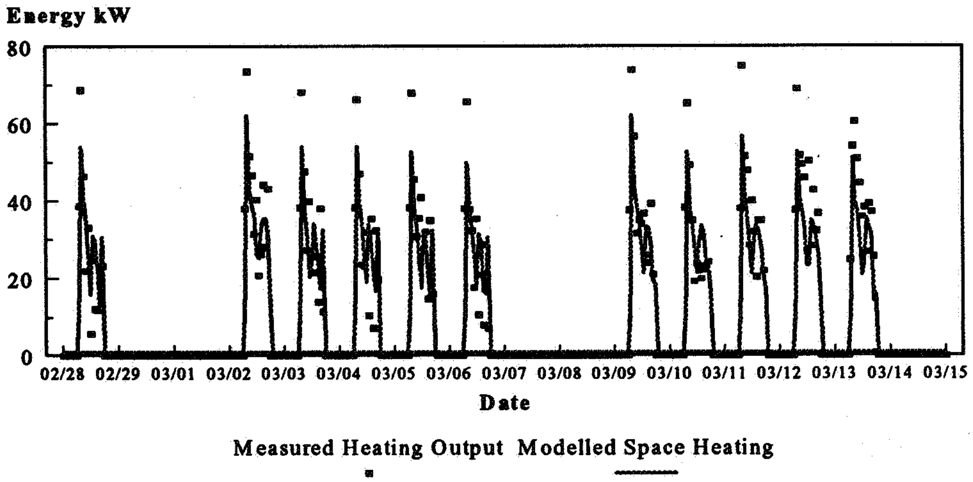

Figure 5b Measured and Predicted Space Heating

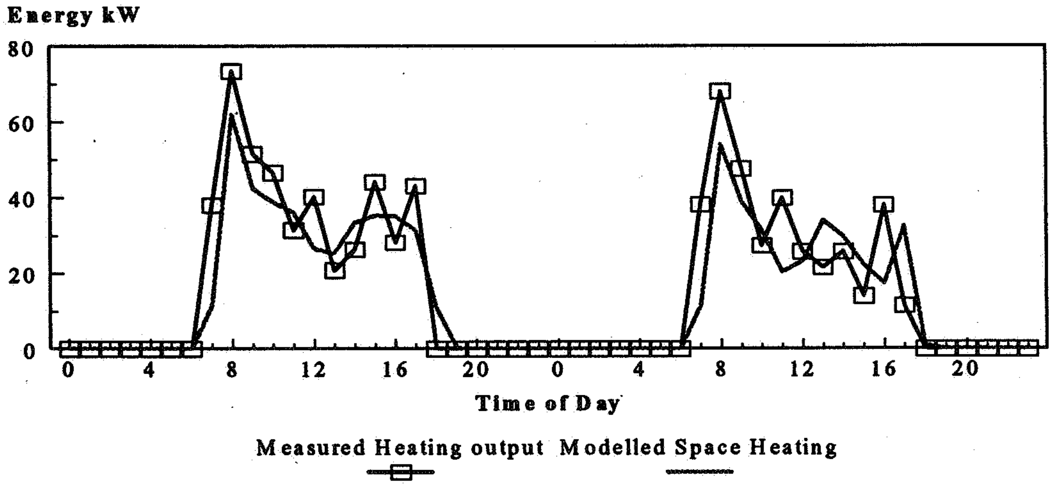

Figure 6 Measured and Predicted Space Heating, Two Days

was good during the heated times, however the predicted temperature during the unheated periods appeared to cool approximately 1 - 2°C below the measured values. Figure 5b compares the measured and predicted energy use for the same period, here the measured energy use (gas input) was adjusted to allow for an average 75% plant efficiency so that comparison to the predicted energy requirement (space heating output) would be more straight-forward. The comparison was again reasonable with the model slightly under-predicting the energy use during warm-up (the simulated warm-up seemingly too rapid), but predicting well the energy use levels over the rest of the heating period. The detail of the heating system operation is obscured, Figure 6 presents a 2-day period for closer examination.

The results show a favourable comparison of measured and predicted conditions. The differences in the night-time cooling and in the peak heating loads have been found before in other tests involving HTB2, although this data set has seemed to emphasize them. The causes for these differences are felt to lie in the simulation assumptions made regarding ground floor slabs and/ or regarding the effects of stratification (which amounted to some 5°C from floor to ridge during heating). This is currently being investigated in greater detail.

5. Seasonal Simulation Using HTB2

Using the building representations thus determined, the model HTB2 was used to predict seasonal space heating and ventilation heat loads, based on a standard meteorological heating season (Kew 1967). A frequency histogram of seasonal ventilation rate is presented in Figure 7a with the seasonal ventilation heat load presented in Figure 7c. The histograms for ventilation heat load include data only during the heating periods, during unheated periods, the ventilation load is typically less than 3 kW. The total space heating load is presented in Figure 7b. Note that the peak at 48 kW was due to the morning heating transient, its' prominance is an artifact of the simulation process. The seasonal ventilation heating load was 16120 kWh, which is 29% of the total predicted space heating load of 56010 kWh.

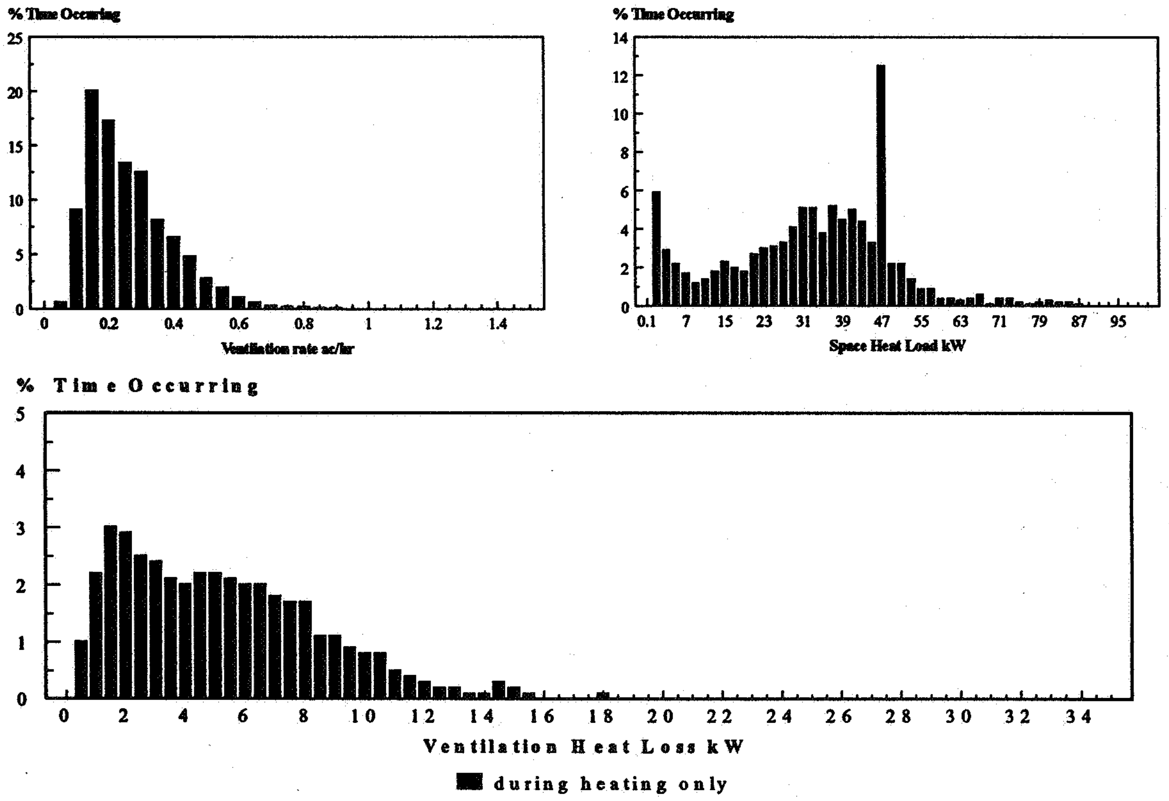

Figure 7a,b,c Seasonal Frequencies of Infiltration, Heating Requirement, and Ventilation Heat Loss.

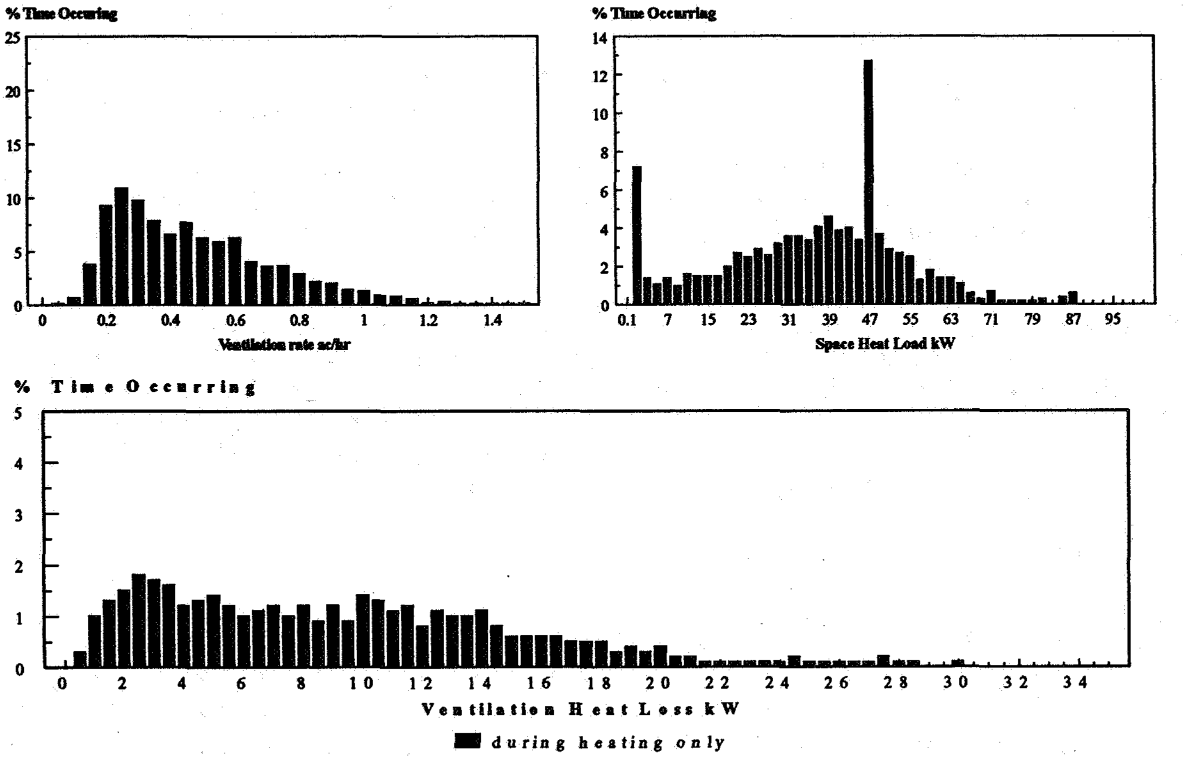

Figure 8a,b,c Seasonal Frequencies of Infiltration, Heating Requirement, and Ventilation Heat Loss, 2x Base Case Leakiness.

The factory that was being simulated had a low air leakage rate in comparison with other similar buildings of its type (typically 50% lower) [1]. The above simulation was therefore repeated with double the air leakage areas - which is probably more typical of current design. The results are presented in Figures 8a, 8b and 8c. In this case the seasonal ventilation heating load increased to 28917 kWh, 44% of the total space heating load of 65172 kWh.

For comparison purposes the simulation was repeated using a constant 0.5 ac/h, which would be typical for a simulation prior to the incorporation of a more complex ventilation model with HTB2. The predicted seasonal ventilation heating load was found to be 27583 kWh, which was 44% of the total space heating load of 62042 kWh.

6. Effect of Loading Door Opening

The above seasonal figures ignore the effect of the periodic opening of the loading door. Whilst this door is open, the ventilation rate and heat loss would be expected to be much higher. Measurements made on site indicated that the ventilation rate with the loading door open was 1.5 to 2.0 air changes per hour. The simulation model could calculate the effect of the open door, however due to the large open area, the value resulting would be very dependant on the surface pressure coefficients used for that area. Since only generic surface average were used in this exercise, this approach was felt to be inappropriate.

The effect of door opening was therefore estimated assuming that 2 ac/h occurred whilst the door was open, and the door was assumed to be opened for 15 minutes twice a day (at 10 AM and 3 PM, to simulate goods received and dispatched). For the short opening times assumed, the space average internal temperature would not be greatly affected and so the previously determined simulation results for the inside-outside temperature difference for those times could be used to estimate the excess ventilation heat loss for each day, due to the door opening. This procedure indicates that the door opening pattern assumed added some 3400kWh heating requirement to the base case, an increase of some 6% over the heating season. The changes to the ventilation heat loss relative frequency is shown in Figure 9.

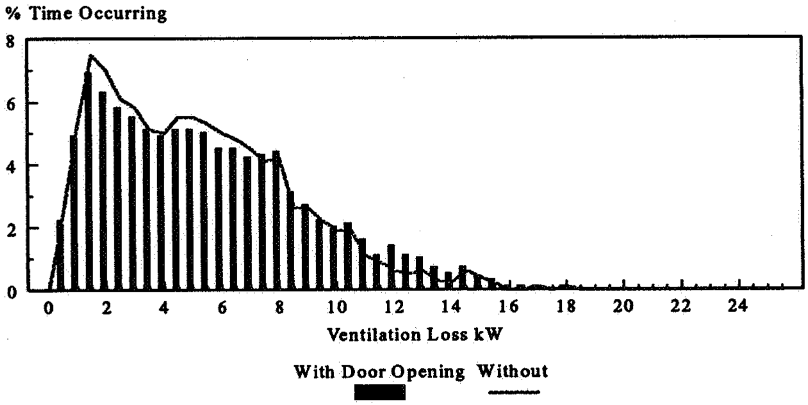

Figure 9 Difference in Seasonal Frequencies of Ventilation Heat Loss, With and Without Loading Door Use, Base Case.

Conclusions

A zonal ventilation model has been successfully integrated into a building energy model to enable a more realistic prediction of seasonal ventilation heating load.

Testing the model at various stages of its application revealed reasonable agreement with measured data. The data required for the simulation were either easily obtainable from the design data, or from simple site measurement (i.e. pressurisation). Differences between measured internal air temperatures and space heating energy were thought to be due to the way the floor heat transfer and/or stratification were modelled, and this aspect is being further investigated.

The average ventilation rate over the heating season was predicted to be 0.24 ac/h with a peak rate of 0.8 ac/h, for the base (tight) case. For this case, the seasonal ventilation heating load was 29% of the total heating load of 56 MWh. There was an increase of 6% over the base case heating requirement when loading door opening was taken into account.

For the standard factory case, where double the leakiness of the base case was assumed, 44% of the space heating load of 65 MWh was due to ventilation heat loss. The seasonal ventilation heating load calculated assuming a constant air change rate (0.5 ac/h, as suggested by the CIBSE design handbook) was also found to be 44% of a total space heating load of 62 MWh. Thus without proper regard taken of modern design and construction techniques, the heating requirement can be significantly overestimated, leading to over-sized, and therefore inefficient, heating systems.

Taking typical system efficiencies into account (75%), the better building design and build quality of the base case could be attributed to reducing the seasonal heating fuel requirement from 87 MWh to 75 MWh, a saving of some 10%, through reduction in infiltration.

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