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HYBRID VENTILATION OF CANADIAN NON-DOMESTIC BUILDINGS : A PROCEDURE FOR ASSESSING IAQ, COMFORT AND ENERGY CONSERVATION

D. Bourgeois [1], A. Potvin [1] and F. Haghighat [2]

[1] École d'architecture, Université Laval,
Québec, Québec, G1K 7P4, CANADA
[2] Department of Building, Civil and Environment Engineering, Concordia University,
Montréal, Québec, H3G 1M8, CANADA

ABSTRACT

Environmental and economic concerns linked to conventional heating, ventilation and air-conditioning systems (HVAC) have sparked a renewed interest in natural ventilation, passive cooling and other low-energy microclimate control strategies for buildings. In Canada, the combination of extreme weather conditions, wind variability, transient occupancy patterns and high internal heat gains may hinder the feasibility of implementing natural ventilation as an exclusive means of ventilating non-domestic buildings. This paper discusses the advantages of hybrid ventilation strategies in Canadian non-domestic buildings, as an alternative to the exclusive application of either natural ventilation or HVAC systems. This paper also presents a procedure for assessing hybrid ventilation efficiency and energy conservation, using commercially-available multizone airflow and thermal/energy models.

KEYWORDS

natural, hybrid, ventilation, architecture, IAQ, comfort, energy, zonal, model.

INTRODUCTION

HVAC has been considered a standard component in Canadian non-domestic buildings for several decades. Environmental concerns linked to excessive energy consumption and the use of ozone layer-depleting refrigerants, as well as concerns regarding perceived building related illnesses, have somewhat stifled the enthusiasm for HVAC systems in recent years. One response has been to reintroduce openable windows in buildings with HVAC. It is however doubtful that the practice of opening windows in conventional mechanically ventilated buildings should be considered sustainable when energy intensive mechanical air-conditioning processes are at work. Opening a window in such a case would often result in flushing out indoor air, since most mechanically ventilated buildings are pressurised.

These concerns have sparked a renewed interest lately in natural ventilation and passive cooling as a sustainable means of providing indoor air quality (IAQ) and thermal comfort. There is however considerable scepticism regarding the feasibility of implementing natural ventilation as an exclusive means of ventilating non-domestic buildings in Canada. Kolokotroni et al. (1995) have demonstrated that with suitable designs, offices should be able to rely on passive devices, such as trickle ventilators, to provide necessary background ventilation during winter in temperate climates such as the UK. However, one must wait until April to find such 'mild' climatic conditions in most Canadian regions - the mean monthly outdoor air temperature in Quebec for January being -10.6°C, as opposed to 3.7°C for London. Draughts and temperature stratification may be too important for thermal comfort without some means of passive or artificial air pre-heating in winter. In addition, summers in central and eastern regions of Canada are generally warmer than the UK (an average of 20°C in Quebec for July, as opposed to 17.4°C in London) and are often subjected to hot and humid air masses that usually originate in the Gulf of Mexico or the Caribbean. During these periods, wind induced pressures may not always be sufficient to ensure adequate airflow for thermal comfort, while night ventilation may not always be a suitable cooling strategy, since humidity absorbs long-wave radiation and condensation may occur on cooler surfaces. Concerns regarding exclusive passive environmental control for IAQ and occupant thermal comfort in Canadian non-domestic buildings appear therefore legitimate. On the other hand, the desire for natural ventilation and its advantages have also been clearly demonstrated. Thus, a sustainable alternative to the exclusive application of either natural ventilation or HVAC is definitely needed.

HYBRID VENTILATION

Hybrid ventilation can be described as a system providing a comfortable internal environment using different features of both natural ventilation and mechanical systems (IEA, 1998). The overall idea is to use mechanical ventilation as a back up system to compensate for natural ventilation insufficiencies. It has been previously established that both HVAC and openable windows are increasingly common in new non-domestic buildings in Canada. Since computerised environmental management systems are commonly found in Canadian non-domestic buildings, it would be quite feasible to use windows as 'switches', capable of overriding automatic environmental control when opened; the intuitive act of opening or closing windows clearly indicating occupant preference. Hawkes (1996) has stated that building occupants are capable of exercising sophisticated and effective control over their environments if they are given the opportunity. In addition, occupants generally accept wider comfort bands in selective modes (Baker and Standeven, 1995), which may further increase the energy conservation potential of hybrid strategies. Partial automatic control is also feasible. For instance, if wind or temperature induced pressures are insufficient for IAQ during mild weather, CO^2 detectors may automatically activate periodic mechanical ventilation. For energy conservation purposes, air-conditioning should only be exploited when windows are closed. In order to offset occupant forgetfulness, windows may need to be equipped with computer-controlled actuators capable of closing windows outside normal occupancy hours, if air-conditioning is required.

Sizing inlets and outlets for natural ventilation may be necessary during the initial design phases, which usually requires the use of multizone airflow models. These models are also practical to estimate the frequency with which natural ventilation may produce the required ventilation rates in a building. However, thermal simulation models may reveal thermal discomfort during certain periods, even if ventilation rates are minimal. Balancing ventilation requirements for IAQ with thermal comfort while using natural ventilation may become a very lengthy and arduous process. In addition, it may be necessary to estimate the overall energy conservation potential related to the implementation of a hybrid ventilation strategy, in order to assess its cost-effectiveness.

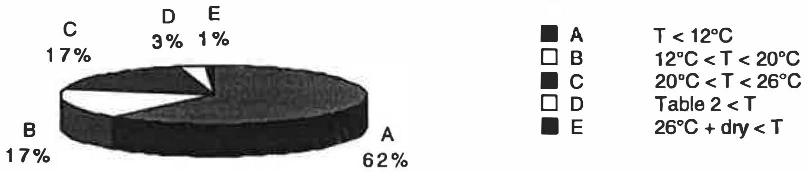

Figure 1 : Yearly mean outdoor air temperature (T) distribution during normal occupancy (Quebec).

The following procedure is aimed at building designers who wish to use low-cost, if not free, easy-to-use airflow, thermal and energy simulation models in order to assess hybrid ventilation efficiency and overall energy conservation. It is implicitly understood that the results obtained from the procedure give approximate estimations; the margins of error being considered acceptable for preliminary design purposes. The use of a spreadsheet program is recommended for calculation purposes.

PROCEDURE FOR ASSESSING ENERGY CONSERVATION

Definition of simulation periods and buildings zones

The first part of the procedure is to define the simulation periods, as a function of normal occupancy patterns. For instance, an office building usually operates from Monday to Friday, from 8h to 18h. Therefore, the year should be divided into 104 simulation periods, two for each week: during and outside normal occupancy hours. The procedure then requires that a building be subdivided in several zones, as a function of internal heat gains, ventilation rates, zone orientation (north, south, east or west) and wind exposure.

Climate analysis

Using a TRY file for any given city, mean outdoor air temperatures must be calculated for each simulation periods, e.g. during and outside normal occupancy hours, for each week.

Definition of hybrid ventilation strategies

The procedure requires the definition of hybrid ventilation strategies for each zone, as a function of outdoor air temperatures (T_{out}). Table 1 shows an example of strategy definition for a single zone. Strategies A, D and E correspond to unacceptable outdoor air temperatures for natural ventilation purposes. Table 2 indicates unacceptable outdoor air conditions with humidex factors exceeding admissible comfort bands. Figure 1 shows the distribution of mean outdoor air temperatures during normal occupancy hours for Quebec.

Appropriate hybrid ventilation strategies should be based on previous simulations of zone thermal behaviour, as a function of outdoor air temperature, ventilation rate, and solar and internal heat gain. This may be obtained through CFD or zonal modelling. Air velocity and temperature distributions are being investigated using the newly developed POMA Zonal Model (Haghighat et al., 1999). Variables include ventilation rates, indoor/outdoor air temperature differences, internal heat gains and architectural parameters (room height, width and length, as well as inlet and outlet position). Results should indicate appropriate natural ventilation strategies according to climatic conditions and occupancy patterns.

TABLE 1

HYBRID VENTILATION STRATEGY DEFINITION ACCORDING TO OUTDOOR AIR TEMPERATURE

PERIOD	CRITERIA	STRATEGY
A	T_{out} < 12°C	HVAC; windows closed; windows may be opened, but will automatically close after 5 min. if T_{in} < heating set point.
B	12°C < T_{out} < 20°C	Natural background ventilation (IAQ); minimum window open area; windows may be opened further, but will automatically close after 5 min. if T_{in} < heating set point; periodic mechanical ventilation if required (CO^2).
C	20°C < T_{out} < 26°C	Natural ventilation (thermal comfort + IAQ); windows may be opened at occupant's convenience; periodic mechanical ventilation if required (CO^2); no air-conditioning.
D	TABLE 2 < T_{out}	HVAC; windows closed; windows may be opened, but will automatically close after 5 min. if T_{in} > cooling set point.
E	26°C + dry < T_{out}	HVAC; windows closed; windows may be opened, but will automatically close after 5 min. if T_{in} > cooling set point.

TABLE 2

ADMISSIBLE OUTDOOR AIR TEMPERATURES AND RELATIVE HUMIDITY FOR SUMMER VENTILATION

DBT	RH	DPT	HUMIDEX
26°C	60%	18°C	32
25°C	65%	18°C	31
24°C	70%	18°C	30
23°C	75%	18°C	29
22°C	80%	18°C	28
21°C	85%	18°C	27
20°C	88%	18°C	26

Natural ventilation simulation using multizone airflow models (AIOLOS, COMIS, etc.)

The procedure requires simulating natural ventilation of each building zone during each period, with inlet and outlet positions corresponding to previously defined hybrid ventilation strategies B and C only. Minimal natural background ventilation will be favoured for strategy B, while for strategy C, inlet and outlet areas should be sized for optimal airflow. The average airflow volume (AAV) produced by natural ventilation for each zone and period should be calculated and then divided by the required airflow volume (RAV) for IAQ. The resulting fraction indicates the natural ventilation efficiency ratio (NVER) as indicated by Eqn. 1. For any given period, if natural ventilation produces on average more ventilation than is required, a NVER of 1 should be indicated.

$$\text{NVER (dimensionless)} = \text{AAV (m}^3\text{/h)/ RAV (m}^3\text{/h)} \quad (1)$$

Thermal comfort simulation using thermal models (TRNSYS, PLEIADES, etc.)

The simulation of the thermal behaviour of each zone for each simulation period is necessary in order to assess if thermal discomfort is encountered when natural ventilation is used. The thermal model should use actual airflow rates calculated by the multizone airflow model. However, airflow rates should never be less than the predetermined values for IAQ purposes. The number of hours during which the system is free-running (FRH), e.g. when air-conditioning is not required, divided by the total number of hours of the simulation period (SPH) should be designated as the passive air-conditioning efficiency ratio (PAER), (Eqn 2).

$$\text{PAER (dimensionless)} = \text{FRH (h)/ SPH (h)} \quad (2)$$

HVAC simulations using energy/ thermal (EE4, DOE-2, etc.)

In order to assess the energy conservation potential of hybrid ventilation, the global energy consumption of the building (GECB) must first be determined when total air-conditioning is used, along with conventional set point temperatures (21°C - 26°C). The simulation must be repeated, but this time with exaggerated set point temperatures (15°C - 30°C). The difference between the two values corresponds to the energy consumption of the mechanical air-conditioning (ECMA), as indicated by Eqn. 3. This should be done for each week.

$$ECMA\ (kWh) = GECB_{21\text{-}26}\ (kWh) - GECB_{15\text{-}30}\ (kWh) \qquad (3)$$

The ECMA for each zone and period may be reasonably estimated by multiplying the weekly ECMA for the whole building by the ratio of the required airflow volume (RAV) in each zone, used in Eqn. 1, over the total building airflow volume (BAV) (see Eqn 4). The partial energy consumption for mechanical ventilation (PECMV) in each zone is also required. It is possible to estimate the energy consumption of all fans to ensure sufficient pressure head for the whole building, as a function of mean ventilation rates and pressure losses. The weekly PECMV for each zone may also be reasonably approximated by multiplying the mean weekly energy consumption of all fans (MECF) in the building by the ratio of the required airflow volume (RAV) in each zone, used in Eqn. 1, over the total building airflow volume (BAV) (see Eqn 5).

$$ECMA\ (kWh) = \text{total } ECMA\ (kWh) \times RAV\ (m^3/h) / BAV\ (m^3/h) \qquad (4)$$
$$PECMV\ (kWh) = MECF\ (kWh) \times RAV\ (m^3/h) / BAV\ (m^3/h) \qquad (5)$$

The minimum weekly building energy consumption (MBEC) is calculated by subtracting the total ECMA and total PECMV from the $GEBC_{21\text{-}26}$.

Calculation of natural ventilation acceptability

The procedure requires that the NVER and PAER values for each simulation period be time-weighed, and given a single value for each week, as shown in Eqns 6 and 7.

$${}_{tww}NVER = ((NVER_{occupancy})10 + (NVER_{non\text{-}occupancy})14)/24 \qquad (6)$$

$${}_{tww}PAER = ((PAER_{occupancy})10 + (PAER_{non\text{-}occupancy})14)/24 \qquad (7)$$

The procedure determines that natural ventilation is considered acceptable for IAQ and thermal comfort, if both the ${}_{tww}NVER$ and ${}_{tww}PAER$ are greater than 0,5 or 50%. The procedure determines that natural ventilation is acceptable for thermal comfort purposes, but not for IAQ if only the ${}_{tww}PAER$ is greater than 0,5 or 50%. Natural ventilation is considered unacceptable if the ${}_{tww}PAER$ is less than 0,5 or 50%, whatever the value of the ${}_{tww}NVER$. During these periods, complete HVAC is used.

Calculation of energy conservation

For each week, the total energy consumption of the building (TECB) is calculated by adding the PECMV and ECMA for zones which fall into cases 1 and 2 to the MBEC (Eqn. 8, Table 3).

$$TECB\ (kWh) = MBEC + (PECMV \text{ of zones in } 1) + (PECMV + ECMA \text{ of zones in } 2) \qquad (8)$$

TABLE 3
CRITERIA FOR SELECTING ZONE CLASSIFICATION

CASE	CRITERIA	ACTION
1	if in zone, $_{tww}$NVER < 0.5, and $_{tww}$PAER > 0.5	Account for PECMV
2	if in zone, $_{tww}$NVER > 0.5, and $_{tww}$PAER < 0.5	Account for PECMV + ECMA

For zones with corresponding strategies A, D or E, TECB is the sum of MBEC, zone PECMV and zone ECMA. The procedure is not able to account for occasional hot, humid periods (see Table 2), or periods when outside temperature exceeds 26°C (see Fig. 1), since it is based on weekly averages. If such phenomenon occur during periods when natural ventilation has been previously determined to be applicable, it is suggested to calculate the additional energy to cool the building, as in Eqn. 3, but only during the period when conditions are worse than those in Table 2 or 26°C. The calculated ECMA will be added to the energy consumption of the corresponding week. Adding the TECB of every week will give an indication of the year-round energy consumption of a building using hybrid ventilation, and the difference between the total TECB and the $GEBC_{21\text{-}26}$ gives an approximation of the total energy savings, due to the implementation of hybrid ventilation.

CONCLUSION

Hybrid ventilation may be an acceptable compromise to the exclusive use of either natural or mechanical ventilation for Canadian non-domestic buildings. Guidelines to the implementation of hybrid ventilation have been given, as well as a procedure for assessing IAQ, comfort and energy conservation. The proposed procedure may lack the precision of direct airflow/ thermal coupling (Dorer and Weber, 1999), but it does offer several definite advantages. It is less costly and it easily integrates results from familiar models which require less expertise to manipulate. Engineers may feel comfortable using conventional energy simulation models, while other consultants may be more at ease with multizone airflow modelling; an integrated process which reduces additional consulting fees.

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