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SIMPLIFIED MODEL AND SENSITIVITY ANALYSIS FOR NATURAL VENTILATION LOAD IN MULTIFAMILY BUILDINGS

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ABSTRACT

A simplified natural ventilation model for dwellings is developed and used to determine the impact of different ventilation strategies on the building loads and zones temperatures. It deals with the sensitivity of loads and temperatures to classical default parameters as : wind velocity, wind coefficient value, building environment and shielding conditions, and the actual cross section of the openings. All the simulations are performed using the TRNSYS 14.2 simulation software, TYPE56. The results based upon the studied case show that the average cooling load over a reference hot "wave" can reach values up to 15-20 W /m² if using an adequate ventilation strategy (night free-cooling), and maximal room temperatures can be damped to about 30° C (4..5 K lower than maximal outdoor temperature).

KEYWORDS

Ventilation, cooling, pressure, wind, schedule, dwellings, windows, occupants.

INTRODUCTION

As most of the common dwellings are using natural ventilation, an insight on its influence on building load and ambient temperature evolution is regarded as helpful for a better estimation of the actual energy requirements. The simulations are performed using the software TRNSYS Type 56, version 14.2. The ventilation model is integrated in the simulation deck so mass flow and heat flow are calculated in correlation. The example studied presents the case of a multifamily building where the air change rate is due only to user dependent ventilation (by windows opening). The cooling demand and ambient temperature, the investigation being performed in correlation with environmental conditions, internal gains and occupancy schedules.

BUILDING CHARACTERISTICS AND GENERAL ASSUMPTIONS

The example of building studied consists in a classical 5-floor apartment building. General information on building characteristics are given in Table 1. The building overall insulation level ("K" coefficient) is calculated according to Belgian standards. The total living area mentioned, corresponds to the horizontal surface of all the building zones.

TABLE 1
Building Data

Characteristic	Value
Insulation Level	K 61
Internal Volume	2530 m^3
Envelope Surface	1187 m^2
Glazed Surface	121 m^2
Total Living Area	768 m^2
Thermal Zones Defined	13

The building is divided in 13 thermal zones: 10 apartments (2/floor), 2 cellars, 1 staircase (as single zone). No heating or cooling power is supposed to be supplied to the zones, and no internal temperature schedule is imposed, so the air temperature is supposed to be free floating. Humidity gains are not taken into account. The weather data used correspond to a reference 25-day hot-dry "wave" for Brussels. The weather inputs are: outdoor temperature, wind velocity, total and direct normal solar radiation on horizontal surface. The wind direction is not available,but considered as normal on the front facade of the building for all the simulations.

SPECIFIC ASSUMPTIONS AND VENTILATION MODEL

Ventilation and infiltration air change rates are calculated separately. The infiltration flow rate is considered as the air flow through the doors and windows cracks. It is continuous and user independent. The ventilation air flow rate is considered as the natural air change due only to windows opening. It is exclusively user dependent.
The following hypothesis are used for the ventilation model : free air circulation inside each zone, no air flow rate between zones, perfect air mixing and no thermal stratification inside the zones, wind velocity calculated in function of the zones height, zone air density and outdoor air density are calculated at each time step in function of the corresponding air temperatures .
The infiltration air change rate is calculated using the following relationship :

$$N_v = \frac{l\,a\left(\frac{\Delta p_w}{1}\right)^{0.66}}{V} \quad (h^{-1}) \qquad (1)$$

where: V - zone air volume (m^3), l - total zone cracks length towards outdoor environment (m), a - crack mean air permeability ($m^3h^{-1}m^{-1}Pa^{-0.66}$)with a default value of a = 0.3 for both doors and windows , ($\Delta p_w/1$) - wind pressure on surface reported to a unitary pressure of 1 Pa.

$$\Delta p_w = c_w\,\rho_{ex}\frac{\dot{u}^2}{2} \quad (Pa) \qquad (2)$$

with: c_w - wind pressure coefficient.
In a first assumption the building is supposed as located in urban environment with the height of the surrounding obstructions equivalent to its own height: (as medium-rise buildings).
The average value of the wind coefficient for these conditions is of 0.2 and is considered constant with the zones height. Wind velocity is calculated as follows:

$$\dot{u} = \dot{u}_r K Z^a \qquad (3)$$

with: u_r - reference wind velocity in open field at 10m height (weather data), Z - windows mean height for each zone (m), K, a - coefficients according to ground roughness .. stimated function of the building environment. Previous research in air (L. Vandaele and P. Wouters - 1994) is providing three different types of roughness as shown in Table 2:

TABLE 2

Ground roughness for different environment

Environment	K	a
City	0.21	0.33
Urban	0.35	0.25
Scattered obstacles	0.52	0.2

The total air change rate for one zone is given by the equation :

$$N_v = \frac{C_D C_E}{V}\left(\sum A_{thri}\Delta p_{thri}^{0.66} + A_w \Delta p_w^{0.66}\right) \quad (h^{-1}) \qquad (4)$$

where : C_D - is the discharge coefficient (default value 0.6), C_E - is the effective window opening ratio (default value 0.5), $\Delta p_{thr\,I}$ - is the mean value of the thermal pressure across the opening "i" (Pa).

$$\Delta p_{thri} = \frac{1}{2}(\rho_{ex} - \rho_z)\Delta h_i g \quad (Pa) \qquad (5)$$

where : Δhi - "stack" height (Hui/2 in Figure 1) (m); "Hui" is the useful height of the opening (m), ρ_z - air density corresponding to the zone temperature (kg m^{-1}),A_{thr} - total cross area of the flow rate due to thermal effect (m^2)(practically it represents 50% of the total window opening area,A_w - zone total windows area corresponding to the N facade (m^2).

As there is no zoning for the staircase, it is assumed that 50% of the cross section is used as inlet (all the windows being on the North facade), the other 50% being used as outlet. The error produced using this simplification is however reduced as there is no air flow coupling between zones. It appears that in this second model the air change rate and zone temperatures are correlated.

SIMULATIONS PERFORMED AND RESULTS ANALYSIS

The results are presented in figure 2. The temperatures plotted correspond to the staircase, cellar and two apartments corresponding to the first floor (AA) and fifth (highest) floor (EA). The outdoor temperature is also plotted. The Figure 3 presents the same simulation but using a default air exchange rate of 0.5 vol/h, which is supposed to cover only the hygienic requirements. It appears that ventilation model approach produce important changes in building thermal response. An unacceptable overheating in the occupancy zones occurs if using the assumptions of Figure 3, while the model assumption provide an efficient natural cooling as the maximum zone temperature does not exceed the maximum outdoor value. It also appears that differences between zones (apartment) temperatures are still insignificant which means the height of the zone is not very important when simulating city environment and medium rise buildings.

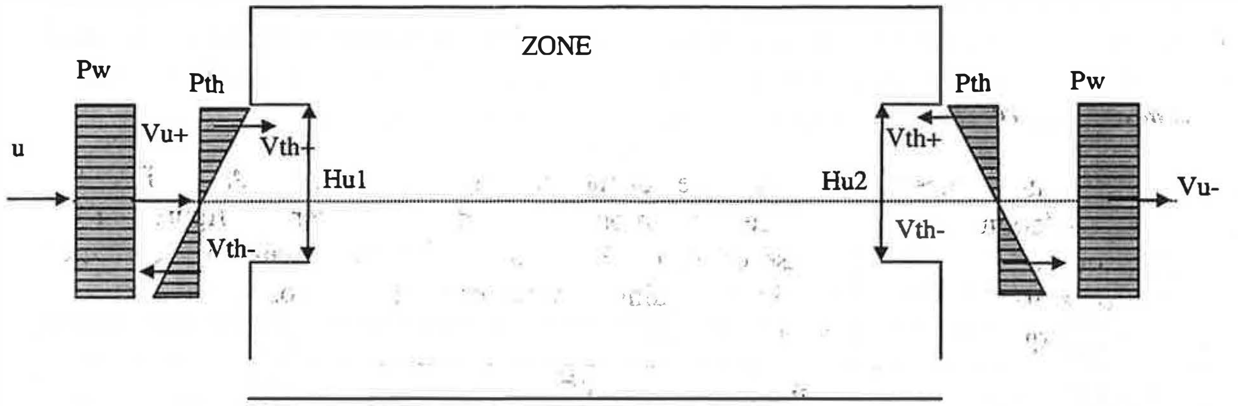

Figure 1: Schematic of the second model of zone natural ventilation

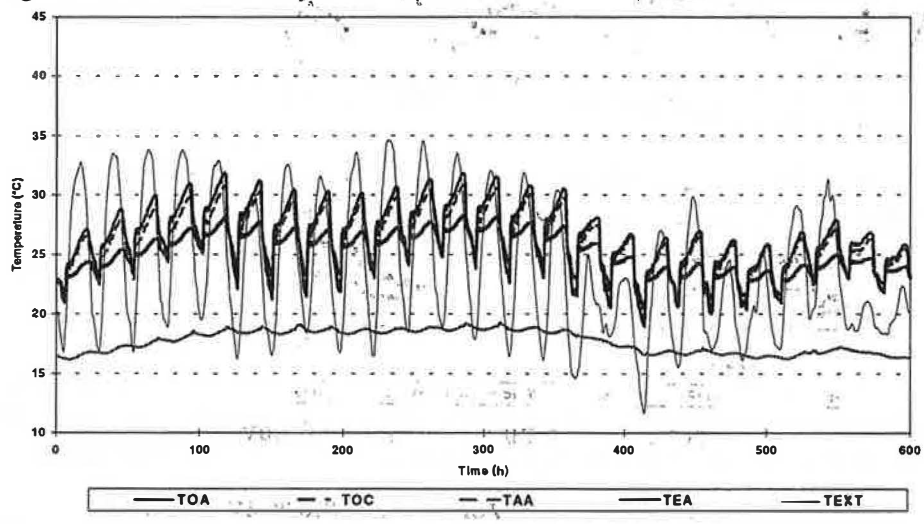

Figure 2. Evolution of zone temperatures when using the ventilation model

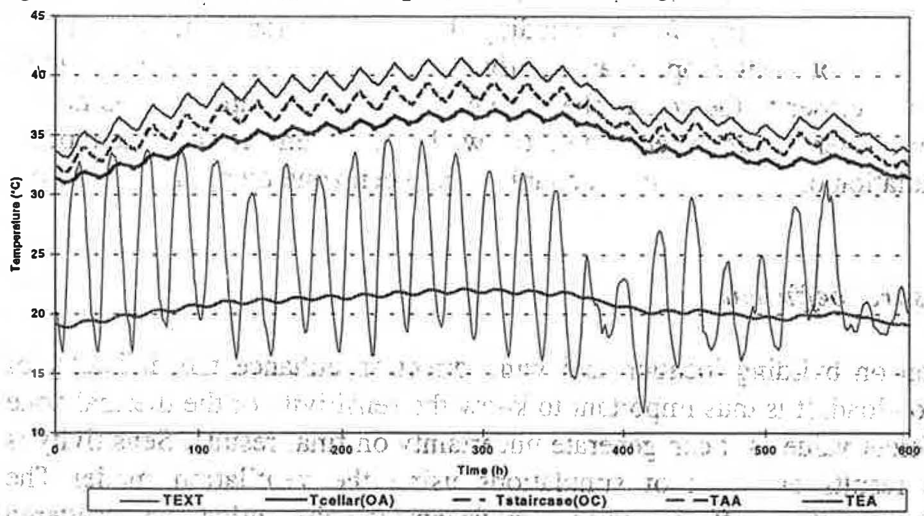

Figure 3. Evolution of zone temperatures for a default value for air exchange rate.

SENSITIVITY ANALYSIS

The thermal pressure

The results presented concern again two zones of the building (apartments) AA and EA (1st and 5th floor). A"zoom" on temperatures evolution over 4 days is given in figure 4. The maximum zone temperature increase of about 3 K and exceeds at certain moments the outdoor temperature. The wind velocity according to weather data and those calculated for each zone using eqn. (3) are also plotted.

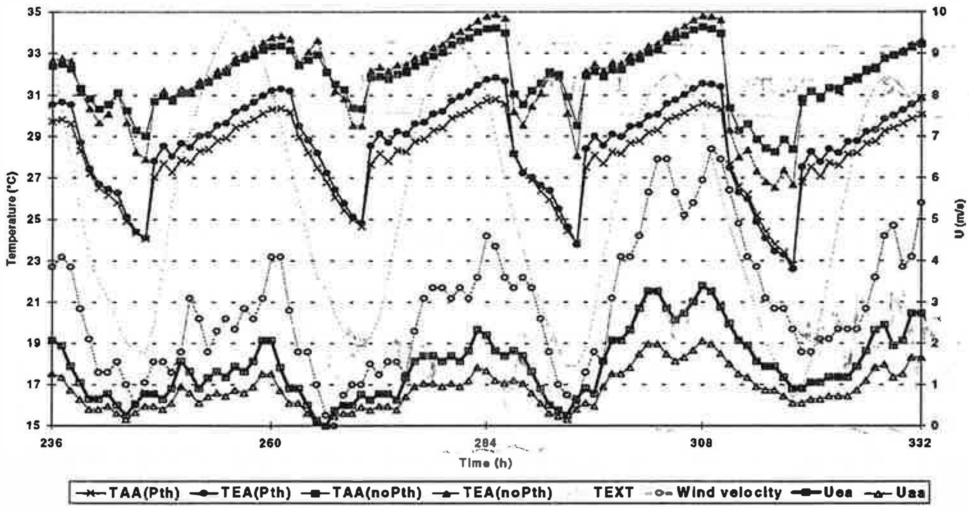

Figure 4. Thermal pressure influence on zone temperature - zoom on a 4-day period

If the thermal pressure is not taken into account, the zone temperature evolution after the windows opening is submitted solely to wind effect. This produces zone temperature fluctuations as wind velocity is varying. When including the heat transfer in the model, the zone temperature has a monotonous slope mainly influenced by the outdoor temperature decrease. It is an evolution closer to the actual phenomena as the zone temperature is not an air temperature but an equivalent value depending on the wall surface temperatures. It appears that for an accurate simulation of night-cooling, a coupling between zone thermal and air flow models is compulsory.

Influence of wind pressure coefficient

The lack of information on building location and wind direction enhance the difficulty of estimating the ventilation load. It is thus important to know the sensitivity of the thermal zone to wind pressure coefficient value as it can generate uncertainty on final results. Sensitivity is evaluated through the results on a set of simulations using the ventilation model The simulations are performed for three different types of environment : city , urban, and scattered obstacles. The environment is simulated by adjusting the coefficients in Table 1 for wind velocity calculation. The results obtained for maximal zone temperature and average ventilation load per square meter are plotted in figure 5 for the zone EA mentioned previously.

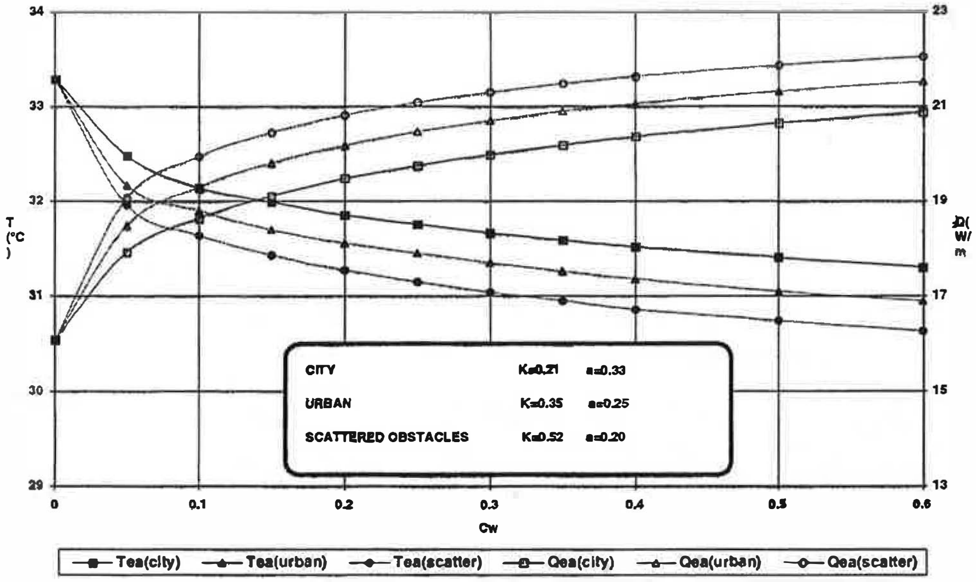

Figure5. Zone maximal temperature and average ventilation load.- zone EA

CONCLUSION AND RECOMANDATION

Natural ventilation can be used as an efficient cooling potential in typical apartment medium-rise dwellings. The results show that the average cooling load can reach values up to 15-20 WW/m² if using an adequate ventilation strategy. Maximal zone temperatures reached are damped to about 30 °C which is 4..5 K lower than maximal outdoor temperature, while if using a default ventilation rate, non scheduled, and covering only the hygienic air requirements, the zones temperatures reach about 40°C. The thermal pressure is capital as it is the driving force of the phenomena. If neglecting it, the ventilation efficiency is reduced at about 40% of the maximal potential. The environment and climate must correspond exactly to buildings location as they influence both wind and thermal pressure.

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