ASSESSMENT OF NATURAL VENTILATION POTENTIAL OF A REGION USING DEGREE-HOURS ESTIMATED ON GLOBAL WEATHER DATA

C. Ghiaus and. F. Allard

Laboratoire d'Étude des Phénomènes de Transfert Appliqués au Bâtiment, Université de La Rochelle
Av. M. Crépeau, 17000 La Rochelle Cedex, France

ABSTRACT

The applicability of natural ventilation depends strongly on climate. The potential of natural ventilation represents a measure of the feasibility of natural ventilation in a specific climate. A quantitative measure of this potential, expressed in degree-hours, may be estimated based on adaptive thermal comfort and monthly mean temperature. Degree-hours for natural ventilation represent the sum of the degree-hours for cooling saved by using natural ventilation when adaptive thermal comfort is considered. Degree-hours are estimated from monthly-average temperatures and standard deviations supplied by Global Resource Information Database (GRID), Geneva centre. This method is applicable at the scale of a region and gives a measure of climate suitability. Local specificity of o site or of a building may be taken into account.

KEYWORDS

Natural ventilation, building simulation, renewable energy

INTRODUCTION

The applicability of natural ventilation depends on climate. The suitability of a specific climate to the use of natural ventilation may be related to the energy consumption saved by using ventilation instead of mechanical cooling and to the existence of the driving forces for natural ventilation: wind and buoyancy. At a given instant, the energy consumption is proportional to the difference between the indoor temperature of the free-running building and the closest limit of comfort zone. Therefore, the application of natural ventilation will depend on three factors: thermal characteristics of the building, comfort criteria and climate. The first factor is synthesised by the indoor temperature of the free running building, which is shifted from the value of the outdoor temperature with a difference that depends on heat loss, ventilation rate, solar and internal gains, and occupancy. This difference may be calculated as a function of outdoor temperature and period of the day. The second factor, the comfort, presents larger ranges in buildings that use natural ventilation as compared with those that have air-conditioning systems installed. Finally, the climate is characterised by the frequency distribution of the outdoor temperature. If outdoor temperature frequency distribution is considered for different time periods of the day, the annual energy consumption can be estimated by using steady-state calculations. Hence, climate suitability for natural ventilation may be defined as a function of the indoor temperature of the free-running building, adaptive thermal comfort and probabilistic distribution of outdoor temperature at different periods of the day. If global and satellite climatic data are used, the climate suitability may be estimated at the scale of a region.

METHOD

Climate suitability of natural ventilation is a measure of energy saved for cooling when ventilation is used, and of the presence of driving forces for natural ventilation: buoyancy and wind. The method presented in this paper considers these aspects, apart from the wind.

First, the frequency distribution of outdoor air temperature and adaptive comfort are discussed. Then, the frequency distribution of degree-hours is derived for ventilation. Finally, the estimation of applicability of buoyancy is presented.

Frequency and probability distribution

The probability density is the limit of relative density when the number of values of the variable is infinity:

$$\Pr = \lim_{N\to\infty}\left(\frac{f}{N}\right).$$

For a discrete distribution having bins of T_{bin}, the probability of the temperature being between $T\text{-}T_{bin}/2$ and $T\text{+}T_{bin}/2$, $T \in \{T_{\min}, T_{\min}+T_{bin}, T_{\min}+2T_{bin}, \ldots\}$ is:

$$\Pr\left(T, T \in [T - T_{bin}/2, T + T_{bin}/2]\right) = T_{bin} \cdot P_{df}(T)$$

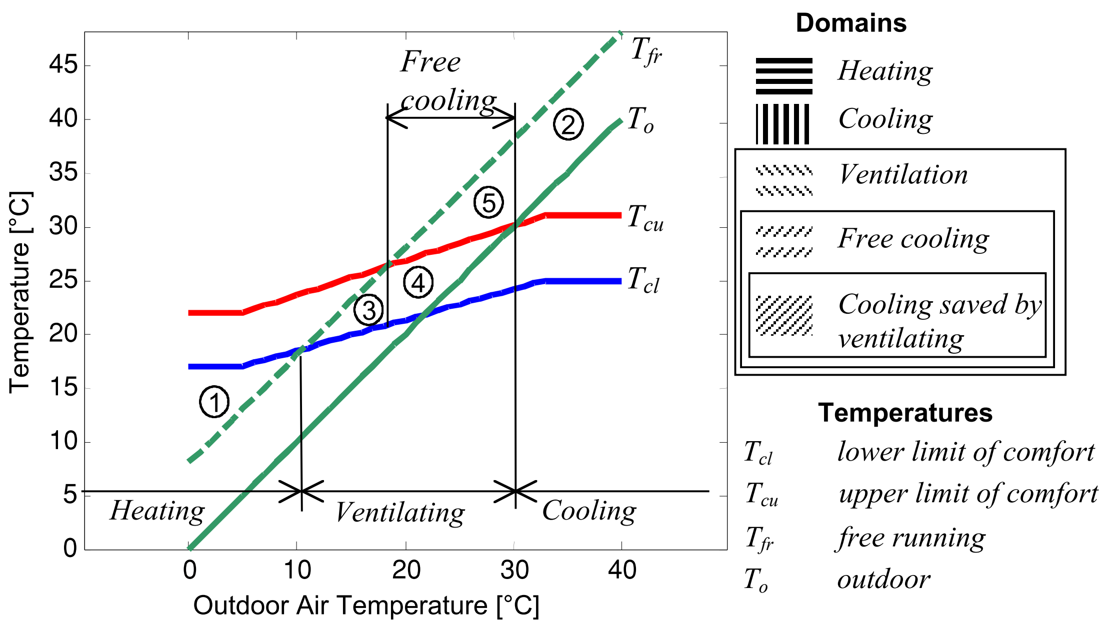

Fig. 1 Heating, ventilating and cooling domains.

The probable frequency of variable T of being in the bin $\left[T - T_{bin}/2, T + T_{bin}/2\right]$ is:

$$f(T) = N \cdot T_{bin} \cdot P_{df}(T).$$

Indoor temperature of a free-running building

A free-running building does not make any use of mechanical heating or cooling. Its indoor temperature, T_{fr}, depends on the outdoor temperature and the total heat gains (from sun, occupants, lights and so forth). It may be considered that, for a given month of the year, the indoor temperature of the free-running building depends on the hour of the day and the outdoor temperature.

Adaptive comfort

It is argued that in naturally ventilated buildings thermal comfort has larger seasonal differences in occupant requirements than assumed by ISO 7730 and ASHRAE 55 Standards (Fountain 1996; Brager 1998; de Dear 1999; Nicol 2001). Although the values are controversial, the thermal comfort exhibit a zone delimited by a lower, T_{cl}, and an upper comfort limit, T_{cl}; these limits vary with the outdoor temperature (Fig. 1).

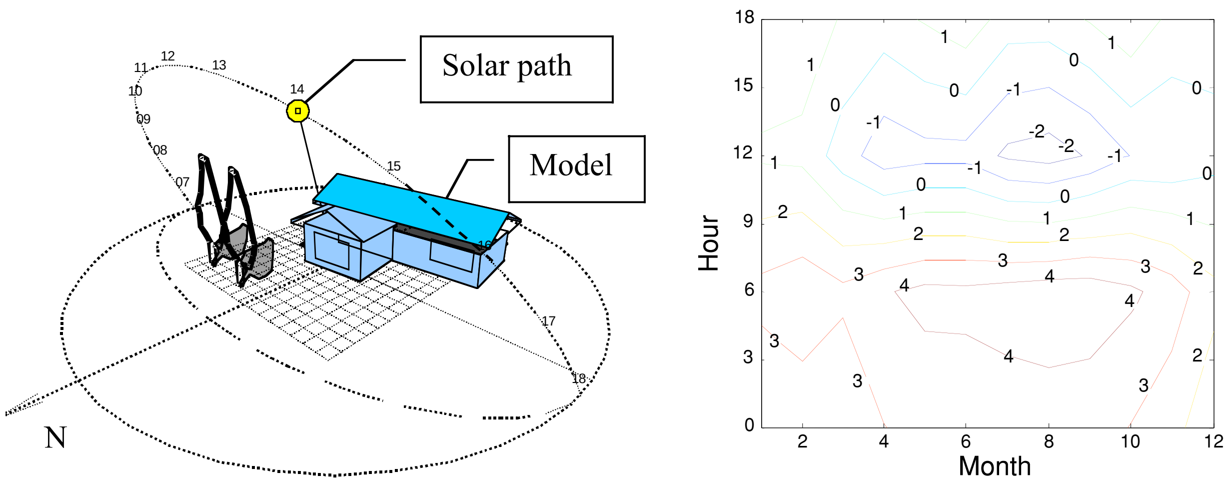

Fig. 2 a) Model of building obtained by using ECOTECT software. b) Temperature difference between inside and outside temperature obtained for the model using weather data for Athens.

Frequency distribution of degree-time for ventilating

Using the indoor temperature of the free running building, the outdoor temperature and the comfort zone, we can define the domains for heating, ventilating and cooling (Fig. 1). Similarly to the bin method used for building energy analysis (ASHRAE 2001, pp. 28.3-28.8), a measure of climate suitability may be obtained using probability distribution of outdoor temperature and the domains defined in Fig. 1. The variation of T_{fr} as a function of T_o may be defined for a time interval of the day, typically 1 or 3 hours. Then, the product between a temperature difference (defined for heating, ventilation or cooling) and the probable frequency of this difference, $N \cdot T_{bin} \cdot P_{df}(T_o)$, gives a probability distribution. Its unit of measure is degree-time, where time has the value of the time interval (typically 1 or 3 hours).

Ventilation may be used in between heating and cooling. Referring to Fig. 1, in the zones 3, 4 and 5, the temperature may be varied from T_{fr} to $\mathbf{max}(T_o, T_{cl})$ by using ventilation. The zones 4 and 5 correspond to passive cooling (when $T_{fr}>T_{cu}$). If the building were maintained tight, then mechanical cooling would be needed. But, by using ventilation, the indoor temperature may be decreased by increasing the airflow, approaching the outdoor air temperature if the air exchange becomes very large. By controlling the airflow rate, the indoor temperature may be varied in the interval defined by the temperature for free-running building (that corresponds to the situation when the building is tight) and the outdoor temperature.

The zone 5 is related to the energy saved for cooling by using ventilation. The frequency distribution of degree-time of passive cooling that saves mechanical cooling is:

$$f_{pc}(t,T_o) = N \cdot T_{bin} \cdot P_{df}(T_o) \cdot (T_{fr} - T_{cu}) \cdot \delta_{pc}\text{, where } \delta_{pc} = \begin{cases} 1, \text{ when } T_{fr} > T_{cu} \text{ and } T_o \le T_{cu} \\ 0, \text{ otherwise} \end{cases}$$

Stack effect

Natural ventilation is driven by wind pressure and buoyancy. Stack pressure difference between two vertical openings separated by a vertical distance h is:

$$\Delta p_s = \rho_i g h (T_i - T_o)/T_o$$

where:

Δp_s pressure difference due to stack effect, Pa;	ρ air density, kg/m^3
g gravitational constant, 9.81m/s^2;	h vertical distance, m
T average absolute temperature, K;	subscripts: i inside; o outside.

The stack effect is proportional with $(T_{cu} - T_o)/T_o$. For the temperature range in which ventilation is applied, the stack effect is proportional to $T_{cu} - T_o$, with an error less then 5%. The frequency distribution of $(T_{cu} - T_o)/T_o$ or $T_{cu} - T_o$ gives a measure of the applicability of stack effect:

$$f_{se}(t,T_o) = N \cdot T_{bin} \cdot P_{df}(T_o) \cdot (T_{cu} - T_o)/T_o \cdot \delta_{pc} \text{ or } f_{se}(t,T_o) = N \cdot T_{bin} \cdot P_{df}(T_o) \cdot (T_{cu} - T_o) \cdot \delta_{pc} \cdot$$

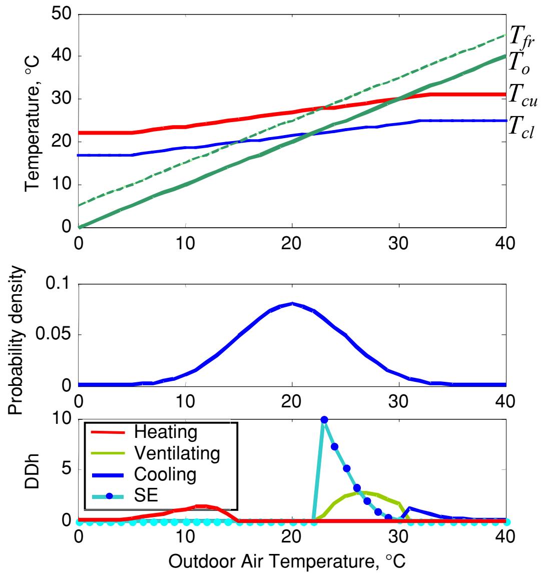

Fig. 3 Climate suitability: a) comfort zone and free running temperature; b) probability density distribution of outdoor air temperature; c) probability distribution of degree-time.

INTERPRETATION OF RESULTS

The three panels of Fig. 3 represent: a) the thermal behaviour of the building superposed on the comfort zone, b) the probability density distribution of outdoor temperature, specific to the local climate, and c) the frequency distribution of degree-time that characterises the climate suitability. A climate is suitable if the energy saved for cooling is important and if the driving force of buoyancy is available. The climate is more appropriate for the application of natural ventilation driven by buoyancy if the distribution of the degree-time for stack effect covers a larger area of the distribution of degree-time for ventilation.

APPLICATION OF THE METHOD BY USING GLOBAL WEATHER DATA

The method presented above allows us to assess the potential buoyancy driven natural ventilation when we know thermal characteristics of the building (the indoor temperature of the free-running building), the comfort zone, and weather data (the probability density function of outdoor temperature). The indoor temperature in free-running can be calculated for new buildings or easily measured for existing ones. The comfort zone is a design requirement. The weather data may be obtained from weather stations. As an alternative, average monthly temperature may be obtained from the Global Resource Information Database (GRID) centre from Geneva, a member of the United Nations Environment Programme (UNEP) global network of environmental information centres. The data used in the implementation of this method is the IIASA Climate Database that was created at the International Institute for Applied System Analyses (IIASA) Laxenburg, Austria (Leemans and Cramer, 1991). The weather records for at least five years during the period between 1930 and 1960 from up to eight different sources were standardised, ranked in quality, selected, interpolated and smoothed to fit a one-half degree latitude/longitude terrestrial grid surface (there are no values for non-land areas). The IIASA Climate Database is considered appropriate for use at least at regional scales, despite certain data gaps and inconsistencies.

Mean and standard deviation of temperature for every month at 3 hours intervals may be obtained from the database of the International Satellite Land Surface Climatology Project (ISLSCP) Initiative. The original data set was represented on a 320 x 160 grid, with a regular spacing of 1.125 degrees (lat./long.) between points along each row for the period January 1, 1987 - December 31, 1988. The global atmospheric data are assimilated data resulting from the combination of atmospheric observations and model calculations. No surface observations are used, so that the surface data comes from the model simulations of surface processes, strongly constrained by observed atmospheric information and "a priori" surface climatological information.

CONCLUSIONS

Climate suitability to natural ventilation depends on energy saved for cooling and the presence of driving forces. It may be assessed by estimating the frequency distribution of temperature difference. The energy saved is related to the distribution of the difference between the indoor temperature of the free running building and the upper limit of comfort zone. The buoyancy effect is related to the difference between the indoor and outdoor temperature. If we admit that a building has the same thermal characteristics in two different sites, the frequency distribution of the above mentioned temperature differences gives us a measure of the climatic suitability.

ACKNOWLEDGEMENTS
This work was supported by the European Regional Development Fund (ERDF/FEDER) and by the European Commission in the 5th Framework Programme on research and technological development.

REFERENCES

1. ASHRAE (1993), *Fundamentals Handbook*
2. ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy*
3. ISO (1994), *International Standard 7730: Moderate Thermal Environments - Determination of the PMV and PPD Indices and Specification of the Conditions of Thermal Comfort*, ISO, Geneva
4. Brager, G., R. de Dear (1998). Thermal adaptation in the built environment: a literature review. *Energy and Buildings* **27**: 83-96.
5. de Dear, R. (1999). Adaptive thermal comfort in natural and hybrid ventilation. Sydney, Australia, *International Energy Agency, Annex 35 Energy conservation in buildings and community systems*.
6. Fountain, M., G. Brager, R. deDear (1996). “Expectations of indoor climate control.” *Energy and Buildings* **24**: 179-182.
7. Leemans, R., W. P. Cramer (1991). *The IIASA Database for Mean Monthly Values of Temperature, Preicipitation and Cloudiness of a Global Terrestrial Grid*. IIASA, Laxenburg, Austria, RR-91-18, 62 pages.
8. Nicol, F. J. (2001). *Characterizing occupant behaviour in buildings: towards a stochastic model occupant use of windows, lights, blinds, heaters and fans*. Seventh International IBPSA Conference, Rio de Janeiro, Brazil.