# RULES FOR COOLING THROUGH MOTORIZED VENT WINDOWS

**A. H. C. van Paassen and P.J.M. van Galen**
Faculty of Mechanical Engineering and Marine Technology
Delft University of Technology
Laboratory of Refrigeration Engineering and Indoor Climate Technology, The Netherlands

## INTRODUCTION

Over 90% of all building complaints arise from user comfort as it relates to the operation of the Heating Ventilation and Air Conditioning systems. What are the reasons that people are complaining about the indoor climate in modern office buildings? And what are the reasons that some people said to be sick of the building? The root of all the troubles may be, that the designers did not listen to the users. Their designs are not in agreement with the climate people wished for.

In Japan an investigation was carried out how people use the varous possibilities to influence their environment, such as opening the window, switching on the air conditioning unit, use the sunshading and so on, /ref. 1/. They were being asked: "what is your first action when you feel hot?". In figure 1 the results of answers are given: 80% of the people said to open the window opening first, 15% put the shading down, and only 5% close the window and switch the airco on. A second question was posed: "When your first action did not help what are you doing next?". Then 80% is said to close the window and switch on the airco.

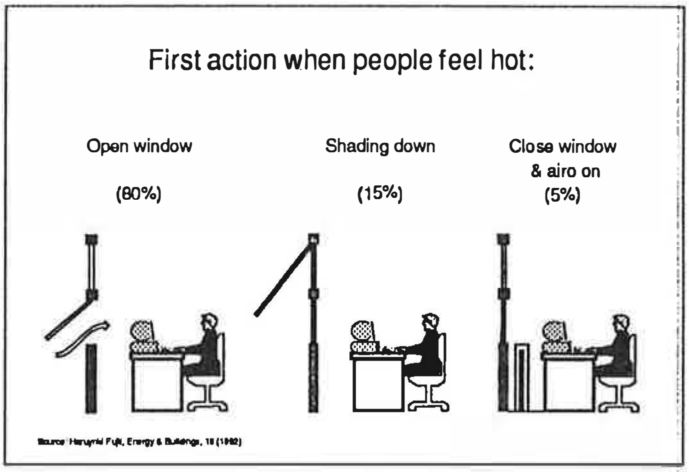


*Figure 1*

So, almost everyone switches the airco on when cooling by natural ventilation is no longer sufficient. This investigation shows clearly that we can not ignore the call for openable windows. With this in mind and the necessity to save energy we designed the socalled "Passive Climate System".

## PASSIVE CLIMATE SYSTEM

The following thoughts have been central to the design of a new system: the "Passive Climate System".

- The occupants must be able to influence everything, even if an intervention spoils energy. An inflamed employee, must be able to divert his frustrations by fully opening a window.
- In order to save energy, the natural sources, such as wind and sunlight have to be taken advantageous of before one switches over to air conditioning system. Wind can be used for ventilation and the sunlight fot lighting and heating.

On the basis of the last aspect the system was called "Passive Climate System", /ref. 2/.
The passive components are, see figure 2:

- The sunshading awning
- High and low placed windows, motorized and automatically controlled together with the active components.

Active components are:

- The radiator or air conditioning unit
- The lighting

Sensors are:

- Indoor air temperature
- Sensor detecting the presence of people.
- Weather station on top of the building, measuring windspeed, wind-direction, outdoor temperature and solar radiation.

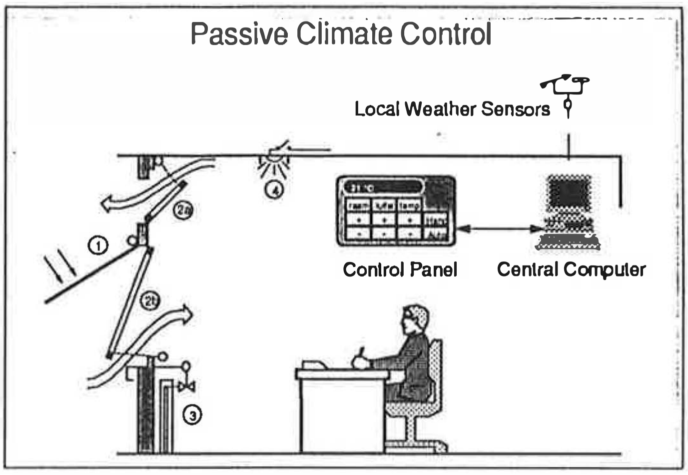


*Figure 2*
*1 Awning; 2 Vent window (a & b); 3 Radiator valve; 4 Lighting*

## CONTROL

In each room a controller controls these components in such a way that comfort is realized with the lowest energy consumption. When people are entering the room the presence-sensor set the controller from the stand-by energy saving mode of control into the comfort mode. This means that the setpoint for the temperature controller goes from a low to a comfort level and the window is put at minimum position for fresh air supply.

When people do not like the automatic control they can take over manually, so each inhabitant can realize his own climate. All the room controllers are connected through a network with a central computer. This central computer is used for optimizing calculations based on the measured weatherdata. An example of such a calculation is: defining the right moment for opening the windows during the night in order to cool down the building in a proper way.

This paper is mainly focussed on ventilation. It is confined to the following aspects: field test experiments, design rules for ventilation windows, comfort mode of control and night cooling.

## FIELD TEST

The Passive Climate System is installed in a part of a small office building. During two years it is monitored and judged to its performance and acceptance by the users. The system was installed in 8 rooms; 4 oriented North-South and 4 oriented South-West. One of SW-rooms was under automatic control, while the others were operated by the inhabitants by remote control. The building is well isolated and it's ability to accumulate heat is moderate (suspended ceiling, one partition wall of plaster board). The internal load was 25 $W/m^2$ (575W in total).

The fieldtest has demonstrated that automatic control could keep the temperatures within the comfort region. In the period July 1993 no temperatures were exeeding the comfort limit of 24 °C. This is not the case in the other room with manual control. There, it was too warm during a long period of time.

*Figure 3*
*Radex Building*

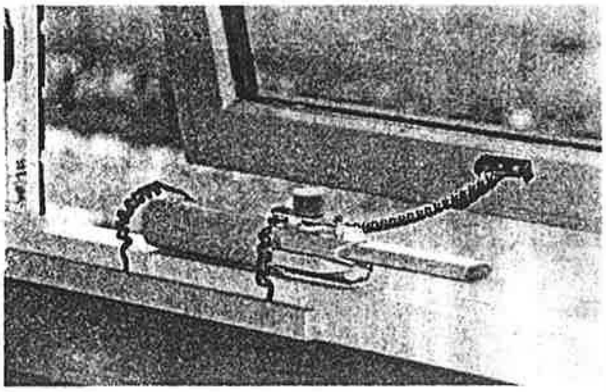

*Figure 4*
*Window motordrive*

The maximum temperature was 27.5 °C and 35% of office time the temperature was higer than 24 °C. During the extreme warm summer period at the end of July 1994, the differences in temperatures between manual and automatic controlled rooms were less dramatic.

High temperatures during the night result in little or no night cooling. Moreover, during the day people open doors and windows to improve the cooling effect by cross ventilation. These kind of actions overruled the effect of automatic control.

## WINDOW DESIGN

Ventilation through openable windows raises questions such as: what is the best position of the openable window; what dimensions are needed for cooling and how to control the openings?

## POSITION OPENABLE WINDOW(S)

In office-rooms heat sources like, human beings, computers and copy machines, cause a rising air flow due to the release of heat. One of the functions of the passive climate system is to remove superfluous heat by adjusting the window openings properly.

High and low placed windows are used to remove this heat. Due to the buoyancy effect the released heat will be transferred through the upper window and cooler outside air will enter through the lower window. Consequently, this system behaves like a displacement system, sothat the internal heat from persons and computers can be removed efficiently.

The process described above only occurs when there is no wind. At wind-speeds above 2 m/s wind driven flows became the dominant driving mechanism. Then the boyency effect is completely overruled by the turbulance character of the outside air. In that case outside air is moving in or out through both the upper and lower window opening and the resulting air flow in the room is less predictable.

During the fieldtest it was observed that inhabitants open doors and windows during extreme hot periodes. It did show cross ventilation is more effective than the single sided ventilation. This aspect is not discussed in this paper. To answers the questions about dimensionering and control a ventilation model is required.

## SINGLE SIDED VENTILATION MODEL

The ventilation rate was measured in the RADEX building at various window openings and weather using tracer gas techniques. Based on the measured data a model is developed. It relates the ventilation flow, with the angle under which the window is opened, the wind speed ,$v_{wind}$, and the winddirection (weather- and leeside).

The structure of the model is based on those earlier proposed in literature. /Ref. 3, 4 and 5/. A compact outline is given in figure 5. There are two types of ventilation flows.

Boyancy-driven flows. The temperature differences, $\Delta T$, between the building and the outside air can be used to drive ventilation flows using the" stack effect".

Wind driven flows. When doors are closed the turbulence of the wind causes air flows going in and out the room. The higher the wind speed, $v_{wind}$, the more dominant this effect will be. Also the wind direction showed to be important. The leeside rooms has a tendency to be underventilated when compared with the weather side. Therfore, the turbulence factor $C_T$ of the model of figure 5 is different for lee- and weatherside of the building. Open doors can cause higher ventilation rates because of cross ventilation flows from one side of the building to the other. This is not considered in this paper. Doors were supposed to be closed the entire period.

In figure 5 for both driving forces different equations are given.That equation should be selected that shows to be dominant at a specific moment. For weather condition with no wind the boyency effect dominates. But, as soon as the wind speed goes to 2 m/s the wind effect takes over.

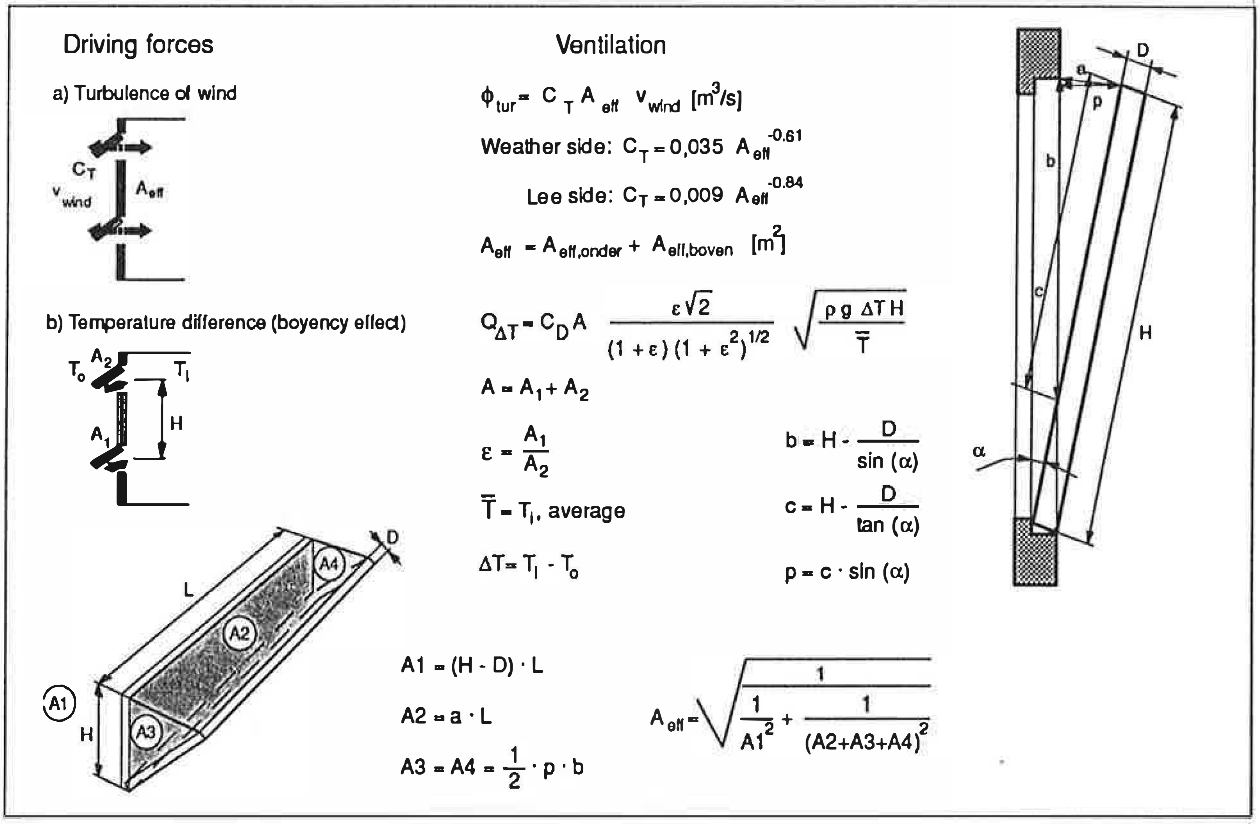


*Figure 5*
*Model for single sided ventilation.*

The model can be used for: calculating those dimensions of the openable window(s) that is needed to get rid of the surplus of the heat; calculating the minimum opening for fresh air supply; making a rough estimate of the ventilation flow during control (the angle is adjusted) and simulating natural ventilation in computer codes.

## DIMENSIONS OPENABLE WINDOWS

The maximum ventilation rate needed in a warm summer period can be calculated with a computer code simulating the thermal behaviour of a building during a reference year. For example, the requirement that 100 hours above 25.5 °C are allowed, leads to: $\Phi_{vent} = 230$ m³/h.

With the proper equation of the ventilation model the area of the window ($H \cdot L$) can be calculated. If a wind- speed of 2 m/s on the weather side of the building is chosen as a design condition the areas of the high and low placed windows are: $A_{high} = A_{low} = H \cdot L = 0.8\ m^2$. Thus, 1.6 $m^2$ of openable window area will give enough cooling in summer. A more simple equation is derived:

$$A_{low} + A_{high} = \frac{2 \cdot \Phi_{vent}}{v_a \cdot \sin(\alpha_{max})} \qquad (1)$$

with $v_a$ = 0.19 (avarage speed in opening) [m/s]
$\alpha_{max}$ = maximum angle with wich windows can be opened [°]

In a testcell twice as high ventilation rates were found. This cell is surrounded by higher building, oriented on south and having 4 openable windows symmetrical positioned in each corner, /Ref. 2/. In that case $v_a = 0.38$ did show a good fit. It proves that the ventilation rates depends strongly on the surrounding. So, ventilation models should be handled with this in mind.

## CONTROL OPENABLE WINDOWS

The task of the control is twofold: supply of fresh air and provide cooling when overheating is likely to happen. For each task control rules are derived.

## RULES FOR FRESH AIR SUPPLY

Wind is a problem to worry about. Especially in winter, when the minimum amount of fresh air has to be supplied. Only the upper window is used to avoid draupht in the heating season. It opens to the inside creating an opening just below the ceiling. This showes to be effective. The coanda effect helps the entering air to be mixed up with warmer room air, so the danger for draupht is reduced. Indeed, this is the case for the weather side of the building. But at the leeside it was noted that at low wind speed the impuls of entering air was too small and at low outside temperatures it falls in the living zone. A higher temperature of the radiator can compensate it. So, the temperature setpoint is set higher. Also fresh air was not enough, and the window must be opened further. This knowledge is translated in following rules.

- Put the window openings in a fixed position ($\alpha = 20\%$).
- For window openings at the weather-side of the building the positions are reduced according to:
  if the average wind-speed > 3 [m/s] then
  $$\alpha = \frac{20 \cdot 3}{v_{wind}} \quad [\%]$$
- At leeside the openings are increased at low wind speed:
  if the average wind speed < 2 [m/s] then
  $\alpha = 20 \cdot 2 - 10\, v_{wind}$ [%]
  increase temperature setpoint with 1K.

These rules are stored in the memory of the controller. According to these rules the positions of the window openings are adjusted. Instead of these rules the ventilation model of figure 5 could be used. However, rules are better understood and can be adjusted easier when the system is in operation.

## RULES FOR COOLING

Control strategy during the day with people inside the room. Window control regulates the amount of cooling necessary to meet the load in conditioned spaces. Minimum outside air needed for ventilation is provided whenever a space is occupied. When outside air temperature is a suitable source for free cooling, it is controlled as needed at values greater than minimum.

To avoid draft problems only the upper window is used at outdoor temperatures lower than 15 °C. In most cases the cooling capacity is then sufficient to get rid of the internal heat load from people and machines.

There are three cooling modes of control:

- Office time with people in the room.
- Cooling while no inhabitants inside.
- Cooling during the night for precooling (night cooling).

Strategy when room is occupied:

- During the day no feedback control of the window openings is applied. The field test in the Radex-building did show, that frequently adjusting the positions of the windows will not be accepted by the inhabitants.
- Feedforward control is then applied. This means that at proper moments, such as lunch time, the windows are put in those position that are most likely the best for the next period. These positions are based on rules, inwhich experimental results and general common sense knowledge are implemented. In figure 6 this is demonstrated. For example, at ten o'clock the indoortemperature is 22 °C, then the upper window is opened with 37%, while the lower window is kept closed. To avoid draught the openings will be decreased by multiplying it with a correction factor being dependent of the outside temperature.
- Manual take over by the inhabitants when these positions are not accepted.

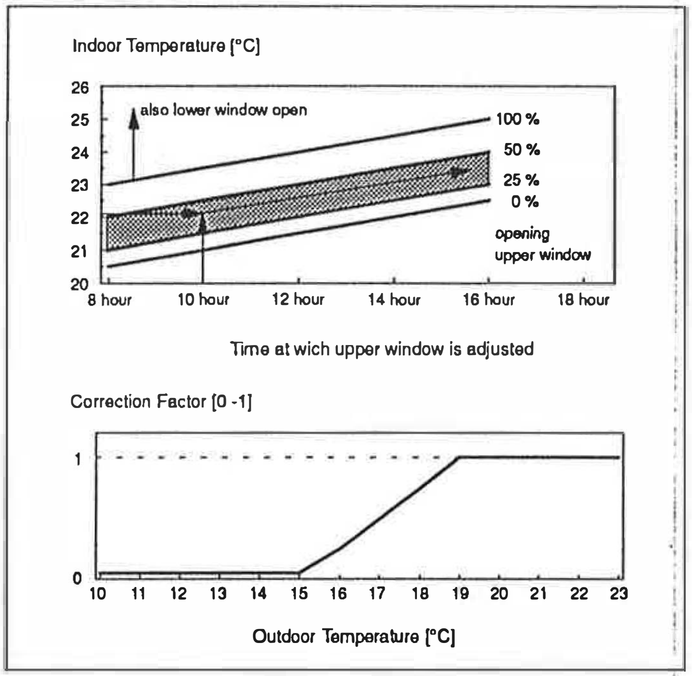


*Figure 6*

## COOLING WITH NO INHABITANTS INSIDE

A feedback algorithm is active then. It tries to keep the temperature at the cooling set point, $T_{spH}$ (normally 24 °C). There are no limits for the control because comfort is not relevant. The algorithm adapts itself for colder outside air by dividing the output of a PI-algorithm, $q_W$, with the temperature difference between the in- and outside air. This adapted signal for the window position, $X_W$, then warrents similar control behaviour over the entire year.

$$q_w(k) = q_w(k-1) + K_{p,w} \cdot \left((1+K_{i,w}) \cdot (T_{spH}(k) - T_i(k)) - (T_{spH}(k-1) - T_i(k-1))\right) \quad (2)$$

Met:

| | | | |
|---|---|---|---|
| $q_w(k)$ | = | output PI algorithm at moment $k$ | [%] |
| $q_w(k\text{-}1)$ | = | output PI algorithm at moment $k$-1 | [%] |
| $K_{p,w}$ | = | proportional gain | [%/K] |
| $K_{i,w}$ | = | integral gain | [-] |
| | = | $\frac{\{t(k) - t(k-1)\}}{\tau_i}$ with $\tau_i$ = integral time [s] | |
| $T_{spH}(k)$ | = | cooling setpoint during day | [°C] |
| $T_i(k)$ | = | indoor temperature at moment $k$ | [°C] |

$$X_w(k) = \frac{10}{T_O(k) - T_i(k)} \cdot q_w(k) \quad (3)$$

Met:

| | | | |
|---|---|---|---|
| $X_w(k)$ | = | window opening at moment $k$ | [%] |
| $T_O(k)$ | = | outdoor temperature at moment $k$ | [°C] |
| $T_i(k)$ | = | indoor temperature at moment $k$ | [°C] |

Stable control could be earned with: $K_{pr}$ = 10 [%/K] and $\tau_i$ =900 [s].

## NIGHTCOOLING

Predictive control is used during a warm summer. This could be done by a mathematical model that can be identified from the measured data. With this model and the weather predictions, it could be calculated at what time the windows will have to be opened at night in order to cool the building in such a way that it will not be too hot the next day, /Ref. 6/.

For the sake of simplicity, here the following rule based prediction is used. "If during the day the windows were open for cooling the maximum value for the night setpoint, $T_{spH\text{-}night}$, is decreased from 24 to 20 °C". If the next day the same cooling situation occures then $T_{spH\text{-}night}$ = 18 etc..

By this procedure the building is precooled and prepared to stand the high load. Ofcourse, windows are closed automatically at stormy weather conditions.

## CONCLUSIONS

The fieldtest proved automatic control of vent windows ensures a comfortable indoor climate during normal summers in moderate climate regions, provided the internal load is not higher then 25 W per $m^2$ floor area.The indoor tempertature in rooms with automatic control was typically 4K cooler then those with manual control.

During the extreme summer of 1994 the number of hours with too high indoor temperatures was much higher then normally is accepted as a design limit. However, because of night cooling the wall temperatures were far below the outside temperature during the warmest period of the day. This combined with the fairly high air speed in the living zone at fully openend windows makes these high temperatures acceptable.

A ventilation model is derived from field test measurements. It can be used for dimensioning the area of the openable windows, simulation studies, and finding control rules. Algorithmes and rules for the control of openable windows are tested.

## ACKNOWLEDGEMENT

This research was sponsered by the Netherland Agency for Energy and the Environment (Novem).

## REFERENCES

/1/ Haruyuki Fujii, Loren Lutzen Hiser
"Japanese Residential Air-Conditioning:
Natural Cooling and Intelligent Systems".
Energy and Buildings, 18 (1992) p. 221-233.

/2/ Paassen, A.H.C. van, Lute, P.J
"Energy saving through controlled ventilation windows".
3rd European Conference on Architecrure 17-21 May 1993,
Florence Italy, pp 208-211.

/3/ Warren, P. J.
"Ventilation through openings on one wall only"
Building Research Establishment, Garston, Batford, England.
Energy Conservation in Heating, Cooling and Ventilation Building, 1978.

/4/ Phaff, J.C.
"Onderzoek naar de gevolgen van het openen van een raam
op het binnenklimaat van een kamer.
IMG-TNO, maart 1980.

/5/ British Standard
"Ventilation, principles and designing for natural ventilation".
BS 5925, 1991.

/6/ Lute, P.J.
"The use of predictions in temperature control in buildings"
A passive climate application
PhD thesis TU Delft, WbMT, Koudetechniek en Klimaatregeling, oktober 1992.

## ABSTRACT

During two years the Passive Climate System with motorized openable windows is monitored in a real office building. During this period the control system is improved. Control rules for window design, fresh air supply and cooling are discribed in this paper.

Experiments are carried out with a tracer gas techniques to find ventilation rates under all kind of realistic conditions. From the measurements a ventilation model could be derived. It gives the ventilation rate as a function of the window openings, the wind speed, the wind direction and the difference between the inside and outside temperature. With this model adequate and simple rules for the control of ventwindows could be derived.