Natural ventilation and automation with manual overriding are health solution

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Summary

The need for individual control with manual overriding combined with controlled natural ventilation is discussed. It is made plausible that with these two facitilies problems related with the Sick Building Syndrome can be avoided.

This principle is applied in a so-callled passive climate system. A system is devised setting the level of heating and ventilation by controlling motors fitted to radiators, ventilation openings in windows, Venetian blinds and outside shading. Moreover, it will switch on the lighting when natural lighting is inadequate. The system comprises a weather station on the roof, a network of sensors and controllers in each room hooked up to a control computer. The room controllers can be overridden manually by the occupants.

With computer simulations it has been demonstrated that through noctural air cooling with opened windows and predictive control a comfortable indoor climate can be realized year round, provided that the internal load lies between 15 and 20 W/m^2. Higher loads require additional mechanical cooling. Moreover, it is shown that a proper combination of controlled natural ventilation and mechanical cooling leads to an enourmous reduction in energy consumption. It can be reduced to 20% of the amount that is normally required in buildings with closed facades. Moreover, the capacity of the cooling room unit can be reduced with 50%. The ability to remove internal heat and the costs of the passive climate system is compared with that of more conventional systems. It has been shown that the passive system is very promising and that the option with the additional cooling unit is superior to all the other systems.

1. Introduction

1.1. Creating a comfortable environment means more than meeting specifications

As is clearly shown in actual practice, a building with a climate system that has been constructed according to regulations, does not necessarily have to be free from complaints concerning the health of its occupants. People are beginning to realize that something is lacking in our modern office-buildings. Whoever reflects, in an unbiased manner, on this whole issue, will be able to imagine that some employees in our modern office blocks cannot speak of a comfortable situation. In fact, they have to enter the building through one secured entrance, have to spend the whole day in one room in which they have a poor contact with the outside world because of the fully closed facade and in which, in addition to this, nothing at all can be

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regulated by themselves. If, furthermore, one considers that this employee is probably too tired to get up in the morning because the sort of work that he has to do can hardly be characterized as his life's fulfillment, then we can imagine that the "more sensitive types" amongst us will experience problems that will be transformed in physically demonstrable complaints, that have been synthesized in the ominous epithet "Sick Building Syndrome". In literature and in the media the reason for all this misery is attributed, either to the building or to the climate system. The building with its synthetic building materials is said to exude all kinds of dangerous substances, and the installations are said to be full of pathogenic bacterias. Whenever an investigation is conducted in such a problematic building, there is always some kind of result that points in either way. But one might ask if in that case the main cause has been found.

1.2. Individual control with manual overriding

A much more important cause for this "syndrome" may lie in the fact that for the occupant there are no possibilities whatsoever to intervene in his own environment: the awning is regulated centrally, turning up or down the thermostat does not help, and to catch a fresh breath of air by opening the window (and thus escaping from this so neatly regulated climate) is not possible. Kurvers (1990) and Vroon (1990) have recently pointed out these aspects. According to them, the most important causes lie in the inability to open the windows and to influence the climate installations. These sort of statements appear to be like forcing open doors. However, anyone who listens carefully to the occupants of modern office buildings, will hear what exactly it is that people do not like in their buildings and in the indoor climate. They always point out the two, above-mentioned aspects. Unfortunately, the scientifically proven fact that there are always 5% complainants is misused by explaining away complaints or by just ignoring them. It would be far better to provide the installation with control systems, so that the occupants themselves would be able to influence their environment and everybody would be satisfied. Here lies a clear task for the controlling technicians who have disposal of powerful tools, such as the "Building Energy Management System" (BEMS). Unfortunately, the present BEMS do not yet offer these possibilities. They seem to be designed rather for the convenience of the owner of the building and the technical service, than that of the occupants. The desire of individuals to control their climate is only slowly getting through to the manufacturers and the buyers of BEMS. Unfortunately, the reaction of the latter group is still limited to the application of an single thermostat of the radiator or the climate unit. The goal of individual control, however, is only then achieved when the occupants, from their desk, will be able to influence all aspects, such as heating, mechanical and/or natural ventilation, awning and lighting. In this article a controlled climate system is discussed with which all this is possible. The following thoughts have been central to the design of this system:

- the occupants must be able to influence everything, even if a specific intervention is not sound from an energetic point of view. An inflamed employee, for example, must be able to divert his frustrations by fully opening a window.The control system will, in fact, secretly help him a little by nearly shutting off the radiator, so that the effect of his action will be well perceptible;
- in order to save energy, the natural sources, such as wind, the difference between in- and outdoor temperature and sunlight have to be taken advantage of before one switches over to these mechanical tools. On the basis of this aspect the system was called the "Passive Climate System".

1.3 Open windows

One explicit desire of the occupants concerns the possibility to open windows. In fact, it is so explicit that there is no need to expand on that any further. Unfortunately, designers have up till now been unwilling to listen and have rejected this desire with the following arguments:

- natural ventilation is not a feasible option because it leads to occurrences of draft and uncontrolled heat releases.
- natural ventilation is incompatible with a properly functioning heating ventilating and airconditioning-installation.

Both arguments are correct if one looks at this problem from a traditional point of view. But things change when one wonders whether these points also hold in the application of windows that can be opened automatically and in the possibilities of modern, digital control systems, that offer immensely more possibilities than the old, analogous control systems. As will be shown, an intelligent use of the window offers considerable advantages as regards both the use of energy, convenience and comfort. Indeed, these advantages are so considerable that we might ask ourselves why it has not been applied earlier.

2. The Passive Climate System

The Passive Climate System is shown in Figure 1. It is able to influence the periphery of the building in combination with the heating and lighting installation, in such a manner that a comfortable indoor climate is created with minimal energy costs. Influencing the periphery implies the ability to automatically adjust the window openings, the awning and the rolldown shutters. Automatically adjusting window openings implies the application of natural ventilation. The authors do realize that this constitutes an extreme difficulty, especially if it concerns the control of minimal ventilation. The advantages, however, are very enticing, such as free cooling by

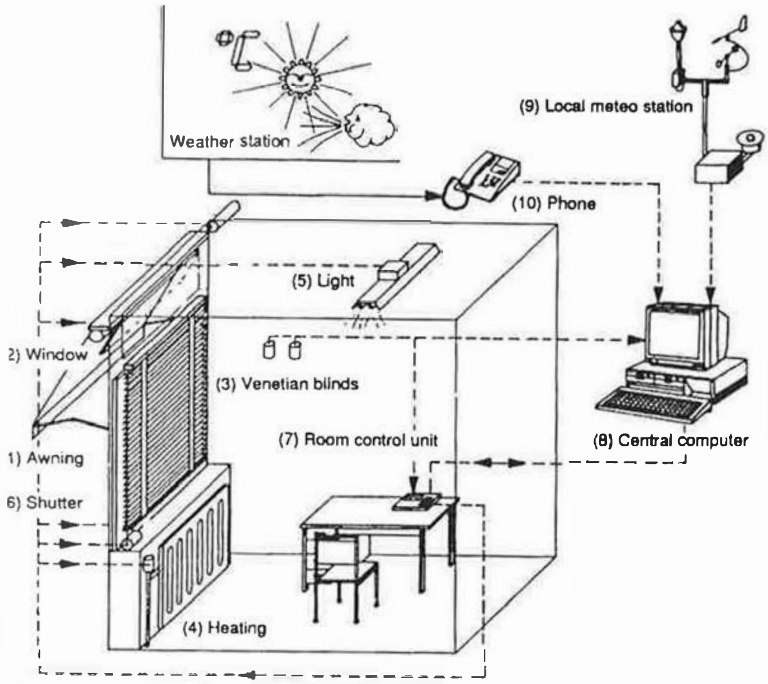


Figure 1 Passive Indoor Climate System.

way of nocturnal air ventilation, and no need for a cooling machine, nor for a mechanical ventilation system. This last aspect requires that, indeed, it ought to be possible to control the minimal free supply of air. More on this matter in paragraph 2.4.

2.1. The control system

In every room a digital controller is situated, the so-called local controller. This controller controls the following six components: ventilation-windows, awning, roll-down shutters, venetian blinds, radiator and artificial lighting. By fine-tuning these components, one can make the most of the possibilities of the outdoor climate, such as solar energy for heating and/or lighting on the one hand, and natural ventilation for the supply of free air or cooling on the other.

Optimal fine-tuning takes place in a central computer, which, by way of a network, is connected with the local regulator. The computer combines the weather forecast of a meteorological institute with the data issued by a weather station that is placed on the roof of the building. This weather station measures sunshine, temperature, the speed and the direction of the wind. In addition to this, the orientation of the offices and the typical aspects of the specific building, such as the storage accumulating ability, are taken into account. These are deduced from measurements in a gradual, learning process. The computer calculates the optimal position of the ventilation windows, roll-down shutters, awning etc. Furthermore, it determines the values to which the temperature in the various rooms have to be adjusted and by which means this should happen (radiator, awning, or window opening). The desired values are passed through via a network to the regulators positioned in the rooms. A local regulator of this kind can thus be considered as a sort of enhanced thermostat that is meant to realize the situation that according to the computer should be desired. If the user is to prefer a different position of the window components, he can indicate this on the dashboard of the local regulator. Every desirable position can then be realized through remote control.

2.2. The local controller

The local controller is laid out in the form of a dashboard (see figure 2). It contains a number of function keys and a small display for messages. As soon as an occupant enters a room, he presses the ON-button, thus activating the local controller. This implies that the temperature,

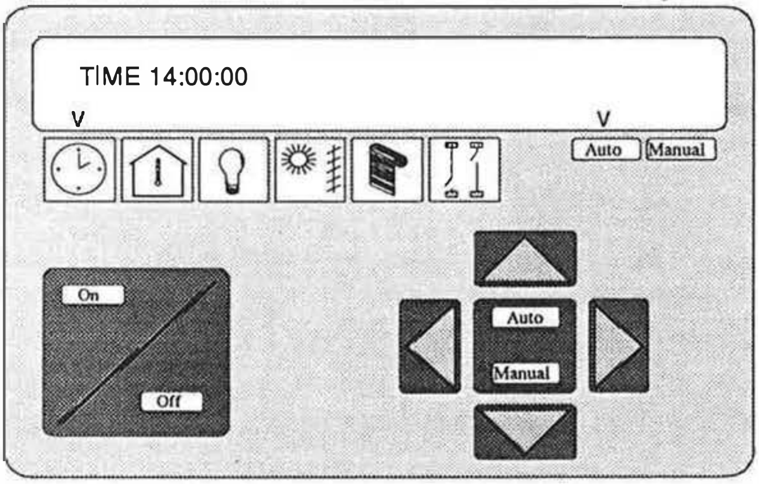


Figure 2 The dashboard of the Local Controller with remote control (a conceivable design).

for example, is increased from 18C to 20C, that the venetian blinds are set in the right position, that, if necessary, the roll-down shutters are pulled up, and that the lighting is adjusted to the right level.

If the ON/OFF button happens to be in the OFF-position, a so-called stand-by situation is created. This means that an optimal situation (from an energetic point of view) is realized by establishing the right indoor temperature and the "correct" position of the window system. Whereby "correct" really means: "deemed right according to the computer".

The local controller functions in an autonomous way and realizes the desired temperature and the positions of the window system calculated by the central computer. If the calculated situation does not comply with the user's wishes, then the latter will be able to alter the set values within specific boundaries by switching the local controller to manual control (i.e. by pressing the AUTO/MANUAL-button). The cursor on the right is moved to MANUAL. Once it is set to this position, the user can intervene in the local control system. By pressing either the (<)- or the (>)-button, the user can choose the variable he wants to change. The cursor on the left then moves to the icon of the specific variable, thus popping up on-screen the calculated positions and the actual status of this variable. By pressing the (▲)- or the (▼)-button, he can then alter the desired temperature. By pressing the AUTO-button, the link with the central control system is restored and the manually set positions of the temperature are replaced by the optimal values calculated by the central computer.

The optimizing activities of the computer concern, for example, the fact that the control system takes care to cool the space on sunny days by opening the windows and, if necessary, letting the awning come down. At night, the windows are kept open if a calculation predicts that it will become too hot inside. During the heating season, however, the windows are closed after hours and the roll-down shutters lowered in order to preserve the heat that is stored in the building and to use it during business hours.

2.3. The central computer

The central computer has the following functions:

- measuring and storing database-files (weather-data, indoor temperature)
- weather forecast
- identification (determining the model of the specific building)
- optimizing (optimal start-up procedures for heating and cooling by way of nocturnal air ventilation).

An important part of the central system concerns the identification-program, that, with the values measured, determines the parameters of a model (see figure 3). The model describes the effects of sunshine, the outside temperature and the heat emission of the radiator on the inside temperature. For instance, the effect of sunshine Q z on the inside temperature T i is described with a first-order differential equation:

$$T_i + \tau \frac{dT_i}{dt} = kQ_z$$

The parameters K and τ are determined by a search-algorithm in such a way that the result of this differential equation is adjusted as well as possible to the temperature measured inside. If the situation changes, for example because of pollution of the windows, then the parameters K and τ are adjusted automatically. In the real control system higher order differential equations are used. (Lute, 1990). With the help of the identified model and the weather-conditions that have been predicted, the optimal controlling strategy can be determined for the next 24

hours, for example by starting the heating installation on the right time. This will happen in the following way. With the data of model of the building and the weather predictions, it is calculated, time after time, how the inside temperature will vary if on that precise moment the installation would be started. If the calculations prove that the desired temperature ought to be reached at 8 o'clock, then the installation is switched on. If the temperature appears to be higher, then it is not switched on and the calculations are repeated some time later on.
It will be clear that such a start-up procedure is far more accurate than the procedures that have been used up till now in the BEMS (Building Energy Management System). With this new system it will be possible to predict that on a sunny day in spring the building does not have to be warmed up, because there will be sufficient sunshine to realize the desired temperature. One will also be able to avoid the situation that on the very same day heating and cooling are to be used. Another application might be used during a warm summer. With the model and the weather predictions, it is 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.

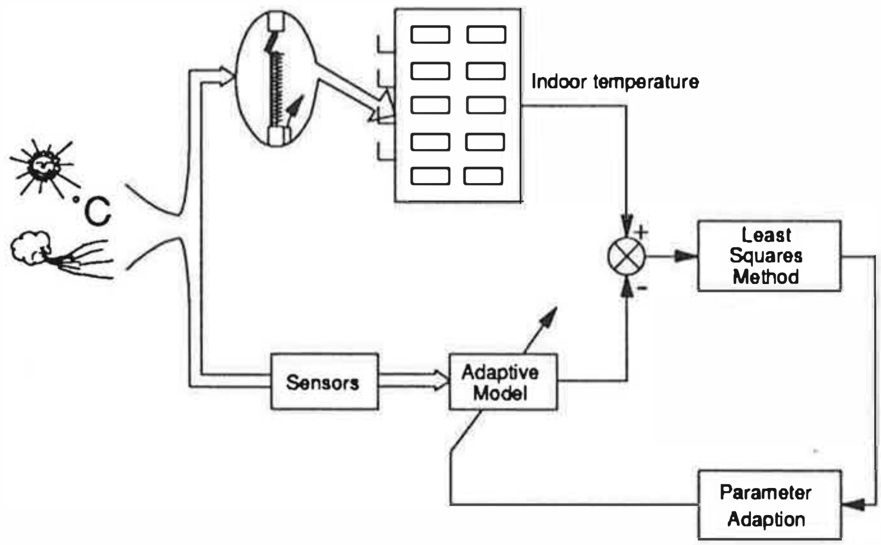


Figure 3 Adaptive model of the building

2.4. Controlling the minimally required quantity of fresh air

Controlling the input of the correct quantity of fresh air constitutes the biggest problem. The supply of fresh air does not only depend of the windows opening, but also of the wind speed Vw and the difference in temperature between indoor and outdoor climate, ΔT. This relationship is depicted in the following formula:

$$\Phi_v = A_w \sin(wa) \cdot \sqrt{C_1 V_w^2 + C_2 |\Delta T| + C_3}$$

Φ_v = air flow through the window [m^3/s]
A_w = half of the surface area that can be opened [m^2]
wa = the angle of the opened window [rad]

The coefficients C_1, C_2 and C_3 are highly dependable of the location of the building and of the type of window. Therefore, they ought to be deduced from measurements on-site in every application. The learning process will develop in the following way. In the morning, before the occupants have arrived in the building, the windows are opened for a few minutes in order to speedily decrease the temperature. From the speed with which this happens, and with the help of a heat balance, one will be able to deduce the quantity of fresh air that has flowed into the room.

This will be repeated in various weather situations. After a learning period the coefficients C_1, C_2 and C_3 will be determined with the calculated values of Φ_v and the measured values of V_w and ΔT. From this moment on, one can determine the position of the window (wa) that yields the desired ventilation with the above-mentioned equation (2). Experiments that were carried out in a test cell proved that this approach can lead to satisfactory results. Further research will be conducted in order to fine-tune this method and to make it workable in practice. One problem that has not yet been resolved concerns the influence of open doors. Open doors do, of course, considerably heighten the degree of ventilation.

2.5. Cooling by way of natural ventilation

If a very hot day is predicted, the windows will be opened during a period at night to cool the building in advance. This cooling effect can only then be achieved if opening windows results in high air changes. This is particularly important on a windless night. For this purpose, upper and lower windows have been used that can be opened separately.

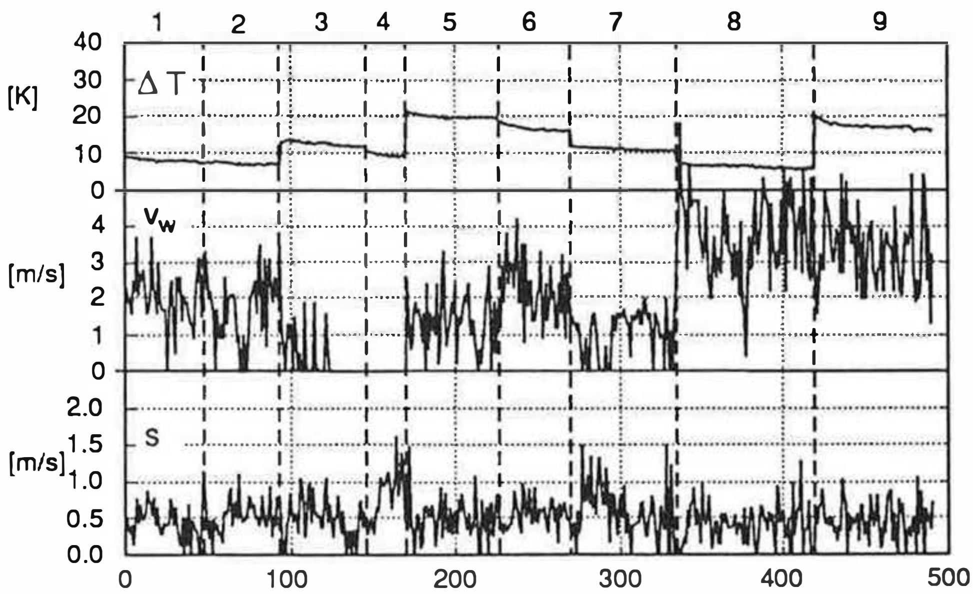


Figure 4 Air speeds in a windowopening at various windspeeds and temperature differences.

From experiments it became clear that with upper and lower windows the air changes are five times higher than the result of a calculation based on the formulas of Phaff (1980) showed for a single vertical window with the same surface area. Experiments in the testcell point to a selfregulating behaviour of the natural ventilation. It is observed that the mean value of the airspeed in the window-opening is almost constant. In figure 4 the measured air-speed is shown at various windspeeds and temperature differences. It shows a noisy variation around the average value of 0.5 m/s. The airflow through the windows depends linearly on the area of the window-opening. For the window configuration of the testcell it can be calculated by:

$$\Phi_v = 0.5\, A_w \sin(wa)$$

With A_w = surface of the upper or lower window-opening.

3. Cooling capacity of the Passive Climate System

In order to determine the performance of this system, a computer simulation was used. The results of the calculations are depicted in figure 5. The conclusion is that in the case of a heavy building with a window surface area of 40% and an internal heat load of 10 W/m² the indoor climate is still acceptable (number of times an exceeding of 26°C took place <80 hours; cf. the guide number of the Rijksgebouwendienst (Ministry of Housing and Enviroment): occurrences of an acceptable exceeding of 25°C is 90 to 110 hours (Brouwers, Van de Linden, 1989).

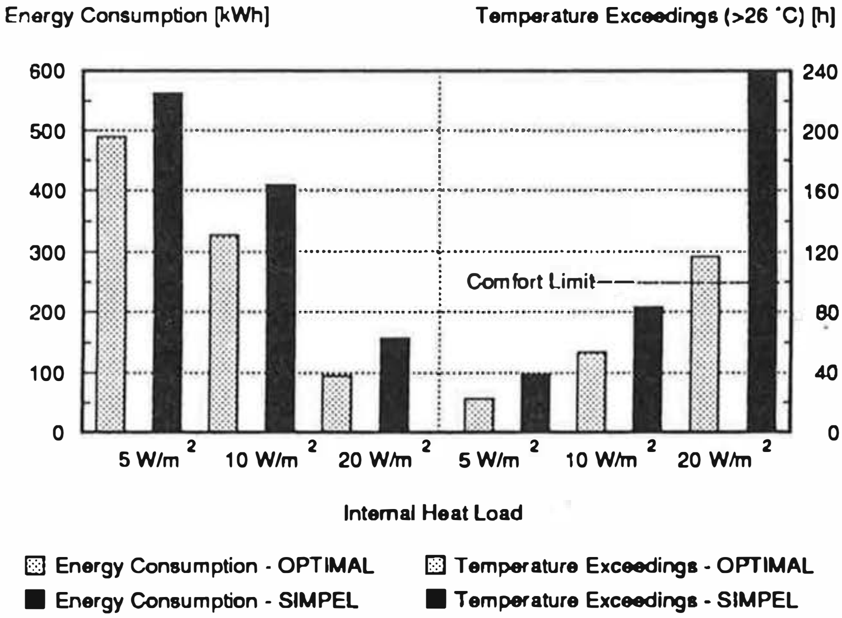


Figure 5 Yearly energy consumption and number of hours with temperature exceedings 26°C at various internal heat loads per m² floor area (occupants + machines) (Heavy building with 40% glass-weather data TRY-UCCLE)

Depending on the internal heat load, the predictive character of the control system yields a saving in heating that varies from 14% to 40%. The decrease in occurrences of an exceeding of temperature varies from 35% to 50% In the case of the simple control system, the inside climate is totally unacceptable with an internal heat load of 20 W/m², whereas in the optimal control system with a little good will this may still be called acceptable. Thus, a properly functioning control system, such as the predictive system discussed here, has a considerable influence. We can, therefore, state that an extra heat load of 10 W/m² can be allowed without mechanical cooling being necessary.

4. The Passive Climate System and mechanical cooling

In this paragraph we will outline how the Passive Climate System can be expanded with a cooling system, for example a ventilator-convector that will only then be switched on if cooling with natural ventilation does not suffice. The possibilities of this combination has investigated in relation to a building of medium weight with 40% glass and an internal heat load of 40 W/m².

4.1. Adjustable window ventilation reduces cooling energy and improves a comfortable environment.

We have investigated the situation in which cooling capacity amounts to 50 W/m^2, which, with a fully closed facade, suffices to remain below the bounds of a comfortable situation. Figure 6 shows energy consumption for cooling, as well as the number of times limits were exceeded in the following three situations:

A Closed facade with mechanical cooling only
B Nocturnal air cooling with natural ventilation through the open windows
C As in (B), but with open windows on opportune occasions during the day.

The capacity of the cooling system (50 W/m^2) has been adjusted to the situation with the closed facade (situation A). In this specific case the number of times the temperature exceeded the limits was lower than is permitted (46 hours).
The figure shows that nocturnal air ventilation with open windows more than halves the consumption of energy (57%). If, in addition to this, people ventilate in favourable conditions during the day, then consumption decreases to a very low level (reduction of 84%). What is more is that in this case a very comfortable situation has been created. There will be no more hours during which the temperature exceeds 26°C.

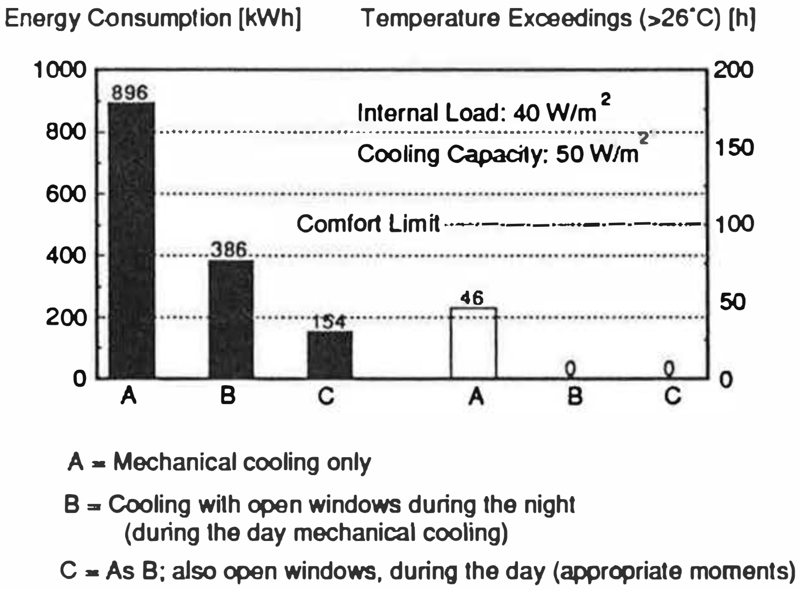


Figure 6 Influence of controllable window ventilation on the consumption of energy by the cooling unit and the number of times temperature limits were exceeded (cooling capacity tuned in to top cooling with fully closed facade).

4.2 Adjustable window ventilation reduces cooling capacity

For the same building module the cooling capacity has deliberately been halved (25 W/m^2). In Figure 7 we see the result: a gigantic number of times temperature limits were exceeded in the building with the closed facade (1012 hours). If at night the windows are opened to exude the warmth stored in the walls, then an interesting reduction occurs; limits are, however, still exceeded too many times (187 hours). Now, if during the day people also ventilate on opportune occasions, then the limits are hardly exceeded (8 hours) any longer and the consumption of energy reaches a very low level (reduction of 87%). Thus, calculations indicate unlimited possibilities of the adjustable window openings. We can state that the capacity of the cooling system is reduced with 50% and the consumption of energy with more than 85%, if the following rules are obeyed: "Cooling with adjustable window openings has priority. If natural ventilation does not suffice, then do close the windows to the minimum position and switch on the cooling system."

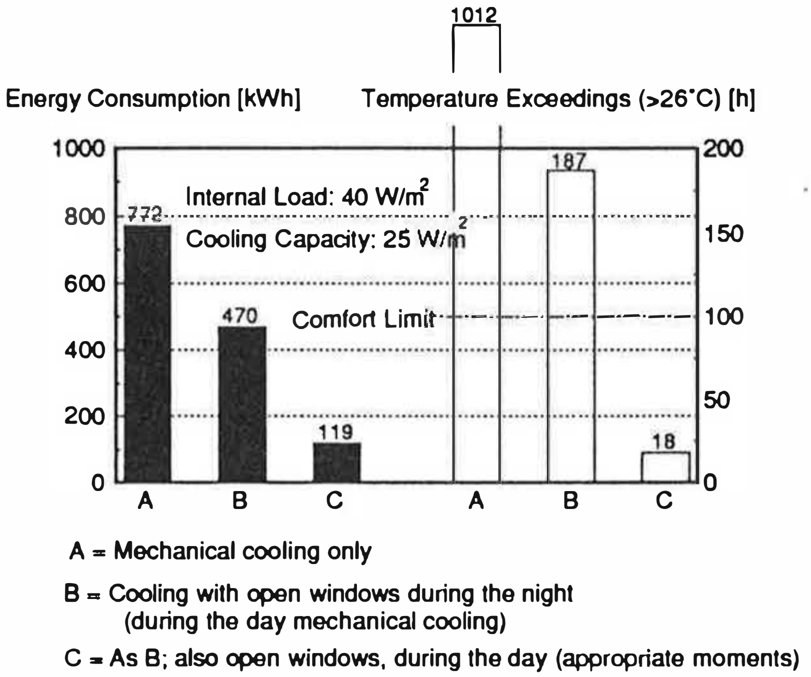


Figure 7 Influence of controllable window ventilation on the consumption of energy by the cooling unit and the number of times temperature limits were exceeded in the case of a cooling capacity that was too small.

4.3 Predictive Control

The above-mentioned data have been calculated while the predictive control system was being used. We have already indicated that with this system the acceptable limit for the internal heat load is allowed to be 10 W/m^2 higher. In other words, if mechanical cooling is unavoidable, the required cooling capacity may be lowered by 10 W/m^2. This reduction pales into insignificance compared to the reduction realized by nocturnal air ventilation with open windows, so that we can state that the above-mentioned conclusions also hold for the use of a simple control system without using predictions.

5. Economic feasibility

5.1. Global survey

Calculations on the basis of simulated circumstances show that the Passive Climate System, as far as performance is concerned, ought to be compared to a mechanical ventilation system with top cooling. In the feasibility study, calculations have been based on the assumption that roll-down shutters were not put into use. The fact is that it has been shown that the small savings they yield are out of all proportions to the extra costs. The Passive Climate System has the following cost-cutting advantages.

- There is no need for air channels or central air treatment (savings estimated: *f* 150,- per m^2).
- There is no consumption of electricity for the transport of air, or for cooling.
- Extra savings of 15% on heating costs are possible if the predictive control system is applied.

A disadvantage, however, lies in the lack of any heat recovery. The loss of energy that arises in this way is, however, considerably lower that the savings on the consumption of energy, so that the system, energetically speaking, still remains preferable. For simplicity's sake we have assumed that the only advantage lies in the savings on installation costs. In the case of a room of 20 m^2, this amounts to 20 x 150 = *f* 3.000,-. This sum suffices to compensate for the extra costs of the Passive Climate System. If we assume that in the near future the Building Management System (BMS) provide for one local controller per room, as well as an automatic control system for the outside shading and the lighting, then the extra costs for the Passive Climate System consist of the following items:

- the motor drive that is necessary to adjust window openings
- the motor drive for the adjustable inside shading
- the extra costs for the digital control system (extra exits)

It will be clear that *f* 3.000,- is amply sufficient to make up for these costs, so that we can conclude that for buildings in which the Passive Climate System can be applied, this system is certainly preferable. If, in addition to this, we take into account that the possibility of opening windows is a necessity when we want to avoid the symptoms of the Sick Building Syndrome, then the result of the comparison turns out to be highly in favour of the Passive Climate System.

5.2. The Passive Climate System compared to other systems

The Passive Climate System will be compared to five other systems. The systems compared are mentioned in Schonewille's article "Invloed van de installatiekeuze op levensduurkosten" ("The influence of the choice of the installation on the life expectancy costs"). In addition to this comparison with the normal Passive Climate System, we will also compare the five systems to a Passive Climate System to which a cooling unit has been added. Thus, the following systems are being compared:

A The Passive Climate System.
B The Passive Climate System in which the radiator has been replaced by a ventilator-convector with a cooling and heating battery. Ventilation takes place through the windows. The cooling capacity of the cooling unit has been chosen in such a way that the same internal heat load (of persons and equipment) can be exhausted in the same way as in system G (see below).
C Central heating and natural ventilation.
D Central heating and mechanical ventilation.
E Central heating and mechanical ventilation, supplemented with central, limited top cooling (also known as top cooling).
F Central heating and mechanical ventilation supplemented with individual control of the quantity of cooled air supplied to the room.
G Complete airconditioning system with central air treatment and individual after-heating or after- cooling per room (four pipes-induction system).

5.3. A comparison of performance and costs

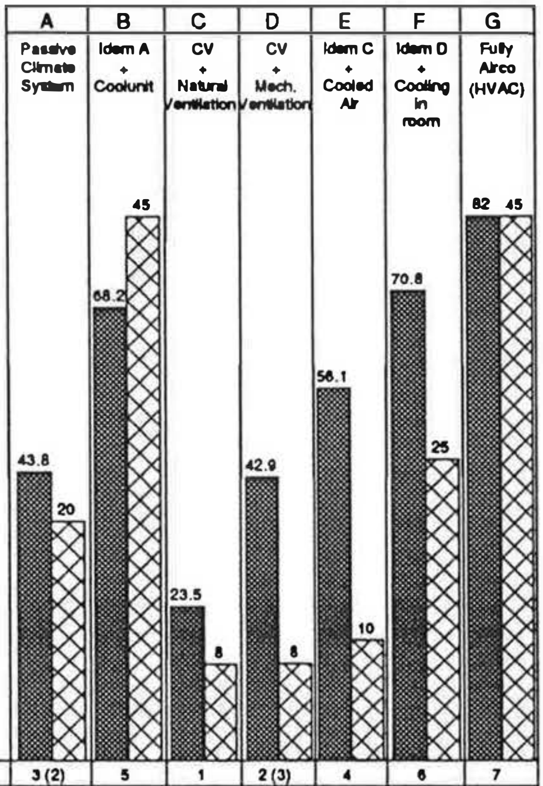
The various systems have been compared as far as costs and performance is concerned. The performance of the respective systems have been compared in view of the internal heat load caused by persons and equipment that the system is able to exhaust in addition to the heat load from lighting and sunlight that in spite of the outside shading enters the room. The comparisons have been conducted on the basis of a room of 20 m^2. In this room two persons (8 W/m^2) were present.

The systems mentioned in 5.2 have also been compared as far as costs are concerned. These have been expressed in terms of costs per m^2 of floor surface, on the basis of an office building with a floor surface area totalling 5.000 m^2. Investments have been converted to costs per annum, as indicated by Schonewille (1991).

The systems have been judged with a ranking number, with costs and performance issues being taken into account. The order of ranking has been determined in the following way:

$$R_i = 1 - \frac{\text{costs of system i}}{\text{costs of system G}} + \frac{\text{internal heat load of system i}}{\text{maximum internal heat load (system G)}}$$

The system with the highest value for Ri is the best system and is ranked as number 1. In Figure 8 the order of ranking of the various systems has been sketched according to the above-



Ranging	A	B	C	D	E	F	G
Costs	3 (2)	5	1	2 (3)	4	6	7
Performance	4	1	7	6	5	3	1
Both	3	1	6	7	5	4	2

Total costs per year in Dutch guilders per m^2 floorarea

Internal heat load (inhabitants + machines)in W/m^2 floorarea

Figure 8 The order of ranging of the various systems.

mentioned formula. As far as performance is concerned, the Passive Climate System emerges between system E and F. With the added cooling unit, the Passive Climate System will be able to offer the same performance as the complete climate system. If we look into the costs, the Passive Climate System with cooling unit turns out to be cheaper than the systems F and G, and in the total comparison even surpasses a complete climate system.

5.4. An assessment taking into account the possibility of "Sick Building" complaints

The "Sick Building Syndrome" turns out to be the cause of a high level of absenteeism. Major causes of the "Sick Building Syndrome" lie in the inability to open windows and to influence the own indoor climate. These factors are not present in the above-mentioned systems A and B, so that the level of absenteeism will be less high. Suppose costs of personnel involve a sum of *f* 10.000,- per m^2 per annum. It is being estimated that "Sick Building" complaints cause a 1% decrease in productivity. Thus, the costs amount to *f* 100,- per m^2 per annum. If systems are assessed with the "Sick Building" complaints being taken into account, then the order of ranking of the various systems will become as shown in table 1.

Table I Order of ranking of the systems, giving weight to the savings resulting from a different approach to "Sick Building" complaints.

SYSTEM	A	B	C	D	E	F	G
RANKING	2	1	6	7	5	4	3

If savings resulting from a decrease in the absenteeism that can be attributed to "Sick Building" complaints, are taken into account, then the Passive Climate System without cooling unit will even surpass the complete climate system G.

6 Conclusions

The Passive Climate System with predictive control is able to realize a comfortable indoor climate, provided the window surface area does not exceed 40%, the partioning walls are made of stone and a ceiling is applied that is accessible to the air. Also, the internal heat load ought not to be higher than 20 W/m^2 floor surface. The combination of controllable natural ventilation with windows that can be opened automatically on the one hand and a cooling unit on the other results in tremendous advantages. Control of the window opening in connection to control of the cooling unit reduces the consumption of energy for the purpose of cooling to a very low level (from 100% down to 20%). In addition to this, the capacity of the installation for a certain internal heat load can be 50% lower than would have been necessary in the case of a fully closed facade. A cost/performance analysis also shows that the Passive Climate System can be highly recommended. If systems are judged on cost and performance, the Passive Climate System with cooling unit takes the lead. Summarizing, it may be concluded that natural ventilation by controllable window openings in combination with a cooling unit, can make the concept of a closed facade and a complete air conditioning redundant. Special attention, however, ought still to be given to housebreaking and traffic noise.

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