VENTILATION AND COOLING

18 ANNUAL AIVC CONFERENCE
ATHENS, GREECE, 23-26 SEPTEMBER 1997

Hardware and controls for natural ventilation cooling

S.H. Liem, A.H.C. van Paassen

Delft University of Technology
Faculty of Mechanical Engineering and Marine Technology
Process and Energy Department
Laboratory of Refrigeration and Indoor Climate Technology
The Netherlands

Hardware and controls for natural ventilation cooling

S.H. Liem, A.H.C. van Paassen

Delft University of Technology
The Netherlands

Summary

This research is part of project NATVENT^{TM}, a concerted action of nine institutions of seven European countries under the Joule-3 program. It aims to open the barriers that blocks the use of natural ventilation systems in office buildings in cold and moderate climate zones.

Natural night-time ventilation cooling is a very effective means to remove the heat, accumulated in the building fabrics during office hours. Moreover, it requires no energy at all. Cooling with natural ventilation has it limits; more than 6 air changes per hour have no more cooling effect. So precautions have to be taken to reduce the heat gain during the day by limiting the glass area to approximately 40% and using effective sun shading devices. The internal heat load is also limited to 25 W.m^{-2}. Hardware for night cooling are the traditional types of windows and trickle ventilators. To obtain the most benefit of night cooling, automatic control is essential. For this the control strategies is of utmost importance. Specially for night-time ventilation cooling developed control strategies are incorporated in the predictive control, cooling day control, setpoint control, slab temperature control, degree hour control.

1. Introduction

For cooling, much higher air flow rates are required than for only refreshing the indoor atmosphere. These flow rates are not always available during the daily office hours, because, for reasons of comfort, the air velocity is limited. At night, without any occupation, these restrictions do not apply and much higher air velocities are allowed. To obtain the most benefits of natural night-time ventilation cooling, automatic control is essential. Automatically the windows or vent openings are closed, when the temperature has reached its setpoint, or when danger of ingress occurs or when wind speed exceed a given speed limit. In well designed office buildings with internal loads not exceeding 25 W.m^{-2}, automatic controlled natural ventilation with night cooling control will satisfy [1,2]

First a review of components applicable for natural night-time ventilation cooling, that are available in the market or under development will be given. This will be followed by a discussion of complete systems. Because the importance of automatic control with night-time ventilation, also an overview is given of strategies that can be applied for an optimal use of natural night-time ventilation cooling.

2. Cooling by natural ventilation

Natural ventilation is a free source of cooling at our disposal. The wind and the temperature difference between the outdoor and the indoor are the main driving forces for the transport of this free cooling medium. Unfortunately, during office hours, for comfort reasons, the indoor air velocity is limited to 0.15 m.s^{-1}. At night, this constraint is not there and the windows can be more opened, but precautions have to be taken to prevent burglary. Cooling with natural ventilation has its limits. More than 6 air changes per hour (ach) have no more cooling effect [2]. So during the day the heat gain must be as small as possible. It can be stated that in buildings with maximum heat accumulation, 40% window area and with an effective automatic outside sun shaa...g device, night-time ventilation cooling can keep indoor temperatures at an acceptable level with an internal load not exceeding 25 W.m^{-2} [1,2,6,7]. So only with automatic control the full benefits of natural cooling can be obtained.

3. The basic ventilation patterns

Three basic ventilation patterns cooling can be distinguished: a. single sided ventilation, b. cross ventilation and c. natural or fan assisted cross ventilation with an atrium or shaft.

3.1 Single sided ventilation

Single sided ventilation occurs, when the inlet and the outlet windows are placed in the same wall, see figure 1. The inlet and the outlet openings can be at different heights (left), or form one opening (right). The available air movement on the windward side is about 10% of the outdoor wind velocity at points up to a distance one sixth of the room depth from the window. Beyond this, the velocity decreases rapidly [3]. On the leeward side less air movement is produced. The ventilation is induced by the turbulence of the outside air that increases with higher wind speeds [2].

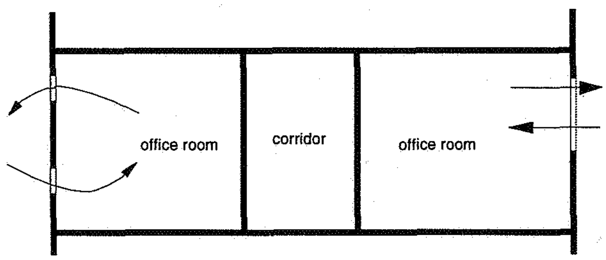


Figure 1 Single sided ventilation

3.2. Cross ventilation

Cross ventilation has a much higher ventilation rate than single sided ventilation. One configuration is shown in figure 2 (top); the air flow goes via the windows of the windward sided rooms and through vents near the ceiling via the corridor to the leeward sided rooms. Another configuration is shown in figure 2 (bottom): the air flow enters the windward sided rooms near the ceiling. There it sticks to the ceiling due to the Coanda effect and deep inside the room it drops to the floor where it goes to the corridor via the crack under the door. The first configuration is more comfortable for a summer situation because the fresh air passes the living zone, but for the winter situation the second configuration is better, because it prevents draught from entering the living zone. The disadvantage however is the transportation of the polluted air to the leeward sided rooms. However, this does not apply for night ventilation.

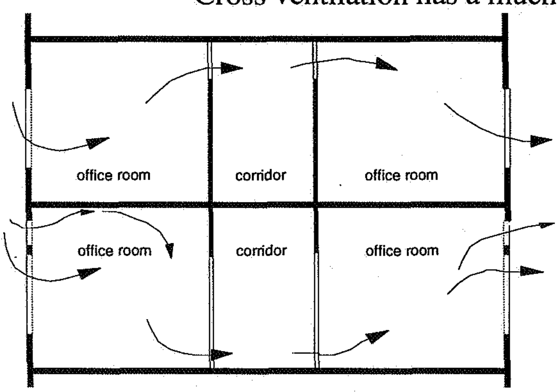


Figure 2 Cross ventilation

3.3 Natural or fan assisted cross ventilation with an atrium or shaft

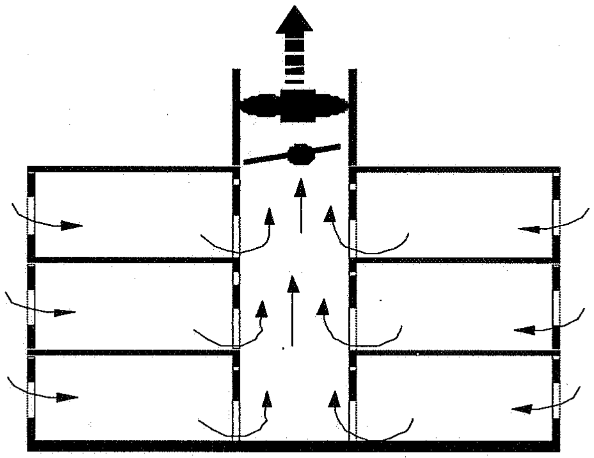


Figure 3 Fan or shaft assisted cross ventilation

With an atrium in the centre of the building the office rooms around this atrium are also cross ventilated, see figure 3. Due to the buoyancy forces in the atrium the air leaves the building from chimneys in the roof. The same pattern occurs also when there is a shaft in the building. But here we must observe stringent fire regulations. The air flow can be increased by adding an electric fan in the shaft or chimney. For a building with more floors the flow differs on the different floors due to the changing active height of the chimney. This depends on the wind speed, wind direction and temperature difference between indoor and outdoor.

3.4 Situation in some European countries on night-time ventilation cooling

In Switzerland research on night-time cooling is focused on optimising night-time cooling strategies for chilled ceilings. A pilot project of the Union Bank of Switzerland investigates passive night-time cooling by ventilation flaps and external blinds for solar protection, automatically set by a Building Management System [6]. In Norway many new office buildings are atrium buildings with glassed sun space between the buildings. These are normally naturally ventilated through motorised openings (shutters) in the roof. These openings are equipped with temperature and rain-sensors and therefore can be controlled for night-time cooling. Another system that include night-time cooling is the "ThermoDeck" system. It is a ventilation system integrated in the concrete structure of the building. Normally the floor have hollow core slabs where the supply air is circulated before entering the room [7]. In The Netherlands [1, 2, 8, 9] and The United Kingdom [10, 11, 12, 13, 14, 17] the research on natural ventilation with night cooling in office buildings is gaining momentum and many natural ventilated buildings with natural or fan assisted night-time cooling are being realised. Results of PASCOOL, a JOULE funded project, are collected in PASCOOL CD ROM [19].

4. Components for natural night-time ventilation cooling

For cooling, much higher air flow rates are required than necessary for refreshing the indoor climate. So in general the same components can be used: the traditional types of windows such as: inside/outside turning windows, trap windows, turning-trap windows, Louvre (glass) windows, vertical/horizontal sliding windows, etc. These components are all day life in building business, but as so not suitable for night cooling in office buildings because of security reasons and human behaviour. Besides keeping intruders out, these components must also prevent inrain and papers from flying all over the place. For optimal benefits of night cooling, automatic control of these components is necessary. Essential parts for night cooling are actuators and a automatic control system. The actuators can be connected to the window with a rod mechanism (figure 4), a special designed mechanism for Louvre windows (figure 5) or a chain (figure 6).

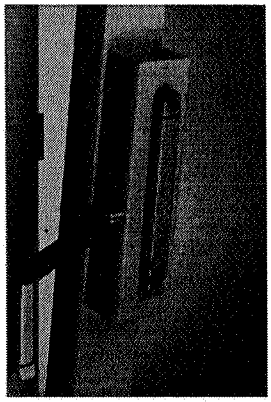


Figure 4 An actuator with a rod mechanism

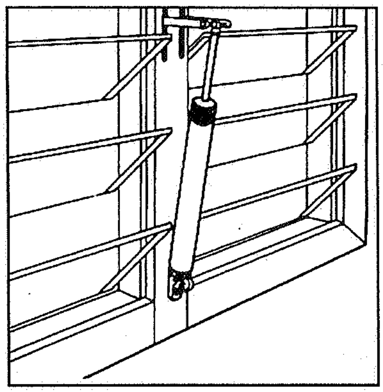


Figure 5 An actuator connected to a Louvre window

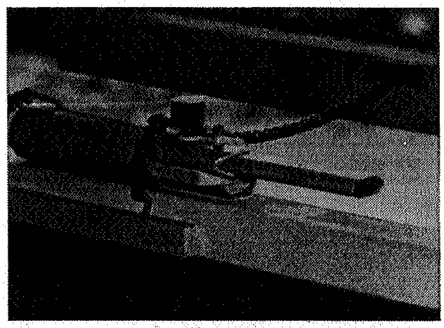


Figure 6 A chain connects the the actuator with the window

At present, electronic controlled trickle ventilators, see figure 7, are already available on the market. Each ventilator is equipped with a print board, a duct, a sensor and a servo motor to control the moving sleeve. The air speed in the duct is measured based on the cooling time of a heated metal wire. The output of the sensor is converted into an electronic signal. This is passed to the controller which steers the servo motor to adjust the sleeves in the right position, such, that the air flow is constant, nominal 10-18 [$m^{-3}.s^{-1}$ per m length]. This ventilator is very suitable for night cooling because it is easy to connect it to a building management system. The capacity can be increased by adding a mechanical exhaust fan. No exact figures are available regarding the energy consumption and the life span of the servo motor. The price is comparable to a mechanical ventilation system.

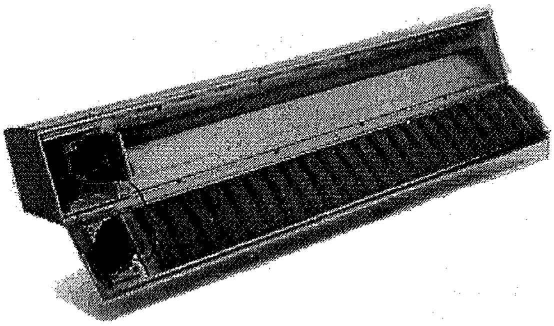


Figure 7 The electronic trickle ventilator

A newly developed natural ventilation system, as applied in a new domestic housing project, called Urban Villa [15], is worth mentioning here, because this system is also applicable for office buildings. Cooling is provided by a combination of an opening in the parapet and an outside turning trap window above the vision window, see figure 8. The dimensions of the opening under the parapet is approximately 1 * 0.5 m. At the outside this is covered by an aluminium grill with fine small-mesh wire netting for insects. At the inside this can be closed by a well isolated hatch that can be manually opened with a spindle and positioned in any desired position. The air flow enters the room via the external louvres and leaves the room via the two upper trap windows, each also measuring approximately 1*0.5 m. A ventilation rate of 6 ach can be obtained in a summer night.

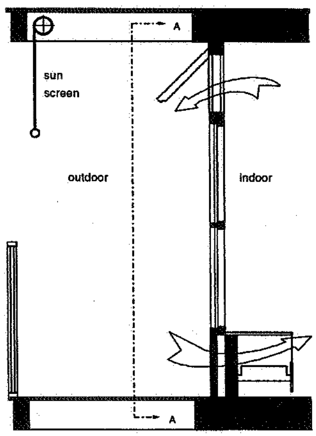
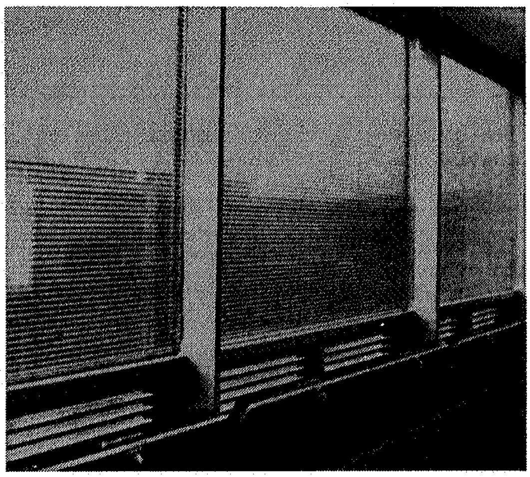


Figure 8 Vent openings in the parapet and above the vision windows



By the refurbishment of Regent House in Great Britain [15] is used the same principle. Around the whole perimeter of the building, below the fixed vision windows, mesh screens with external louvre (dimension 850*600 mm) provide 24-hour security and weather protection. Inside bottom hung hatches keep the cold out in winter. Above the vision windows are place cord operated trickle ventilators.

Figure 9 *A similar principle is used by the refurbishment of Regent House in London, England.*

A new development is an integrated self inducing trickle ventilator in the facade [16]. The advantage of this design is that the air flow is introduced into the room just below the ceiling; thus optimal use of the Coanda effect is guaranteed. The longer the air flow sticks to the ceiling, the deeper the air penetrates into the room and the more time is available to heat the cold air before it drops to the living zone. Slit 'B' can be adjusted manually or mechanically by valve 'O', so that the ventilation rate can be adjusted according seasonal needs. Noise reduction canals can be incorporated, see figure 10.

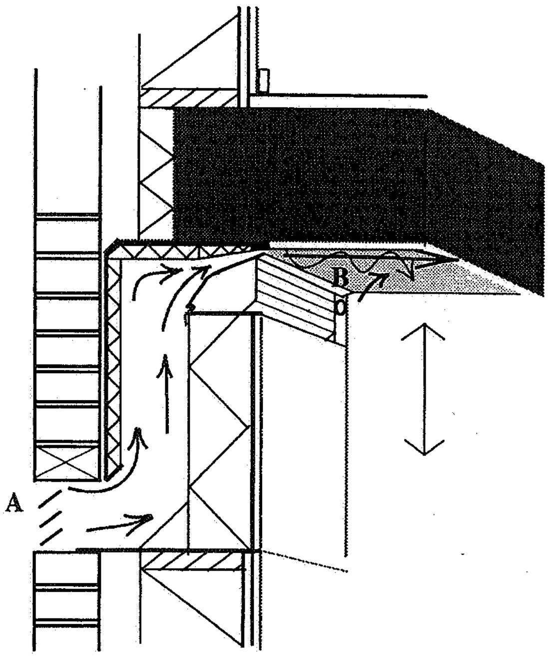


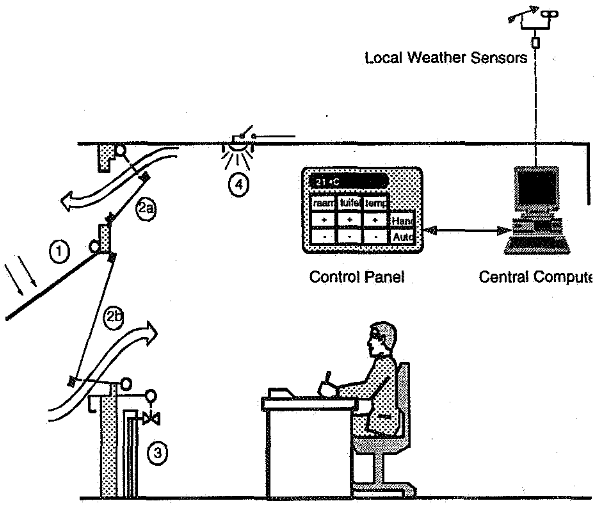
Figure 10 Integrated trickle vents in the facade with a noise reduction canal.

5. Automatic controlled systems for natural night-time ventilation cooling

It has been mentioned in the preceding paragraphs, that optimal benefits from night-time cooling in office buildings are only possible with automatic control. Although developments in this field are very intensive, complete ventilation systems with night-time ventilation cooling designed for office buildings are not yet available on the market. Two systems having control features will be discussed here. These are the Passive Climate System and the Window Master.

5.1 The Passive Climate System

The Passive Climate System is an integrated system and consists of a central computer, local controllers and a weather station. The three most essential parts, the outdoor sun shading device controller, the room controller for the heating and the actuators for the windows are already available on the market.



The central controller co-ordinates the information flow between the weather station and these local controllers. The system allows the occupant to overrule the control actions of the central controller during office hours with a remote controller. After working hours the central controller regains control and resets the manual set control actions of the day. A kind of predictive control action takes over to precool the office building during the night.

Figure 11 The Passive Climate System

5.2 <u>The Window Master</u>

The Window Master is developed for ventilation purposes and security. This system consists of a central controller and a number of local controllers or under stations. They are connected by a local network. The central controller controls all windows of the whole building .Window Master with a restricted number of control functions is already on the market. This system is very suitable for controlling inside turning trap windows. In the trap position the window is automatically controlled by the system. During office hours the occupant can disconnect the spindle from the actuator (see figure 6) and operate the window manually. Before leaving the office it has to be reconnected again to the actuator before the central controller will regain control. With an infrared remote control unit the occupant can overrule the centrally realised action and open/close the motorised windows according its own wishes. This system is very suitable for night ventilation. Developments are going on to add more functions to this system (indoor temperature control with a timer and precipitation sensor for the outdoor sun shading device).

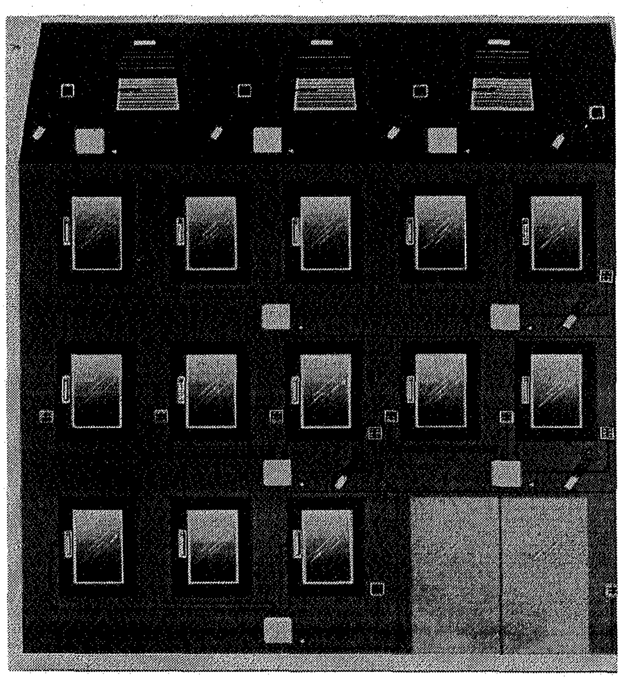


Figure 12 Window Master

6. Control strategies for night cooling

A review of hardware components for night cooling is not complete without mentioning the control strategies. To mention some strategies that includes night cooling: predictive control, cooling day control, setpoint control, slab temperature control and degree hour control

6.1 Predictive control strategy [8]

Only in the summer the pre-cooling mode of the predictive controller is activated. This is done by a mathematical model that is identified from the measured data. With this model and the weather prediction, it calculates at what time the windows must be opened at night in order to cool the building in such a way that it will not be too hot the next day. Afterwards the prediction is compared with the real condition and the next prediction is adapted to these results. Wind and rain interlocks are utilised to prevent water ingress and damage due to high air velocities. A low external temperature interlock (e.g. 12 ^{0}C) is also provided.

6.2 Cooling day control strategy [2]

The predictive control can be simplified by using a rule based prediction: There are 2 setpoints, the upper temperature setpoint , θ_{SPH}, is for cooling, and the lower temperature setpoint, θ_{SPL}. is for heating, The strategy is based on the occurrence of a cooling day. This is defined as the day, that the indoor temperature during working hours exceeds θ_{SPH}. When a cooling day is detected, the windows are opened for night cooling. They are closed when the indoor temperature drops below the night setpoint temperature, $\theta_{SPH-night}$. If this is the second cooling day, $\theta_{SPH-night}$ is decreased one step, f.i. form 24 to 23 ^{0}C. If the same cooling situation occurs the next day, then $\theta_{SPH-night}$ is decreased again until finally the minimum value of $\theta_{SPH-night}$ = 18 ^{0}C is reached. When there is no cooling day, $\theta_{SPH-night}$ will be increased step by step until 24 ^{0}C is reached again. The windows stay closed.

Wind and rain interlocks are utilised to prevent water ingress and damage due to high air velocities. A low external temperature interlock (e.g. 12 ^{0}C) is also provided.

6.3 Setpoint control [13]

The mean outdoor temperature for a specific time interval during the afternoon is determined. In the event that this is above the "precool initial setpoint" (e.g. 20 ^{0}C) and the indoor temperature is greater than the outdoor temperature, precooling will starts after office hours. This will continue until the zone temperature drops to the minimum allowable space temperature, say 16 ^{0}C. All inlet and outlet vents will be closed. Due to the passive heating process of the building the indoor temperature rises again, say to 19 ^{0}C, at which point the inlet and outlet vents are again opened. This cooling and heating process continues until such time as the "preheat" period is reached. Wind and rain interlocks are utilised to prevent water ingress and damage due to high air velocities. A low external temperature interlock (e.g. 12 ^{0}C) is also provided to prevent any risk of condensation.

6.4 Slab temperature control strategy [13]

This precooling strategy aims to cool the slab to a predefined slab temperature setpoint during the night in order to offset the heating gains of the next day. This strategy is applicable for mixed-mode operation. In the event that the space temperature is more than, say 0.5 ^{0}C above the cooling setpoint (e.g 23 ^{0}C), passive cooling utilising the casement windows will be maintained in order to reduce the internal space temperature. This amount of cooling is controlled by the internal air temperature. At a predetermined time, and providing that the building is to be occupied the following day, the slab temperature is compared with the required slab temperature setpoint and if this is higher, then the slab cooling will commence. Passive cooling is initially used to facilitate cooling of the slab and this is controlled by the slab temperature setpoint. Wind and rain interlocks are utilised to prevent water ingress and damage due to high air velocities as well as a low external temperature interlock (e.g. 12 ^{0}C) to prevent any risk of condensation.

In mixed-mode control, if at the start of the low electricity tariff period the slab temperature has not achieved the slab setpoint, the time is calculated that the fan assisted cooling is enabled in order to achieve the slab temperature setpoint by the end of the low tariff period. If the building is to be unoccupied for more than 24 hours then at the end of the occupancy period all the plant will shut sown. Natural ventilation will be employed to maintain the space temperature conditions. At say, 18:00 hours before the next occupancy period, the precooling strategy detailed above is initiated for slab cooling.

6.5 Degree hours control strategy [13]

This precooling strategy aims to maintain the equilibrium between the building fabric temperature and the space temperature. The daytime heat gains is estimated by measuring the degree hours of heating. This is defined as the number of hours that the temperature is above the chosen setpoint, totalled for all the hours in the period. The decision as to precool or not is based upon the number of hours that the internal temperature is above the room temperature setpoint. If at the end of the occupied period the degree hours are greater than say, three degree hours and the internal temperature is greater than the external temperature then the decision is made to precool the building during that night. Normal wind and rain interlocks still apply as well as the provision that the external temperature is above the low limit setpoint (12 ^{0}C) to prevent condensation.

7 Conclusions

For natural ventilation cooling much higher ventilation air flow rates are required then necessary for refreshing the indoor atmosphere. Because of comfort requirements, these air flow rates are always possible during working hours in an office. During office off hours, these restrictions do not apply anymore and higher air flow rates are allowed. However, other dangers, such as burglary, rain and dust ingress have to be accounted for.

For natural ventilation cooling, the same components can be applied as for traditional ventilation. But to obtain optimal benefits from night cooling, automatic control is essential. For this actuators and control systems are important hardware.

New developments are the electronic trickle ventilators, actuators with rod, chain or a mechanism to the windows and integrated ventilation systems

Control strategies for integrated systems such as predictive control, cooling day control, setpoint control, slab temperature control, degree hour control, are under development.

Acknowledgment

This work is part of the Pan-European NatVent^{TM} project funded in part by the European Commission under the JOULE-3 program and coordinated by the Building Research Establishment Ltd (BRE-UK). The participating organizations are: Belgian Building Research Institute (BBRI-B), TNO Building & Construction Research (TNO-NL), Danish Building Research Institute (SBI-DK), J&W Consulting Engineers AB (J&W-S), Willan Building Services (Willan-UK), Sulzer Infra Laboratory (Sulzer-CH), Delft University of Technology (TUD-NL) and Norwegian Building Research Institute (NBI-N).

Reference

[1] Paassen, A.H.C. van, P.J. Lute, Performance and feasibility of Passive Climate Systems, Proceedings Clima 2000, November 1-3, 1993, London, Great Britain

[2] Paassen, A.H.C. van, P.J.M. van Galen, Rules for Cooling through Motorized Vent Windows, Proceedings of the 19th International Congress of Refrigeration, August 20-25, 1995, The Hague, The Netherlands, volume IVb, page 1089 -1096

[3] Bansal, N.K., G. Hauser, G. Minke, Passive Building Design, Elsevier Science B.V., The Netherlands, 1994

[4] Paassen, dr. ir. A.H.C. van, ir. S.H. Liem, ir. P.J.M. van Galen, Veldtest Passief Klimaatsysteem, report K-207, TU Delft, Maart 1995

[5] Galen, P.J.M. van, Automatische raamopeningen als bruikbaar onderdeel van de klimaatbeheersing, report KK-1070, TU Delft, Juli 1994

[6] Cotting, René, Night Cooling, the Swiss report, Smart components and Intelligent Control Systems for Night Cooling, Sulzer Infra, Winterthur, April 18, 1996

[7] Brunsell, Jørn, Trygve Hestad, Report Natvent, Activity 3.4, Night cooling, report from Norway, Norwegian Building Research Institute, Oslo, June 16, 1996

[8] Lute, P.J. The Use of Prediction in Temperature Control in Buildings, a Passive Climate Application, PhD thesis, TU Delft, WbMT, Koudetechniek en Klimaatregeling, 1992.

[9] Liem, S.H., A.H.C. van Paassen and R.J.W. Kouffeld, Digital control system for Extreme Low Energy Apartments, Proceedings of the 19th International Congress of Refrigeration, The Hague, NL, August 20-25, 1995

[10] Martin, A.J., Control of Natural Ventilation, TN 11/95, BSRIA, June 1995, ISBN 0 86022 406 6

[11] Fletcher, J., Martin A.J., Night Cooling Control Strategies, Technical Appraisal 14/96, BSRIA, UK, September 1996

[12] Kolokotroni, Maria and Steve Hayes, Detailed Design Tools Night Cooling for Commercial Buildings Control Strategy, IEA Annex 28, Subtask 2

[13] Kolokotroni, Maria, contribution of BRE for Natvent WP 3.4, Building Research Establishment, London, June 12, 1996

[14] Kolokotroni, M, Webb B.C. and Hayes S.D. , Summer cooling for Office-Type Buildings by Night Ventilation, 17th AIVC Conference, Gothenburg, Sweden, 17-20 September 1996.

[15] Zutphen, R.A.J.M., Een regelsysteem voor de Urban Villa, report KK-1017, Laboratory of Refrigeration and Indoor Climate Control, TU Delft, June 1992

[16] Engel, Peter van den, Thermisch Comfort en ventilatie-efficientie door inducerende ventilatie via de gevel, thesis, TU Delft, 1995, ISBN 90-5269-188-6

[17] Webb, B. and Kolokotroni M., Night Cooling a 1950s office, the architects' journal, 13 June 1996.

[18] Van Paassen, A.H.C. and S.H. Liem, The Availability of Hardware suitable for Night-time Cooling and it's Control, Technical Report, Contract JOR3-CT95-0022 (DG 12 - WSME), Joule III, period 1 February - 30 June 1996, Delft, July 1996

[19] Santamouris, Prof. M., PASCOOL CD ROM, University of Athene, Greece