ON A NOVEL APPROACH TO CONTROL NATURAL AND MECHANICAL NIGHT VENTILATION

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ABSTRACT

The aim of the present work is to improve night ventilation control strategies, specially for the mid-season periods where an unadapted control scheme can result in undesirable heat loads. We present a method based on developing an adaptive algorithm suitable for different types of buildings having different thermal masses. The algorithm, mainly based on the history of outside and inside temperatures, is characterized by a set of parameters that we attempt to identify: a coefficient related to building time constant and a couple of fixed set-point temperatures. Results show that the adaptive algorithm was able to *adapt* to the mid-season period, thus preventing unwanted heat loads while preserving remarkable thermal comfort conditions.

INTRODUCTION

Many studies show that high thermal mass coupled to night ventilation is a highly effective passive cooling technique for climates with significant diurnal variation of ambient temperature (Givoni, 1979), (Shaviv, 2001). Indeed, thermal mass activation (TMA) can assure, in certain cases, thermal comfort conditions without the need of mechanical air conditioning systems. However, even if air conditioning systems need to be used, night ventilation will significantly reduce the running time of additional cooling systems. The so-called night ventilation technique can be either natural or mechanical and consists on creating a time lag between the external and internal maximum temperatures: at night, high-ventilation rates will cool-down the thermal mass of the building (walls, floor, ceiling...), which will help reduce the pick indoor air temperatures for the following daytime. This strategy can be more effective if the high-ventilation regime varies intelligently according to outdoor and indoor building conditions. Indeed, numerical simulations show that, in this case, building performance can significantly vary particularly during mild seasons (spring and fall).

The aim of this paper is to develop an adaptive night ventilation control algorithm that is able to ensure thermal comfort, while minimizing the need of air-conditioning systems and preventing unwanted heating demands. After presenting the issues related to classic night ventilation strategy specially for the mid-season period, we detail the development of the adaptive control algorithm and the identification of the different parameters of the algorithm: the building time constant and a couple of set-point control temperatures. Finally, we focus on the impact of this adaptive night ventilation control algorithms by showing the results obtained on a high and a low thermal mass building.

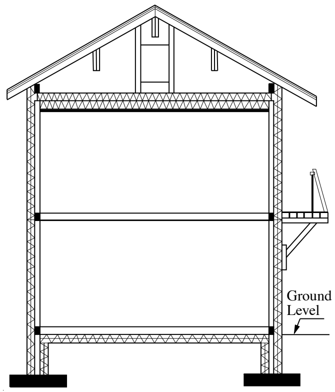

Figure 1: A two-zone building model with concrete and external insulation, INCAS Platform, France

CLASSIC NIGHT VENTILATION MODEL

Impact of night ventilation on summer comfort

To illustrate the effectiveness of night ventilation on annual building energy performance, we considered two different dwellings conception with the same geometry showed in Figure (1) and (2) : a two-storey low-energy consumption house of $100m^2$ net floor area. Daily ventilation rate is constant and equal to 0.6 ACH. The main difference between both houses is the insulation position : in the first one, the insulation layer on the walls and the ground floor is outside. In the other one, the insulation layer is inside. This will indeed have an impact on the thermal mass of the building. In fact, the first house has a significantly higher time constant while having the same U-value.

The envelope characteristics are presented in Table1.

To assess the impact of night ventilation on these houses, 3 modes of ventilation were tested (see table 2). In the 1^{st} Mode , the ventilation rate is constant and equal to 0.6 ACH. In Mode 2, the ventilation rate is 0.6 at daytime and 3 ACH at night from June to August. In Mode 3, the ventilation rate is 0.6 at daytime

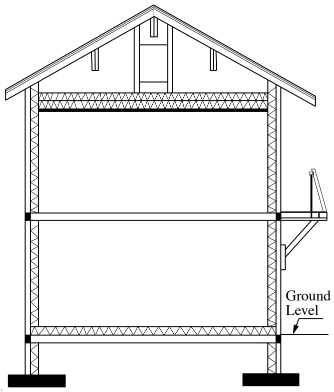

Figure 2: A two-zone building model with concrete and internal insulation

Table 1: Building elements characteristics (house with external insulation)

	Floor	North	South	West	East
Glazing Area (m^2)	1^{st}	0.9	10.0	3.5	1.0
	2^{nd}	0.9	6.0	2.3	1.3
Glazing Type / Characteristics	$1^{st}, 2^{nd}$	Triple glazing	Double glazing		
		U=0.86, g=0.44	U^a=1.3, g^b=0.54		
Walls (Ext→INT)	$1^{st}, 2^{nd}$	20 cm extruded polystyrene, 15 cm high density concrete U = 0.15 $W/m^2.K$			
Ceiling (Ext→INT)	2^{nd}	40 cm Fiber Glass, 1 cm Gypsum Board U = 0.11 $W/m^2.K$			
Floor (Ext→INT)	1^{st}	25 cm extruded polystyrene, 20 cm Hollow-core concrete U = 0.11 $W/m^2.K$			
Mezzanine Floor	–	22 cm high density concrete			

and 3 ACH at night from April to October. Throughout this study, the simulation will be done using the on site measured meteorological data of Chambery in France. Indoor space is heated to maintain indoor air temperature at $19°C$ in winter. Annual primary energy consumption, Q_h $(kWh/(m^2.yr))$ and the sum of discomfort hours OH (h/yr) are evaluated in table 3. OH is the time when the indoor temperature exceeds the comfort temperature T_c.

When night ventilation is applied during the 3 months summer period (Mode 2), it is noticed that overheating periods are drastically reduced for both houses. Extending the night ventilation during mild seasons (Mode 3) still reduce significantly overheating hours but it involves energy demand to increase for about 30% in each house.

This example shows that even during early and lately summer periods, there is a need in exploitation of night ventilation to passively reduce peak cooling loads. In addition, to make the ventilation strategy more efficient, it requires an algorithm to make a decision according to outdoor/indoor conditions and building thermal mass for the need of a night activation process.

Table 2: Classic ventilation modes tested

	Mode 1	**Mode 2**	**Mode 3**
Lower flow rate ACH	0.6	0.6	0.6
Higher flow rate ACH	0.6	3.0	3.0
Starting day	–	Jun 1^{st}	Apr 1^{st}
Ending day	–	Aug 31	Oct 31
Starting hour	–	10:00 pm	10:00 pm
Ending hour	–	7:00 am	7:00 am

Table 3: Simulation results for the high and the low thermal mass buildings for classic ventilation modes 1, 2 and 3

	Ventilation mode		
House with external insulation	**1**	**2**	**3**
Energy consumption $[kWh/(m^2.yr)]$	45.3	47.4	68
Sum of hours when $T_i > T_c$ $[h/yr]$	1146	39	0
	Ventilation mode		
House with internal insulation	**1**	**2**	**3**
Energy consumption $[kWh/(m^2.yr)]$	48.3	50.5	72
Sum of hours when $T_i > T_c$ $[h/yr]$	1388	323	151

Assessment of thermal comfort

The way people react with thermal indoor environment is extremely complicated and depends on several conditions. A number of these parameters are part of the thermal comfort concept defined as the condition of mind which expresses satisfaction with the thermal environment (ISO7730, 1994). Several methods exists to "measure" thermal comfort, but we will use the "adaptive" approach where comfort temperature is closely related to the prevailing outdoor temperature, and could be expressed by the following equation (McCartney, 2002):

$$T_c = aT_{RM} + b \quad (1)$$

Where T_c is the comfort temperature (°C), T_{RM} is the running mean temperature (°C) and a, b are constants to be determined experimentally. In a EU-funded project: Smart Controls and Thermal Comfort (SCAT's) (SCATS, 2001), an adaptive control algorithm was developed, and data were provided for the evaluation of both constants "a, b", and it was found out that for France (McCartney, 2002):

$$T_c = 0.049T_{RM} + 22.58 \quad T_{RM} \leq 10\,°\mathrm{C} \quad (2)$$

$$T_c = 0.206T_{RM} + 21.42 \quad T_{RM} > 10\,°\mathrm{C} \quad (3)$$

where T_{RM} is given by the following equation :
$T_{RM_n} = 0.8T_{RM_{n-1}} + 0.2T_{DM_{n-1}}$ and T_{DM} is the daily mean temperature on day n-1 (°C).

ADAPTIVE VENTILATION MODEL

Night ventilation control algorithm

The adaptive control algorithm takes in consideration the thermal mass of the building and the history of outside and inside temperatures to control internal temperatures. The concept based on running mean temperature is similar to half-life decay calculations in nuclear physics and medicine and is expressed as

$$T_{RMn} = cT_{RMn\text{-}1} + (1-c)T_{DMn\text{-}1} \quad (4)$$

where T_{RMn} is running mean temperature on day *n* (°C), T_{RMn} running mean temperature on day *n-1*,

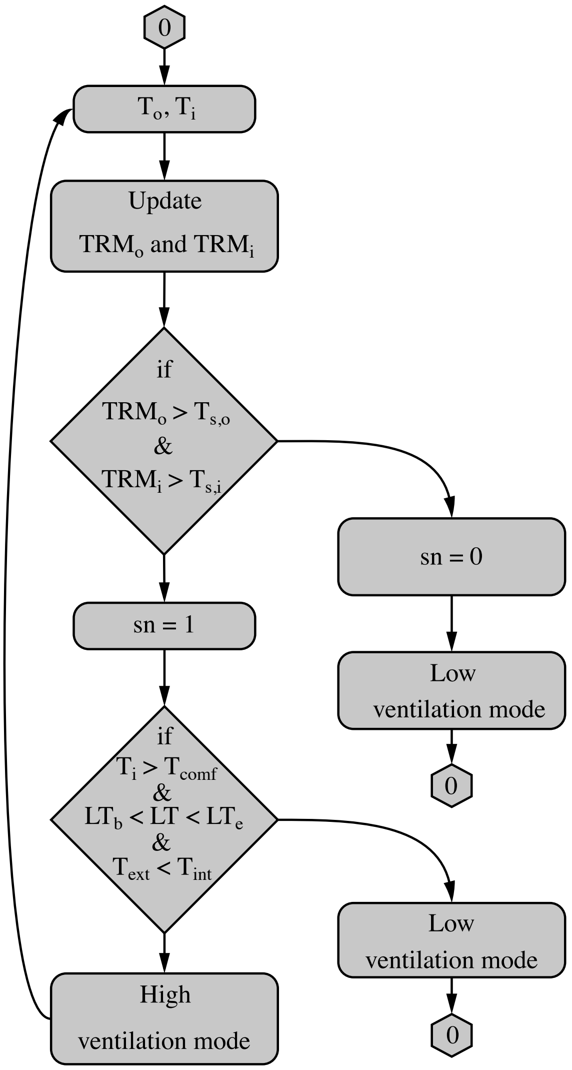

Figure 3: Adaptive algorithm procedure

T_{DMn} daily mean temperature on day *n-1* and *c* a constant.

The value of constant *c* is between 0 and 1 and defines the quickening response of the running mean changes in temperature.

For the adaptive control algorithm, we will evaluate both outside and inside running mean temperature TRM_o and TRM_i corresponding respectively to the outside and inside air temperature T_o and T_i. And depending on the values of TRM_o and TRM_i and a set of complementary criterias, we will select a proper night ventilation mode.

The procedure is described in Figure (3). For every time step of the simulation, TRM_o and TRM_i are compared to fixed setpoint control temperature values related to those mean running temperature, respectively $T_{s,o}$ and $T_{s,i}$in °C.

If the conditions are satisfied, variable sn will be set to 1 otherwise sn is equal to 0 and the low ventilation mode is selected. In fact, variable sn defines the time span when high ventilation rates could be activated. In case $sn = 1$, the following needs to be considered:

- when the condition $TRM_o > T_{s,o}$ and $TRM_i{>}T_{s,i}$ is satisfied, if T_i exceeds adaptive comfort temperature T_c, the variable sn is equal 1. Then, only when the Local Time (LT) belongs to the specified maximum interval [TL_b;TL_e], the high ventilation rate is activated. TL_b and TL_e define the night ventilation beginning and ending hours of the nighttime cooling period. For this study, TL_b and TL_e are constant and equal to $10h$ pm and $7h$ am.
- if the condition $TRM_o > T_{s,o}$ and $TRM_i{>}T_{s,i}$ is not satisfied, sn is equal to 0 and the low ventilation is still activated.

Assessment of the coefficient c according to building time constant

As mentioned previously, the value of constant c defines the quickening response of the running mean changes in temperature. The 'half-life' (HL) in days of a particular running mean temperature is approximately (McCartney, 2002)

$$HL = 0.69/(1 - c) \quad (5)$$

The greater the value of c, the longer the half-life HL, or reaction of the running mean temperature TRM_o/TRM_i to a change in outside/inside conditions. In this work, we choose to evaluate building Time Constant and use it as a reference for the value of constant c_i that will be used to determine TRM_i.

Different parameters and tools were found for describing the thermal mass effects in numerical simulation (Balaras, 1996), (Hoffman, 1981), among these, the *admittance factor* and the *Diurnal Heat Capacity* (Balcomb, 1992).

Givoni (Givoni, 1981) and Hoffman (Hoffman, 1981) introduced the total thermal time constant of a Building that was derived from the analogy between the heat flow through the building's materials represented by a thermal circuit and the time constant of an electric circuit, as a single parameter that can be used for evaluating the thermal performance of a building.

Building Time Constant (τ) is defined as the heat stored in the whole enclosure, including internal air, per unit of heat transmitted to or from the outside through the elements by ventilation.

Evaluation of the time constant τ is useful not only for the thermal design of buildings and the selection of building materials, but also for the design of cooling passive methods considering thermal storage and insulation properties also.

Simplified method In un-air conditioned buildings, envelope element thermal mass is effective for dampening the wide range temperature fluctuation from the outdoor and maintaining the indoor air temperature within a comfortable range (Asan, 1998).

The Thermal Time Constant of a building element is the sum of the products of heat capacity, Q, and the resistance, R, of the different layers in the element (Givoni, 1979).

Considering a n-layer wall, the QR value of the $j-th$ layer counted from the external surface is

$$(QR)_j = [1/h_0+(1/k)_1+...+((1/2)/k)_j]*(e*\rho*c)_j \quad (6)$$

The (QR)-value of the building element is the sum of the n layers (QR)-values

$$(QR)_e = \sum_n (QR)_j \quad (7)$$

and its total heat capacity Q_e in Wh/K can be expressed as

$$Q_e = \frac{(QR)_e}{\sum_n (\frac{e_j}{k_j})} \quad (8)$$

The total Building Heat Capacity (BHC) in J/K is the amount of energy stored within the building per degree temperature difference maintained between indoor and outdoor. The BHC is considered like the sum of the m-elements heat capacities Q_e and the indoor air heat capacity.

$$BHC = \sum_m Q_e + (\rho c_p)_a * V_i \quad (9)$$

where $(\rho c_p)_a$ is the product of air density by air heat capacity and V_i is the volume of indoor space.

The total Building Heat Loss coefficient BHL in W/K representing the rate of indoor space heat loss per degree temperature difference between indoor and outdoor temperature is expressed as

$$BHL = \sum_m (UA)_e + q_a * (\rho c_p)_a \quad (10)$$

where $(UA)_e$ is the heat loss coefficient of an element "e" and q_a is the ventilation rate in ACH.

We considered the Building Time Constant as the ratio of the Building Heat Capacity BHC over the Building Heat Loss coefficient BHL

$$\tau = \frac{\sum_m Q_e}{\sum_m (UA)_e + q_a * (\rho c_p)_a} \quad (11)$$

This simplified approach could be useful for a fast estimation of building thermal response relative to outdoor fluctuation.

Dynamic method The time constant τ is evaluated with inside temperatures predicted from a numerical model thermal response. This model is using finite difference method to solve a set of coupled differential equations expressing transient one-dimensional

Table 4: Building Time Constants for external and internal insulation houses

τ (Days)		Method 1	Method 2
House 1 : H-EI	zone 1	12.1	9.9
	zone 2	7.1	5.9
House 2 : H-II	zone 1	2.3	1.9
	zone 2	2.3	1.9

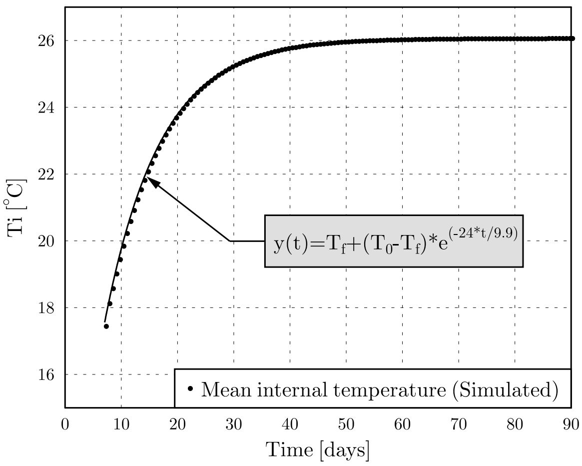

Figure 4: Least-squares fits of Equation 12 to the predicted indoor temperature variations for the house with external insulation zone 1.

heat conduction in the various multi-layer elements of building envelope. These equations are coupled with the indoor thermal energy balance, which includes heat flows from all building surfaces exterior and interior walls. Convection, short-wave and long-wave radiation heat exchange on wall surfaces were considered. This simulation tool is developed and solved in the environment simulation SimSPARK (Chahwane, 2009), (Stephan, 2010), (LBNL, 2003).

Building time constant is obtained by performing a least-squares fit of Equation 12 with the indoor temperature variation T_i resulting from the building simulation model when an outside temperature unit pulse is applicated. Minimization of Equation13 leads to the building Time Constant.

$$y(t) = T_f + (T_0 - T_f) * e^{(-24*t/\tau)} \quad (12)$$

$$Err(t) = \sum T_i - [T_f + (T_0 - T_f) * e^{(-24*t/\tau)}] \quad (13)$$

T_0 and T_f are initial and final building indoor temperature before and after the outside temperature fluctuation.

Time constant calculation results with the 2 methods on the houses are shown in Table 4 and display a good agreement in the prediction on building thermal response. Therefore, we will use in this study the first method to simplify the algorithm assessment procedure.

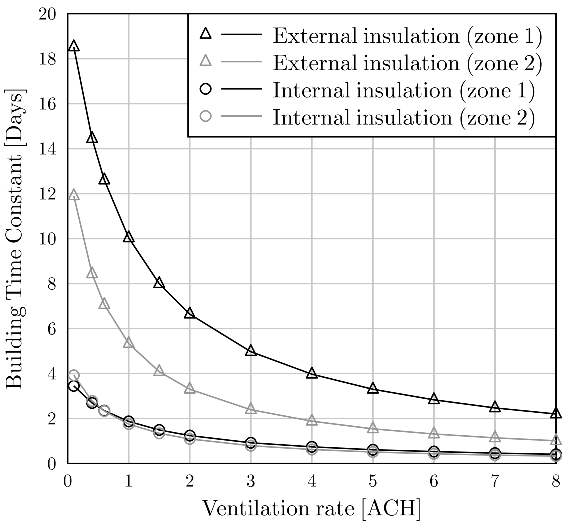

Figure 5: Effect of ventilation on building Time Constant

Table 5: ***Values of*** c

Variable	Related temperature	'c' value
c_o	T_o : outside temperature	0.72
$c_{i,ei}$	$T_{i,ei}$: room temperature for external insulation case	0.72
$c_{i,ii}$	$T_{i,ii}$: room temperature for internal insulation case	0.19

Selection of c_i value To determine the value of c_i which enters in TRM_i calculation, we set the half-life for an inside condition fluctuation equal to the value of the building Time Constant during high ventilation mode. Actually, the building Time Constant evolves with the ventilation rate as shown in Figure (5) : τ decreases when the ventilation rate becomes higher. When the building is under high ventilation mode (3 ACH), τ will be respectively 2.5 days for the external insulation and 0.85 days for the internal insulation house. The Time Constant relative to zone 2 is chosen for the external insulation house to consider the worst case. In the internal insulation house, time constant is the same for the 2 zones. Selected values of c are shown in table 5.

To determine the value of c_o relative to TRM_o calculation, we set the half-life HL for an outside weather condition change equal to 2.5 days.

Evaluation of setpoint control values ($T_{s,o}$; $T_{s,i}$)

Parametric study In this section, we try to define a couple ($T_{s,o}$; $T_{s,i}$) for which the adaptive control of night ventilation is optimized. The analysis is based on the minimization of the following criteria :

- the sum of overheating hours, OH (h/yr).
- the sum of hours when heating and night ventilation work simultaneously, X_s (h/yr).
- the annual night ventilation electric consumption, Q_{el} (kWh/yr) in the case of a mechanical night ventilation.

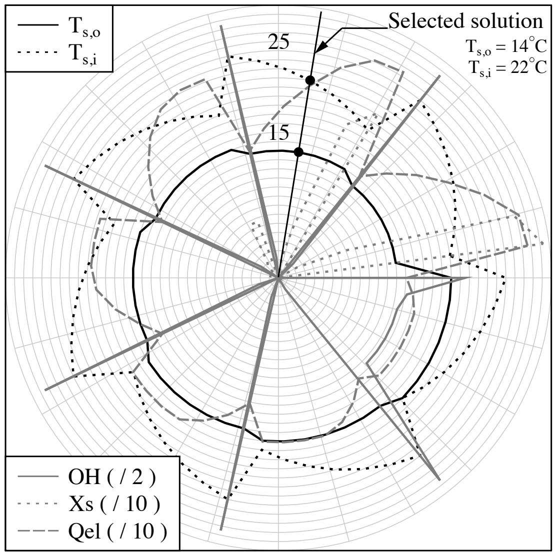

Figure 6: Effect of $T_{s,o}$ and $T_{s,i}$ on the external insulation house energy performance

The diagrams of Figure (6) and (7) show the values of OH, X_s and Q_{el} resulting from a parametric analysis on $T_{s,o}$ and $T_{s,i}$. For every variation of $T_{s,o}$ between 13°C and 19°C, $T_{s,i}$ varies from 19°C to 25°C.

Selection of an optimized solution For the external insulation house, OH is almost always equal to zero except in the case where $T_{s,i}$=25 °C with any value of $T_{s,o}$ between 13 and 19 °C and $T_{s,o}$=19 °C with any value of $T_{s,i}$ between 19 and 25 °C (see Figure (6)).

As expected, there are configurations of $T_{s,o}$ and $T_{s,i}$ for which the heating and night ventilation are working simultaneously. For the house with external insulation, it is noticed for (13;19), (13;20), (14;19), (14;20) and (15;19). For the external insulation house, many couples of $T_{s,o}$ and $T_{s,i}$ satisfies the solution OH=0 and X_s=0.

In the case of the internal insulation house, several combinations satisfy X_s=0 but OH becomes very important. Provided that the priority is the comfort criteria, low values of X_s are tolerated. According to these assumptions, the solution ($T_{s,o} = 14$;$T_{s,i} = 22$) seems the most appropriate ; in this case OH is less than 140.

The solution couple ($T_{s,o} = 14$; $T_{s,i} = 22$) is common for the 2 houses, and then, convenient for both low and a high thermal mass building. Consequently, it is interesting for the development of a control algorithm, because of its adaptability of different building thermal mass type. The only parameter that will be needed to be determined is the constant "c" that will depend on the building time constant.

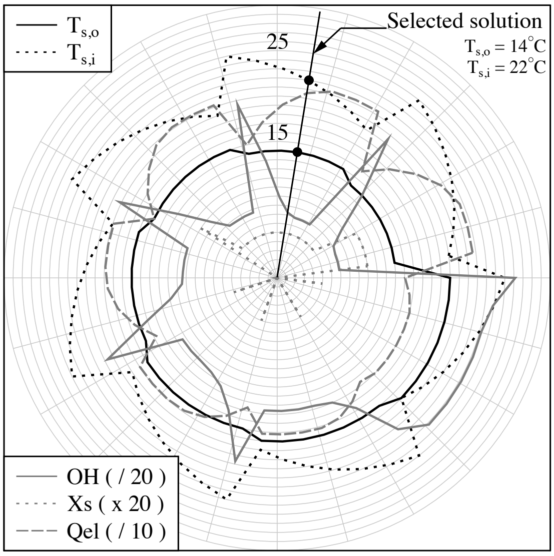

Figure 7: Effect of $T_{s,o}$ and $T_{s,i}$ on the internal insulation house energy performance

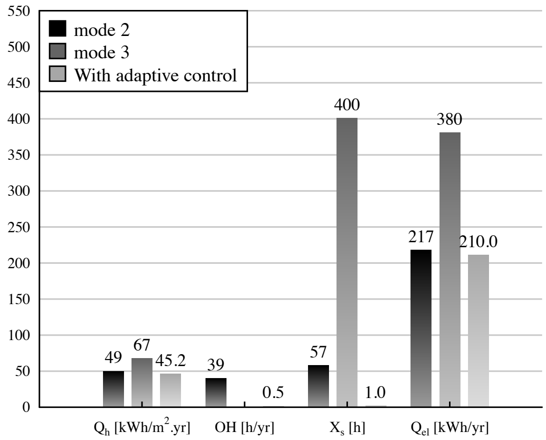

Figure 8: Comparison between adaptive and classic ventilation modes in a high thermal mass building

COMPARISON BETWEEN CLASSIC AND ADAPTIVE METHOD

Annual building performance evaluation

Figure (8) and Figure (9) present simulation results of the adaptive control and classic night ventilation modes 2 and 3.

In both houses, adaptive control shows the same comfort conditions than mode 3 with an energy demand reduction of 30% comparing to mode 2 and 10% to mode 3. In the case of the internal insulation house, it ensures up to 57% less discomfort hours than classic modes. The period X_s of simultaneous heating and high ventilation totally disappears. If the night ventilation is mechanically driven, we notice that the electric power demand is 45% lower comparing to mode 3.

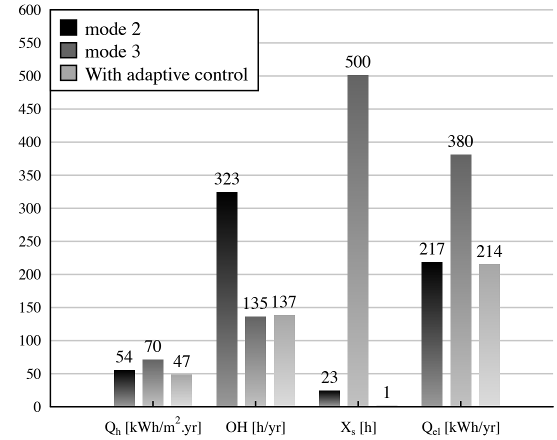

Figure 9: Comparison between adaptive and classic ventilation modes in a low thermal mass building

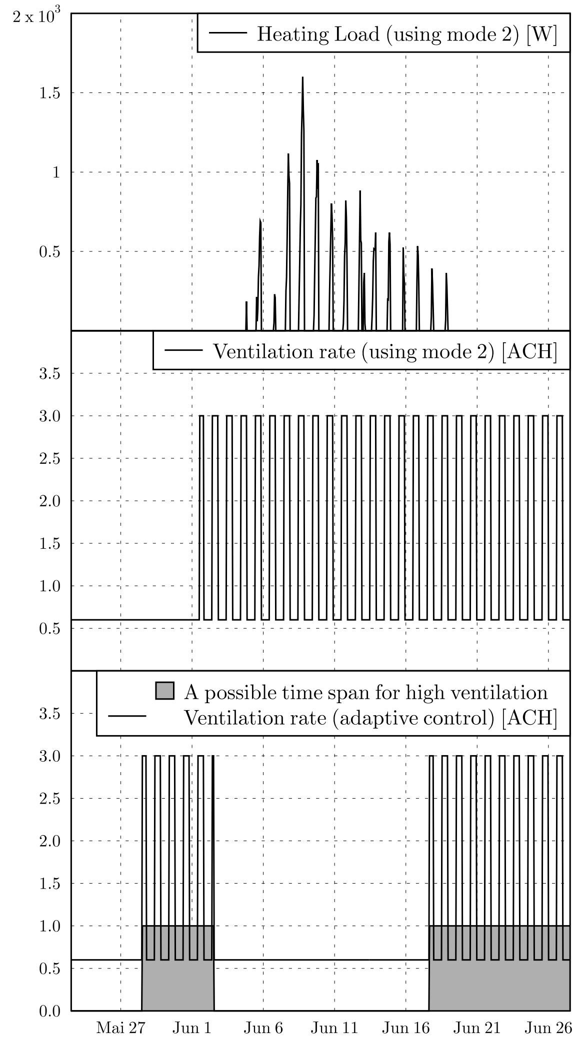

Figure 10: Comparison of the ventilation rate between adaptive and classic ventilation mode 2 in the high thermal mass building during a mid-season period

Mid-season building performance

In Figure (10), we compare the ventilation rate in the case of an adaptive control mode and the classic mode 2 for the high thermal mass building from June 1st till June 26. In the graph at the bottom, variable 'sn' delimits the gray area representing the intervals where high-ventilation mode could be activated if the conditions on TL, T_i and T_o are to be satisfied. The graph in the middle shows the ventilation rate for the classic ventilation mode 2 and the graph at the top illustrates the corresponding evolution of heating demand. We notice that, for the classic ventilation case (mode 2), the heating load from 6 to 21 of June is not negligible and could be avoided with the use of the adaptive control algorithm. In fact, we can clearly see that the variable 'sn' took the value '0' from June 2 to June 16 thus preventing the activation of high night ventilation rates and, therefore, prevent the unnecessary triggering of heaters.

In Figure (11), we will consider the case of the internally insulated building with a low time constant. Starting from the bottom of figure 11, the first graph delimits the intervals where the high ventilation is feasible and shows the evolution of the ventilation rate for the adaptive control. The second graph illustrates the corresponding heating load. The following chart shows the ventilation pattern for mode 3 and the graph at the top trace the evolution of relative heating demand. We clearly identify the fact that using mode 3 induces consequent heating demand during the mid-season period, whereas the application of the adaptive control scheme eliminates the periods with concomitant night ventilation and heating load. Besides, for the periods extending from the first till the 11th of October, setting variable 'sn' to zero prevents the activation of high-ventilation mode resulting in low-heating demand (4 times lower than the case with the classic control). On the other hand, we can point out that the frequency and the extent of high ventilated nocturnal periods could diminish in the case of an adaptive ventilation compared to mode 3. This is mainly due to the fact that, even if 'sn' is equal to one, the internal temperature Ti could be lower than $\mathrm{Tc} - 3$ causing the algorithm to switch to low-ventilation mode.

CONCLUSION

A method has been established for the development of an adaptive algorithm to control night ventilation for different types of building thermal mass in order to improve the effectiveness of this passive cooling strategy. After assessing thermal comfort adaptive criteria, we defined the structure of the algorithm based on indoor and outdoor running mean temperature evaluation. By estimating the building time constant with 2 different methods, we could determine the constant weighting the influence of external and internal temperature fluctuation entering in the algorithm process. Secondly, by

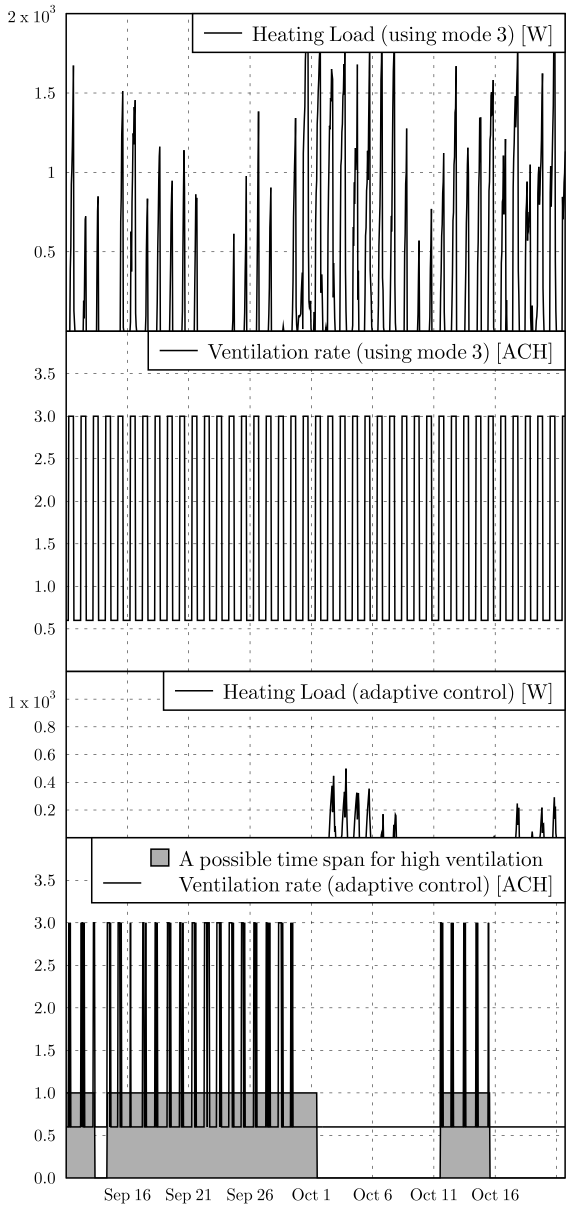

Figure 11: Comparison of the ventilation rate between adaptive and classic ventilation mode 3 in the low thermal mass building during a mid-season period

a parametric study, we could identify the more suitable couple of control running mean temperature setpoint adapted for a low and a high thermal mass building. Finally, a comparison with a classic night ventilation showed that besides feasible energy savings, the algorithm was effectively able to identify the periods where the night ventilation should be activated in the building and the periods where it shouldn't, thus limiting drastically concomitant night ventilation and heating load hours. A main advantage of such algorithm is that after determining the couple of setpoint temperatures that are mostly depending on the climate, the only parameter that will be needed to be determined is the constant "c" related to the building time constant. Results show that the adaptive algorithm was able to *adapt* to the mid-season period thus preventing unwanted heat loads while preserving very good thermal comfort conditions.

NOMENCLATURE

τ	Building time constant [h]
t	Time [Days]
T	Temperature [°C]
T_{DM}	Daily mean temperature [°C]
T_{RM}	Running mean temperature [°C]
LT	Local Time [h]
LT_b	Starting hour for night ventilation mode
LT_e	Ending hour for night ventilation mode
e_j	Thickness of the j-th layer of a building element [m]
k_j	Thermal conductivity of the j-th layer of a building element [W/m.K]
h_o	Heat convection coefficient at the exterior surface [W/m^2.K]
QR_j	Product of heat capacity by the thermal resistance of an element layer 'j' [s]
QR_e	Total value of (QR) for a building element [s]
Q_e	Heat capacity of building element "e" [Wh/K]
UA_e	Heat loss coefficient for element "e" [W/K]
$(\rho C_p)_a$	Heat capacity of Air [J/m^3.K]
q_a	Ventilation rate [ACH]
Q_h	Annual primary energy consumption [kWh/m^2.yr]
Q_{el}	Annuel electric consumption for mechanical night ventilation [kWh/yr]
Xs	Number of hours when heating and night ventilation are activated at the same time [h]
OH	Sum of hours where T_i exceeds the comfort temperature [h/yr]
BHL	Building heat loss coefficient [W/K]
BHC	Building heat capacity [J/K]

Subscripts

i, o	Indoor respectively Outdoor condtions
s	Set point

REFERENCES

H. Asan, Effects of Wall's thermophysical properties on time lag and decrement factor, Energy and Buildings 28 (2006).

H. Asan, Investigation of wall's optimum insulation position from maximum time lag and minimum decrement factor point of view, Energy and Buildings 32 (2000).

J.D. Balcomb, Passive Solar Buildings, MIT Press 8-9 (1992).

C.A. Balaras, The role of thermal mass on the cooling load of buildings. An overview of computational methods, Energy and Buildings 24 (1996).

Blondeau, Night ventilation for building cooling in summer, Solar Energy 61 (1997).

Chahwane, Using an inverse method to evaluate envelope thermal properties, 11th IBPSA Conference, Glasgow, Scotland, July 27-30, 2009.

B. Givoni, Climate considerations in Building and Urban Design, John Wiley and sons (1998).

B. Givoni, Man, Climate and Architecture, Applied science, London (1981).

E. Hoffman, Calculation of the thermal response of buildings by the total thermal time constant method, Building and Environment 16 (1981).

ISO7730, Moderate Thermal Environments- Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort, Geneva, 1994.

EN15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, 2006.

LBNL, SPARK 2.0 reference manual, Lawrence Berkeley National Laboratory and Ayres Sowell Associates Inc, 2003.

K.J. McCartney, Developing an adaptive control algorithm for Europe, Energy and Buildings 34 (2002).

J.F. Nicol, K.J. McCarteney, SCATS: Final Report to Task 2. Oxford Brookes University , UK, 2001b.

E. Shaviv, Thermal mass and night ventilation as passive cooling design strategy, Renewable Energy 24 (2001).

L. Stephan, Optimizing opening dimensions for naturally ventilated buildings, Applied Energy 88 (2010).