Improving energy performance of buildings using the controlled buildings envelopes

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ABSTRACT

The paper is devoted to the analysis of possibility for construction of low energy buildings with envelopes controlled for minimization of energy consumption by air conditioning systems. It describes the possibilities to reduce energy consumption of large public buildings mainly in summer time when there are the highest electricity demands for cooling. The paper proposes constructive suggestion to create buildings whose walls, roofs and glassed surfaces have changeable thermal characteristics and methodology of control for separate elements. Building energy performance simulation models during the whole year allow choosing optimal characteristics of building envelope on the basis of annual heat consumption. The paper analyses the impact of building envelope thermodynamic characteristics on the parameters of supply air in air conditioning systems. It describes the change modes of thermal resistance, resistance to water vapour transfer and resistance to solar radiation considering the different states of inside and outside air conditions.

KEYWORDS

Regulation, buildings envelope, energy performance, modelling.

INTRODUCTION

Traditionally low energy buildings are supposed to have maximally big thermal resistance of building envelope. In reality big thermal resistance is justified only in coldest winter days in countries with cold climate or in hot summer days with intensive solar radiation. In other periods buildings with full air conditioning would have to have different properties of building envelope that could allow heat flow in one or another direction. There are also periods when minimal resistance to vapour transfer is required. Sometimes the building envelope is needed only to prevent from rain, insects or to give the intimacy and it is not needed from the point of energy efficiency, as it does not have to form the shield against the heat or vapour flow(Todorovic 2004).

The fact is known to the scientists who use simulation of building energy performance during the whole year. Building energy performance simulation models allow choosing optimal characteristics of building envelope on the basis of annual heat consumption. The model described in this paper would help to optimise building energy performance even more on the condition that we can change the properties of building envelope.

The properties of real building envelope allow:

1) to minimize heat flow from the inside space to outside environment and vice versa;
2) to minimize or completely prevent vapour transfer across the building structures;
3) to minimize or prevent the influence of solar radiation on the inside space conditions.

The abilities of building envelope to prevent heat flow arousing due to the temperature differences of inside and outside air is characterized by thermal resistance of building stricture R_T, m^2K/W.

The ability of building structure to prevent water vapour transfer is characterized by the resistance to water vapour transfer R_V, $m^2\ h{\cdot}Pa/mg$.

Speaking about the solar radiation there is no common parameter for characterization of the building envelope ability to resist the influence of solar radiation. But this property of building envelope may be shown as resistance to solar radiation R_R. The resistance to solar radiation:

$$R_R = \frac{\Phi_R - \Phi_I}{\Phi_I}, \quad (1)$$

where: Φ_R is heat flow from solar radiation coming to the outer side of building envelope, W; Φ_I is the solar radiation heat flow that got inside, W.

AIR CONDITIONING SYSTEM WORKING REGIMES

In order to ensure optimal comfort conditions of indoor air quality in dwelling buildings the air conditioning system has to consist of the following main parts: heating devices, humidifier, air cooler, control equipment for the automatic regulation of heating devices and air humidity. For the comfortable air conditions the supply air temperature has to be in the *comfort zone* confined in area of temperatures $\theta_{Smin} \ldots \theta_{Smax}$ and air humidity $\varphi_{Smin} \ldots \varphi_{Smax}$. This zone is shown at the *H-x* diagram (Figure 1) and represents the calculated climatic conditions that can be ensured by the previously mentioned regulation facilities of ventilation system(Kreslins 1976).

There are eighth system regulation regimes depending on the conditions of the outdoor air and required indoor air parameters:

1. in the 1st zone the outdoor air parameters match required indoor air parameters so the heating devices and air humidifier are switched off;
2. in the 2nd zone the air is heated by the convector till the minimal required temperature θ_{Smin} if $\varphi_{Smin} \ldots \varphi_{Smax}$ or till maximal relative humidity φ_{Smax} if $\theta_{Smin} \ldots \theta_{Smax}$;
3. in the 3rd zone the air is heated by the convector till enthalpy is H_{Smin} and then it is moisturized till φ_{Smax};
4. in the 4th zone the air is only moisturized till the comfort zone upper level - till φ_{Smin} if $\theta_{Smin} \ldots \theta_{Smax}$ or till θ_{Smax} if $\varphi_{Smin} \ldots \varphi_{Smax}$;
5. in the 5th zone the air is moisturized till moisture content is x_{Smin} and then additionally heated by other heating devices till θ_{Smin};
6. in the 6th zone the air is heated till the maximal possible temperature $\theta_{Tmax} = t_{Tmax}$; moisturized till moisture content is x_{Smin} and then additionally heated by other heating devices till θ_{Smin}
7. in the 7th zone the air is cooled till comfort zone minimal temperature, θ_{Smin} or less in case, when internal heat gains are too high;
8. in the 8th zone air is cooled till X_{Smax} or till X_{Smax} and then additionally heated by heating device till θ_{Smin}.

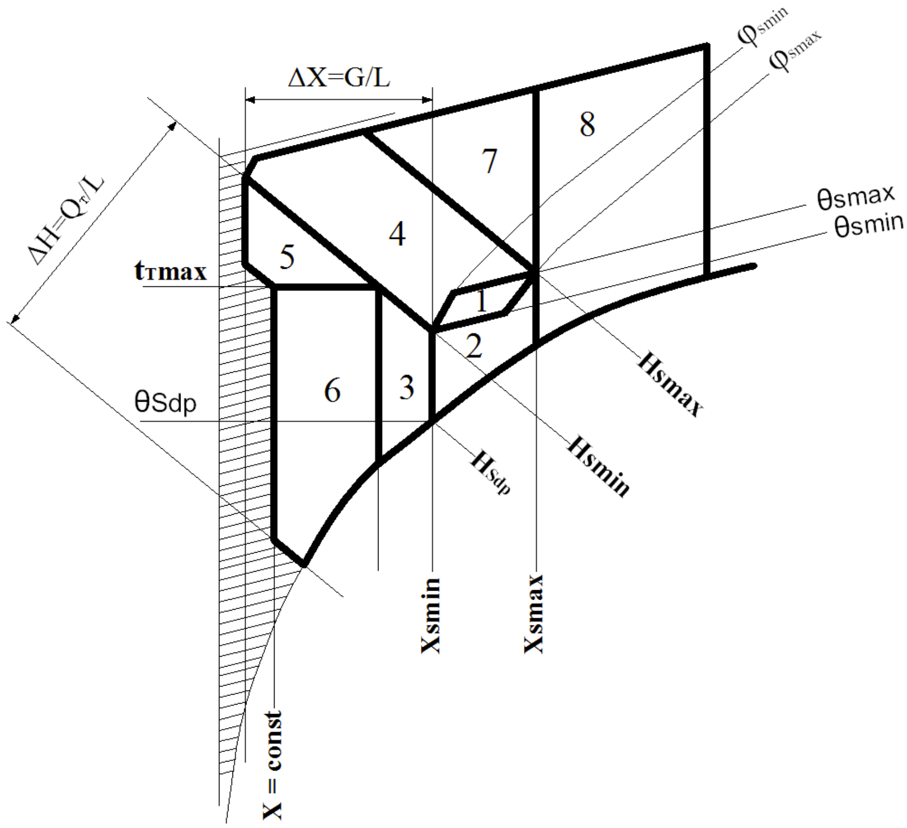

Figure 1The indoor air comfort zone and regulation regimes on H-x diagram(H – enthalpy, kJ/kg; x – moisture content, g/kg; θ – temperature, ºC; φ – relative humidity; Q_T – heat source capacity, kW; G – humidifier capacity, g/s; L - air quantity, kg/s)

IMPROVING OF PERFORMANCE OF AIR CONDITIONING SYSTEM USING BUILDING ENVELOPES WITH CONTROLLED THERMAL RESISTANCE

Building envelopes with controlled thermal resistance can be efficiently used in hot summer periods, when the outside air temperature is much higher than inside air temperature. In such case the classic air conditioning system should work in 8th regime (Figure 3).

In that working regime after the outdoor air cooling (process A-B-C) the heating device heats up supply air till minimal required temperature (C-D) and internal heat gains further heat air till comfort zone (D-E). Although it is possible to reduce heating loads using solar radiation and heat transfer from outside air to inside thought the building envelope in order to heat up outdoor air till minimal required supplying air temperature. For that purpose it is necessary to reduce thermal performance of building envelope and resistance of glazing surface to heat radiation.

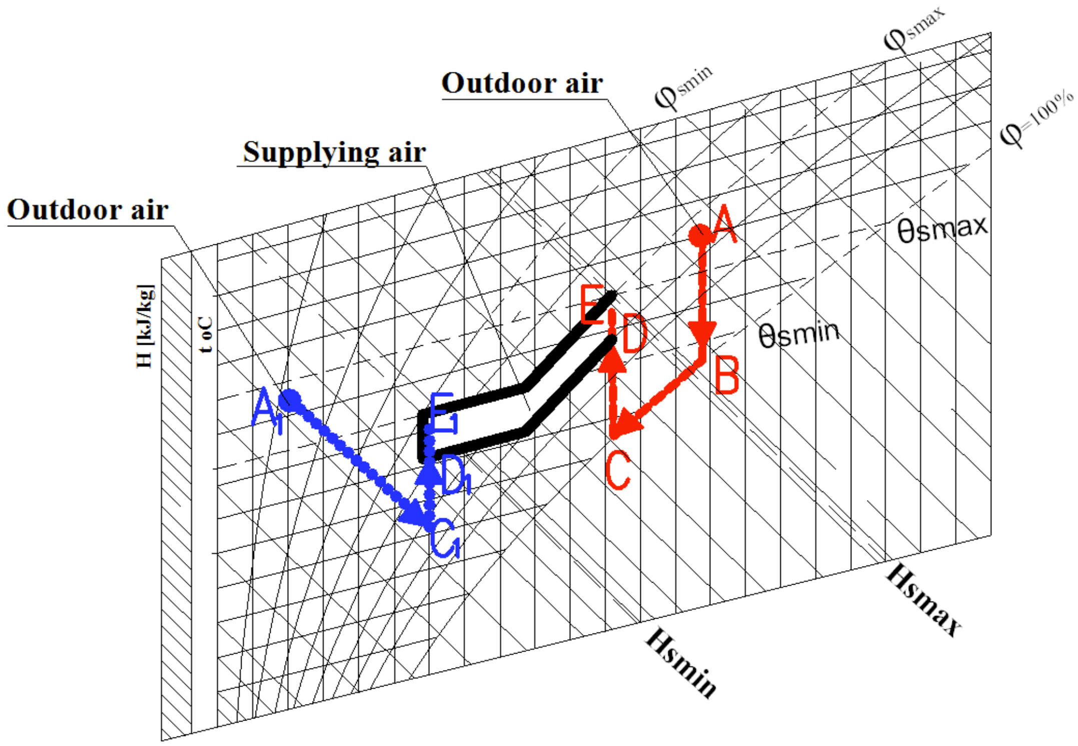

Figure 3 Typical air conditioning working regimes ("dew point regime")

In general the capacity of air conditioning system could be calculated using the following equation:

$$Q_{total} = \Delta H_{cooling} + \Delta H_{heating}, kWh \quad (2)$$

where: ΔH_c – energy consumption for outdoor air cooling, kWh; ΔH_h – energy consumption for supplied air heating, kWh.

In case when external heat gains could be used for supply air heating the energy consumption of air conditioning system for air heating will be equal to external heat gains: $\Delta H = Qe.g$ 3)

The simplified external heat gains could be calculated as follows (ASHRAE 2001):

$$Q_{e.g} = \frac{1}{R} A(\theta_i - \theta_e), kWh \quad (4)$$

where: R - thermal resistance, m^{2}K/W; A – area of building envelope, m^2; θ_i – indoor air temperature, ^{0}C; θ_e – outdoor air temperature, ^{0}C;

On the basis of the before mentioned equation the thermal resistance of building envelope could be calculated:

$$R = \frac{A(\theta_i - \theta_e)}{Q_{e.g}} \text{ m}^2\text{K/W}$$

RESISTANCE AND RADIATION RESISTANCE REGULATION IN IDEAL BUILDING ENVELOPE

If there are heat sources in the inside space and outside air temperature θ_e is lower than inside air temperature θ_θ, to ensure constant inside air temperature the building envelope heat losses has to be equal to the internal heat gains. In that case the thermal resistance of building envelope structures has to be:

$$R_T = \frac{(\theta_i - \theta_e)A}{\Phi}, \; m^2K/W \qquad (6)$$

- where A is area of building envelope structures in m^2; Φ is heat gains or heat losses in W.

If in the same situation with internal heat gains (Φ>0) outside air temperature is higher than internal air temperature, thermal resistance of structures has to be as big as possible (∞), but in case when $\theta_i=\theta_e$, the value of thermal resistance does not matter and it may have any value.
The similar analysis of other possible situations gives an algorithm of change and optimal values of thermal resistance and resistance to solar radiation. The algorithm of changes in values of thermal resistance and resistance to solar radiation is shown in Table 1.

TABLE 1 The algorithm of changes in values of thermal resistance

Outdoor air position	Difference in air parameters	Thermal resistance of building envelope
1	$\theta smin \le \theta_e \le \theta smax$	any
2	$\theta smin \le \theta_e$ and $Xs_{min} \le X_e \le Xs_{max}$	∞
	$\theta smin \le \theta_e \le \theta smax$ and $Xs_{min} \le X_e \le Xs_{max}$	any
3	$\theta smin \le \theta_e \le \theta smax$	∞
4	$\theta_e \ge \theta smin$ and $\varphi_e \le \varphi s_{max}$	∞
	$\theta smin \le \theta_e \le \theta smax$ and $\varphi_e \le \varphi s_{max}$	any
5	$\theta_e \ge \theta smin$ and $X_e \le Xs_{min}$	0
6	$\theta_e \ge \theta smin$ and $X_e \le Xs_{min}$	0
	$\theta_e \le \theta smin$ and $X_e \le Xs_{min}$	∞
7	$\theta_e \le \theta smin$ and $\varphi_e \le \varphi s_{max}$	∞
8	$\theta_e \ge \theta smax$ and $X_e \ge Xs_{max}$	0
	$\theta_e \le \theta smin$ and $X_e \ge Xs_{max}$	∞
	$\theta smin \le \theta_e \le \theta smax$ and $X_e \ge Xs_{max}$	any

VAPOUR RESISTANCE REGULATION IN IDEAL BUILDING

Similarly to the analysis of thermal and radiation resistance regulation we can analyse the regulation of the resistance to water vapour transfer.
If there are moisture sources in the air of inside space characterized by moisture production rate G, kg/h and water vapour pressure of outside air is lower than water vapour pressure of inside air ($p_e<p_i$), the resistance to water vapour transfer has to be:

$$Rv = \frac{(p_i - p_e)A}{G}, \; m^2s\cdot Pa/kg \qquad (7)$$

In case when both pressures are equal the resistance to water vapour transfer can have any value, but when $p_e>p_i$, the resistance has to be as big as possible (∞).

The algorithm of water vapour resistance regulation is shown in Table 2. It takes into account also moisture content x in grams in the kg of dry air.

TABLE 2: The algorithm of vapour resistance regulation

G	x_e	R_V	x_{ex}	x_s	x_I
>0	$>x_i$	∞	$> x_s$	$< x_I$	$> x_s$
	$= x_i$	any	$> x_s$	$< x_I$	$> x_s$
	$< x_i$	$\frac{(p_i - p_e)A}{G}$	$= x_s$	$= x_I$	$< x_s$
=0	$>x_i$	∞	$= x_s$	$= x_I$	$= x_s$
	$= x_i$	any	$= x_s$	$= x_I$	$= x_s$
	$< x_i$	∞	$= x_s$	$= x_I$	$= x_s$
<0	$>x_i$	$\frac{(p_i - p_e)A}{G}$	$= x_s$	$= x_s$	$> x_s$
	$= x_i$	any	$< x_s$	$> x_s$	$< x_s$
	$< x_i$	∞	$< x_s$	$> x_s$	$< x_s$

R_V- resistance to water vapour transfer, m^2 h·Pa/mg;G -moisture production rate, kg/h; x_e – outside air moisture content, g/kg; x_{ex}- exhaust air moisture content, g/kg; x_I - internal air moisture content, g/kg; x_s- supply air moisture content, g/kg

CONCLUSIONS

In practice the choice of the regulation mode depends on the level of technical development and economical considerations.

Some of the regulation decisions, such as shutters or solar reflectors, are known for generations. They are in compliance with the model described in the paper but they were known long before and without it. On the other hand the given algorithm shows all possible directions of technical development in order to minimize annual heat consumption of buildings.

At the present stage of scientific and technical development it is naturally to expect fast progress of technology toward the building structures with changeable characteristics. For example, even now it is possible to imagine inflatable buildings with changeable thickness' insulation air layers, or regulation of structures' vapour permeability by perforation with changeable dimensions.

The paper gives the algorithm of regulation for hypothetical ideal constructions, which can be used as the guide for the future development of building structure technique.

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