PASSIVE USE OF SOLAR ENERGY IN DOUBLE SKIN FACADES FOR REDUCTION OF COOLING LOADS

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ABSTRACT

The paper presents methods how the solar energy can be used for improvement of energy efficiency of large public buildings without using technical equipment such as solar collectors, solar panels and etc. The paper is devoted to the analysis of possibility for construction of double skin facades with changeable thermal performance for minimization of energy consumption by air conditioning systems. It describes the possibilities for optimization of thermal characteristics of double skin facades in order to improve buildings energy performance by maximal use of solar radiation including also the hot summer days with intensive solar radiation when usually shading devices prevent solar radiation. The paper gives mathematical model for regulation of elements of double skin facades depending on outdoor air parameters and level of solar radiation. It proposes constructive suggestion to create buildings whose walls, roofs and glassed surfaces have changeable thermal characteristics and methodology of control for separate elements.

KEYWORDS
Controlled thermal resistance, energy performance, solar energy, double skin facades

1. INTRODUCTION

Since 1970ies the U-value of building envelope has reached reasonable minimums: 0.1 W/(m^2·K) for walls, roofs (9) and 0.8 W/(m^2·K) for windows (10). The principles of solar geometry are well described and efficiently used in buildings design stage (11).

At the moment there exist various technical decisions of facades, which give the possibilities to improve performance using solar energy (8). The double facades have the main role in creation of energy efficient public and office buildings.

Research (8) shows the influence of different technical decisions of double skin facades on reduction of room cooling loads. In addition data (4) shows that summer ventilation through a double facade will increase room cooling loads even more and should not be recommended.

The study (6) shows that excessive increase in temperature in the space between the facade skins in summer has a number of disadvantages such as affecting the comfort of the occupants due to the hot radiation coming from the interior skin.

There are also existing approaches (5) to use the building envelope with changeable thermal resistance for night cooling. These methods propose to reduce thermal resistance during the night in order to cool down space. The reduction of thermal resistance is achieved by using moveable parts of building envelope such as roof construction and attic floor.

All before mentioned studies are focused on use of double facades for maximal reduction of heat gains in summer period and use of solar energy for heating during the spring and autumn. These methods usually are used together with passive heating and passive cooling strategies as well as with active heating and cooling methods.

So as it can be concluded the traditionally energy efficient buildings are supposed to have maximally high thermal and solar resistance of building envelope. But in practice high thermal resistance is only needed in coldest winter days in countries with cold climate or in hot summer days. Also the data (13) proposes idea that 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.

In other days, buildings with full air conditioning would have to have different properties of building envelope, including also shading devices that could allow heat flow in both directions (2).

The paper presents innovative method how the increase of heat gains can reduce total energy consumption by full air-conditioning systems. The double skin facades can be efficiently used for regulation of building envelope thermal and solar resistance.

2. RESEARCH METHODS

Research method is based on analysis of interactions between climate, HVAC systems working regimes and thermal properties of building envelope.

For 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:

$$R_R = \frac{\Phi_R - \Phi_I}{\Phi_I}, \text{ m}^2\text{K/W} \qquad (1)$$

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 gets inside, W.

If there are heat sources in the inside space and outside air temperature t_e is lower than inside air temperature t_i, 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:

$$R_T = \frac{(t_i - t_e)A}{\Phi}, \text{ m}^2\text{K/W} \qquad (2)$$

where: A is area of building envelope structures, m^2; Φ is heat gains, W.

In order to evaluate the potential of passive solar energy for reduction of cooling loads, which can be absorbed by external building envelope, the research is based on HVAC working regimes during the year (2, 3).

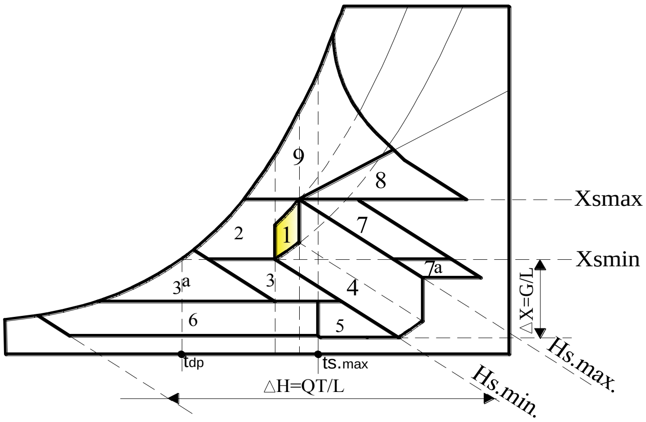

Fig. 1: The supply air parameters and main regulation regimes of HVAC on psychometric chart

- in the 1st zone the outdoor air parameters match required supplying air parameters so the heating devices and air humidifier are switched off;
- in the 2nd zone the air is heated by the convector till the minimal required temperature t_{Smin} if φ_{Smin} ... φ_{Smax} or till maximal relative humidity φ_{Smax} if t_{Smin} ... t_{Smax};
- in the 3rd zone the air is heated by the convector till enthalpy is H_{Smin} and then it is moisturized till φ_{Smax};
- in the 4th zone the air is only moisturized till the comfort zone upper level – till φ_{Smin} if θ_{Smin} ... θ_{Smax} or till θ_{Smax} if φ_{Smin} ... φ_{Smax} ;
- 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};
- in the 6th zone the air is heated by the wall mounted convector with intake air supply till the maximal possible temperature t_{Tmax}; moisturized till moisture content is x_{Smin} and then additionally heated by other heating devices till θ_{Smin}.
- 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;
- in the 8th zone air is cooled till X_{Smin} or till X_{Smax} and then additionally heated by heating device till θ_{Smin}.
- In the 9th zone air is cooled till X_{Smin} and then is mixed with outdoor air using bypass.

3. SPECIFICS OF HVAC WORKING REGIMES IN SUMMER TIME

There are four main temperatures that are usually used to evaluate the air conditioning working parameters:

- ✓ temperature of outside air t_e, ^{0}C;
- ✓ temperature of inside air (working zone) t_i, ^{0}C;
- ✓ temperature of supply air t_s, ^{0}C;
- ✓ temperature of exhaust air t_{ex}, ^{0}C.

The temperatures of supply air and exhaust air are the most important for creation of optimal indoor air parameters and ensuring of HVAC energy efficiency.

The typical office building has the heat and moisture production (ΔQ>0, ΔG>0) during the summer time. So the supplying air passing through the working zone assimilates the heat and moisture and the temperature and moisture content of exhaust air rises.

Figure 2 shows the process in room with normal solar radiation and thermal resistance.

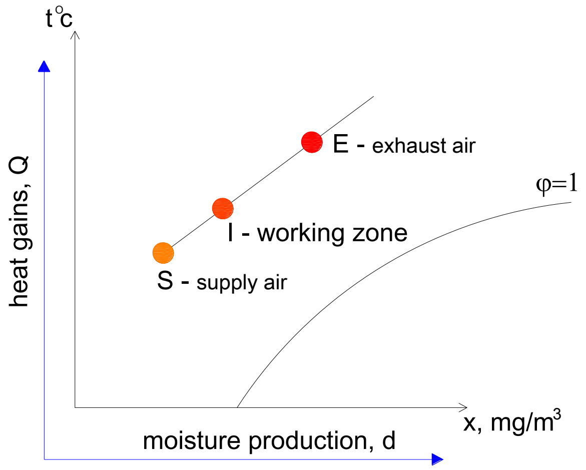

Fig. 2: Process in room with normal solar radiation and thermal resistance

The direction of process of changes of air parameters can be described as following (air exchange rate 0 <n<1):

$$\varepsilon = \frac{\Delta Q}{\Delta G} > 0 \qquad (3)$$

$$m = \frac{t_i - t_s}{t_{ex} - t_s} = \frac{x_i - x_s}{x_{ex} - x_s} \qquad (4)$$

where: t_i, x_i – temperature and moisture content in the work area; t_s, x_s - in supply air; te, x_e - in exhaust air.

Double skin facades can be used in innovative way in hot summer periods, when the outside air temperature is higher than inside air temperature and/or when solar radiation is active enough.

In that working regime after the cooling of outdoor air (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) (Fig. 4). Also it is possible to moisturize air (A_1 - C_1) and then heating device heats up supply air till minimal required temperature (C_1-D_1) and internal heat gains further heat air till comfort zone (D_1-E_1).

In general the capacity of air conditioning system in “dew point regime” could be calculated using the following equation:

$$Q_{total} = \Delta H_{cooling} + \Delta H_{heating}, kWh \qquad (5)$$

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

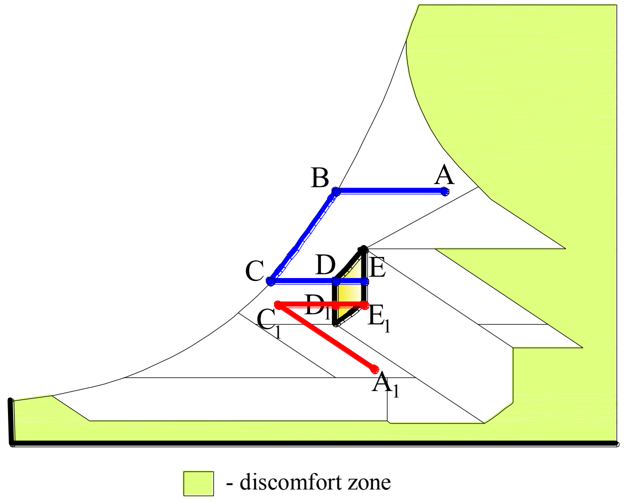

Fig. 3: Typical air conditioning working regimes (“dew point regime”)

As it can be seen from above mentioned figure, solar energy through the double skin facades can be used in order 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.

Discomfort zone means that the capacity of air-conditioning systems is not enough to ensure required parameters of indoor air.

For that purpose it is necessary to reduce thermal performance of building envelope and resistance to solar radiation. In that case the process in room D-E and D_1-E_1 can be extended.

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:

$$\Delta H = Q_{e.h.g} \qquad (6)$$

Changes of air parameters in room with normal and reduced solar radiation and thermal resistance are shown in Figure 4.

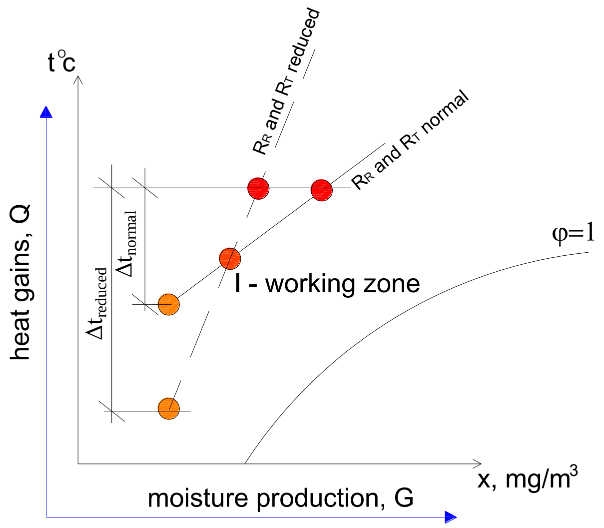

Fig. 4: Process in room with normal and reduced solar radiation and thermal resistance

The temperature of supply air can be significantly lowered in case of reduced thermal and/or solar performance of building external envelope. Thus the required energy consumption for supplied air heating ΔH_h can be reduced.

In practice parameters of supply air varies in allowed limits: temperature and relative humidity. Parameters of supply air in 2-dimension model (temperature and relative humidity) can be expressed by the following equitation:

$$\int_{\varphi smin}^{\varphi smax} f(tsmax)d(\varphi) - \int_{\varphi smin}^{\varphi smax} f(tsmin)d(\varphi) \quad (7)$$

Since t_{smax} and t_{smin} are constant under all values φ, equitation 7 can be modified as follow:

$$\int_{\varphi smin}^{\varphi smax} (tsmax) - \int_{\varphi smin}^{\varphi smax} tsmin = (tsmax * \varphi smax - tsmax * \varphi smin) - (tsmin * \varphi smax - tsmmin * \varphi smin) = tsmax * \Delta\varphi - tsmin * \Delta\varphi \quad (8)$$

The changes of supply air parameters in case of different air exchange rates are shown in Figure 5.

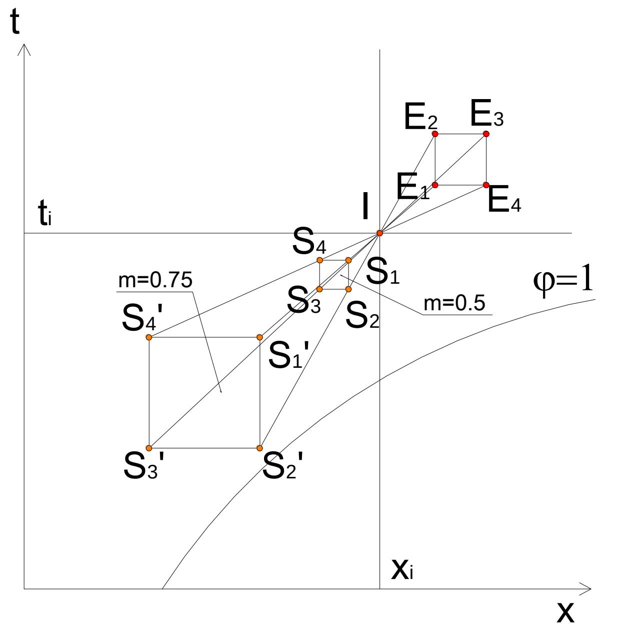

Fig. 5: Dependence between parameters of supplying air and air exchange rate in case of building envelope with regulated thermodynamic parameters

In order to keep constant t_i and x_i, it is necessary to change the location of supply air parameters S. Border area of supply air parameters depends on air exchange rate. For example, if m = 0.5, S varies on figure $S_1S_2S_3S_4$, when m = 0.75, then $S_1'S_2'S_3'S_4$.

Schematic process in room is shown in Figure 5.

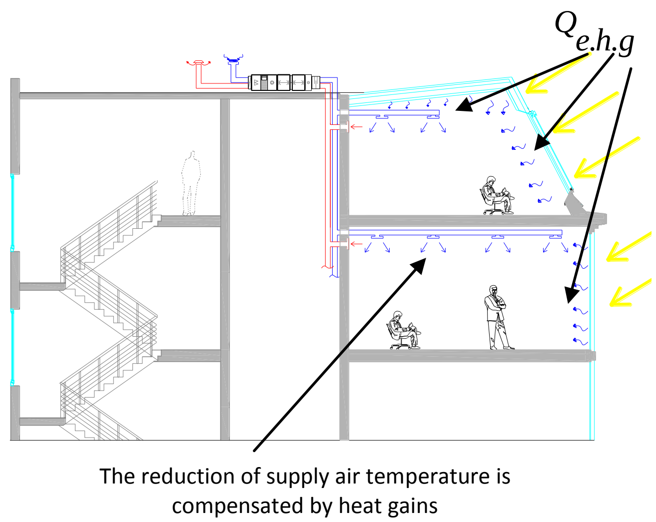

Fig. 5: Schematic process in room

The existing study (13) shows that optimal difference between the supply and exhaust air temperatures is:

- ✓ 6 ^{0}C – 9^{0}C for industrial buildings;
- ✓ 4^{0}C – 10^{0}C for sales areas;
- ✓ up to 14^{0}C for spaces for ceiling height more than 3m.

The chosen supply air temperature should insure not only the energy efficiency but also human comfort. The general value which characterizes the human comfort level is draft rate. The draft rate could be calculated using the data in existing standards (1).

The difference between the supply and exhaust air temperatures can be reduced below the data (13) in case of reduction of air velocity in working area and optimal planning of space floor. The reduction of air velocity in working areas can be achieved by using appropriated types of diffusers.

Preliminary diffusers testing results have shown that the most optimal are diffusers with plain and perforated face plates. At ΔT = 8 K plain diffusers performed very good results with respect to human thermal comfort. Diffusers with perforated face plate are recommended when warmer air is supplied or at low-impulse supply conditions.

4. OPTIMAL THERMAL AND SOLAR RESISTANCE OF DOUBLE SKIN FACADE FOR REDUCTION OF COOLING LOADS

On the basis on equitation 1 the necessary optimal thermal performance of building envelope for summer working regimes of HVAC system can be calculated according to:

$$\text{If } t_i > t_e \text{ then } R_T = \frac{(\theta_i - \theta_e)A}{\Phi} = \frac{\infty * A}{\Phi} = \infty \qquad (9)$$

$$\text{If } t_i < t_e \text{ then } R_T = \frac{(\theta_i - \theta_e)A}{\Phi} = \frac{-\infty * A}{\Phi} = -\infty \qquad (10)$$

As R_T cannot be negative it should be 0

$$\text{If } t_i \approx t_e \text{ then } R_T = \frac{(\theta_i - \theta_e)A}{\Phi} = \frac{0 * A}{\Phi} = 0 \qquad (11)$$

In case of summer working regime the following interaction can be used in order to find optimal thermal resistance of building envelope:

$$R_T = \begin{cases} any, tsmin \le te \le tsmax; \text{Xsmin} \le \text{ Xe} \le \text{Xsmax} \\ 0, \quad te \ge tsmin; \text{Xsmin} \le \text{ Xe} \le \text{Xsmax} \\ \infty, \quad te \le tsmin; \text{Xsmin} \le \text{ Xe} \le \text{Xsmax} \end{cases}$$

At the moment one of the possibilities to regulate thermal performance of building envelope is applying of different modifications of double-skin facades (3).

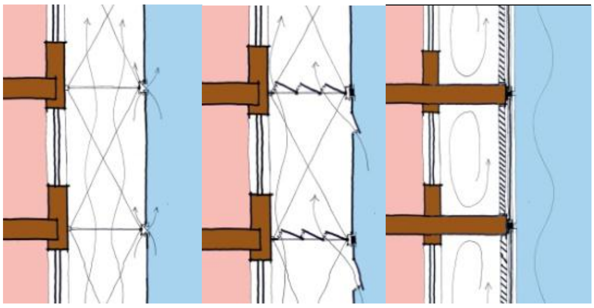

Fig.6: Possible regulation of thermal resistance by changing air velocity in air gap

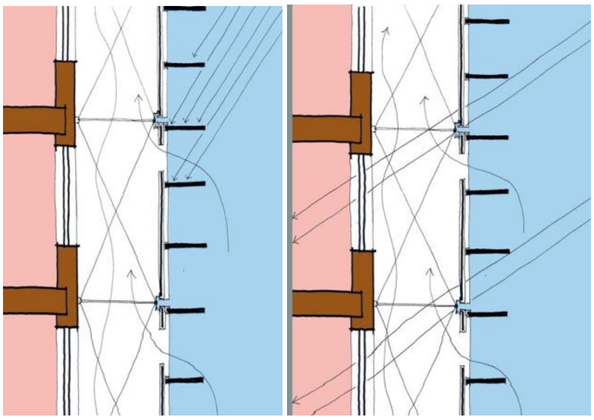

Fig.7: Regulation of solar resistance using external shading

Comparing to the other technical decisions described above, controlled building envelope provides the possibility to reduce energy consumption both in the wintertime and in the summertime. The simple method for regulation of thermal performance of envelope is to change insulation properties of air layer. Although such way of regulation of thermal performance of buildings is not ideal, it could be regarded as the first step in creation of a new generation of building envelopes, which provide possibilities for reduction of energy consumption using solar energy.

In addition to methods presented by data (5) also the principles of TOMBLE wall (7, 12) can be adopted for use of solar heat gains for reduction of building cooling loads.

5. RESULTS

If there are heat sources in the inside space and outside air temperature t_e is lower than inside air temperature t_i, 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:

If in the same situation with internal heat gains ($\Phi>0$) outside air temperature is higher than internal air temperature, thermal resistance of structures has to be as big as possible (∞), but in case when $t_i=t_e$, 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.

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

Building envelope with changeable thermal resistance, solar radiation resistance gives the possibility to reduce energy consumption by second heater and to reduce cooling loads.

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