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SOLAR FACADE FOR CLIMATIC CONDITION IN THE CZECH REPUBLIC

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ABSTRACT

The energy saving double solar facade of the Moravian Regional Library building in Brno has been experimentally and numerically investigated to predict the heat gains utilized for heating by the air ventilation system in the library. The double-skinned facade consists of an outer single glazing system with adjustable louvers, a shading system and the inner wall consists of double glazed windows and the sill wall from porous concrete. In order to evaluate the characteristics of the solar facade, thermal and solar measurements were carried out using a fragment taken as a sample of the solar facade. The influence of inner air space (ventilated cavity) and the construction of the solar facade on both recovery of the solar energy during sunshine periods and on heat losses during night hours have been assessed for the heating period. Results from the experimental and numerical investigations will be used in the regulation system and for the operation of the solar facade. At the present time, the library building is still under construction. Complete monitoring including further experimental measurements on the solar facade will be carried out later this year and in the following year as well.

KEY WORDS

- *double facade,*
- *solar energy,*
- *buffer zone,*
- *building simulation.*

1 INTRODUCTION

Double-skinned solar walls with external transparent glazing systems have been used in modern or intelligent office buildings for the last two decades in Europe. A transparent external skin designed as a part of an interactive double solar facade is very sensitive to climate changes and must be carefully designed for the required functions of a building. Regional and local climatic conditions throughout the year have to be taken into consideration, too. A properly designed double-skinned facade can bring environmental benefits with respect to the protection of the building interior against weather. When used together with passive or active solar systems, it provides higher energy efficiency and energy savings.

The concept of the solar double-skinned facades on the south-facing walls of the Moravian Regional Library in Brno with total area of 1740 m^2 makes use of a low energy design, which includes passive solar heat and natural ventilation. The outer glazing skin applied on two southward facades of the building eliminates the impact of wind and rain by means of reducing unwanted infiltration and heat losses. This way, natural ventilation can be utilized much longer. The shading system of the facade is created by adjustable shutters installed on the windows in the inner wall, and by opening grate walkways placed on each floor on the facade (Fig. 1). The structure of the double facade provides external and internal walkways used for windows cleaning and maintenance. The natural cross ventilation of the library building is enabled by opening windows placed in the inner wall and adjustable glass louvers of the outer glazing skin

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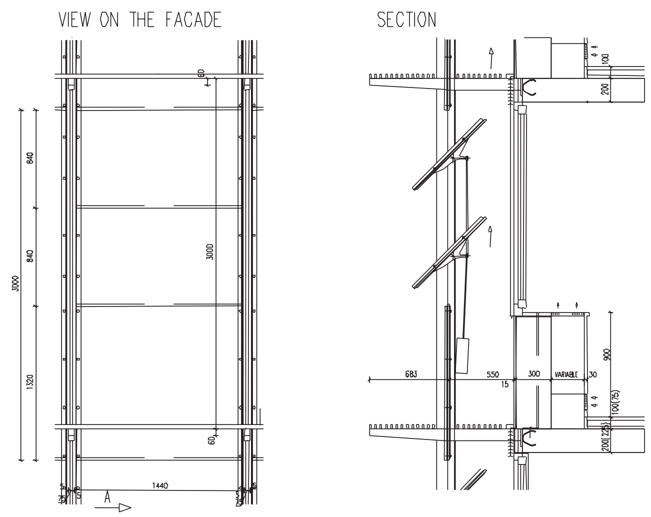

Fig. 1 *Section of solar double-skinned facade with opening louvers and internal and external open grate walkways on the Moravian Regional Library in Brno*

controlled by an automatic measuring and regulation system.

The natural ventilation is increased by the stack effect in the space between the outer skin and the inner wall and is regulated by means of motorised dampers at the top of the solar facades. The inner space of the double facades induces stack effect, which is beneficial in providing ventilation and free cooling appropriate to the season. One of two double-skinned solar walls of the area of 1170 m^2 placed on a south wing of the building provides on cooler but sunny days the solar-warmed air in the void between the outer glazing skin and the inner wall which is used by the mechanical ventilation system to reduce heating load in the heating period between September and May.

The aim of this contribution is to present some experimental measurements (carried out during construction of the building) and numerical investigations of the breathing double-skinned ventilated glazed solar wall projected for the Moravian Regional Library in Brno. These results should be used for the improvements of the project before completion of the building construction to ensure the operation and energy management of the building.

2 PROBLEM DESCRIPTION

Solar double walls used as air heaters in heating periods can provide heat supply during recovery periods, i.e. when incident solar energy sufficiently raises the temperature of the channel bordering walls above the ambient temperature. In the heating period, an additional heat is delivered from the adjacent rooms by conduction through the internal wall of the double facade when temperatures in the channel are lower in cooler days and in non-recovery periods. Sufficient thermal capacitance of the internal wall due to thermal mass of the structure can prolong heat supply also after recovery periods. As far as night hours and cloudy periods (non-recovery periods) on cooler days are concerned, the double facade shows a heat loss comparable to a normal facade. In order to limit the extent of these losses, inlet and outlet sections have to be closed, thus preventing the inflow of cold air into the channel due to stack effect of preheated air from the internal wall or from effect of wind.

The aim of the experimental and numerical investigation of the solar facade on the south wing of the building was to predict the influence of construction materials designed for the facade, and the influence of convection channel spacing on both recovery of solar energy (of the solar-warmed air in the void between the outer glazing skin and the inner wall) for the ventilation and heating system during sunshine periods and on heat losses during night hours.

The measurements of the solar double-skinned wall were carried out on the facade element (Fig. 1) before the facade erection to evaluate the architectural design and to predict energy and thermal functions of the facade for regional climate conditions. The element of the facade used for thermal measurements consists of two vertical modules-floors installed in the south wing of the building. The facade elements of 1.5 m width had an inlet and outlet sections that enabled measurements under different conditions for air flow in the convection channel of the double facade. For the convection of air in the facade element due to stack effect in the space between the outer glazing skin and the inner wall, the inlet and outlet sections were opened and for non-ventilated cavity of the facade element the inlet and outlet sections were closed. The measurements were carried out in the three periods from January to March in the given year. The experimental measurements were evaluated with respect to the climatic data of global solar radiation, air bulb temperature, relative humidity, wind direction and prevailing wind speed. These data were received from the meteorological station located in the university building that is approximately 200 m far from the Moravian Regional Library.

ANSYS/FLOTRAN software was used for numerical investigations of the solar double facade. The simulation model for energy and thermal analyses of the solar facade (that, in full size, consists of 8 vertical modules) was carried out for two velocities of air flow in the double facade. The simulation of thermal and energy balance of the solar facade during winter period (use of solar-warmed air in the void between the outer and inner wall for mechanical ventilation and heating system in the building) was based on the input climatic hourly data for the South Moravia region. The input data are in the format TRY and are set according to the meteorological measurements

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of the station Kucharovice. The influence of convection channel spacing on both recovery of solar energy during sunshine periods and on heat losses during night hours was evaluated by simulation of the thickness of 0.55 m and 0.80 m of the channel.

3 MATHEMATICAL FORMULATION

The double-skinned solar ventilated facade represents a solid (external glazing, internal sill wall and double glazed window) and a fluid surface (ventilated air cavity). The mathematical formulation therefore conjugates the heat-transfer problem which is mainly based on the following assumptions:

- Conduction and convection are non-steady states.
- Flow and temperature fields are two-dimensional.
- Air flow is laminar. Calculations of the different models show that in the range of our simulation, a transition to turbulent flow in the ventilated cavity does not arise.
- The ideal gas equation of state with constant pressure is valid in order to evaluate density variations in the fluid flows.
- Viscous dissipation and compressibility effects are neglected in the energy equation.
- Physical properties of air and all materials involved are constant.

With regard to the general assumptions, the governing and basic equations for the convection heat and fluid flow inside the convection air gap in the facade cavity can be formulated as follows:

Heat flow

The first law of thermodynamics states that thermal energy is conserved and it transforms according to a differential control volume which is given by the equation:

$$\rho c\left(\frac{\partial T}{\partial t}+\{v\}^T\{L\}T\right)+\{L\}^T\{q\}=\ddot{q} \tag{1}$$

where $\{L\}=\begin{Bmatrix}\frac{\partial}{\partial X}\\ \frac{\partial}{\partial Y}\end{Bmatrix}$ = vector operator

$\{v\}=\begin{Bmatrix}v_x\\ v_y\end{Bmatrix}$ = velocity vector for mass transport of heat

$\{q\}$ – heat flux vector

$\ddot{q}$ – heat generation rate per unit volume

Applying the Stefan-Boltzmann Law to a two-surface radiation equation, the heat transfer rate between two surfaces *i* and *j* can be expressed as:

$$Q_i=\sigma\varepsilon_i F_{ij} A_i\left(T_i^4-T_j^4\right) \tag{2}$$

where Q_i – heat transfer rate from surface *i*

σ – Stefan-Boltzmann constant

ε_i – effective emissivity

F_{ij} – view factor from surface *i* to surface *j*

A_i – area of surface *i*

T_i, T_j – absolute temperature at surface *i* and surface *j*

Fluid flow

The FLOTRAN (ANSYS) solution method with elements FLUID 141 was used in order to calculate the 2-D velocity and pressure distributions in a single phase, Newtonian fluid, and thermal effects. The fluid flow problem is defined by the laws of conservation of mass, momentum, and energy. Assumptions for the fluid flow calculations of the facade are the following: the fluid is Newtonian, there is only one phase, the problem domain does not change, and the problem is turbulent and incompressible.
The continuity equation can be drawn on the basis of the conservation of mass law:

$$\frac{\partial\rho}{\partial t}=\frac{\partial(\rho V_x)}{\partial X}+\frac{\partial(\rho(V_y))}{\partial Y}=0 \tag{3}$$

where V_x, V_y – components of the velocity vector in the *x* and *y* directions

ρ – density

x, *y* – global Cartesian coordinates

t – time

In the Newtonian fluid, the relationship between the stress and rate of deformation of the fluid is:

$$\tau_{ij}=-P\delta_{ij}+\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)+\delta_{ij}\lambda\frac{\partial u_i}{\partial x_i} \tag{4}$$

where τ_{ij} – stress tensor

u_i – orthogonal velocities

($u_i = V_x$, $u_2 = V_y$)

μ – dynamic viscosity

λ – second coefficient of viscosity

The last value mentioned above, i.e. the product of the second coefficient of viscosity and the divergence of the velocity, is zero for

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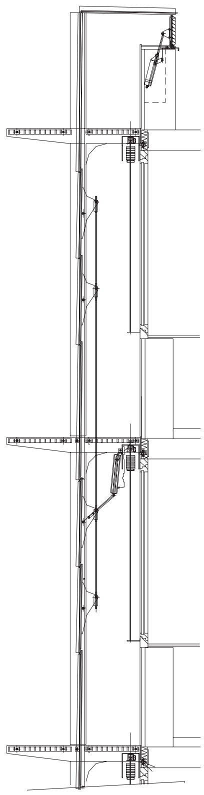

Fig. 2 *Two segments used for preliminary thermal measurements of the solar double facade*

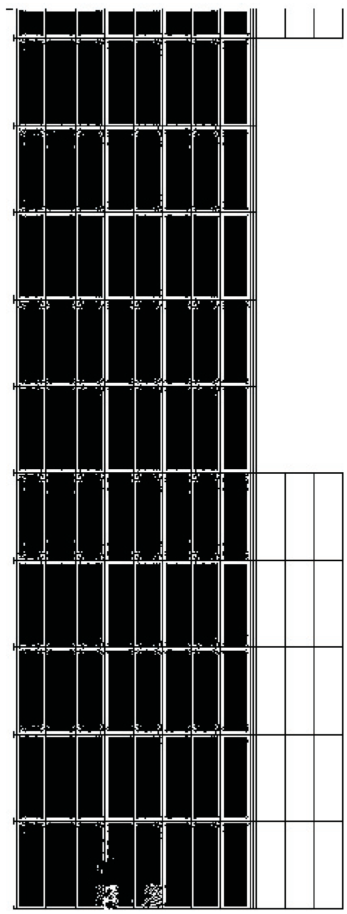

Fig. 3 *Example of the grid size distribution of the first segment of the facade model (8 segments)*

a constant density fluid. The equation (4) transforms the momentum equations to the Navier-Stokes equations.

4 MEASUREMENT METHOD APPLIED TO THE SOLAR FACADE

The solar double façade characteristics were measured and experimentally evaluated on the solar double wall element in three different periods within January, 2000. The solar wall element consists of two vertical modules with the height of 7.2 m and 1.5 m width, and is installed on the level of two last floors of the building (Fig. 2). Results of measurements carried out on the solar double facade of the Moravian Regional Library in the period from 28 January to 3 February (Fig. 3) are for the non-ventilated channel (cavity of double facade) with the closed inlet and outlet section. The increased temperatures in the cavity of the facade element are in good relation to the direct solar radiation for the measured period. The increased temperatures in the solar cavity for non-recovery periods and cloudy days were influenced by heat transfer through the internal wall.

Residuals of temperatures between the external temperature and the temperature in the cavity were elevated up to 15 °C. Higher temperature was achieved on sunny days and recovery periods, lower temperatures, i.e. less than 5 °C, in night hours and on cloudy days. The internal temperature in the cavity of the facade and the direct solar radiation (measured on the meteorological station located at the university campus 200m from the site) are in good correlation (see Fig. 3).

Lower air temperatures from the measurement in the cavity of solar element were influenced and limited by the vertical size of 7.2 m of the facade element in comparison to the facade height 24.7 m. Measured data in the winter period were used for an assessment of thermal properties of the double facade constructions, and the

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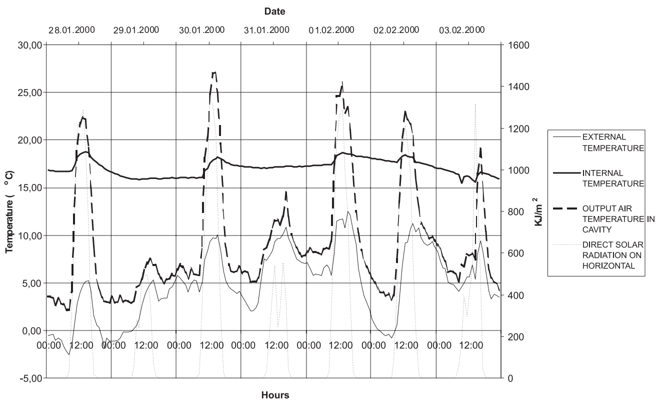

Fig. 4 *Measurements of the solar double facade Moravian Regional Library in the period 28.1-3.2.2000*

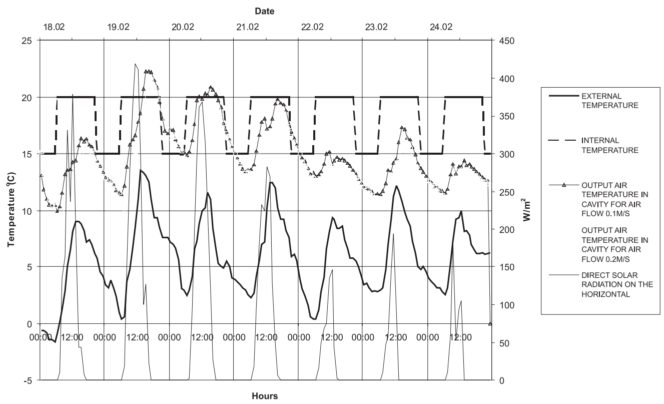

Fig. 5 *Simulation of air temperatures in the cavity of double solar facade preheated from direct radiation for two steady forced air flows 0.1 and 0.2 m.s-1. Climate output data are used from TRY (station Kucharovice, CZ)*

effect of a buffer zone (air void between the inner and the outer skin of the solar facade) reducing heat losses of the building. Further evaluation of low energy design and proposed energy balance expected during the operation of the building including ventilation and heating system will be carried out after the completion of the facade structure in the following winter period.

5 COMPUTER SIMULATION AND RESULTS

In order to simulate the thermal behaviour and the energy balance of the solar facade, climate hourly data from the test reference year obtained from the meteorological station Kucharovice validated for the South Moravian region were applied.

The calculation of energy balance was carried out by means of the simulation of air temperatures in the convection channel (forced air flow in the cavity) for the period 18 – 24 February (Fig. 4). Thermophysical properties of the construction materials used for the physical model are specified in Tab. 1.

Geometry of the 2D model (8 sections) was created in ANSYS/FLOTRAN environment and it consists of 1000 CFD elements FLUID 141. Example of the grid size and the distribution of elements in one segment is shown in Fig. 3. Model facade is created from 8 segments.

Table 1 *Thermophysical properties of materials used for simulation of solar double-facade (specification in section of sill wall)*

Material	Thickness (mm)	Density (kg/m3)	Specific heat (J/kg.K)	Conductivity (W/m.K)
Ytong	300	600	840	0.21
Wood-chips boards	10	800	1500	0.22
Air cavity	500			
Glass	10	2600	840	0.76

Other properties of the facade construction necessary for creating of the physical model were determined for glazing of external envelope (thickness of glass 10 mm, transmittance τ = 0.80). For the absorption of solar radiation α = 0.20 in case of windows in the internal wall, and α = 0.90 for wood-chips board.

Incompressible and turbulent air flow was determined for the simulation purposes. At the beginning of the simulation, 50 iteration steps were applied to calculate the introductory stationary state. Next calculation was carried out under non-stationary state. In each step (each one lasting one hour) 15 iterations were solved with the help of the pressure solver CFD (TDMA method).

Boundary conditions: for outer glazing of the facade, an external temperature (Fig. 5) with a convection film of 15 $W.m^{-2}.K^{-1}$ was applied. An internal temperature of 20 °C (Fig. 5) was applied to the surface of the internal wall in the heating period from 6.00 a.m. to 8.00 p.m., and 15 °C for night time with convection film of 8 $W.m^{-2}.K^{-1}$.

Zero velocity was applied in the convection channel on both surfaces. On the top of the channel in the outlet section, two variants of an air flow velocity of 0.1 and 0.2 $m.s^{-1}$ were determined.

Ventilation of the channel was regulated according to the difference of the external and the output cavity temperatures. The ventilation required a minimum difference of 5 °C. Ventilation (forced air) was active only in the heating period (Fig. 6), and in the time when the outdoor temperature was lower than 15 °C. Hourly sums of direct radiation data obtained from the TRY (Fig. 5), calculated for the vertical wall, were used for incident solar radiation.

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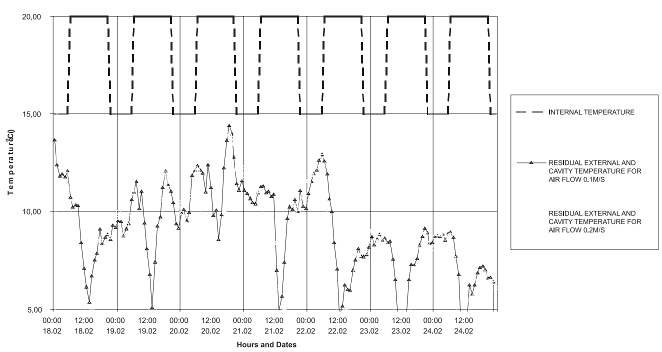

Fig. 6 *Residuals of external and cavity output temperature simulated for air flow velocity 0,1 m/s and 0,2 m/s in the convection channel of the solar facade in the recovery period*

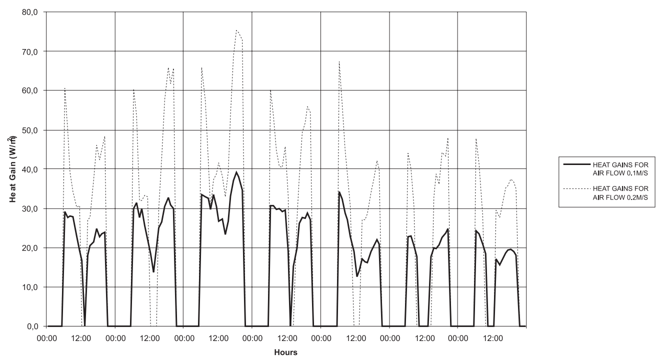

Fig. 7 *Simulation of heat gains from solar preheated air in the facade used for heating in ventilation system*

CONCLUSIONS

Based on the results achieved in the measurements and numerical investigations, the following conclusions can be drawn:

(1) Simulation of heat gains from solar heated air in the convection channel (cavity) of the solar facade for heating system in the evaluated period shows high energy efficiency. Heat gains calculated from the residuals of the external and the cavity output temperatures (Fig. 6), and the volume of solar heated air, reach the average level of 24.5 W.m^{-2} in the facade, and 28.7 kW (for 1170 m^2 of facade) with the velocity of 0.1.s^{-1}. Average value is 42.2 W.m^{-2} in the facade and 49.4 kW (for 1170 m^2 of facade) with the velocity of 0.2 m.s^{-1}. Distribution of heat gains simulated for the period from 18 to 24 February is expressed in graphs in Fig. 7.

(2) The energy efficiency of the facade is high enough for the maximum velocity of air flow 0.2 m.s^{-1} in the convection channel, and sufficient for the ventilation and the heating system.

(3) Based on the complementary simulation studies and the results achieved, the large channel spacing (cavity) exceeding the width of 0.6 m is not suitable both for the recovery and the non-recovery periods.

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