SIMULATION OF THE DOUBLE FACADE IN THE BRNO METROPOLITAN LIBRARY

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ABSTRACT

Objective of this paper is to present results from experimental measurements and computer simulations of thermal behaviour and energy efficiency of the solar double skinned ventilated façade of the Brno Metropolitan Library in Brno in the Czech Republic. Simulations were provided for the period of heating season between September and April and for the reference climatic conditions with hourly climatic data in the format TRY created for the South Moravia climatic region. The paper deals with the simulation of 1-zone and 9-zone models of 6 variants of the double solar ventilated façade integrated into the central air heating and ventilation system of the building.

Simulations and modelling of the double façade were carried out by the last version of the BSim 2002 software. For the modelling of the double façade was specified air change rates to zones and airflow network for bulk airflows through the external and internal envelope of the double façade presenting infiltration or exfiltration. In this modelling is specified for the external envelope a leakage network consisting of a number of internal and external nodes connected by a variety of airflow component such openings, lowers, fans and gaps between components. The internal surface convective transfer process and air flow in the channel of the cavity of double façade are influenced by forced convection during the operation of central ventilation and air space heating system during winter season. External convection coefficient calculation is based on empirical relationship between wind speed, wind direction, surface orientation and geometry of the building. During the simulation the solar processor calculated the incident direct and diffuse radiation on the external surface of the solar double façade.

For analysis of results from the simulations and measurements of the solar double façade are compared courses of temperatures in the cavity of the façade, climatic data and energy balances for the heating season.

1. INTRODUCTION

The new Directive 2002/91/EC of the European Commission on the energy performance of buildings EPBD which will come into force in January 2006 in Member States requires several different measures to achieve prudent and rational use of energy resources and to reduce the environmental impact of the energy use for buildings. The EPBD directive focuses its attention on the fact that the heating and cooling air-conditioning plants have become, in the last decade, widespread systems used in office and public buildings, in particular in the countries of Central and Southern Europe.

New architectural tendency to use fully glazed facades for building envelopes very often with the absence of previous experience and with missing necessary calculations for the prediction of thermal and energy performance of buildings during the summer and winter period is in many cases speculative and it means many problems in new or renovated buildings with the next operation to provide reasonable indoor climate conditions and to fulfil energy requirements and respect energy performance building directives.

Numerous works have analysed the thermal behaviour of dwellings in order to reduce the energy consumption for space heating and cooling in buildings. Architectural and building practice in passive solar design and its implementation in new and retrofitted buildings to reduce cooling and heating demands is not still widely or efficiently used. Passive systems in solar architecture must cooperate with building services to reduce energy with improved thermal and other hygiene indoor climate conditions in buildings.

Ventilated glazed double facades used in passive solar design are made up of two layers of different materials, opaque or transparent, that are separated by an air channel used to collect or evacuate the solar radiation that is absorbed by the façade. Application of single or double glazed facades in buildings without environmental design, thermal and energy numerical analysis creates considerable problems in indoor climate conditions at peak load times in summer and in winter periods. The use of well designed ventilated facades and roofs can help to reduce summer thermal loads due to direct solar radiation (Ciampi et al.,
Ventilated facades can be used even in case of renovation of existing buildings, for instance, in the balance of rules relating to historic-architectural preservation. Ventilated façade components and structures can prove useful also for the cooling of photovoltaic panels in order increase their efficiency (Brinkwört et al., 2000; Mei et al., 2003). Building integrated PV systems in connection with energy efficient heat recovery in double ventilated facades was used for solar low-energy retrofit housing project at Osterbo and in other 3 housing schemes in Copenhagen. PV modules with a glass-glass structure can be applied when integrated as cladding device component (BIPV) into the double façade with forced ventilation (Library in San Mataro, Spain). BIPV case study for modelling and analysis was carried out in JRC Ispra (Bloem, 2003). The aim of the work was to investigate the heat exchange of a PV device, the effect of using different material for PV modules and optimise construction design of façade components in a typical built environment. Hybrid PV systems with integrated PV glass-glass semitransparent structure was successfully used in the double ventilated façade of library in San Mataro in Spain. Energy efficiency of the façade for space heating is about $\eta = 30\%$.

In building research and for environmental and energy conscious design of buildings are contemporary used several methods for simulation of airflow and heat transfer in the facade to predict thermal behavior, energy efficiency and indoor quality of buildings. Advanced simulation tools, e.g. ESP-r, TRNSYS, DOE, BSim 2002, PHYSIBEL or CFD codes (Star-CD, Fluent, Fluent, ANSYS-FLOTRAN) are based on a computer simulation. In the area of fluid flow simulations, two principal simulation methods prevail. Network flow models divide the investigated space (or building) into small number of relatively large zones represented by a single value of governing or solved quantities only (temperature, air velocity, pressure etc.). Consequently, they can predict only bulk flows between individual spaces. On the other hand, these methods are relatively simple to use and require only small computational effort, and therefore they are widespread and often used.

In the Computational Fluid Dynamics (CFD) the simulated space is divided into a finite, but very large number of control volumes, much more than in the above-mentioned approach. Each control volume must obey the fundamental laws of physics governing motion, energy transport and conservation of mass with an appropriate extension for turbulence modeling. As a result, a space distribution and time history of solved quantities in the solution domain are obtained. Moreover, no additional relationships between particular quantities of a model (e.g. pressure drop vs. air velocity dependence), as in the zonal approach, have to be supplied. Nevertheless, the validity of the models is very dependent on right definition of boundary conditions, as inlet or outlet velocity, outer temperatures, energy gains etc.

For the analysis and prediction of thermal and energy behaviour of ventilated glazed facades and their components are available various specialized simulation tools developed in the last decade for evaluation and analysis of building envelopes. A specific code, called AGLA (Advanced GLAzed facades simulation code) for the numerical simulation of the thermal and fluid-dynamic behaviour of ventilated glazed facades has been developed for ventilated facades in Mediterranean climates (Soria et al., 1998, Costa et al., 2000a). After it was validated (Faggembauu et al., 2003), the code proved to be a useful design tool for ventilated facades. The code AGLA was designed for the transient simulation of all the facades (ventilated or conventional) of a building over long time intervals (one year). Therefore, to reduce the CPU time to a reasonable level, one-dimensional discretizations of the air channel are used in this specific code.

Recently was created and completed new ESP-r CFD module (Strachan et al. 2005) for one or more zones simulation of a model for double facades presented in a report for BBRI (Annex 5 ESP-r software). CFD simulation of a model of the double façade in ESP-r can be done in conjunction with the remainder of the whole building simulation in order to calculate the detailed zone temperatures and air flow distribution.

### 2. DESCRIPTION OF DOUBLE VENTILATED FAÇADE AND SITE MEASUREMENTS

The Moravian Regional Library in Brno includes two double-skin solar facades placed on south sides of both wings of the building. Fig. 1 shows double-skin solar facade on the southern wing of the library building used for the monitoring and numerical investigation.

Fig. 2 shows the construction and functional principles of the double façade with the total area 1135 m². The load bearing cantilevered structure of the double glazed facade attached to the wall of the building is
from the zinc galvanized steel elements. The outer skin of the façade is created from the single hardened glass of 10 mm thickness. The outer single glass façade is with the adjustable lovers for summer cross natural ventilation. The metal grid of walkways on the level of each floor serves for maintenance purposes, and as shading devices against direct solar radiation in summer. The upper part of the facade is closed by a glass sheet, but the ventilation slot located on the back side of the double façade can be remotely opened for free passing of the air through the façade to outside. When closed, the air from the facade can be sucked into the central ventilation and space heating system. Air inlets are located on the ground level of the facade.

Figure 1. Solar double ventilated façade on the southern wing of Brno Metropolitan Library.

The double facade has the concept of low energy design includes passive solar heating and natural ventilation. The outer single glazing skin applied on the double facade of the building provides protection from wind and rain, buffer zone for reducing heat losses and noise, and offering possibilities for natural cross ventilation in the southern wing of the library. Adjustable shutters in the channel of the double facade windows create the shading system in inner wall. The structure of the double facade provides the external

Figure 2. Details of structure inside the channel of double glass façade (a), performance of outlets over the roof on the top of the façade, (b) – outlets are closed, (c) – outlets are open.

The double façade has the concept of low energy design includes passive solar heating and natural ventilation. The outer single glazing skin applied on the double facade of the building provides protection from wind and rain, buffer zone for reducing heat losses and noise, and offering possibilities for natural cross ventilation in the southern wing of the library. Adjustable shutters in the channel of the double facade windows create the shading system in inner wall. The structure of the double facade provides the external
and internal walkways in each floor for windows and external glass cleaning and maintenance. Both walkways have function of shading in summer period.

For the site investigation and monitoring of thermal behaviour and energy efficiency of the double facade the measurement data acquisition system ADAM 4000 Series has been installed on the Moravian Regional Library building in 2002. Measurement system on the double façade is described in Fig. 3. The measurements were carried out continuously in the whole period 2002-2004 for monitoring of operational temperatures and air velocity of flow in the cavity of the double solar façade and external weather conditions on the site. Subject of measurements were air temperatures and flows in the cavity, surface temperatures on the glass façade, windows, building components, and measurements of weather site conditions - ambient temperatures, prevailing wind speed and global radiation measured on the wall (on the vertical plane) and on the roof (on the horizontal plane). Configuration of the measurement and data acquisition system with the PC-based automation used for the monitoring in the façade and on the library building are presented in other previous papers (Charvat and Jaros, 2002, and Sedlak and Jaros 2003).

Figure 3. Monitoring system and placing of sensors for measurements on the facade.

3. METHODS OF NUMERICAL INVESTIGATION

This paper is focused on the validation of multi zone models used for simulation of thermal and energy behaviour of the double ventilated solar façade with forced ventilation incorporated into central heating and air conditioning system of the library building in winter season.

The double-skinned façade of the Moravian Regional Library in Brno consists from the outer skin of the single glass with adjustable louvers enables natural cross ventilation in summer and mid seasons. These type of double solar ventilated facade required more advanced and integrated approach of design with
application of simulation methods and analysis for the real climate conditions of the building site. For evaluation of indoor climate conditions in a building with glass facades to predict their thermal behaviour and other functions (ventilation, natural illumination) are useful reference climatic data for instance in the format of the Test Reference Years (or DRY, SRY). For a shorter period of evaluation four hours (in hot days), one-day (typical day for each season) or two weeks the standardized regional climatic data should be used according to the national standard requirements.

Simulation models with the application of CFD methods (in Star-CD) were used for the prediction of temperature fields, airflow and aerodynamic performance of individual façade components and in the whole façade of the Moravian Metropolitan Library and they were carried out in earlier research projects presented in papers, (Charvat 2002, Sedlak 2003). The simulation by Star-CD was carried out as transient, with time step of 1 second. For the modelling of turbulence, the Re-Normalization Group (RNG) k-ε model of turbulence (Star-CD 1996) was applied. With the application of CFD methods two main cases were studied (Jaros 2004): the forced passing of air (during the air suction from the façade into the ventilation system), which is supposed on sunny days in winter or in transitional periods, and free passing of air through the façade on hot sunny days. The thermal boundary conditions in both cases have been determined by global solar radiation and outdoor temperature (taken from standards or from TRY), which is simultaneously taken as entering air temperature, and temperature of the interior of the building (20 °C for winter, 22 °C for summer season).

Objective of this paper is to present examples of integrated numerical simulation of one and more zone models of the ventilated double façade with the application regional reference climatic data created in the format TRY and validated on demonstration buildings within the previous research project (Sedlak et al. 2000). In the project were created TRYs for six professional meteorological stations located in typical climatic regions in the Czech Republic.

The test reference year TRY for the Southern Moravian region was created from climatic data of the meteorological station Kucharovice located in south-west part of Moravia. For the validation of climatic data in the format TRY (Sedlak et al. 2000) created for four meteorological stations in the Czech Republic were used two simulation programs ESP-r, TSBI5 and CFD codes Fluent and ANSYS.

Validation of TRYs was carried out on several demonstration buildings in the Czech Republic due to analysis of simulation building models using weather data from TRYs and site climate measurements and monitoring of indoor climate conditions and energy balances. Measured data of air atmospheric temperatures, global radiation and sun duration were compared between site climate measurements on demonstration buildings and regional TRYs. Validation of simulation models of the demonstration buildings was provided from analysis of indoor climate temperatures and energy balances received from the simulations carried out for input climate data received from site meteorological measurements and climatic data received from the regional stations in the current year and, for climatic data in the format TRY created for various climatic typical regions in the Czech Republic.

Validation of six building zone models created for the double façade in heating season 2003/2004 was carried out by analyses of courses of operational temperature in the channel of the façade, energy balances and energy efficiency of the façade due to comparison of results received from the integrated simulation and real site measurements. For simulation model of the façade and building library were used weather data from the test reference year TRY (Kucharovice). Climatic data of the TRY were compared with actual weather site conditions measured on the site in winter period of the heating season 2003/2004. For the validation of numerical model of the façade and adjacent southern wing of the library building were evaluated measured and simulated operative temperatures and energy balances with consideration of differences in global radiation and air ambient temperatures.

4. DESCRIPTION OF BUILDING MODELS

Model of the façade was created in environment of the simulation program BSim2002. Technical specifications of materials used for the double façade are specified in Ph.D. thesis (Mracek 2005). Constructions of the outer glass façade is suspended on cantilevered steel galvanized structure. The outer envelope of the double façade consists from individual glass components and adjustable louvers with the total area 1135 m². Façade is 47 m long and 25.1 m height with the channel 0.575 m wide. The outer skin of the façade is without seal with gaps 4 - 10 mm between individual glass components pervious for air infiltration and exfiltration. Open area of the façade through leakages is 17.7 m² what is about 1,6 % of the
total area of the façade. Fig. 4 presents the block model representing the geometry and volume of the all building library with the southern solar double façade. For the simulation was created model of the double façade placed on the south wing of the building with division into 6 vertical segments creating the shape of a curve of the façade. Verified segment used for the simulation model of the façade and adjoining building is includes of 5 modules of 1.5 m wide with the total width 7.5 m of the model (Fig. 5). The segment used for the façade model validation consists from the modules where is measurement system installed for long time monitoring operation of the Brno Metropolitan Library.

**Figure 4.** Block model of the Moravian Metropolitan Library building with the south double glass façade.

For thermal simulation and evaluation of energy behaviour of the double façade with forced and non forced ventilation were created six simulation models of the double façade. Two models with one real zone of the façade were created: model indicated VAR 1 without consideration of forced ventilation and without considering infiltration or exfiltration through leakages in outer glass façade and model VAR 2 with considering of infiltration or exfiltration through leakages in outer glass façade which passes into the current real zone. In each model VAR 1 and VAR 2 is one real zone determines physical room of the whole façade and virtual zone of outdoor climate (TRY), virtual zone of a reference room (zone of a reference typical office or study room adjoining to the facade on the southern wing of the library) with determined thermal conditions and zone determines ground conditions.

Further two models with one real zone of the façade with forced ventilation were created: model VAR 3 without considering infiltration or exfiltration through leakages in outer glass façade and model VAR 4 with considering of infiltration or exfiltration through leakages in outer glass façade which passes into the current real zone. In each model VAR 3 and 4 is one real zone determines physical room of the whole façade and virtual zone of outdoor climate (TRY), virtual zone of a reference room (zone of a reference typical office or study room adjoining to the facade on the southern wing of the library) with determined thermal conditions, virtual zone of central ventilation and zone determines ground conditions.

Last two models with nine real zones of the façade with forced ventilation were created: model VAR 5 without considering infiltration or exfiltration through leakages in outer glass façade and model VAR 6 with considering of infiltration or exfiltration through leakages in outer glass façade which passes into the current nine real zones. In each model VAR 5 and 6 are nine real zones determining of physical room of the façade with divisions presenting individual floors and virtual zones, zone of outdoor climate (TRY), virtual zone of a reference room (zone of a reference typical office or study room adjoining to the facade on the southern wing of the library) with determined thermal conditions, virtual zone of central ventilation and zone determines ground conditions. To determine operational thermal condition of the reference virtual
zone of a typical office or study room located in the fifth floor (Fig. 5) representing adjoining spaces of the library building the other surrounding spaces of virtual zones were determined by temperature 20 °C in office rooms and by 15 °C in passage corridors and stair well.

Figure 5. Selected part of the vertical profile of the façade used in one zone model and multi zone model divided into 9 zones (in each floor is one zone).

For the case of a blind in the façade a division into double thermal zones for the airflow network in each floor in the models was not used for the models and simulations. In the library is not central control of blind and most of blinds were not been used in the period of the monitoring in Brno Metropolitan Library.

For the simulation of thermal behaviour in the façade was used a simple model for the approximation of vertical temperature distribution and stratification in the channel of the double façade. The Kappa model which is implemented in BSim2002 was used for natural, hybrid ventilation and forced ventilation in the channel of the façade. Unstable stratification of air in the channel of the façade for both the natural ventilation and forced ventilation with the exhausting of air into the central air heating and ventilation system is influenced by infiltration and exfiltration through leakages in all area of the outer skin of the façade. The influence of leakages in the external envelope of the facade to the air infiltration and exfiltration were monitored by thermovision camera Thermacam Flier 695. The thermovision measurements (in February) and analysis of values of IR information confirmed higher infiltration and exfiltration through outer skin of the façade. Inside the channel of the façade and in individual gaps between glass components air flow velocities were measured by ultrasonic anemometer Anemosonic UA6 to give information to determine boundary conditions for zone model simulation.

Definition of infiltration is calculated as an outside air flow which passes into the current zone. Exfiltration, i.e. air which passes out of the zone through leakages could not be indicated directly. The simulation program in the model checks for each time step of the simulation, that there is a balance between air flows passing in and out of the zone. In the event of imbalance, an air deficiency in a real zone of the façade is equalised by infiltration, whereas an air excess is equalised by exfiltration. The model for infiltration
defines the air-change rate for the each real zone in following terms: a basic air exchange, difference between the inside and outside temperature, aerodynamic coefficient of internal (in the channel) and external air pressure.

For the forced ventilation which is integrated in the central air ventilation system is basic air change derived from the power of the fans with average volume exhausting air capacity 16990 m³ per one hour. The capacity of exhauster fan was measured within the period of measurements. The total volume of the façade channel is 595 m³. Volume of the zone model used for simulation is 103 m³.

5. VALIDATION OF SIMULATION MODELS

For the validation of simulation models were used climatic data from two meteorological stations and results from measurements on the double façade of the Brno Metropolitan Library carried out in the period from September 2003 until April 2004. Evaluation of results from measurements of global solar radiation, outdoor and indoor air temperatures, and wind velocity are executed for each hour of the whole period of monitoring.

Effect of solar radiation to indoor air temperatures in the channel of the façade with forced ventilation and during operation of the central ventilation with exhausting of preheated air from the façade is shown for two typical periods in mid season in October (Fig. 6) and in winter period in January (Fig. 7).

**Figure 6.** Measurements of global radiation on vertical plane (IglyM) and horizontal plane (IghM) and external air temperature (TeM) and temperatures in the channel of the façade, near inlets (2/00) and close to outlets (5/04) of the façade in the period 13th - 19th October 2003.

Average values of hourly sums of global solar radiation measured on the vertical plane of the façade and on the horizontal plane in the level of the roof and temperatures in lower part (near inlets) and upper level (near outlets on the top of the façade) are evaluated (Table 1) for the period from Septmeber 1st until April 30th. Evaluation of solar energy gains in the façade are calculated from temperature differences and volume of exhausting air for each hour of the operation time of the central air heating system (Table 2). The theoretical energy gains were calculated for the double façade with forced ventilation and air ventilation system in the library which is in operation for all days of the evaluated period. Energy efficiency of the double façade was calculated from the ratio of energy gains received from preheated air in the channel of the façade and used for the central air heating system in the library, and energy received from the total incidence of global radiation on the vertical façade within the evaluated period.
Figure 7. Measurements of global radiation on vertical plane (IgvM) and horizontal plane (IghM) and external air temperature (TeM) and temperatures in the channel of the façade, near inlets (2/00) and close to outlets (5/04) of the façade in the period 19th - 25th January 2004.

Table 1. Average values of hourly sums of global solar radiation and temperatures measured in the lower level and upper level in the channel of the façade in the period of September 2003 – April 2004.

<table>
<thead>
<tr>
<th>2003/2004 Month</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>IX-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>IghM (kW/m²h)</td>
<td>0.149</td>
<td>0.065</td>
<td>0.028</td>
<td>0.014</td>
<td>0.028</td>
<td>0.054</td>
<td>0.080</td>
<td>0.146</td>
<td>0.069</td>
</tr>
<tr>
<td>IgvM (kW/m²h)</td>
<td>0.082</td>
<td>0.056</td>
<td>0.040</td>
<td>0.034</td>
<td>0.048</td>
<td>0.059</td>
<td>0.051</td>
<td>0.061</td>
<td>0.054</td>
</tr>
<tr>
<td>TeM (°C)</td>
<td>16.520</td>
<td>8.730</td>
<td>8.000</td>
<td>2.220</td>
<td>-0.820</td>
<td>3.540</td>
<td>6.180</td>
<td>13.210</td>
<td>7.040</td>
</tr>
</tbody>
</table>

Notes: IghM – global solar radiation on the horizontal plane  
IgvM - global solar radiation on the vertical plane  
TeM – ambient external temperature  
TdM – temperature in the lower part of the channel in the façade  
ThM - temperature in the upper part of the channel in the façade

The methodology used to validate zone models and to evaluate reliability of results from simulation are based on:
- Comparison of climatic data from the climatic reference year (TRY) used for simulation and weather data from the same period of the current years 2003/2004.
- Comparison of monthly values of temperatures in reference periods and situations.
- Comparison of thermal experimental results received in real-site test façade and from monitoring of Metropolitan Moravian Library.

The comparison between the reference climatic data in the format TRY determined for the South Moravia (station Kucharovice), used for the simulation in all six façade building models VAR 1 – 6, and the reference climatic period 1961-1990 of two stations (Brno-Turany and Kucharovice) for monthly mean temperatures is presented in Fig. 8. Between temperatures generated in TRY and temperatures received from the Climatological Normal (climatic reference period 1961-1990) of two stations are differences of monthly average temperatures about 1 °C (Fig. 8) in January – March and September of the current years 2003-2004.
Table 2. Energy gains and efficiency of the solar double glass façade of the Metropolitan Moravian Library in the period of September 2003 – April 2004.

<table>
<thead>
<tr>
<th>Month</th>
<th>Energy gains</th>
<th>Theoretical energy gains</th>
<th>Global solar radiation on inside the façade</th>
<th>Global solar radiation on the horizontal plane</th>
<th>Operation time of forced ventilation</th>
<th>Global solar radiation on the vertical facade</th>
<th>Energy efficiency of solar façade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q [MWh]</td>
<td>Q_{theor} [MWh]</td>
<td>I_{gfv} [kWh/m²]</td>
<td>I_{gh} [kWh/m²]</td>
<td>I_{gfv} hours/month</td>
<td>I_{gsv} [MWh]</td>
<td>η [-]</td>
</tr>
<tr>
<td>September</td>
<td>5.06</td>
<td>11.90</td>
<td>40.39</td>
<td>65.36</td>
<td>263</td>
<td>45.84</td>
<td>0.11</td>
</tr>
<tr>
<td>October</td>
<td>13.13</td>
<td>21.88</td>
<td>40.91</td>
<td>48.14</td>
<td>426</td>
<td>46.44</td>
<td>0.28</td>
</tr>
<tr>
<td>November</td>
<td>11.96</td>
<td>20.85</td>
<td>28.87</td>
<td>20.16</td>
<td>392</td>
<td>32.76</td>
<td>0.37</td>
</tr>
<tr>
<td>December</td>
<td>9.92</td>
<td>26.03</td>
<td>25.16</td>
<td>10.64</td>
<td>306</td>
<td>28.56</td>
<td>0.35</td>
</tr>
<tr>
<td>January</td>
<td>16.29</td>
<td>31.01</td>
<td>36.01</td>
<td>20.88</td>
<td>404</td>
<td>40.87</td>
<td>0.40</td>
</tr>
<tr>
<td>February</td>
<td>22.31</td>
<td>22.73</td>
<td>38.49</td>
<td>35.17</td>
<td>691</td>
<td>43.68</td>
<td>0.51</td>
</tr>
<tr>
<td>March</td>
<td>12.63</td>
<td>21.96</td>
<td>36.96</td>
<td>58.98</td>
<td>414</td>
<td>41.95</td>
<td>0.30</td>
</tr>
<tr>
<td>April</td>
<td>8.90</td>
<td>17.60</td>
<td>38.75</td>
<td>94.30</td>
<td>356</td>
<td>43.98</td>
<td>0.20</td>
</tr>
</tbody>
</table>
| Total    | 100.19       |                          |                                            |                                               | 3252                                 | 324.07                                 | 0.31                             

Figure 8. Comparison of monthly mean temperatures between the reference climatic period (climatological normal) 1961-1990 of two meteorological stations and TRY (station Kucharovice) in South Moravia.

The comparison of monthly sums (in hours) of sunshine between the Climatological Normal for the period 1961-1990 of two meteorological stations, and TRY (station Kucharovice) in South Moravia is in Fig. 9. Large fluctuations of monthly values of duration of sunshine (monthly sums in hours) are in summer months from May until August. In winter period are smaller differences between Climatological Normal and climatic data in TRY generated from station at Kucharovice (located near Znojmo in the South Moravia), and Climatological Normal for the station at Turany (located in Brno), for about 8-11 hours per month in January-April.

Courses of monthly sums (in hours) of sunshine from the station in Brno-Turany for the current period 2003-2004, monthly sums of sunshine from climatological reference period 1961-1990 of two meteorological stations at Kucharovice and Turany, and monthly sums from TRY (station Kucharovice) are shown in Fig. 10. Larger differences between measured meteorological data at the station Turany and data created in TRY for the station at Kucharovice are shown in residue with differences of monthly values (in hours) about 23-34 hours in December 2003 and January 2004.
Figure 9. Comparison of monthly sums (in hours) of sunshine between the reference climatic period 1961-1990 of two meteorological stations and TRY (station Kucharovice) in South Moravia.

Figure 10. Comparison of monthly sums (in hours) of sunshine between the climatological period 1961-1990 of two meteorological stations, TRY (station Kucharovice) in South Moravia and climatic data from two meteorological stations in the period of winter season 2003-2004.

Courses and evaluation of temperature differences (mean values) inside the channel of the façade, with forced ventilation, received from the simulation of one zone models (VAR 3,4) and multi zone models (VAR 5,6), and measured air temperatures in the period of September 2003 – April 2004 are in Fig. 11.

Comparison of mean temperatures received from the simulation of the façade model, in all six variants VAR 1-6, for lower (a) and upper (b) temperatures (T_{d,l}, T_{b,l}) and measured temperatures (T_dM, T_bM) in the channel of the façade in the period 2003-2004 is in Fig. 12. Differences between measured temperatures in the channel of the façade and temperatures received from the simulation in the model VAR 6 are more close to the real situation of thermal and energy behaviour of the ventilated façade with comparison with the other models VAR 1-5. For the overall evaluation of the simulation models VAR 1-6 was carried out the...
comparison of monthly energy gains calculated by simulation and calculated from thermal and air flow site measurements in the double façade, with forced ventilation, for the time of operation in the period of September 2003 – April 2004. (Fig. 13). Energy efficiency of the façade was calculated from the ratio between energy gains used for the central air heating and ventilation system in the library and energy from the total incidence of global solar radiation on the vertical double façade. Energy efficiency of the façade evaluated from the site measurements is $\eta = 0.31$ and from the simulation of the façade model indicated VAR 6 for the reference climatic conditions (in TRY) is $\eta = 0.26$ for the period of heating season September 2003 – April 2004. For the verification of results the analysis of boundary climatic conditions represented by atmospheric air temperatures, global solar radiation and sun duration and between TRY and actual climatic conditions were carried out within the estimated period 2003/2004. The difference of energy efficiency of the double façade received from simulation in the multi zone model VAR 6 and real site measurements is about 16 %. The reliability of results received from the simulation are acceptable for the approximate prediction of thermal behaviour of the double façade and this numerical tool should be useful for the evaluation of different building double facades with the forced ventilation.

![Figure 11. Comparison of mean temperatures inside the channel of the facade in one zone models (VAR 3,4) and more zone models (VAR 5,6) from simulation and measured air temperatures from the period September 2003 – April 2004.](image1)

![Figure 12. Comparison of mean temperatures from the simulation of double façade models in 6 variants for lower (a) and upper temperatures (b) and measured temperatures (TdM, ThM) in the channel of façade in the period 2003-2004.](image2)
Figure 13. Comparison of energy gains from the double ventilated solar façade form the simulation in one zone models (VAR 1-4) and in more zone models (VAR 5-6) and, measured energy gains in the period of September 2003 – April 2004.

6. CONCLUSIONS

The solar double ventilated façade in the Metropolitan Moravian Library is integrated into the central air heating system of the building and supplied air heating system by solar energy gains for about 100.2 MWh in winter season 2003/2004. Solar energy use from the double facade reduced total energy demands in the southern wing of the library from the central heating plant for about 30%. Also approximate the same results were received from the experimental investigation in the previous heating season 2002/2003.

Facades play a fundamental role in the thermal performance of buildings. In the case of passive solar design and integration of the double ventilated solar façade in air-conditioning systems can help to reduce the consumption of energy for heating, ventilation and air conditioning in buildings. To use large or fully glazed facades is a common contemporary practice. In applications of transparent facades with the preference of aesthetics and architectural design aspects without adequate acceptance of environmental requirements in buildings are in many cases responsible for overheating in summer season and for higher heat losses in winter to create uncomfortable or non acceptable indoor climate conditions. Last development in façade techniques, integrated design and advanced numerical calculation methods implementing the performance-based approach in the design process can change of culture in contemporary architecture respecting environmental requirements and sustainable development in buildings declared in the European directives EPBD which will come into force in 2006.

Results from the modelling of the double ventilated façade with the application of 9-zone model and reference climatic data in the format TRY are comparable with the measurements and monitoring carried out at the Moravian Metropolitan library. Multi-zone simulation shows a possibility to be use for the prediction of zonal temperatures and energy efficiency of double facades integrated into building constructions and operation of HVAC systems.

Monitoring of the Metropolitan Brno Library with the application of CFD codes and multi zone models for simulation, with the application of the climatic reference data (TRY), used for analysis of thermal and energy behaviour of the double ventilated façade is the first examples of long time and large scale experimental and numerical investigation on the demonstration monitored building in the country.
REFERENCES


