411: Thermal characteristic of building envelope in revitalized post-industrial buildings.

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Abstract

Presented work is devoted to analysis of heat exchange on external surfaces with a complex geometry. Thermal processes in a thin layer enclosing external wall are determined by both: surface parameters (surface temperature and it's geometry) and weather conditions (external temperature, solar radiation and wind induced). Heat exchange on the external surface depends on air flow (natural or/and forced convection), temperature difference and heat flow density. The character and magnitude of physical processes is conditioned by heat flux and temperature on external surface. In this study, heat exchange processes on external surface were evaluated using numerical techniques. On the beginning, surface temperature as well as heat flux density were estimated for selected cases of heavy, homogeneous, masonry brick walls and glazing. Additionally, air flows around detailed wall's ornaments were calculated using CFD techniques. The numerical study were empirically validated based on the infrared camera measurements.

Keywords: revitalisation, historical buildings, architectural detail, heat exchange, numerical simulation, infrared measurements.

1. Introduction

Historical buildings are usually characterised by very complicated shapes of external wall surfaces. The ornamental elements such as stucco, cornices, strings, arches, portals, pilasters etc. make the wall texture very rough with hollows and bulges. Additionally some of them consist of fine-featured elements. Substantial proportion of hundreds year old buildings is nowadays renovated and adopted for completely new purposes of different functions and intended occupation. Higher building standards and more advanced indoor requirements, especially in post industrial buildings lead to inevitable changes in building envelope resistance and overall durability of building structure.

The renovation of old, post industrial areas in the city centres has many different aspects and used to be recognized as a part of sustainable development. In XIX and in the beginning of XX centuries industrial zones were closely connected with residential areas. Nowadays, after urbanization process many of them found themselves in city centres.

In 1989, after political and economical transformations in Poland many of textile companies suffered a crisis which led to their subsequent liquidation. Old factories buildings were abandoned and nowadays they make common challenge for developers, architects and urban planners. Recovery of these areas should be one of the priorities according to sustainable development. Currently developing project "Manufactura" in Lodz is a good example of collaboration between local government, ecologists, historian and architects and city planners (Fig.1). However, incredible lack of detailed analyses of environmental impact and microclimate parameters, within new urban structure is noticeable.

Fig 1. Manufaktura today – general view.

2. Revitalisation of post-industrial areas

2.1 Urban scale

Lodz is a capital and main district of textile industry in Poland. By the and of 19th century the city become a cosmopolitan city and the world biggest cotton factories. A particular characteristic feature of Lodz are it's factory complexes – the owner mansion, the factories and also the residential blocks of flats for workers, hospitals, fire-stations and schools. A good example of such kind of architecture is the weaving-mill complex and mansion of magnate Israel Poznanski. The complex is a series of gigantic, masonry halls built at the end of 19th century by the Lodka river to supply cotton and textile for Russian market. Nowadays, the former Poznanski Empire is a 27's hectare site located in the very heart of the city, a few hundred meters from main city square – Plac Wolnosci.

Fig 2. Manufaktura complex – bird's eye view. (source: http://maps.google.com).

The Manufaktura redevelopment project will convert the abandoned textile buildings into a modern and functional centre of culture, entertainment and commerce. The project comprising of 12 buildings with the construction of modern retail complex. Manufaktura fits perfectly into the history of Lodz, cleverly echoing its industrial development, and creating a new image for a large sector of the city centre.

The revitalisation is not only the protection but sometimes is connected with adding a new elements to the empty ground (Fig.2) (bold line indicates the new building covering the valley). These actions leads to crowding of buildings in city centre, limitation of green spaces and the significant changes in building arrangements. In analysed case the old factories were located on the river's valley. The valley enabled fresh air to ventilate the city. When the new buildings arisen on the spot of the river bed the local microclimate were change considerably. It had a significant influence on climate both in urban and local scale. Buildings blocked the wind flow entering to the city and weaken the ventilation. On the other hand in the dense urban structure local zones with high wind speed and vortices appeared. In some locations buildings were exposed to the strong wind what could has influence on their thermal behaviour and surroundings.

2.2 Building scale

The former function of historical buildings in Manufaktura complex was textile production. The buildings were occupied 24 hours a day with a huge number of internal vapor and heat gains. During winter period the gains covered energy requirements whereas in summer the internal spaces were strongly overheated. The fabric halls were also very well ventilated removing damp excess from the zones providing dry indoor conditions. Therefore neither surface condensation nor interstitial condensation appeared.

Together with revitalization buildings received also new functions completely different from the previous one. The old factories transformed into shops, restaurants, cinemas, galleries, hotels etc. (fig. 3). These changes create a new kind of problems for 100 years old buildings and their historical walls. The modernisation were done without any adjustment of wall properties to actual interior and exterior conditions. It means that the wall structure were left unchanged with its original masonry character.

Fig 3. New functions of old factories.

2.2 Detail scale

The unique character of 100 years old post industrial buildings results from masonry bricks elevations with precise ornamentation and sophisticated details. The proper revitalisation should retain and reconstruct the original structure of the walls. Any changes of wall properties such as adding of new layers (insulations or plasters) is at variance with cultural heritage protection. Therefore the wall structures as well as geometry of external surface have to remain unchangeable. The exemplar details from existing buildings after renovation is presented on figure 4.

Fig. 4. Architectural details of XIX century buildings.

The complicated geometry of wall elements cause physical processes more complex. There are a lot of environmental factors which determined the magnitude of this effect. One of them is the air flow around building. The higher roughness of the wall creates small zones characterized by low speed and turbulent wind flow with small eddies. On the other hand near the sharp edges of the architectural elements the flow accelerates creating different conditions for the heat exchange processes (convection). The second factor which is an additional source of heating energy during a day is solar radiation. When the surface is completely flat and exposed the effect of sun beam radiation is constant. But when the geometry becomes more carving the sticking elements obscure part of the wall causing difference in temperature between shadow and full sun areas.

All the factors mentioned above creates an unequal heat flux density and changeable temperature of selected elements, thereby causes the risk of local vapor and dirt condensations. These physical processes have significant impact on durability and stability of modernized historical constructions.

3. Heat exchange

The analysis of heat exchange between buildings and environment was calculated using simulation model proposed by Clarke [3]. The building was divided into selected number of thermal zones for which different indoor conditions were defined. The air parameters inside the buildings were controlled by ideal heating/cooling system. The values of temperature and relative humidity depend on the period of a day, occupancy and kind of the building. The analysis were done for the following building types: commercial, offices, service and entertainment. The main difference between selected types of buildings displays in occupancy time, internal gains and assumed temperature during occupancy period.

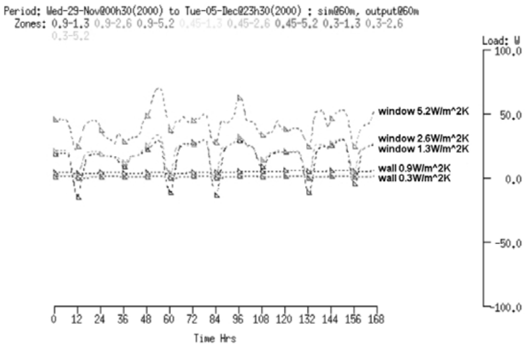

Fig. 5. Convection heat flux through the wall and window (commercial building).

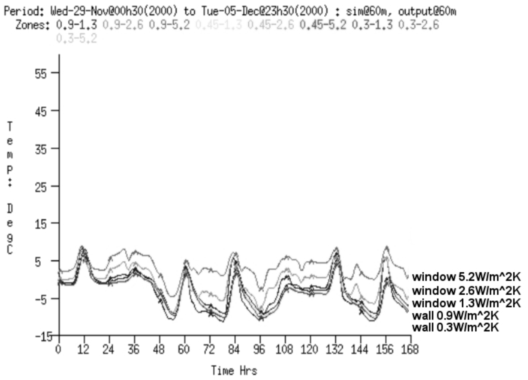

Fig. 6. Temperature of external surfaces, wall and window (commercial building).

The analysis were done for the selected week of winter. The ambient temperature changes from +1°C to -15°C. The control system was defined as a constant heating, lower power out of occupancy period and no control out of occupancy period. The results presented in figure 5 and 6 represents the heat exchange by convection (fig. 5) and temperature (fig. 6) history for commercial building. The substantial fluctuations of both parameters are noticed for windows where heat gains during some days gave positive values of heat balance. On the other hand during the night the heat losses by the windows are 10 times higher than by the masonry wall. The massive structure of the wall allows to keep constant heat flux (constant zone's temperature) but the temperatures varies very deeply between day and the night.

4. Air flow – CFD analysis

4.1 Wind flow pattern

When the approaching wind hits the windward face of the building at about two-thirds of the building height the flow split up [3]. Part of the air flows up and over the roof of the building. The rest is compelled to go to the ground level where it generates a standing vortex in front of the building, which spreads around the building corners (corner streams). The ornamental elements such as cornices or stuccos disturb this basic flow pattern and create zones with different flow characteristic. In order to investigate this micro scale processes numerical simulation of wind flow in the vicinity of detailed wall's ornament has been done.

4.2 Numerical simulation

As our research include also experimental measurements in wind tunnel we used the achieved results in boundary condition setting. Numerical analysis were conducted using realizable K - ε model.

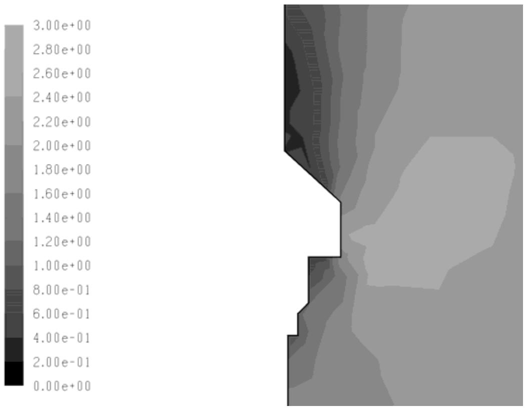

Fig. 7. Mean velocity field near the wall with cornice.

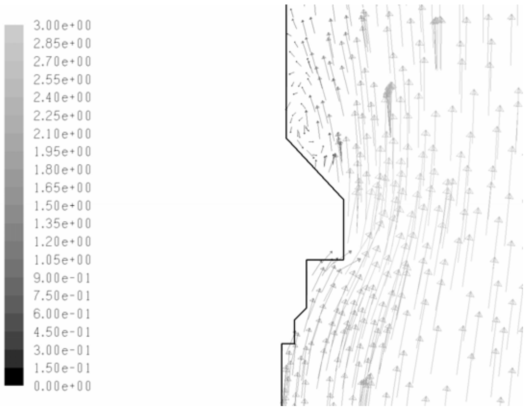

Fig. 8. Wind velocity vectors near the wall with cornice.

The architectural detail as well as wind tunnel were modelled in a real scale. It was possible to get information about wind speed distribution near the architectural element located in a tunnel. The inlet profile were established on basis of the previous experimental measurement. The maximum wind speed in inlet were 2,5m/s. Figures 7 and 8 present a part of the wall with architectural detail, which constitute cornice located above a window. We assumed that the flow comes from bottom of the wall up to the roof. This is an effect of vertical temperature and pressure gradient along the wall. In the result of numerical simulation distribution of wind speed near the wall have been achieved. The highest velocities can be observed along the most protruding part of the wall. The flow separates on the sharp edges of the cornice and accelerates reached the maximum value (about 2.8m/s). In the hollows the air flow is more disturbed. Because of the sheltering effect wind speeds in these areas are clearly lower, reaching about 0.3m/s. In some situation one can expect dead field in these zones. Simultaneously, the shelter areas are characterized by variable wind direction. Fig. 8 illustrate very clearly complex model of the flow. In the hollow zones small eddies can be observed.

5. Infrared inspections

The numerical results obtained by simulation techniques (heat and air flow) were empirically validated on existing buildings. The temperature on selected parts of external wall were measured using infrared camera. All analysis were done for winter season. During the inspections the weather conditions were stable with external temperature T_e=5ºC. There was no wind and rain. The interior conditions were stable with constant temperature T_i=20ºC in the whole building.

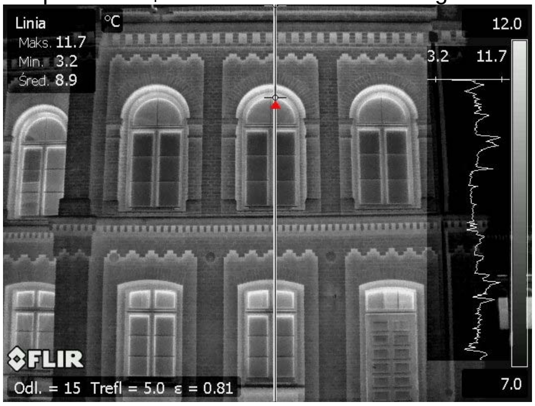

Fig. 9. Results from infrared camera – vertical temperature profile along the elevation.

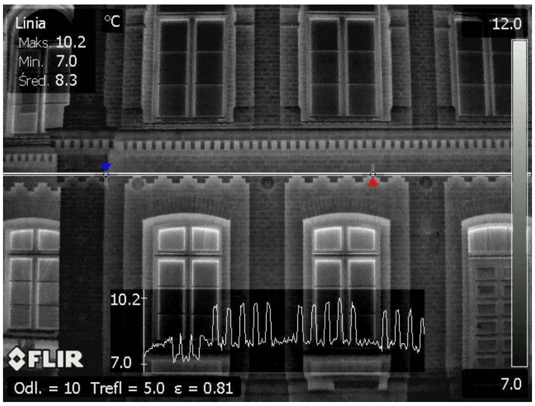

Fig. 10. Results from infrared camera – horizontal temperature profile along the elevation.

The selected results of IR measurements are presented in figures 9 and 10. The effects of complex physical processes described by numerical simulations are also clearly seen on thermovision images. The warmer areas are noticed in the hallows under the sticking elements. It is effect of:

- lower wind flow in deeper spaces thus lower convection heat exchange,
- different thickness of the wall around ornaments and different temperature of selected surfaces of detail elements,
- different conductivities of mortar and bricks
- huge heat flux coming through the window surface.

The images obtained by infrared scanning confirmed the results of numerical analysis. The differences in temperature of selected areas can create a several problems like: uneven condensation, deposition of pollutant and unequal aging of selected parts of the wall. By using this method it is possible to quickly obtain the information about potential risk and indicate which element should be especially protected.

5. Conclusion

The obtained results show the complex character of physical processes in vicinity of building's details exposed to environmental influence.

The simulation results of heat exchange processes on external surface showed the significant differences between selected part of the wall. This differences cause natural vertical convection flows along the wall and influence on heat exchange around details above the window.

The CFD analysis of air flow confirmed that wind speed and direction are very variable. Near the protruding parts of the wall higher values of wind speed can be observed. At the same time in the hollows velocities fall down creating the shelter zone with higher turbulence and small eddies.

The effects described above were confirmed by temperature measurements on renovated walls of historical buildings.

This paper describes the close connections between historical protection and building physics problems. It is mainly conditioned by untypical, rough and complex geometry of external wall surfaces. Presented analysis are only the part of broadly conceived research devoted to interaction between building and environment. This is specially important in the context of durability of revitalized historical buildings.

6. Acknowledgements

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7. References

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