Cooling potential of heating-cooling wall panels

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ABSTRACT

This paper presents the technological part of activities executed in the framework of MUSEUMS Project Slovene Ethnographic Museum, Ljubljana, Slovenia. To assure thermal stability of exhibition rooms and to achieve optimal relation between air temperature and walls surface temperature a combined thermal insulation and heating-cooling wall system was designed as a low temperature large surface heating and cooling vertical system. The thermal comfort is improved because of surface temperature – air temperature relation lateral radiation effect.

Optimal relation between air temperature and surface temperature is achieved with the use of heating/cooling wall panels. System is connected to district heating system for heating purposes in winter and to cooling plant for cooling purposes in summer. Wall cooling system starts to work if outside conditions do not enable cooling of the building with ventilation.

1. INTRODUCTION

The majority of museum buildings in Slovenia are placed in historical buildings: castles, palaces, public buildings, which have been adapted to new functions. Practically no interventions have been made in the direction of g envelope is composed of walls with partly brick partly stone masonryenergy savings and ilumination upgrading. Daylighting is poor, installations are old and obsolete. Heating costs are high, there are problems with moisture in the rooms. There is no common doctrine for reconstructions. Because the majority of museums is in old buildings, declared as cultural heritage, facades and roofs must be preserved.

The SEM building envelope is composed of walls with partly brick partly stone masonry with plaster on both sides. Total floor area is 3913.88 m^2, from this total exhibition area 2884.6 m^2 (Fig. 1.). Typical floor area is 1056 m^2. Floor to ceiling height is 3.5 to 4.0m. The floors have partly original brick arch structure,

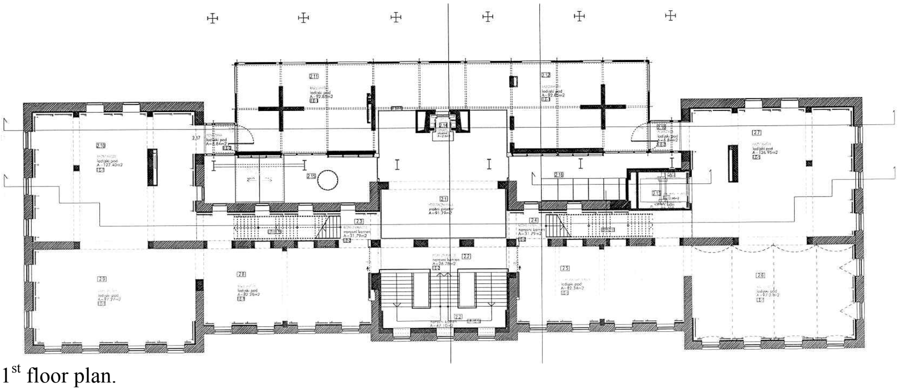

Figure 1: 1st floor plan.

which was partly replaced with reinforced concrete plates. Walls, floors, roof and basement were thermally not isolated. The windows were double-glazed in box type and wooden frame. Space heating was executed with radiators. For water heating electrical boilers were used. There was no mechanical ventilation or air condition in use.

The most important positive characteristic of the building is its basic architetural concept with big spaces which can be optionaly connected and adjoining administrative building of SEM.

2. OBJECTIVES

The main objectives of the project are:

- To assure optimal conditions for exhibitions and for storage of museum objects in accordance with international standards.
- To assure appropriate environment for visitors from the visual and from the thermal point of view.
- In the framework of this project the priorities for both objects and visitors are optimal daylight and rational use of energy without prejudice to quality of use.
- To assure and define the possibilities of natural light use in exhibition rooms.
- To assure and define optimal bioclimatic conditions (internal climate) in rooms from the point of view of exhibits and visitors.
- To assure rational use of energy for heating and cooling with the intention of reduction of operating costs under the control of central control system. The basic concept of system performance is presented in Figure 2.

There were 7 main spheres of activities resulting in the framework of the following interventions: thermal energy with heating and cooling part, ventilation, daylight, control and management, constructional complexes, simulations and testing and measurments.

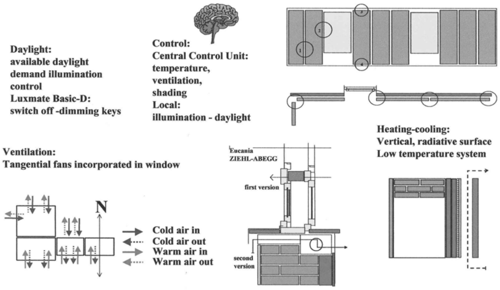

Figure 2: Scheme of system performance parameters.

The interventions in the cooling part of thermal response and resulst of simulations and measurements will be described here.

In the starting phase of the project no requirements existed for thermal insulation of buildings under the historical monument preservation protection neither for heating nor for cooling.

First thermal insulation was placed on the existing outer brick wall on the inner side in two layers with corresponding vapour barrier.

Optimal relation between air temperature and surface temperature is achieved with the use of heating/cooling wall panels (Fig. 3). They represent the main intervention in the framework of the construction. System is connected to district heating system for heating purposes in winter and to cooling plant for cooling purposes in summer.

Window integrated BMS controlled ventilation system (small tangential fans) is used for necessary ventilation during opening hours (0.5 ACH) and for cooling purposes (night ventilation) harmonised with wall cooling system. Wall cooling system starts to work if outside conditions do not enable cooling of the building with ventilation.

Window integrated BMS controlled roller blinds with special fabric are used for reduction of direct solar gains and UV protection.

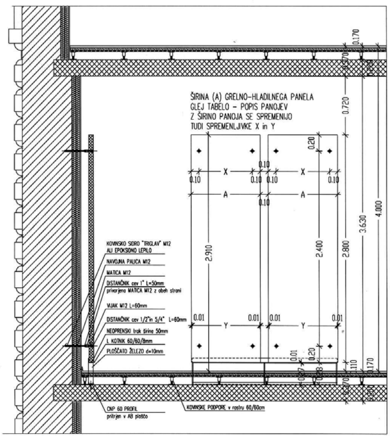

Figure 3: Schematic cross-section through the new outer wall system.

3. PRELIMINARY MEASURES

First measurements of empty building before any intervention during summer 2000 (Fig. 4.) and preliminary simulations have shown that air condition system, which was selected first of all for cooling purposes, included in the original design before the start of the MUSEUMS project, is questionable. Consideration of foreseen interventions based on preliminary measurements and on the new design of combined heating-cooling wall system resulted in the decision that the air condition system foreseen in the existing project was totally excluded. This set free of 158 m2 of space for depository area, about 100-150.000 € value and the reduction of investment budget in the field of HVAC from 530.000 to 434.000 €. The quantity of blown in air is reduced from 36.500 m3/h to 10.000 m3/h. The power of heating station is diminished for 110 kW and for cooling for 62 kW.

4. COOLING WALL SYSTEM PERFORMANCE

To assure thermal stability of exhibition rooms and to achieve optimal relation between air temperature and walls surface temperature a combined thermal insulation and heating-cooling wall system was designed. With this design several problems and functions were solved. First the execution of thermal insulation in the selected, not limited dimensions on the inner side of the walls. Thus quick thermal response of the building was achieved which enables effective intermittent heating and cooling. At the same time the outer side of the protected facade was not touched and it can retain its original structure. Second low temperature large surface heating and cooling vertical system is used. Third non manageable thermal mass of the original wall is excluded from the wall's thermal conduction transport system but at the same time replaced by a designed thermal mass in the reinforced concrete wall panels separated from the other parts of the outer wall structure. Forth thermal comfort is improved because of surface temperature – air temperature relation lateral radiation effect.

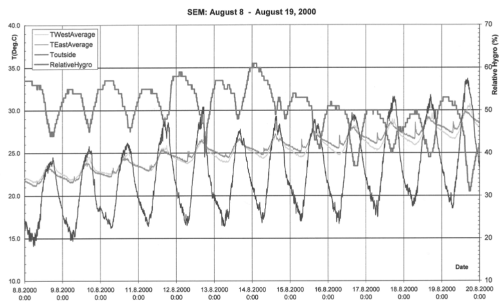

Figure 4: 1st phase of measurements, summer 2000. Internal air temperature in free running mode rose beyond 30^0C only on one day in a room with 1/3 eastern and 2/3 southern windows without shading.

Roler blinds for glare prevention and shading. Window integrated BMS controled roller blind system was organised in three separate cones: East, South and West with the posibility of individual control in all exhibition spaces. Selected material for roler blinds is "Mermet" - Inntermarisen, E-Screen 4203, Sample 0202.

Daylight - artificial light harmonisation with daylight dependent dimming system as general illumination. General lighting control is executed in exhibition areas with time control/daylighting sensors/occupancy sensors and in other areas with time control/occupancy sensors. High efficiency lamps (linear fluorescent T8 for general illumination) are used for general illumination.

Wall cooling system is connected to common cooling plant (McQuay AGF-XN 070.2, cooling power: 218 kW, electric 88 kW, 2 compressors, 4 steps (25, 50, 75, 100%)). The same divisions of spaces as for heating are used for cooling.

Temperature sensitive control system is assured by ventilation and by wall panels cooling system. Wall cooling system starts to work if the outside conditions do not enable cooling of the building with ventilation.

Both systems are linked and harmonised.

5. TESTING AND MEASURMENTS

At the end of 2001 two testing rooms were constructed (Fig. 5). One served as a reference room. In both rooms there was the same thermal insulation. In the reference room there were insulating clear double-glassed windows, and in the model room there were low-IR, argon filled double glazed windows. In the reference room common heating with radiators was installed, while in the model room new system of heating-cooling wall panels was installed and equipped

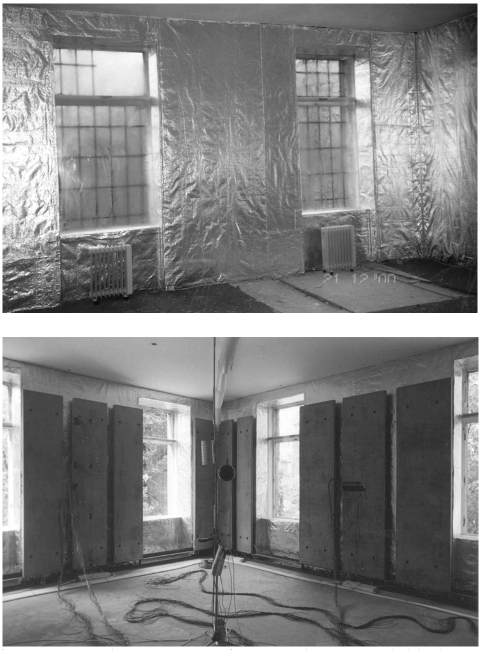

Figure 5: Testing rooms: reference above, model below.

with heating and cooling power plants and ventilation system. During summer period reference room was in free running mode.

For monitoring and data acquisition two PC controlled HP3852A Data Acquisition systems connected by HP 37204 HP-IB Extenders and supported by UPS were used. Both systems supported the following sensors: for temperature thermocouples type T, for illumination Chauvain Arnoux 1017.18, for relative humidity Rotronic Hygrometer MP and for global solar radiation Kipp&Zonon CM-6B. The following quantities were measured: microclimate: ambient air temperature, ambient air humidity and global solar radiation on horizontal level; energy systems: cooling consumption (electricity), lighting consumption (electricity), total electricity consumption; indoor comfort: indoor air temperature, indoor air humidity, lighting levels.

Energy consumption for cooling was measured in the summer period August 2001 and June 2002, i.e. two seasons. Different set point temperature series were tested: 24h/day continuous cooling and two modes of intermittent cooling, from 08-20 h with 22.5^{0}C and 25^{0}C set point temperatures. These results were derived into seasonal specific energy consumption between 10 and 15 kWh/m^2 for intermittent cooling and 25 to 30 kWh/m^2 for continuous cooling. Details are presented in Table 1.

In Figure 6, 6 day period in summer (August) in intermittent cooling mode is presented. The first three days represent typical hot period conditions. The reference room is not cooled. Set point temperature in the model room is 22.5^{0}C (straight interrupted lines). In the reference room the temperature is between 25 and 30^{0}C. In the model room the cooling wall retains temperatures between 22 and 24^{0}C also during the period when cooling is switched off.

Panel temperatures were measured on 5 different heights (Fig. 7). The middle position was on the surface, the distance between individual

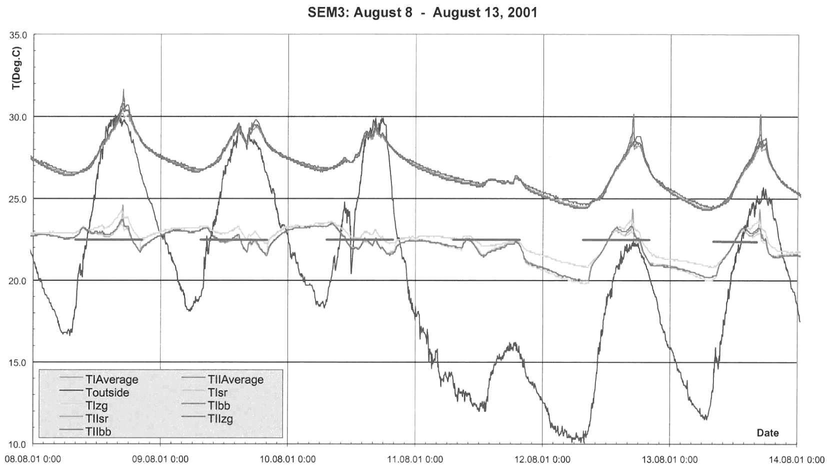

Figure 6: 6 day period in summer (August) in intermittent cooling mode.

Table 1: Specific daily and seasonal consumption for cooling in August 2001 and June 2002.

	kWh/m²/day				Season (60 days, kWh/m²)			
	2001			2002				
	August			June				
	1	2	3	4	1	2	3	4
	24 h/day no set point T	12 h/day, 8-20h, 22.5C set point T	12 h/day, 8-20h, 25C set point T	24 h/day no set point T	24 h/day no set point T	12 h/day, 8-20h, 22.5C set point T	12 h/day, 8-20h, 25C set point T	24 h/day no set point T
I. Floor	0.48	0.25	0.17	0.42	**28.8**	**15**	**10.2**	**25.2**

sensors was 2.5 cm, laterally. The lower and the upper pair of sensors were in the middle of the panel, i.e. 3 cm from the surface. Temperature oscilations inside reinforced concrete concrete panel with inflow and outflow cooling water temperature for one day in August for continous mode are presented in Figure 8.

Maximum outside air temperature was 32.5^{0}C, at 9AM it was 23.5^{0}C and at 10PM 26.5^{0}C. Incoming water temperature in the panel was 9^{0}C - 13^{0}C and oucoming water temperature between 11^{0}C and 13.5^{0}C. Designed set point temparature was 22^{0}C and actual one during 24 hours between 21 and 22.5^{0}C. Temperatures in the panel and panel's surface on different positions were wery stabile, in the range of less than 1K! The difference between the highest and the lowest temperature inside the panel and on its surface was less than 3K (Fig. 8.). Temperature ocsilation on all measured positions were negligibe (+/- 0.1 K, which is below the level of sensors acuracy). Temperatures on different positions of the front surface were below 1K.

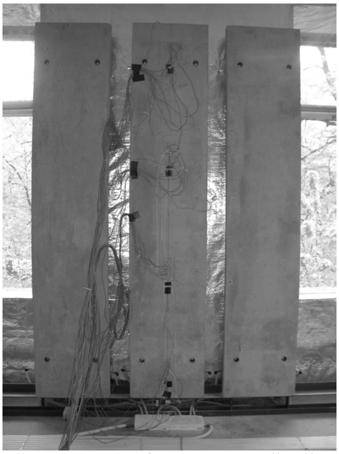

Figure 7: Measurements of temperature distribution inside reinforced concrete panel.

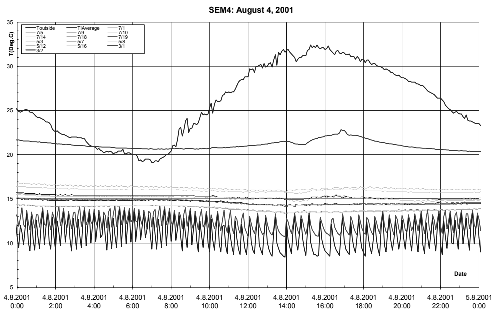

Figure 8: Temperature profiles inside cooling panel with inflow and outflow water temperatures.

Comparison of temperature profiles in reference room without cooling and model room with cooling panels is presented in Figure 9. Observed rooms are on SW side in the 1st and 2nd floor. Average inside air temperature in the reference room was between 27.5 and 31^{0}C while in the model room this temperature was between 20.5^{0}C and 22.5^{0}C. Differences in temperatures on different possitions in the room were in the range of 2K. These data proved that cooling system is able to follow very well the demanded set point temperature profile. Difference between inside air temperature and the highest and the lowest panel temperatures was between 5.5 and 8K.

6. CONCLUSIONS

On the basis of measurements during summer 2000 and consideration of the foreseen interventions resulted from new design of combined heating-cooling system, the air condition system foreseen in the existing project was totally excluded. The consequences were reduced energy consumption but also space set free for other uses, diminished capacity of power station for

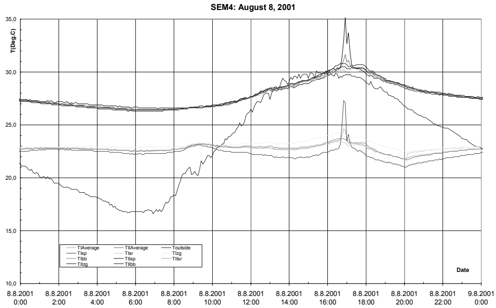

Figure 9: Comparison of temperature profiles in model and reference room.

heating and reduced budget foreseen for HVAC. Measurements of energy needed for cooling in the following two summer seasons demonstrate specific energy consumption between 0.42 and 0.48 kWh/m2day in the 24 hours performance mode and even between 0.17 and 0.25 kWh/m2/day in intermittent cooling mode. With heating-cooling wall panel system an excellent inside air temperature profile has been attained. To achieve optimal performance of the whole system designed and executed, a serious tuning is needed.

ACKNOWLEDGEMENTS

This project has been supported by European Commission 5th Framework Programme MUSEUMS Energy Efficiency and Sustainability in Retrofited and New Museum Buildings, NNE5/1999/20, by Ministry of Education, Science and Sport, Republic of Slovenia, Research Programme Renewable Energy Sources, P0-504-0792-02 and by Chair for buildings and constructional complexes, Faculty of Civil Engineering, University of Ljubljana.