

HEATING-COOLING WALL PANELS SYSTEM IN SLOVENE ETHNOGRAPHIC MUSEUM**Aleš KRAINER Prof. Dr.¹**Rudi Perdan²
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Summary

Technological part of one of the activities executed in the framework of EC /MUSEUMS Project Slovene Ethnographic Museum, Ljubljana, Slovenia is presented in this paper. The construction of new envelope design, new heating-cooling wall panels system, replaced originally designed air condition system. The control and management system is taking care of harmonization of demands on the temperature, humidity and air quality level upgraded with permanent monitoring system.

The SEM building envelope was composed of walls with partly brick partly stone masonry with plaster on both sides. Total floor area is 3913.88 m², from this total exhibition area 2884.6 m².

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.

First measurements of empty building before any intervention together with the preliminary simulations have shown that air condition system included in the original design before the start of the MUSEUMS project is questionable. A new design of combined heating-cooling wall panels system resulted in the decision that the air condition system foreseen in the existing project was totally excluded.

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.

The same division of spaces to seven zones as for heating is used for cooling. Wall cooling system starts to work if outside conditions do not enable cooling of the building with ventilation. Both systems are linked and harmonized.

Two testing rooms were constructed before selection of the final version for construction: one served as a reference room. In both rooms there was the same thermal insulation. In reference room there were insulating clear double glassed windows in model room there were low-IR, argon filled double glazed windows. In reference room common heating with radiators has been installed while in the model room new system of heating-cooling wall panels has been installed and equipped with heating and cooling power plants and ventilation system.

The energy consumption in winter period was measured in winter 2001/2002 in two rooms with the same thermal insulation, on the 1st and 2nd floor, respectively. In the room with the new system, the energy consumption for heating was 92 kWh/m² i.e. by 12%. Energy consumption for cooling was measured in 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°C and 25°C set point temperatures. These results were derived into seasonal specific energy consumption between 10 and 15 kWh/m² for intermittent cooling and 25 to 30 kWh/m² for continuous cooling.

1. Introduction

The Slovene Ethnographic Museum, SEM is situated in a 19th century building in the center of the city. The beginnings of the Ethnographic Museum were the “ ethnographic” and “folklore collections” of “The Carniolian Provincial Museum” in Ljubljana founded in 1821. In 1923 the permission was obtained to found The Royal Ethnographic Museum. After Second World War museum changed its name into Ethnographic Museum, and the adjective Slovene was added in 1964. On 1994 the government of Slovenia decided to allocate the southern part of the complex of former Yugoslav military buildings in “Metelkova” street to the cultural institutions.

The building has ground floor three floors for exhibitions, basement for storage and attic for additional storage and offices. The building is longitudinal, longer facades face south and north. The massive construction, partly stone, partly brick masonry was not thermally insulated. Windows were double-glassed box types. All installations were destroyed.

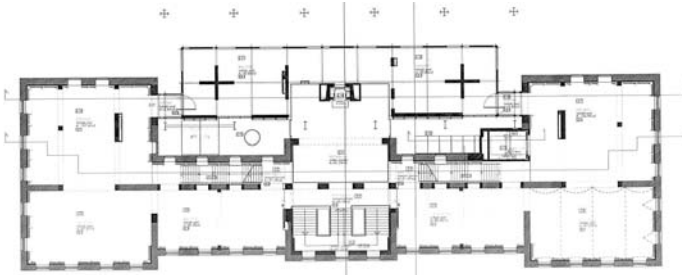


Figure 1 Ground plan of 1st floor

Figure 2 Existing state after renovation

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 energy savings and illumination 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 are in old buildings, declared as cultural heritage, facades and roofs must be preserved. The collaboration with the responsible heritage protection administration is practically impossible and based on the principle of negative intervention.

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 m², of this total exhibition area 2884.6 m². Typical floor area is 1056 m². Floor to ceiling height is 3.5 to 4.0 m. The floors have partly original brick arch structure, which was partly replaced with reinforced concrete plates. Walls, floors, roof and basement were thermally not insulated. The windows were double-glazed box types with wooden frame. Space heating was executed with radiators. For water heating electrical boilers were used. There was no mechanical ventilation in use.

The most important positive characteristic of the existing building is its basic architectural concept with big spaces which can be optionally connected and the connection to the adjoining administrative building of SEM.

2. Objectives

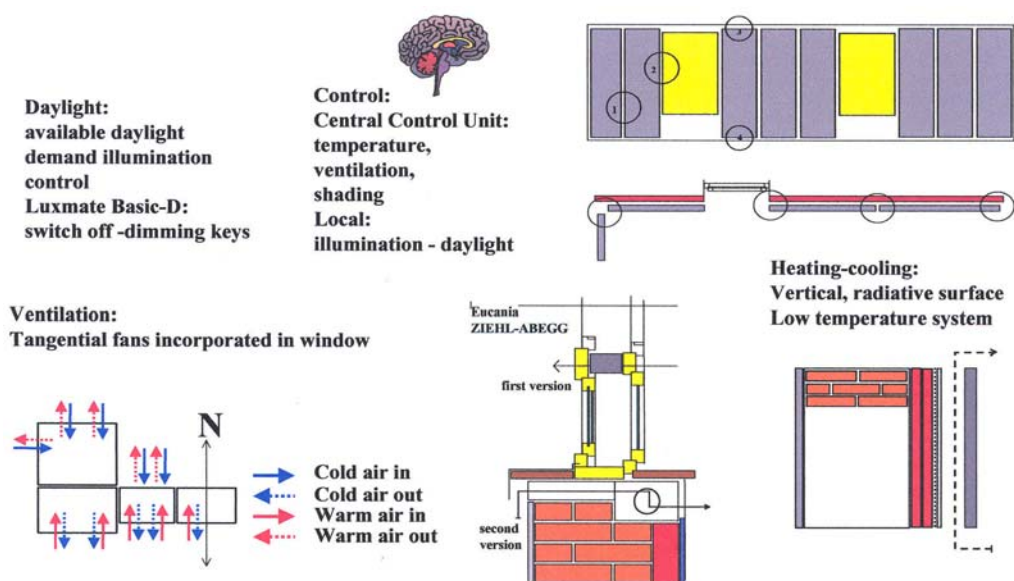


Figure 3 Scheme of system performance parameters

The main objectives of the SEM – Museums project were:

- To assure optimal conditions for exhibitions and for the storage of museum's 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 both for objects and visitors are optimal daylight and rational use of energy without prejudice to the quality of functional 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 to reduce operating costs controlled by a central control system.

3. Spheres of Activity

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 measurements.

3.1 Thermal energy

In the starting phase of the project no requirements existed for thermal insulation of buildings under the historical monument preservation protection. First thermal insulation was placed on the existing outer brick wall on the inner side in two layers with corresponding vapor barrier.

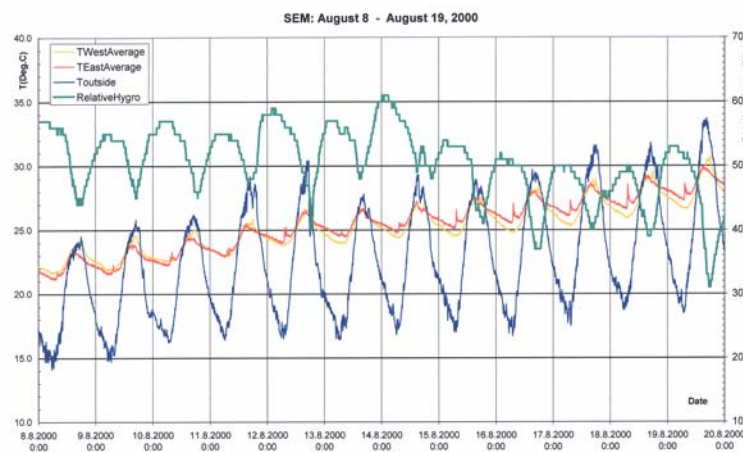


Figure 4 1st phases of measurements, summer 2000. Internal air temperature in free running mode rose beyond 30°C only on one day in a room with 1/3 eastern and 2/3 southern windows without shading.

The first measurements of empty building before any intervention during summer 2000 together with the preliminary simulations showed that air condition system included in the original design before the start of the MUSEUMS project is questionable. Consideration of the foreseen interventions based on the preliminary measurements and on the new design of combined heating-cooling wall panels 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 reduced by 110 kW and for cooling by 62 kW.

Optimal relation between air temperature and surface temperature is achieved with the use of heating/cooling wall panels. They represent the main intervention in the framework of the construction. The system is connected to the 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 the necessary ventilation during opening hours and for cooling purposes (night ventilation) harmonized with wall cooling system. Wall cooling system starts to work if the outside conditions do not enable cooling of the building with ventilation.

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

3.2 Heating & Cooling

To assure thermal stability of exhibition rooms and to achieve optimal relation between air temperature and wall surface temperature, a combined thermal insulation and heating-cooling wall system was designed (Figure 6). With this design several problems and functions were solved. First the execution of thermal insulation in the selected not imposed 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 could 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 it is 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.

4. Control and Management

Exhibition area with the total surface of 2884 m² is divided into seven zones: in the East wing of ground floor and in the 1st, 2nd and 3rd floor (East and West zone in each floor), which are separately controlled by BMS. Scheme of the central control system and an example of opening BMS screen for heating-cooling panels system is presented in Figure 5.

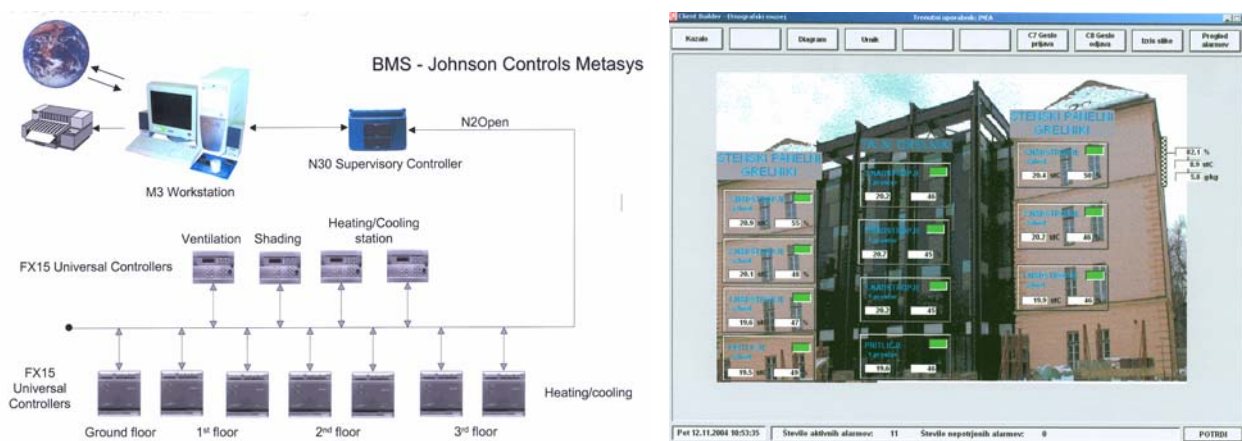


Figure 5 Scheme of central control system and opening BMS screen for heating-cooling panels.

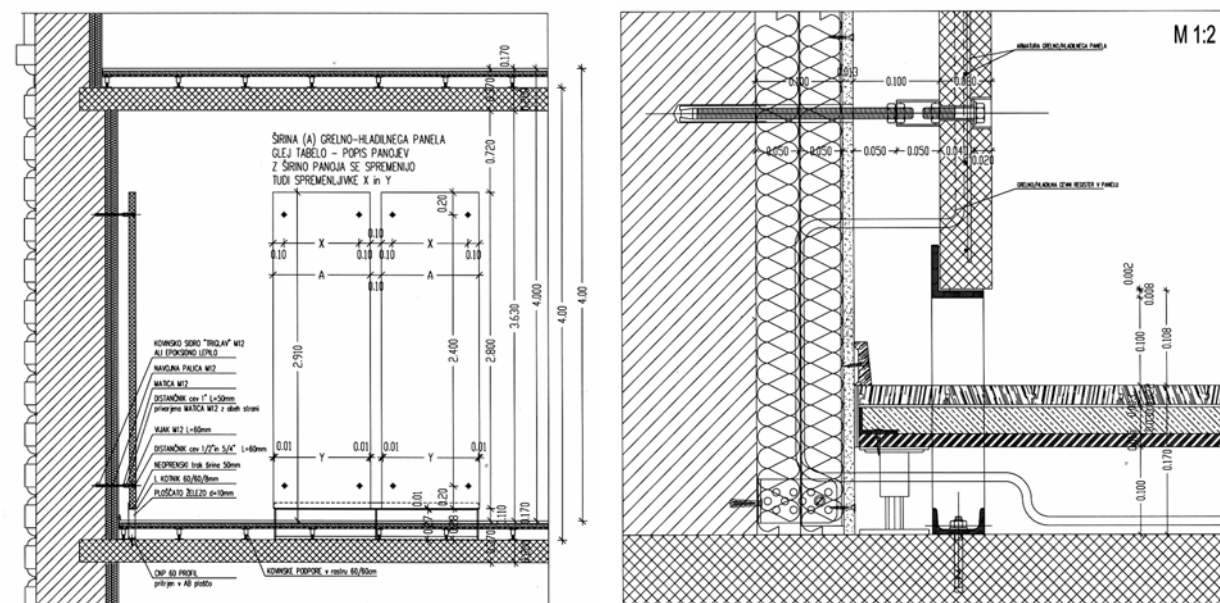


Figure 6 Heating-cooling panel in the cross-section outer wall – floor: construction detail.

Heating wall system of the building is connected to the city district heating system. It is divided into 7 zones: East part and West part of the building and each floor separately. Temperature/time/season sensitive control

system is designed and enables establishing of different set-point temperature profiles during opening and non-opening hours.

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 division of spaces as for heating is 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 harmonized.

The following quantities will be permanently controlled and collected by BMS:

1. Microclimate: ambient air temperature, ambient air humidity.
2. Energy Systems: heating consumption (district heating, each zone separately and total consumption), cooling consumption (electricity), lighting consumption (electricity), total electricity consumption.
3. Indoor Comfort: indoor air temperature, indoor air humidity, and lighting levels.

5. Testing

Experiments of heating-cooling panels performance

The first period of monitoring started in summer 2000. Temperature and humidity oscillation and daylighting levels were measured in different rooms of the building.

At the end of 2001 two testing rooms were constructed. 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 with heating and cooling power plants and ventilation system.



Figure 7 Two testing rooms: model room, 1st floor, and reference room, 2nd floor.

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: heating consumption (district heating), cooling consumption (electricity), lighting consumption (electricity), total electricity consumption; indoor comfort: indoor air temperature, indoor air humidity, lighting levels.

Table 1. Comparison of energy consumption for heating from October 2002 to May 2002 and seasonal consumption in 1st floor with classical radiator heating and in 2nd floor with heating wall system.

	2001			2002					Season
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	
I. Floor	5.1	13.3	24.2	23.8	12.7	5.6	6.8	0.8	92.3
II. Floor	6.1	15.0	27.3	26.3	15.1	7.7	7.1	0.4	105.1

The energy consumption in winter period was measured in winter 2001/2002 in two rooms with the same thermal insulation, on the 1st and 2nd floor, respectively. The comparative room was heated with classical

radiators in order to enable objective performance of the new heating wall panel system installed in the 1st floor. In the room with the new system, the energy consumption for heating was lower by 12% (Table 1).

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°C and 25°C set point temperatures. These results were derived into seasonal specific energy consumption between 10 and 15 kWh/m² for intermittent cooling and 25 to 30 kWh/m² for continuous cooling. Details are presented in Table 2.

Table 2. Specific daily and seasonal consumption for cooling in August 2001 and June 2002.

	kWh/m ² /day				Season (60 days, kWh/m ²)			
	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

The presented data show important differences in energy consumption between the reference room and the model room for heating and small specific energy consumption for cooling.

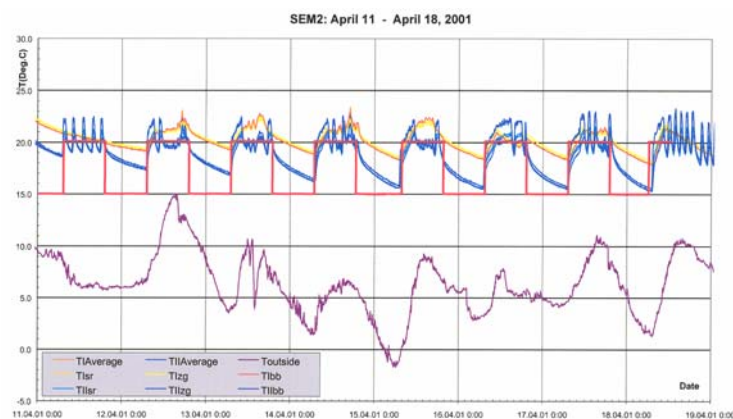


Figure 8 An 8-day period in spring (April) in intermittent heating mode.

The influence of thermal capacity of heating panel (light line) is evident. This case shows the possibility of temperature managing in order to decrease energy consumption. Lower temperatures can be used without the danger of going under the prescribed 15°C , which is not the case in the reference room (blue lines).

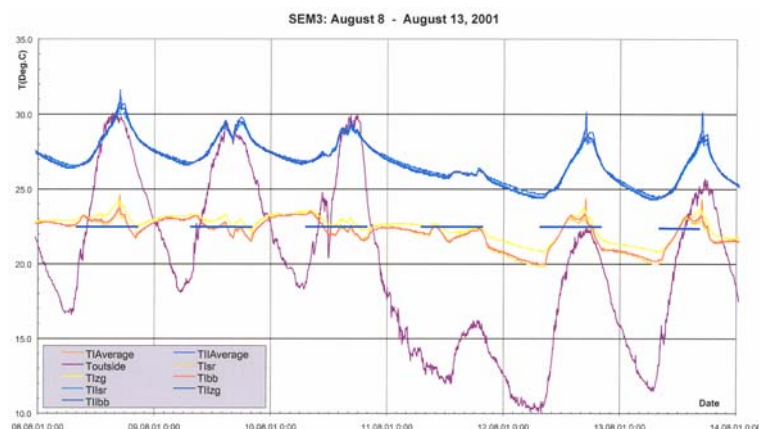


Figure 9 A 6-day period in summer (August) in intermittent cooling mode.

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°C (straight interrupted lines). In the reference room the temperature is between 25 and 30°C. In the model room the cooling wall retains temperatures between 22 and 24°C also during the period when cooling is switched off.

Panel temperatures – plane distribution and average inside air temperatures.

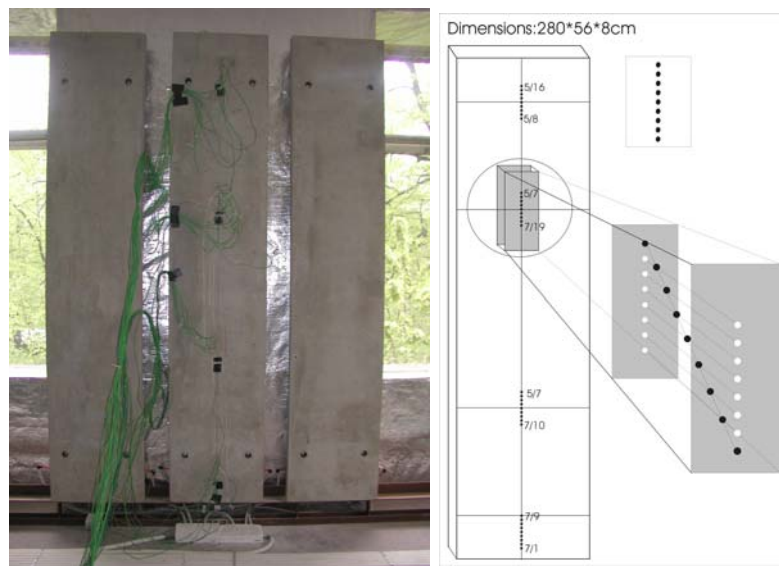


Figure 10 Measurements of temperature distribution inside reinforced concrete panel.

Panel temperatures were measured on 5 different heights. Measurements took place from October 26, 2001 to April 01, 2002. The measuring cycle included three months: October (typical autumnal month), December (typical winter month) and November.

During the whole measurement period the distribution of temperatures in the panel was in the 2 K zone, the biggest difference was 3 K. The conclusion is that the temperature distribution over the whole surface of the panel is very good.

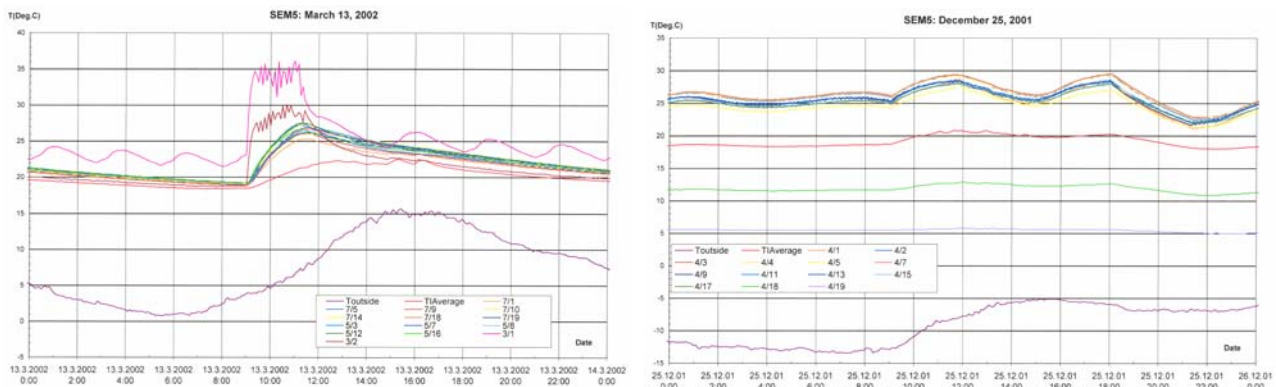


Figure 11 24 hours temperature distribution inside the panel and inflow and outflow water temperature during March 13, 2002 and 24 hours temperature distribution on the surface of the panel, temperature inside thermal insulation and temperature between thermal insulation and outer load bearing wall during December 25, 2001.

The inside air temperatures were oscillating between 18 °C and 21 °C during the December period with a few exceptions where the lowest temperature was 17.5 °C and the highest 22 °C, during the November period between 18 °C and 21 °C (50% of time) and between 18 °C and 22 °C (50% of time) and during the October period mainly between 18 °C and 22 °C.

During working hours between 10 AM and 6 PM temperatures were oscillating within 19°C and 21°C. The temperature of 20°C was reached in the period of 1-2 hours after 9 o'clock, when the change from reduced to normal working regime starts.

Absolute measured temperatures in the panels were between 20 °C and 30 °C, ± 1 K during the whole measured period.

In the coolest December day the outside air temperatures were between - 7 °C and - 14.5 °C and in the warmest between 1 °C and 7 °C. In the coolest November day the temperatures were between - 4 °C and 7 °C. In the October outside air temperature was not lower than 4 °C and not higher than 18 °C.

Panel temperatures – depth distribution and average inside air temperatures.

Panel temperatures were measured at 35 different places on 4 height levels (Figure 10). In this part of experiment also inflow and outflow water temperatures were measured, together with standard outside air temperature and the series of inside air temperatures. The highest inflow water temperatures never rose above 40°C, in most cases it was oscillating around 35°C. A period of 1-2 hours was needed to change the average inside air temperature from reduced to normal profile during working hours. Measurements took place from October 26, 2001 to May 16, 2002. The relation between the inflow and the outflow temperature confirms very good efficiency of the heating system. The outflow water temperature was close to panel temperatures. Two selected days are presented in Figure 11.

6. On-line Monitoring

Protocols for on-line monitoring of control system are implemented in refurbished building for different day-night, summer-winter regimes, for different sources: heating-cooling panels for heating and cooling function, physiological ventilation, for the combination of cooling and relative humidity with corresponding descriptions of interventions in tabular form.

The following information are available and stored on 1 minute basis: outside air temperature and relative humidity, temperature and relative humidity in zones, temperature of heating/cooling medium by zones, energy use (heating, cooling), daily/seasonally by zones, electrical energy use daily/seasonally by zones, condition of panels and ventilators and all corresponding data for mechanical installations (valves, pumps, etc.)

Conclusion.

The interventions on the level of advice, R&D activities, design for execution, supervision and control of works, result in the field of changes of originally designed HVAC system components and capacities, envelope design, additional space, diminished budget, improved inside environment conditions and reduced energy consumption. On the basis of measurements during summer 2000 and consideration of foreseen interventions resulted from new design of combined heating-cooling system the air condition system foreseen in the existing project is totally excluded. The consequences were not only reduced energy consumption but also space set free for other uses, diminished capacity of power station for heating and reduced budget foreseen for HVAC. Comparative measurements in two rooms with the same geometry and thermal insulation on the outer wall in the room with the new heating wall panel system 12% smaller consumption in comparison with the room heated with classical radiators. Measurements of energy needed for cooling in two summer seasons demonstrate specific energy consumption between 0.42 and 0.48 kWh/m²day in the 24 hours performance mode. With heating-cooling wall panels system an excellent inside air temperature profile has been attained with heating water temperatures not higher than 40°C. To achieve optimal performance of the whole designed and executed system serious tuning is needed. Measurements in refurbished building from 2004-01-01 to 2004-12-31 confirmed results of preliminary testing. Gross energy demand in 2004 was 50.4 kWh/m² for heating and 11.2 kWh/m² for cooling.

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