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Dissertation Thesis Abstract

INDOOR ENVIRONMENTAL TECHNOLOGY FOR INTELLIGENT BUILDINGS

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0 INTRODUCTION

As there is a need for an increase in the efficiency of energy utilisation in buildings and in the energy supply system, low-exergy systems are being increasingly implemented in the building technology. Radiant heating systems are suitable for combination with renewable energy sources such as heat pumps and solar collectors, therefor their implementation to the building systems turns out to be more and more popular.

Thermal environment in offices designed according to new trends and standards still shall fulfil the requirements on healthy and comfortable work environment of the occupants. With respect to the recent trend to construct light-weight facades with high portion of glazed components in combination with radiant heating/cooling systems, there comes an increasing risk of overheating, as the lightweight glazed facades are very sensitive to the change in climatic conditions. The potential problems may be represented by the fact that the outside weather conditions, solar irradiance, changes in internal heat gains and small heat accumulation capability of the light-weight facade can result in relatively dynamic changes in thermal balance of the building.

Therefore, a properly designed combination of HVAC, lighting and solar shading set-points are crucial to achieve a comfortable thermal environment at high energy performance, especially in fully glazed buildings or zones.

Inteligent heating, ventilation, air conditioning and cooling systems controlled by building automation systems are implemented during the design process. The smarter the systems in the building are, the more difficult is for us to control them. How do these systems actulally behave in a real building? In this thesis the problems with thermal discomfort and redundant energy consumption are observed, evaluated and consequently being solved by chosing proper systems with its control strategies and settings.

1 State of the art

The discussions around smart systems and intelligent buildings (IB) have increased dramatically in the past decades years for a reason of lowering the energy demand of the buildings and highering the indoor environment quality. IB and building automation systems now play an essential role in most sophisticated modern buildings. Monitoring and automatic control of building services systems are also important to ensure that the design objectives are met in operationeing to be considered healthy.

1.1 Thermal comfort

Requirements for general and local comfort can be found in standards and guidelines EN ISO 7730, EN 15251 and ASHRAE 55. General thermal comfort is usually being expressed by thermal indexes - the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) developed by Fanger using heat-balance equations and empirical studies about skin temperature to define comfort.

According standard EN 15251 there are four categories of thermal environment – I, II, III and IV. Normal level of expectation (Category II) and should be used for new buildings and renovations. In EN ISO 7730 and EN 15251 the ranges of acceptable operative temperatures for thermal comfort are based on the PMV-PPD index (Tab. 1.1), howevee ocal thermal discomfort is neglected in the limits.

Table 1.1 The criteria on indoor air temperatures in the office (single, landscape, conference room) according to standards EN ISO 7730 and EN 15251

Category		Operative temperature (summer) °C		Operative temperature (winter) °C	
EN 15251	EN 7730	EN 15251	EN 7730	EN 15251	EN 7730
I	A	23,5 - 25,5	24,5 ± 1	21 - 23	22 ± 1
II	B	23 - 26	24,5 ± 1,5	20 - 24	22 ± 2
III	B	22 - 27	24,5 ± 2,5	19 - 25	22 ± 3

1.2 Radiant low temperature heating and high temperature cooling systems

Radiant heating system refer to temperature-controlled surfaces that exchange heat with their surrounding environment mainly through radiation. These systems are usually simultaneously designed to be used also for cooling of the building during summer. Temperature of the heating medium is lower than in the case of convectional heating systems, so they can be combined with renewable energy resources. There are three main types of radiant hydronic heating systems: Radiant systems insulated from the main building structure; Radiant systems embedded in the buildings structur; Radiant hydronic panels.

The standard EN 15377 focuses on embedded water based surface heating and cooling systems. Five types of systems insulated from the main building structure:

- Type A with pipes embedded in the screed or concrete (wet system);
- Type B with pipes embedded outside the screed (dry system);
- Type C with pipes embedded in the leveling layer, above which screed layer is placed;
- Type D include plane section systems;
- Type G with pipes embedded in a wooden floor construction.

Hydronic radiant systems with pipes embedded in the building structure are installed in the middle of the building structure, when the thermal storage capacity of this structure can be utilized. Two system types are defined in standard 15377:

- Type E with pipes embedded in a massive concrete layer;
- Type F with capillary pipes embedded in a layer at the inner ceiling or as a separate layer in gypsum.

Radiant heating systems offer beside the self-control ability, small distribution losses and compatibility with renewable heat sources the advantage of creating more homogenous thermal environment than convective heating systems. When combined with mechanical ventilation, which takes care of the latent load, the radiant heating system can maintain desirable thermal environment. The floor heating creates the most ideal temperature profile for human comfort.

1.3 Mechanical ventilation

There are two main primary purposes of the ventilation. The first is providing and acceptable indoor air quality by reomoving or the indoor air pollution concentration. The other is to provide thermal comfort by heat transport mechanisms. In commercial and institutional buildings, there are a number of different types of systems for delivering this air:

- Constant air volume (CAV) systems
- Variable air volume (VAV) systems

The amount of air supplied to a zone varies while holding the supply air temperature constant. This strategy saves fan energy and uses less reheat than in a CAV system. VAV systems, however, can have problems assuring uniform space temperature at low airflow rates. At times, the minimum airflow required for ventilation or for proper temperature control may be higher than is required to meet the space load.

- Low-flow air diffusers in VAV systems
- Fan-powered VAV terminal units
- Raised floor air distribution

1.4 Building automation and control

To reduce the costs and maintain proper environmental conditions computer-based control and monitoring systems have to be implemented. A building automation system is a system that controls and monitors building services. The Automation level includes all the advanced controllers that controls the filed level devices in real time.

Several control modes are in use and it is important to select the appropriate for the system:

- Two-position (on/off) control;
- Proportional control;

- Integral control;
- Proportional plus integral (PI) control

PI control is the most widely used mode in HVAC control and when correctly set up is capable of providing stable control with zero offset. The controller integrates the deviation from set point over time and uses this value to adjust the control output to bring the controlled value back towards the set point. The proportional band may therefore be increased to give stable control, the load offset that would otherwise be introduced is eliminated over time by the integral action. The integral setting is characterized by the integral action time, which is the time it takes for the integral term of the control output equation to match the output change due to the proportional term on a step change in error;

- Proportional plus integral plus derivative (PID) control;
- Digital control;
- Cascade control.

There is not always a need to use the most innovative and precise control mechanism. The recommended controllers in HVAC engineering are shown in the Tab. 1.2.

Table 1.2 Control modes in HVAC systems

Application	Recommended mode	Notes
Space temperature	P	
Mixed air temperature	PI	
Coil discharge temperature	PI	
Chiller discharge temperature	PI	
Air flow	PI	Use wide proportional band and short integral time, PID may be required
Fan static pressure	PI	Some applications may require PID
Humidity	P	Possibly PI for tight control
Dew point	P	Possibly PI for tight control

2 Objectives and methodology

The research is focused on the indoor environment and building energy performance in the office buildings with high ratio of glazed façade and a heating / cooling system with high thermal inertia, in particular on the problems with thermal discomfort and energy consumption.

2.1 Objectives of thesis

The particular objectives of thesis are:

- Identify the problems with thermal discomfort in the buildings with light-weigth envelope and radiant heating / cooling system;
- Compare three different radiant systems in terms of thermal comfort and energy performance with emphasize on heating;

- Verify of interactions between buildings systems and technology and their impact on thermal comfort and energy consumption for heating / cooling;
- Compare of the individual and combined operation of three different radiant systems;
- Illustrate the heat transfer in the thermally activated constructions created by individual and combined operation of the radiant systems;
- Optimize the operation of the whole system focusing on thermal comfort.

2.2 Methodology

Particular objectives (each connected with one methodology step):

- Experimental measurements were carried out in the experimental laboratory object Energetikum located in Pinkafeld, Austria, which was chosen to be the representative object due to the ability of the object for designing experiments on HVAC control, thermal comfort and energy performance in 1:1 scale.
- The simulation model of the reference room of the Energetikum was created on the basis of the project documentation using simulation program TRNSYS. Model was consequently validated by the real measured data and calibrated;
- Implementation of air conditioning, ventilation and shading systems and enhancement of the simulation model;
- Computational program CalA can provide description of 2D heat transfer in the construction, where the radiant heating is implemented.
- The most suitable HVAC operational and control strategies will be generated to optimize thermal environment at the lowest possible energy consumption and the continuous operation of the systems.

3 Experimental evaluation of indoor environment

The measurements of indoor Environment took place in Pinkafeld, Austria, where the reference object is located. The data served to detect the crucial areas of the indoor environment deficiencies. During three time periods, the data were gathered and consequently evaluated.

3.1 Description of the reference object

The experimental measurements were carried out for a new-type office building called the Energetikum (Fig. 3.1). There are several aspects which make the building modern and new comparing to traditional buildings:

- The building is a “living laboratory“, where people have offices, and perform their everyday working activities. On the other hand, it contains a number of technologies, and it is equipped by hundreds of sensors monitoring the indoor environment, energy consumption and boundary conditions. This allows performing field research of various systems at well-defined and well-monitored boundary conditions;

- The building includes three different types of radiant systems that can be run individually or simultaneously, mechanical ventilation, external blinds, three different types of heat withdrawal systems, which can be combined with innovative types of heat pumps. It is possible to combine the technologies and run them under various control strategies defined by the investigator [10].

Figure 3.1 Energetikum, Pinkafeld, Austria [Source: Author]

3.1.1 Building envelope, construction and thermal properties

The two-storey building, located in Pinkafeld (Austria) has two types of façade to eliminate the risk of high heating demand during winter, and to provide enough daylight. The glazed light-weight (post and beam) façade is implemented in the parts of the building envelope oriented to the West-South-West, East-North-East and South-South-East. The North-North-West facade consists of reinforced-concrete walls with 160 mm of thermal insulation. All the transparent parts of the façade are with triple glazing. The heat transfer coefficient of the individual components varies between 0.79 and 1.10 W/(m^2.K) depending on the ratio of glazed area to total surface area of the component.

3.1.2 Description of installed HVAC systems and technology

A brine/water heat pump supplies the object with heat and cool. Three independent heat emission systems are installed in the building (Fig. 3.2):

- Floor heating / cooling with pipes embedded in concrete, insulated from the concrete core;
- Thermally active core with pipes embedded in the middle of the concrete ceiling;
- Thermally active core with pipes embedded near the surface of the concrete ceiling.

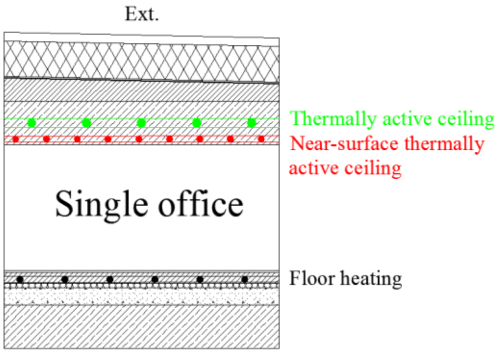

Figure 3.2 Position of three radiant systems regarding to Single office

Energetikum is mechanically ventilated and provides the complex air-conditioning. The central air conditioning unit providing adiabatic cooling is installed in the engine room. Air exchange is fully covered by mechanical ventilation. The air distribution system is performed by ventilation pipeline to dedicated air zones, where each room is considered as a separate zone. Variable volume flow controllers adjust the desired amount of the air.

Three shading systems are implemented to reduce the redundand solar radiation transmitting to the building through the window:

- Vertical and horizontal columns (part of the window frame – static shading)
- External shading system – venetian blinds (controlled manually or automaticall)
- Internal vertical manually controlled blinds.

3.2 Objectives

The main aim of the study was to evaluate the indoor environment conditions in the new-built office building, Energetikum to consequently suggest the control strategies, which can lead to determination of critical areas and elimination of thermal discomfort.

3.3 Methodology

6 representative offices with the pre-installed inbuilt sensors in Energetikum have been selected and equipped with portable sensor groups for monitoring of the indoor environment parameters indicators such as the air temperature, relative humidity, concentration of carbon dioxide. The portable “monitoring-trees” (Fig. 3.3) supplement the data being gathered by SIEMENS sensors, which are implemented in the BAS system of the object.

Data were gathered during three time periods in 2016 and consequently surveyed and sorted according to points of interests. There were two main scopes of the study:

- Thermal comfort and local thermal discomfort evaluation, represented by indoor air temperature (operative temperature) and relative humidity;
- Indoor air quality evaluation represented by CO_2 concentration.

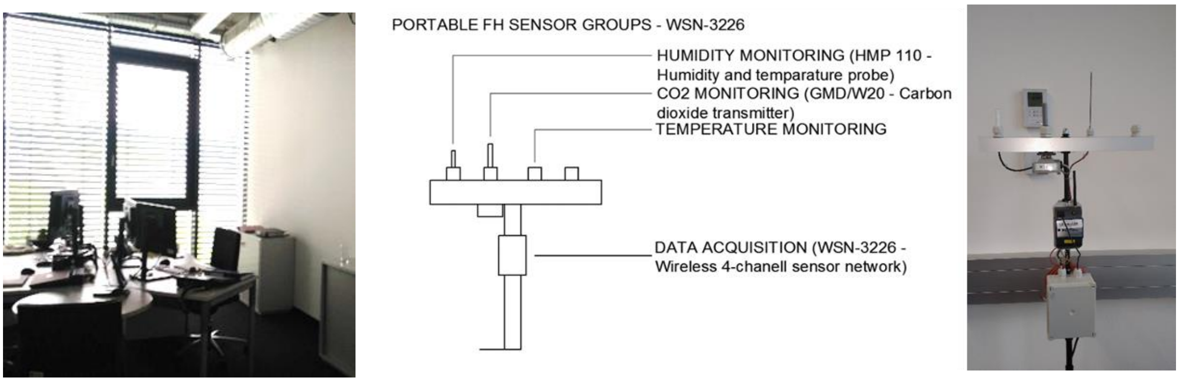

Figure 3.3 Portable monitoring technology – Single office 1

3.4 Results – thermal comfort

The time samples were collected during three reference weeks in year (2016) and the data was sorted out according to the working hours (6:00 AM - 6:00 PM) and assessed in accordance with EN 15251:2007. According to EN 15251, the room can be classified into one of the four categories of the indoor environment. The nominal level of expectations for new and renovated buildings is represented by category II (20-24 °C for heating, 23-26 °C for cooling).

Results of the air temperature and classification into the four categories of thermal comfort (I to IV) are shown in Fig. 3.4. The results indicate that the desired thermal environment was achieved for only a limited periods, mostly caused by excessive air temperature. According to the Fig. 3.4, thermal environment in the building suffers on the thermal discomfort during all three periods. The overheating mainly occurs in the transition and heating period, during cooling period, the discomfort is mainly caused by temperatures inferior to required values.

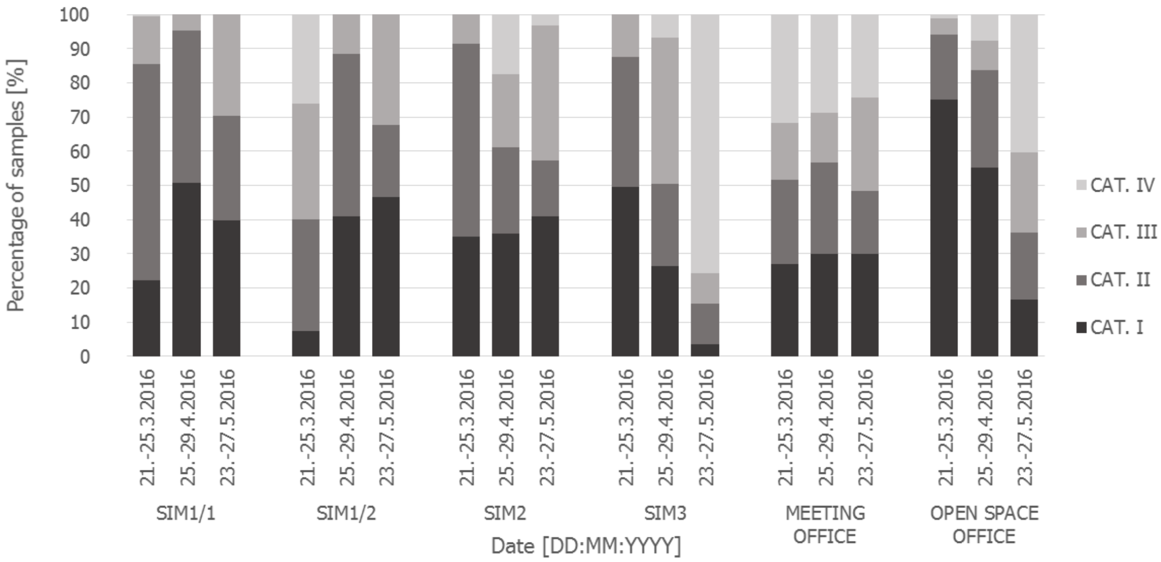

Fig. 3.4 Classification of thermal environment into 4 categories in accordance with EN 15251

The temperature curves in Fig. 3.5 and Fig. 3.6 are presenting the amplitudes of indoor air temperature in the reference offices. Generally, the temperature range is above the desired value during the heating period and below the desired area during the cooling period, which suggests that the control system is not considering the adaptive principle. By adjusting of the set temperatures or control settings (e.g. PI controller, shading devices, flow rates) it would be possible to save the energy simultaneously with thermal comfort enhancement.

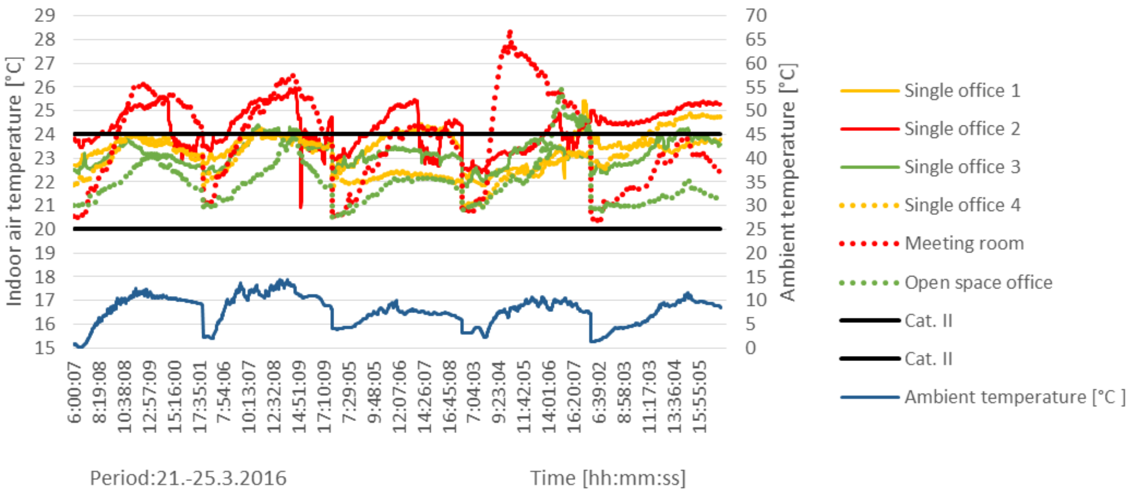

Fig. 3.5 Comparison of indoor air temperatures in the reference offices during the occupied time intervals of evaluated heating period

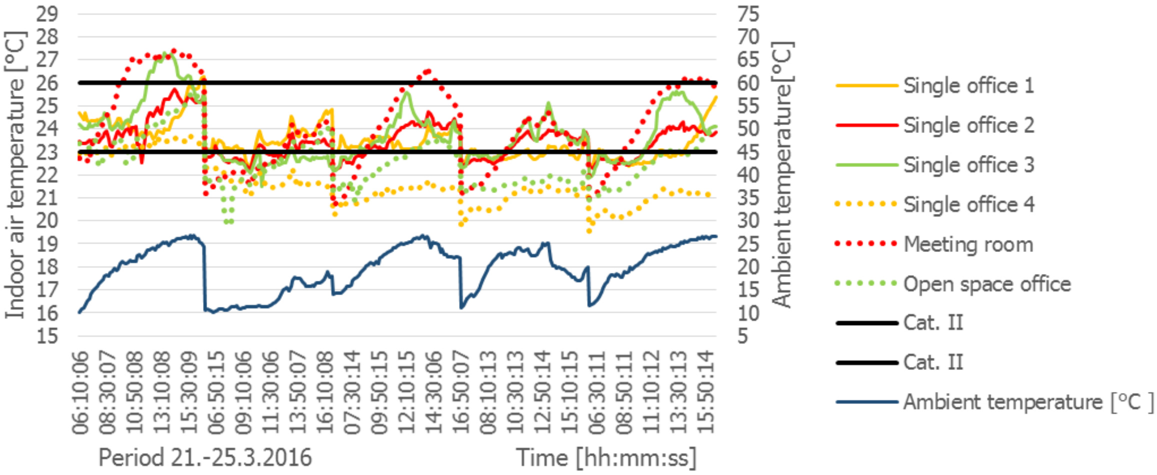

Fig. 3.6 Comparison of indoor air temperatures in the reference offices during the occupied time intervals of evaluated cooling period

4 Experimental evaluation of HVAC operation

All the measurements of HVAC system operation took place in Energetikum, the same object where the indoor environment evaluation was provided. The energy consumption sensors, sensors measuring the heating and ventilation system properties, and a weather station measuring the ambient conditions were installed aditionally.

4.1 Objectives

The main goals of the measurements are to observe the whole system and settings of the systems and consequently detect the possible problems with their fluent and efficient operation. With the properly selected, installed and controlled HVAC systems, the proper indoor environment at the lowest energy consumption can be provided.

4.2 Methodology

All the parameters of HVAC, indoor environment and ambient weather conditions influencing the representative zone, Single office 1 – SO1, were monitored. SO1 has been selected as the reference room with regard to its thermal stability, orientation and possibility of supplementary installation of the sensors. The three groups of measuring instruments were:

- HVAC sensors monitoring fluid temperatures and volume flow rates of the radiant systems and air temperature and air velocity of the VAV ventilation system corresponding with SO 1 – in the engine room;
- Portable stands with sensors monitoring indoor air temperature, humidity and CO_2 concentration – in SO 1 and all adjacent areas;
- Weather station with sensors monitoring ambient air temperature, humidity and global solar radiation – on the roof.

Figure 4.1 VAV system in the corresponding area with the sensors (left); Weather station (middle); Radiant systems in the engineering room on the 1st floor (right) [Source: Author]

The time samples were collected during reference heating time period in December 2016 (3.-11.12.2016). The data were gathered in 10 seconds time step, which was consequently optimized and reduced to 1 minute time step.

4.3 Results

As the variable air volume ventilation is installed in the building, the flowrate is design to vary at the stabile temperature. However, the flowrate, calculated from the velocity and diameter of the duct, fluctuated all the time around 300 m3/h and Inlet temperature varied between 18 °C and 26 °C, depending on the current demand. The inlet and outlet air temperatures and velocity in the ducts 1 meter from the corresponding diffuser of the zone are shown in the Fig. 4.2.

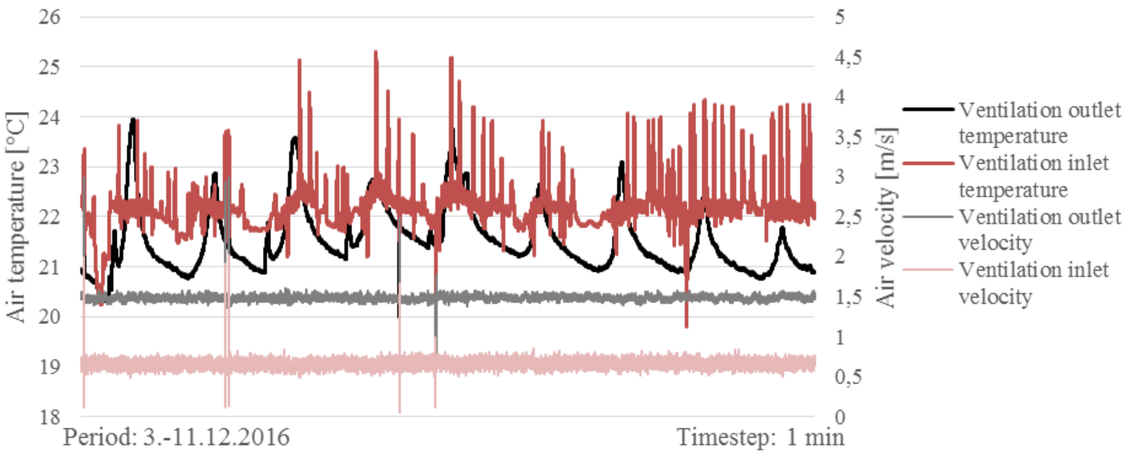

Figure 4.2 Ventilation inlet and outlet temperatures and air velocities in the ductlines of the reference zone

Five different radiant systems are affecting the energy balance in the reference zone. Inlet temperatures may vary at the same stabile flowrate. Inlet and outlet temperatures of the three systems located in the floor of the zone are shown in the Fig. 4.3 Inlet and outlet temperature curves of the two systems located in the ceiling of the zone are displayed in the Fig. 4.4.

HVAC systems were not properly operated during the reference time interval. The ventilation system covered most of the heating / cooling demand as the two main radiant systems were not operating properly. There is a question, if the usage of ventilation system for the heating and cooling of this type of office building, would not be more convenient than the currently used mix of radiant systems.

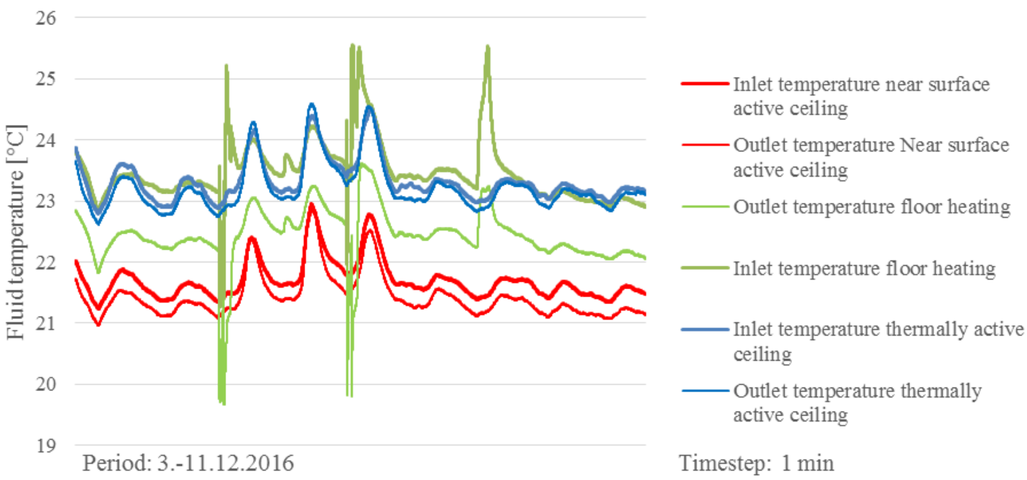

Figure 4.3 Fluid temperatures of three systems located in the floor of the reference zone

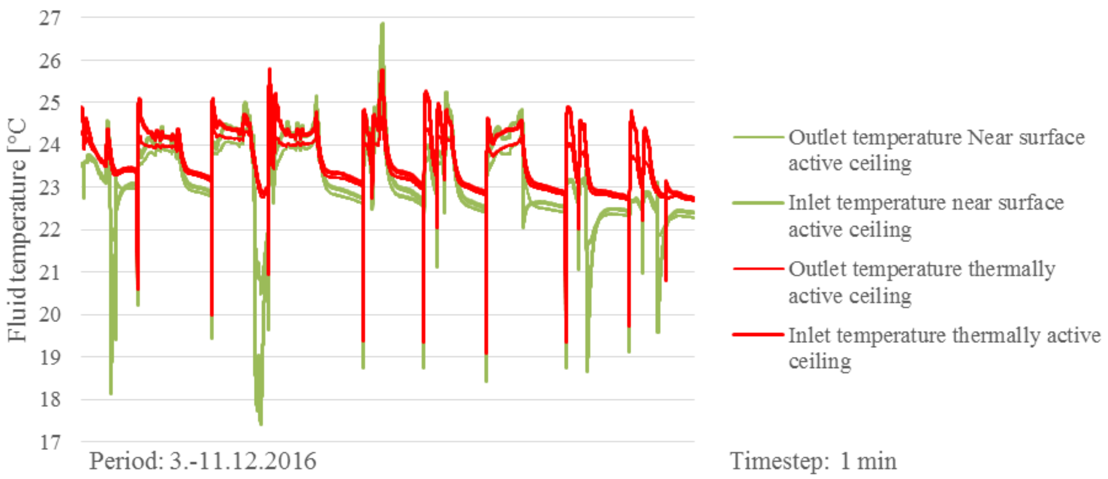

Figure 4.4 Fluid temperatures of two systems located in the ceiling of the reference zone

Indoor air temperature varied between 20 and 24 °C. During the afternoons the temperature raised according to the higher ambient temperature and values of solar radiation. Generally, the temperature is above the recommended limit and set-point for (21 °C) during heating period.

5 Computation simulations and modelling – parametric study

Although measurements on the real building provided closer view on the building operation, it was not possible to observe the impact of more variations and HVAC settings on indoor environment and energy performance of the building. Moreover, the laboratory building was in trial operation which led to deficiencies in the area of building automation and control system, which made it difficult to properly set and monitor all inbuilt systems.

5.1 Aims and objectives

The study was focused on the indoor environment and energy saving potential in a building with radiant heating / cooling system with high thermal inertia. The main aim was to evaluate the potential of thermal comfort enhancement in the selected reference zone by improving the control strategy for heating, ventilation and external blinds.

5.2 Methodology

The control of ventilation, shading operation, and the type of radiant system were varied to determine the optimum control strategy. Ten reference days were selected in January as well as in March to cover both the very cold and the transient weather period. Sixteen variants of control settings and strategies were examined and compared to the initial setting. The simulation model was developed within TRNSYS environment due to its feasibility for transient simulations of HVAC systems.

5.2.1 Creation of the BES model

Using TRNSYS3D, a plugin for SketchUp that allows to draw multizone buildings, the geometry was imported directly from the SketchUp interface (Fig. 5.1). To create and edit all of the non-geometry information required by the TRNSYS Building Model, it was necessary to use TRNBuild. In this interface, wall and layer material properties were applied, ventilation and infiltration profiles were created, gains were added, radiant ceilings and floors were implemented. Main part of the simulation was to create the model representing real behaviour of the system. Types were connected to each other creating interconnections. Data readers for external data files were implemented and prepared for the calibration with measured values.

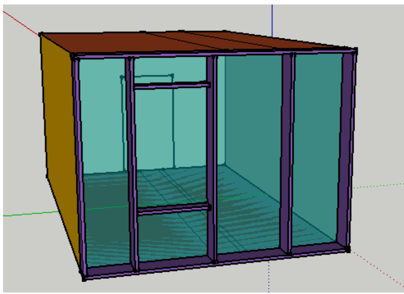

Figure 5.1 3D model of the Single Office 1 – SketchUp (TRNSYS3D plugin)

5.2.2 Calibration and validation of the model

The complexity of the built environment and a large number of independent interacting variables make it difficult to achieve an accurate representation of real building operation. Therefor the model had to undergone the process of validation and calibration to accurately and reliably represent the behaviour of real system. Indoor air temperature in the reference office SO 1 was used as the indicator for validation. The necessity of the model validation is represented by the Fig. 5.2. The difference between the first initial model and the validated and calibrated model is significant and can cause inaccurate results. Comparison of the measured values and simulated data are shown in the Fig. 5.3.

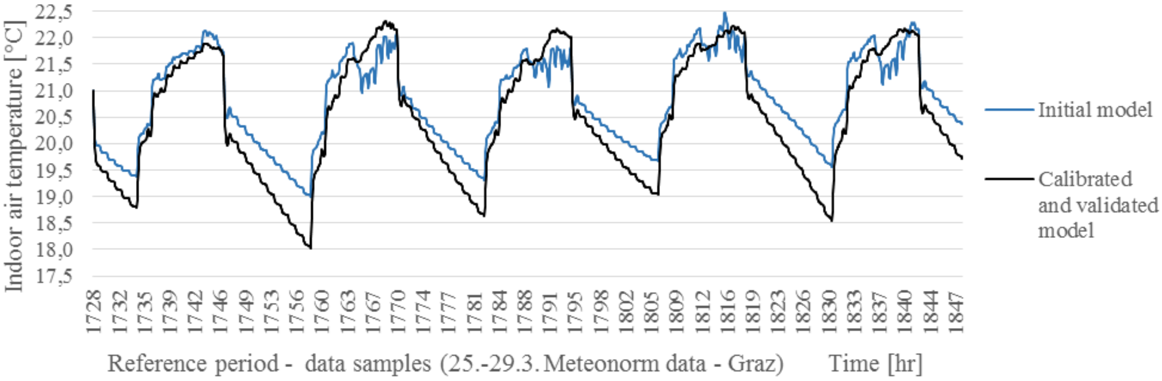

Figure 5.2: Comparison of the indoor air temperature – SO1

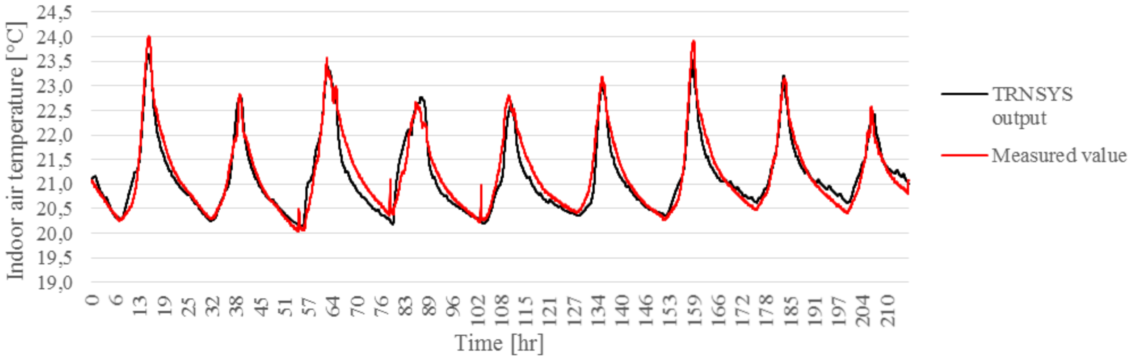

Figure 5.3 Comparison of the measured and simulated data of the indoor air temperature

5.3 Parametric study of the control strategies and settings

5.3.1 Initial setting – V1

The VAV system maintained the air supply at a constant temperature while individual zone thermostats varied the flow of air to each space to maintain the desired indoor air quality and zone temperature. The maximum of four air change rates was provided by the ventilation system to the single office. The inlet air temperature was stable – 22°C. The air change rate was controlled by a three stage controller depending on the CO_2 concentration of the indoor air.

The shading system is represented by external blinds with the solar heat gain coefficient of 0.2.The blinds position was adjusted depending on the amount of incident solar radiation on the external wall by three stage controller. Reaching the solar radiation value of 800 kJ/h.m^2 caused the blinds cover the window, which results in 80 % reflection of the radiation. Otherwise, the shading covered 30 % or 70 % of the window depending on the actual value of solar radiation.

Radiant floor heating with a stable flow rate of 190 l/h was implemented in the model, desired zone inlet temperature was maintained by a three-way mixing valve. The temperature was controlled according to the running mean ambient temperature. A PI controlling algorithm was applied to to keep the air temperature at about 21 °C during the occupied time periods and at 18 °C during the night by adjusting the inlet temperature.

5.3.2 VAV ventilation settings and control strategies

Although the VAV system usually supplies the inlet air at a stable temperature, in accordance with the measurements performed in the building, the inlet air temperature can drop down to 18 °C when necessary. In four variants (V2, V5, V7 and V9) the temperature of the inlet air can drop in the case of excessive indoor air temperature (measured in reference zone). In addition, in the variants V2 and V7 the inlet air temperature was decreased during the night setback, when the heater in the air conditioning unit was turned off.

The air change rate during the night was set to 1 h^{-1}, which caused high energy consumption. Night setback of ventilation was therefore implemented, and the ventilation system was turned off between 6:00 PM and 6:00 AM. To use the VAV system also for heating and cooling, the air flow rate was controlled both depending on the CO_2 concentration as well as on the indoor air temperature.

5.3.3 Shading system settings

The process variable of the shading system control is the incident solar radiation on the external wall. Moreover, the position of the blinds also depends on the indoor air temperature and the combination of indoor air temperature and incident solar radiation.

5.3.4 Variants of radiant heating systems and control strategies

The simulations were performed for three heat emission systems installed in the building to investigate the effect of different emission systems on thermal comfort. The optimal control strategy for the ventilation and shading system, variant V8, was used for this comparison.

The floor heating system and the near-surface ceiling system were controlled by a PI controller sensing the room air temperature. However, thermally active building structures may be operated under various control strategies. Therefore, three more control strategies were implemented to the simulation model for the thermally active ceiling to examine their influence on the energy demand and thermal comfort: (1) on-off (three-step control) in dependence of the room temperature is one of the simplest method to control thermally active building structures; (2) thermal mass of the slab is loaded with thermal energy at night, and it is emitted to the space during the daytime; (3) loading of the concrete core any time based on the difference between supply and return water temperature – the circulation pump is turned off when the difference drops under the limit.

5.4 Results

Comparison of the indoor air temperature over 10 days in January is shown in Fig. 5.4. Although the results for floor heating (V8) and the near surface thermally active ceiling (V12) are similar, the thermal environment created by the thermally active ceiling (V13) is rather different. The decrease in the air temperature is 1-2 °C lower for the thermally active ceiling (V13) than for the floor heating (V8) due to the smaller heat accumulation capacity of the floor heating system. Over the 10 days simulated, the energy input of the thermally active ceiling was 31 % higher than for the floor heating (Fig. 5.5, Fig. 5.6). However the accumulation potential of the thermally active elements would probably occur after the time period longer than 10 days. During the reference days in March the indoor air temperature difference was lower, as the ambient temperatures were milder and the values of incident solar radiation higher. The control variants of thermally active ceiling (V14-V17) are providing good thermal comfort. However, except for the variant V17, the energy inputs were considerably exceeding the value of energy input of the optimal variant V8 (Fig. 5.5, Fig. 5.6).

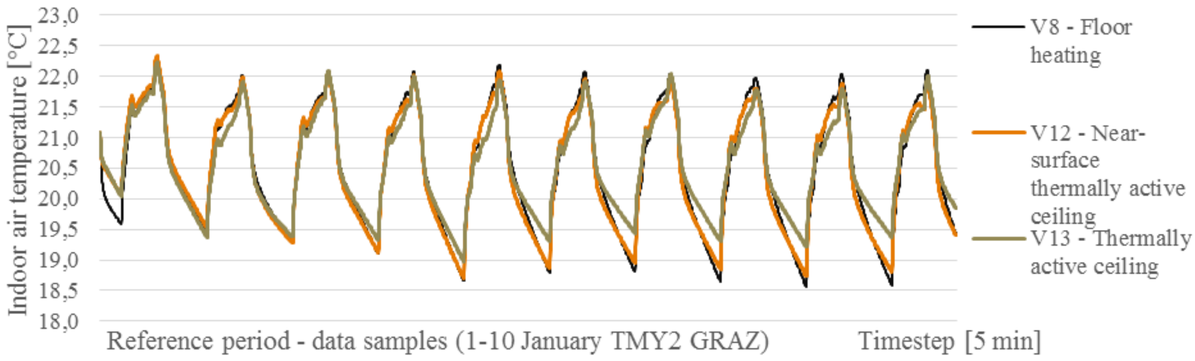

Figure 5.4 Indoor air temperature created by 3 different radiant heating systems

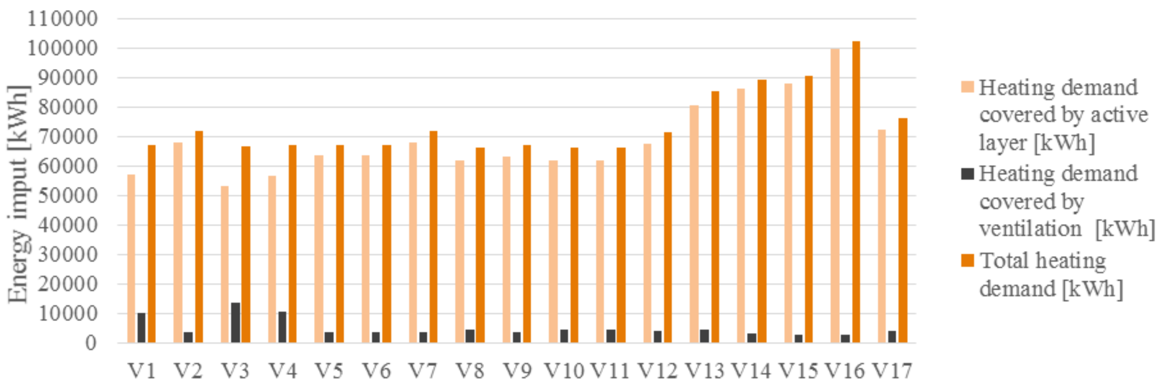

Figure 5.5 Energy inputs and gains by the ventilation system and heating systems in January – 17 variants

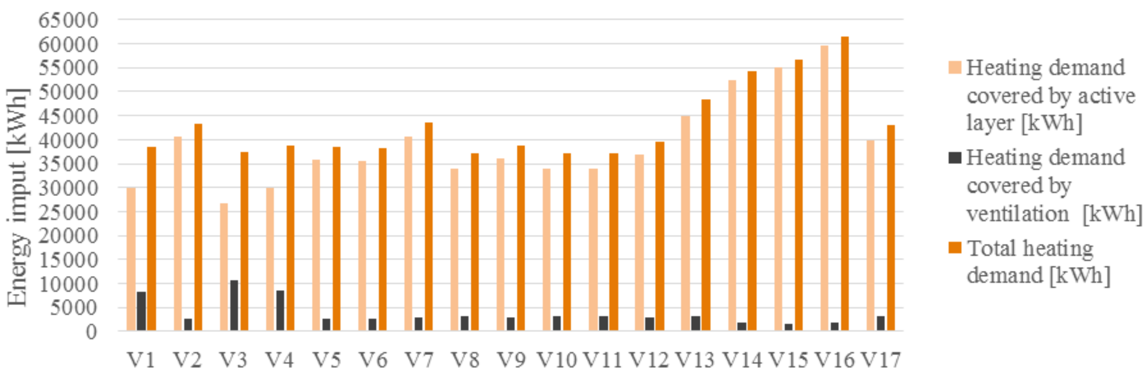

Figure 5.5 Energy inputs and gains by the ventilation system and heating systems in March – 17 variants

6 Simulation of heating/cooling structure temperature profile

For better understanding of the thermal behaviour inside the horizontal thermally active concrete construction, it is necessary to be acquainted with the heat transfer in the structure. As the TRNSYS software is not capable to depict the temperature profile of the thermally active construction, additional study was unavoidable.

6.1 Aim of the study

Three radiant heating/cooling systems were implemented in one structure – Floor heating / cooling; Concrete core activation; Ceiling heating / cooling. Considering the various pipe position of each system in the structure, all they have different impact on the thermal distribution and heat flow in the structure. This leads to different time constants and different accumulation of the systems. The aim of the study is to determine the reaction time and accumulation capability of each system.

6.2 Description of the software and model

CalA (Calculation Area) software enables to solve both time-stable and unstable 2D thermal conduction. CalA is based on the numerical solution of the differential equation describing the 2D heat conduction. Temperature and heat flux density fields are simulated as time unsteady-state. The time step of the simulation is estimated to 60 minutes.

The existing ceiling in building Energetikum was simplified to the smallest section which represents the real behaviour of the whole structure (Fig 6.1). All three radiant systems were implemented to one model, which allows to compare the behaviour of different systems under the same conditions. The unstable-state simulation has to be provided, to resolve the reaction time, accumulance capability of each system and time of the thermal stabilization.

Axes of symmetry allowed us to create the model of the minimum width 75 cells. The size of grid cells are designated by the geometry of the pipes as the tiniest elements of the structure. Position and dimension of the pipes in the structure was withdrawn from TRNSYS model and represent the real building. Thermal characteristics and dimensions implemented to the model are in accordance with the real ceiling in the building Energetikum.

Indoor air temperature was set as the indoor air temperature - 21 °C for both spaces, below and under the construction for all the calculated time steps. The initial temperature in the pipes was set to the same temperature as the temperature in the construction section (21 °C), the temperature in the pipes increased at the time of the system activation to 35 °C, which was the mean heating water temperature in the zone.

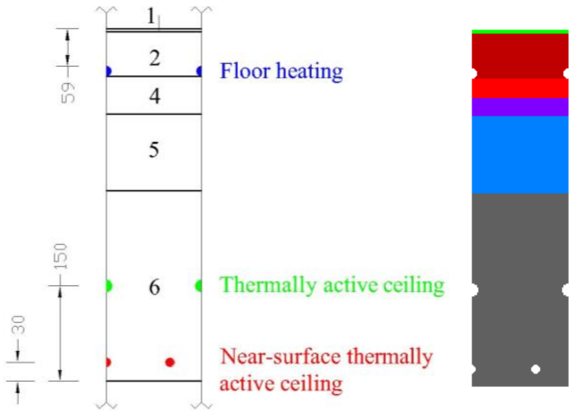

Figure 6.1 Simulated representative section and detail of computational grid

6.3 Results

Six variants of the separated and combined operation of three different systems embedded in one horizontal construction were compared.Temperature fields of various radiant heating systems were simulated and examined during 72 hours after their initialization. Fig. 6.2 represent the temperature fields during after 72 hours.

The layer of the insulation under the pipes of floor heating prevent from the heat to pass through the layer and creates the boarder between floor heating and two ceiling systems. Actually, the floor heating operation affects the surface temperature of the floor, but has almost no impact on the temperature of the ceiling. The ceiling heating combined with thermally active ceiling affects moreover only the ceiling of the structure. These two concrete embedded systems cooperate and influence the temperature field of each other.

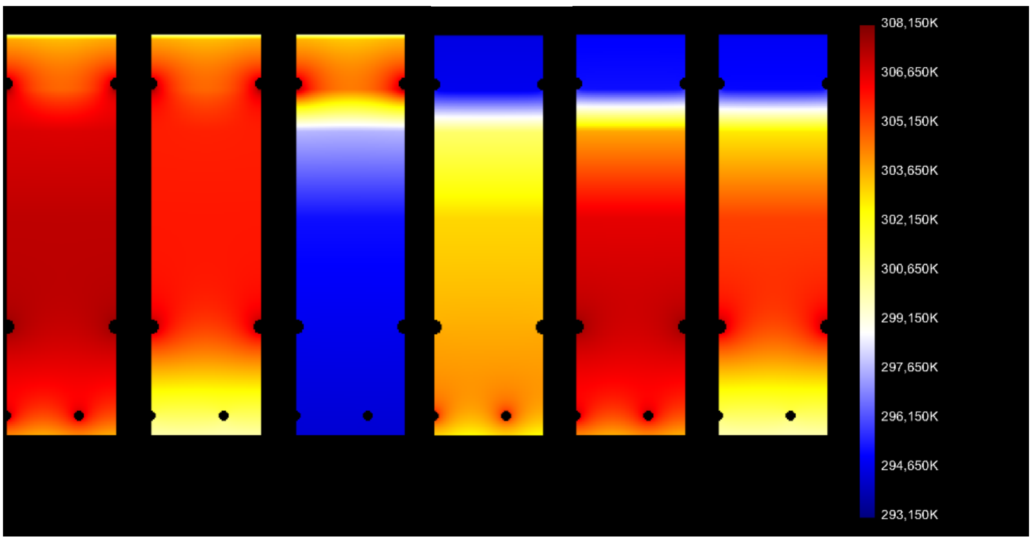

Figure 6.2 Temperature fields after 72 hours of activation: All systems; Thermally active ceiling + floor heating; Floor heating; Ceiling heating; Thermally active ceiling + ceiling heating; Thermally active ceiling

The most significant increase in floor surface temperatures was observed during first 8 hours of the variants where floor heating was activated, which represent the time constant of the floor heating. After 8 hours of the activation, when also TABS is activated, TABS started to influence the floor surface temperature and the surface temperatures between two observed variants started to differ slightly. However, the difference never exceeded 0.1 K (Fig. 6.3).

The results indicate that ceiling surface temperature increase is very similar when using near-surface ceiling heating separately or combined with thermally active ceiling. Separated operation of thermally activated building system (Fig. 6.3) proved the highest time constant of all three radiant systems, which is also associated with highest thermal inertia. Surface temperature 24 °C was reached after 8 hours, even 72 hours were not enough for the system to fully load the concrete. Surface temperature did not achiewed 27 °C, although the system created the most homogeneous surface temperature field.

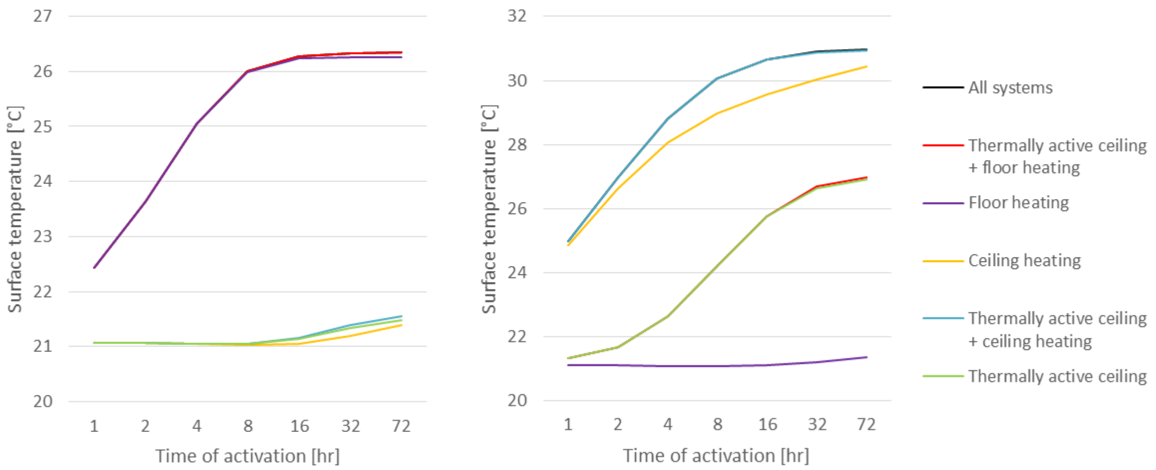

Figure 6.3 Surface temperatures on the floor surface (left) and celing surface (right) during 72 hours

The Fig. 6.4 represents the growth of the surface heat fluxes while activating different systems or their combinations. The floor surface heat fluxes are dependent on the floor heating activation, as there are two main trends of the heat flux growth. The noticeable difference in heat fluxes can be observed only between the variants containg the floor heating and variants where the floor heating was not activated. Though, small differences between heat fluxes can be observed after 16 hours of the operation.

The activation of floor heating system showed almost no effect on the heat flux on the ceiling surface. Slower reaction of thermally active ceiling than near-surface system response is represented in the Fig. 6.4. After 1 hour of the operation TABS did not proved significant gain on the heat flux, whereas the heat flux of the near-surface system reached 30 W/m^2. Combined operation caused the most rapid increase, which stabilized after approximately 32 hours. The heat flux curve of near-surface ceiling growed until the end of the simulation (Fig. 6.4).

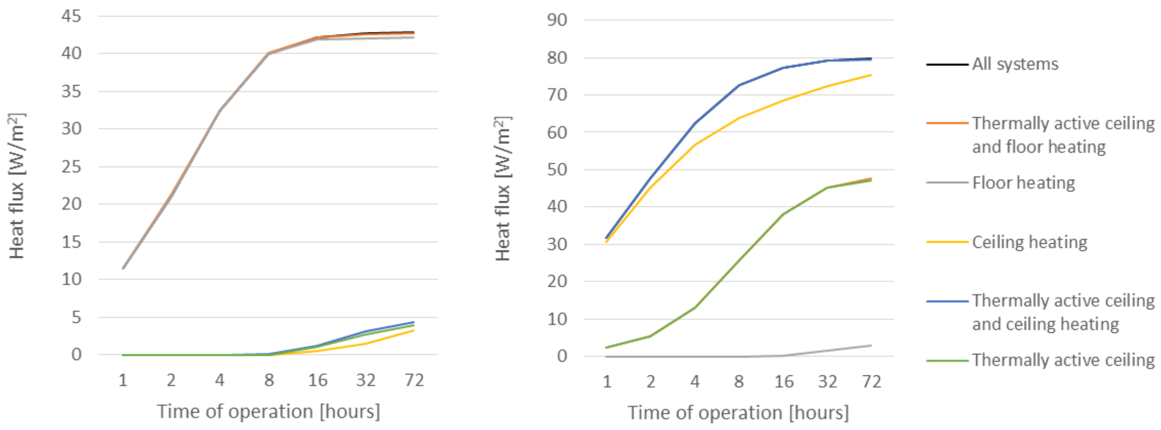

Figure 6.4 Heat fluxes on the floor surface (left) and ceiling surface (right) during 72 hours operation of all 6 variants

7 Contribution for science and praxis

7.1 Contribution for science

- Problems with thermal discomfort in building with glazed façade, heating/cooling systems with high inertia and VAV systems even in the new laboratory-purpose built object with intelligent control system were detected;
- Verification of the TRNSYS model with more active layers in one construction by using fictive layers with low thermal resistance and manual segmentation of constructions was performed;
- Necessity of model validation and calibration with real data was proved and led to higher accuracy of the obtained results and thus the relaiability of study;
- Three different radiant systems in one construction, either separately or their combined operation were compared while using validated and calibrated model;
- Time constant, i.e. reactions and accumulation capability of three different radiant heating systems in horizontal construction were observed and verified;
- Simulataneous operation of the three radiant systems and its effect on the heat fluxes, temperature fields and surface temperatures was investigated.

7.2 Contribution for praxis

- The final optimization of the HVAC and shading control after the trial operation of the building is needed to to lower the energy demands and obtain required indoor environment (mainly thermal comfort);

- Operation of combined radiant heating and VAV ventilation systems in buildings with light-weight façade and impact on the building performance was examined;
- Utilizing the automatically controlled of shading systems (external blinds - most convinient) in the office buildings with glazed façade is fundamental to obtain convenient thermal comfort for the occupants;
- Mechanical ventilation needs to be implemented to the building technology at the early design stage. Consequently proper control of the ventilation has to be set;
- Thermal accumulation of the constructions in buildings with intermittent operation leads to the higher energy demands on cooling even during the heating period what consequently causes higher energy consumption of installed ventilation system;
- Covering of the floor heating by the layer of higher thermal resistanc (carpet) can significantly influence the behaviour and energy output of the floor heating.

8 Conclusion

Energetikum, a new-built the interdisciplinary laboratory building, was constructed for the research purposes. Even this building wher up-to-date HVAC technologies, effective control system and full automation have been implemented, suffer from the problems with thermal environment and excessive energy consumption. The redundant solar gains caused the overheating mainly in southwest-facing zones. The solution can be found in utilization of automatically controlled exteral blinds, improvement of the ventilation control set-points and choosing the most proper radiant system depending on the heating/cooling demand. However, the implementation of the radiant heating systems with high time constant and inertia in the buildings with glazed façade and lack of thermal mass, caused rapidly changing the energy balance and the building became itself hard to control. Even the floor heating system with the lowest time constant of all three examined systems was not able to react properly. The reaction time observed during simulations in program CalA was 8 hours, what is inefficient for the office building with discontious operation and the accumulation of the systems resulted in useless energy consumption during unoccupied time. Therefor the future research dealing with proper design of the HVAC and control settings optimization in the glazed buildings should be considered.

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