COMPUTER MODELLING OF INFRARED RADIANT HEATING IN LARGE ENCLOSED SPACES

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ABSTRACT

The paper is focused on the application of the simulation in the field of the space heating systems, based on the infrared radiant heaters. In the first part is preview of different sw packages. In the second part there is a case-study of local heating design evaluation, where two different sw packages are used. Hefaistos is used to design the layout of the heaters, ESP-r is used to investigate the energy consumption and time dependent temperature variation.

INTRODUCTION

Infrared radiant heating systems provide a reasonable and, possibly, energy-efficient alternative to convective heating systems in large enclosed spaces like the industrial halls or gyms. Ideally, the radiant heating system focuses thermal energy on the occupants and only indirectly heats the rest of the heated space.[Kabele,Krtková 2000]

It is very common to see building designs based on the air temperature as a basic reference parameter. This is not possible if we use infrared radiant heating systems, where we need to know operative temperature distribution in entire hall, which describes simultaneous effect of radiation and convective heat transfer modes. Operative temperature is parameter, which is usually used for evaluation of thermal comfort. [Krtková, Kabele 2000] Several tools using for evaluation of radiant heating spaces are based on calculation of intensity of radiation. This simulation tools enables to make safe design, but not optimal. Optimal design could be based on model , which is able to describe the indoor environment quality and evaluate thermal comfort based on operative temperature. The problem is to balance detail of the mathematical model with possible accuracy of the inputs (description of the boundary conditions) and required accuracy of the outputs.

TOOLS FOR IR RADIANT HEATING SIMULATION

The problem of simulation of infrared radiant heating systems is in simultaneous effect of relative intensive radiation and convection heat transfer modes. Simulation tool should include not only one direction radiation from the primary heat source (usually dark infrared radiant tube heater), but also radiation from secondary sources like are the surrounding walls and floor. Second problem is in air flow modelling.

Simplest modelling tools are describing this reality in two-dimensional models only, more complex include third dimension and most complex tools are based on four dimensional reality description (space + time)- CFD. The thermal comfort approach, which not only requires the quantities and types of building materials but also the installed locations, provides a philosophy derived from delivering thermal comfort to the built environment rather then simply establishing a design air temperature (ASHRAE 1992). The thermal comfort approach, however, is rarely applied since the design engineer and generally require the use of sophisticated computer algorithms. The procedure is complex because of the need to predict the radiation field in the built environment. The radiation field, which translates into thermal comfort parameters such as the mean radiant and operative temperatures, is primarily a function of the room surfaces temperatures and locations and types of windows and heating system. Consequently, the problem evolves from the typical envelope calculation to a sophisticated energy distribution calculation. [Hensen 1991]

Many techniques and standards exist to accurately size heating systems to provide a design air temperature. Little information is available for sizing and placing radiative heating system.

There will be discussed a several tools for infrared radiant heating systems.

The methods described below represent analytical tools for determining the optimal thermal environment for people in buildings.

UK- SCOTLAND

ESP-r [Clarke 1985] is the outcome of model development projects funded over the years by the UK Science and Engineering Research Council (now EPSRC) and the European Commission‘s DGXII.

ESP-r is a transient energy simulation system, which is capable of modelling the energy and fluid flows within combined building and plant systems when constrained to conform to control action. The package comprises a number of interrelating program modules; for instance the Climate database Management Module, the Event Profiles Databases Management Module, the Plant Components Databases Management Module, the Simulator, the Results Analysis Module and so on. One of these modules is the View Factors Module [Sars,Pernot, de Wit 1988]. This module offers possibility to calculate view factors between each zone surface, the mean radiant temperature as a function of position in space and the vector radiant temperature, which is a vector quantity and gives information about the radiation asymmetry in a room. In the calculation method used here is a small cube at the test point. Furthermore it is assumed that the surrounding surfaces are black and that the intervening medium does not scatter or absorb radiation. [Sars,Pernot, de Wit 1988]

The Results Analysis Module enables visual interpretation of the results and numeric as well. We cannot have a graphical rendering of an isomap of the mean radiant temperature in a room. The only possibility is a graphic chart of the time history of the MRT in certain position. [ESRU 1996]

This design methodology is a powerful unsteady algorithm used to evaluate thermal comfort conditions under various indoor, outdoor and time design conditions. [Hensen 1991]

SLOVENIA

There has been developed an algorithm at the University of Ljubljana in Slovenia [Lit.4]. The algorithm is based on the computation of view factors using the additive property.

This algorithm enables the calculation of mean radiant temperature for composite room surface, even allowing for the complex impact of body posture. The matrix-based approach allows us to determinate the effect of various parameters on mean radiant temperature, as well as on thermal comfort or discomfort. This approach also enables the consideration of other parameters (air temperature gradient, air velocity ...) whose impact on thermal sensation is expressed as the PMV value. In order to achieve optimal thermal conditions, the thermal balance between heat sources and sinks must be established. This method enables the determination of the influence of heating source characteristics (temperature, geometrical parameters) on mean radiant temperature as a part of overall environmental conditions. One of the most interesting possibility enables the simulation of the mean radiant temperature under different operating conditions, such as different outdoor temperatures, which create different surface temperatures of the outer wall elements and heating panels. The influence of changeable external parameters is compensated by the heating system with different heat outputs. In the case of a radiant heating system, the heat output is accompanied by different radiant temperatures. A graphical rendering of an iso map is used for better visual interpretation of the results. This method presents a useful tool for determining the correct interplay between heating system and building structure.

GERMANY

At the Faculty of Mechanical Engineering at the Ruhr University in Bochum have been made a mathematical model [Kämpf] that enables optimisation of position of heating sources to make optimal thermal comfort in a room and to criticise the influence of these heating sources on energy consumption. Criterion of the thermal comfort is the operative temperature. This mathematical model offers possibility to simulate different heating systems (infrared radiant sources, radiators, floor heating …), to compute surface temperatures, energy consumption and thermal comfort (PMV, PPD, result temperature).

Outcomes are possible in numeric form and a graphical rendering of an iso map is used for better visual interpretation of the results of the operative temperature in certain plane and PPD.

CZECH REPUBLIC

Hefaistos® is a professional design programme developed by Czech radiant heating systems producing company in co-operation with Czech technical university in Prague. [Kabele, Pinkas, Haken 2000]

Physical model used in the *Hefaistos*® is modified to describe steady-state in large enclosed spaces with IR radiant heating. According to layout of the heaters the programme enables to create a distribution chart of operative temperature and heat radiation intensity in the certain moment in engaged plane. This also calculates estimated annual energy consumption, heat losses of the building and estimate costs. *Hefaistos®* affords opportunity to optimise location, number and output of IR radiant heaters. The programme is used to predict the thermal comfort in the working place and to find optimal location, number and size of the IR radiant heaters.

USA

BCAP (Building Comfort Analysis Programme). To alleviate the problem of designing for thermal comfort, ASHRAE sponsored research project RP-657, RP-907, Simplified Method to Factor Mean Radiant Temperature (MRT) into Building and HVAC System Design which includes the Building Comfort Analysis Program. BCAP, a group of computer programs, have been developed to assist HVAC design engineers in sizing and placing combined radiative and convective in-space heating and cooling systems. Using these factors, the design engineer can maximize thermal comfort and minimize fuel consumption. [DeGreef, Chapman 1998], [Chapman, Zhang 1995], [Chapman, DeGreef, Watson 1997]

The capabilities of the design methodology include :

- predicting the combined effect of radiative, convective and conductive heat transfer and air infiltration in a radiatively and/or convectively heated room
- developing a comfort distribution chart for the occupants in the room
- modelling the effects of objects, such as furniture and partitions, on the comfort distribution chart
- predicting optimum placement of radiant heaters inside the room.
- BCAP enables calculate mean radiant temperatures, operative temperatures, air temperatures, surface temperatures and radiative asymmetry.

This design methodology is a powerful steady-state algorithm used to evaluate thermal comfort conditions under various indoor and outdoor design conditions.

APPLICATION OF SIMULATION IN DESIGN OF INDUSTRIAL HALL

PROBLEM DESCRIPTION

The problem was to investigate the indoor climate and predict the energy consumption in the industrial

Fig.1 Example of the industrial hall heated by IR radiant heating

hall, heated by infrared gas dark radiant heating system. The size of the hall was 10x20x8 meters. The hall was located in the industrial zone in the climatic conditions of the Czech Republic. There was requirement for local heating of the working places located in the centre of the hall, with working time on weekdays 8AM to 4PM. Required minimal operative temperature in the working area was 18°C, the radiation should not exceed 200 W.m^{-2}. Example of the typical hall, solved in this case-study is on the fig.1

METHODOLOGY AND MODELLING

To evaluate required parameters of the energy and environmental behaviour of the designed solution of the heating system in the industrial hall was necessary to use more sw products. To describe the indoor climate, represented by operative temperature and radiant flux, we used static model Hefaistos ®, to describe energy consumption and time-depended variation of the mean radiant temperature during intermittent heating we used ESP-r.

The model in Hefaistos ® enables to find optimal size and position of the gas dark radiant heater. For the specific hall, solved in this case-study, was used heater with output 36,1 kW, located in the centre of the hall in the height 8 meters above the floor. Fig.2 shows the distribution chart of the operative temperature and radiation in the height 1,1 meters

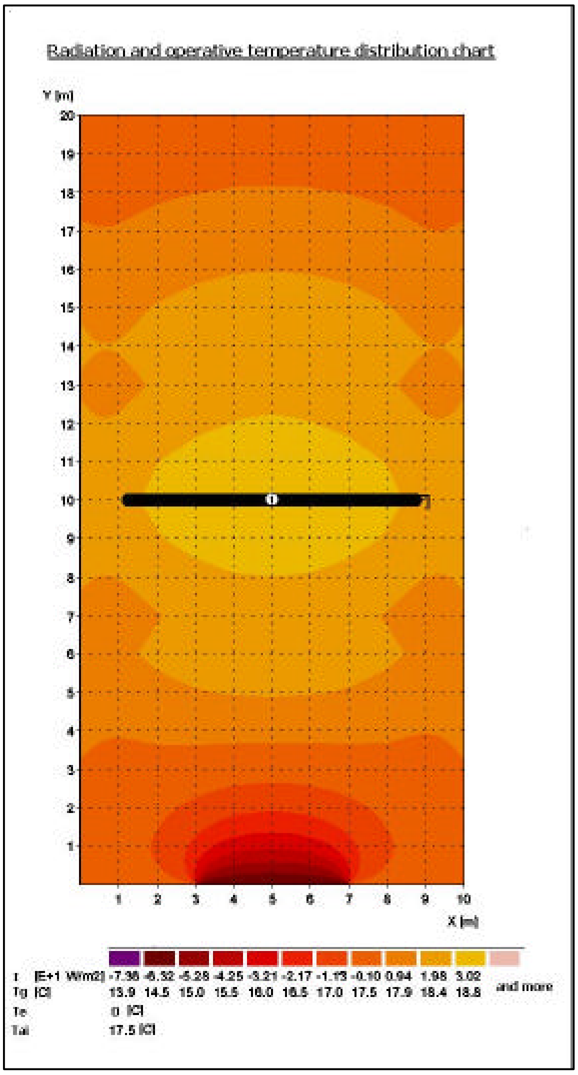

Fig.2 Distribution chart of the operative temperature (Tg) and intensity of radiation (I) on the floor plan of the hall

above the floor level - the result of the heater design optimisation .

The major problem of the modelling of such space in ESP-r was in the model of the dark radiant heater. Theversion of ESP-r, which we used, has no specific model of dark radiant heater body. The surface

# db ref	thick	db name & air gap R
46	0.0040	Grey cotd aluminium
281	0.0800	Glass Fibre Quilt
47	0.0040	Wt cotd aluminium

Fig.3 Layers in the ESP-r model of the heater

temperature of the heater during its operation varies in the range 200°C up to 400°C with average surface temperature 350°C. We specified the construction with similar thermal behaviour like the dark radiant heater. The adequate temperature of the surface of the model was achieved by the input of the energy flux into the construction of the panel. The layers and construction properties of the panel are described in the fig.3. Graphic scheme of the simulated hall is on the fig.4.

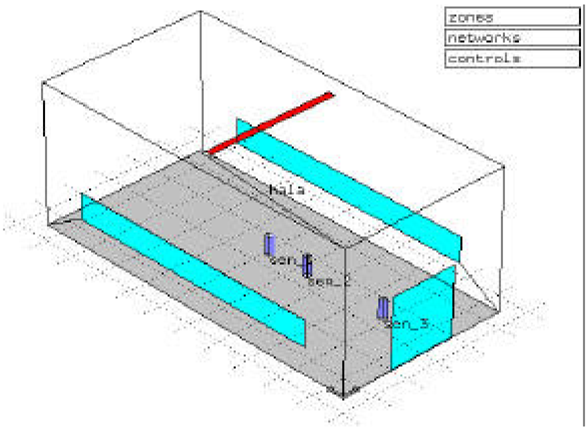

Fig.4 Graphic scheme of the hall with the IR radiant heating. There are 3 sensors, where the MRT was checked, on the ceiling is the IR radiant heater

SIMULATION AND RESULTS

The above specified hall was simulated in the ESP-r environment. We used Czech TRY climate data, where the ambient temperature variation during the year period is shown on the fig. 5

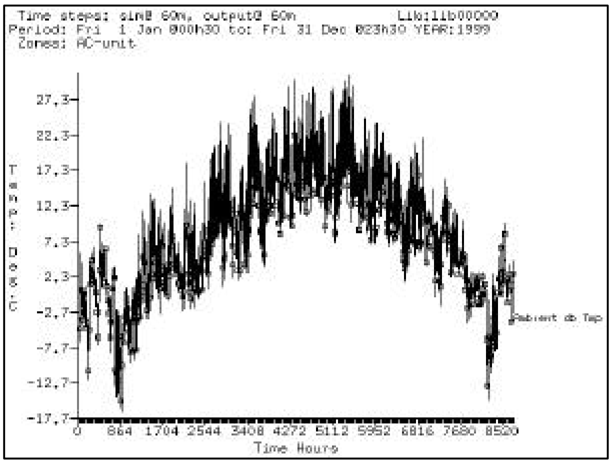

Fig.5 Ambient temperature during TRY used for simulation

The operation of the heating was given by the operation schedule. The required operative

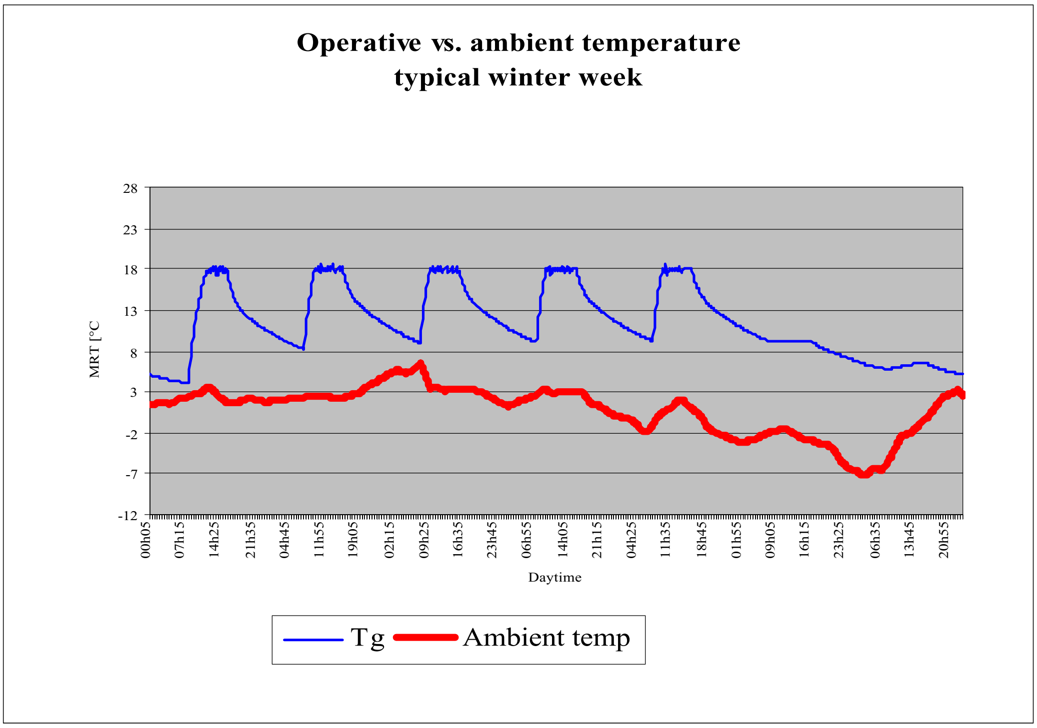

Fig. 6 Operative vs.ambient temperature during typical winter week in the hall with intermittent heating heating. The hall is heated from 8 AM to 4PM, required temperature is 18°C

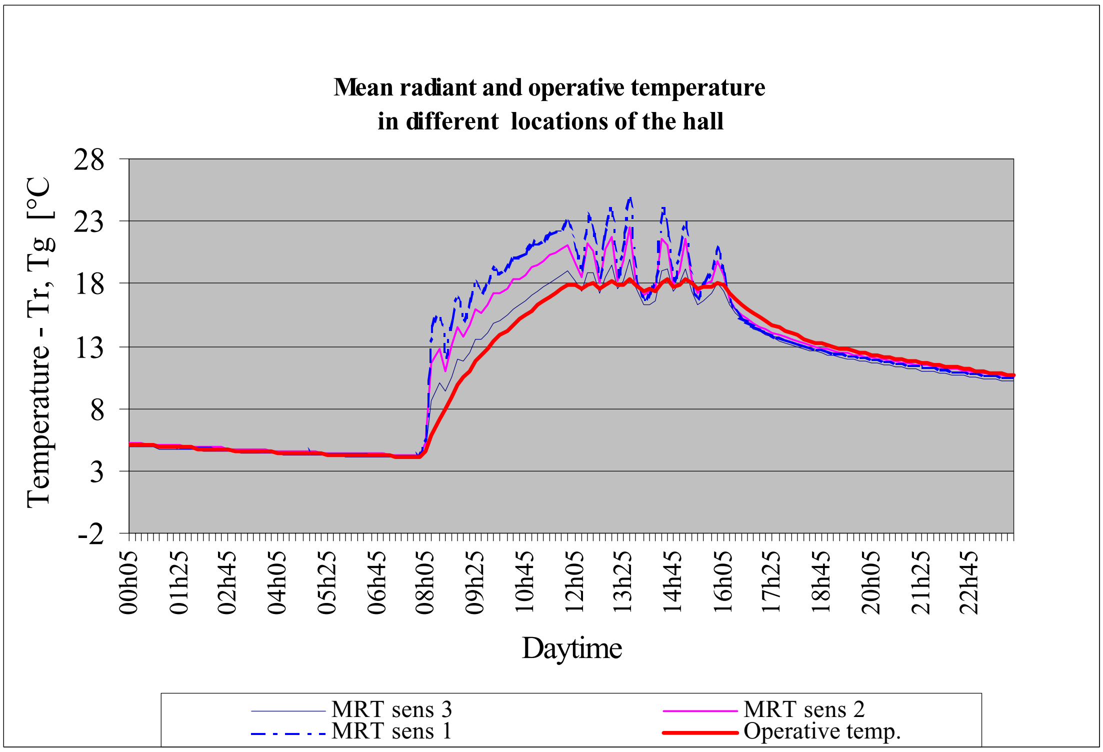

Fig. 7 Mean radiant temeparture (MRT) in different locations of the hall during one winter day. Location of the sensors is at the Fig.4

temperature during the weekdays was set to 18°C from 8AM till 4PM, during the rest of the time the heating was set to the off mode to gain annual energy consumption and to observe the thermal comfort during whole heating period and also during the spring and autumn time. The heating period, used for energy calculation in the Czech Republic is about 220 days.a^{-1} with average temperature +4°C. The results in terms of the mean radiant temperature and energy consumption are in the figures (Fig.6,Fig.7). The simulation was run during the whole year period.

Month	*Energy consumption [kWh]*
January	3833
February	2446
March	1345
April	385
May	0
June	0
July	0
August	0
September	0
October	771
November	2314
December	3728
Total	**14821**

Tab. 1 Energy consumption

Fig.6 shows the operative temperature profiles compared with ambient temperature during the typical winter week .

Fig.7 is focused to analyse one day period. It is possible to recognise difference in the MRT in different location of the hall. All three sensors are placed in the axis of the hall. Sensor nr.1 is just below the heater, sensor nr.2 is 2,5m from the axis of the heater and sensor nr.3 is 7,5 m from the axis of the heater.

Tab.1 is summarising the results in terms of energy consumption.

CONCLUSIONS

IN TERMS OF SOLVED CASE-STUDY

Designed heating system, based on infrared radiant heating, is sufficient to keep thermal comfort in the part of the hall with intermittent, local heating. Using the first tool, static model Hefaistos, enables to find the range of possible working area in the hall and to get general overview about non-uniformity of temperature distribution in the plan of the hall. With use of the second tool - ESP-r it is possible to investigate time-dependent thermal behaviour of the hall and optimise the operation of the heating system. The hall in this case had a heavy construction and the time between the start of the heating system and time of achieving of the required operative temperature was relatively long - about 4 hours. It is possible to tune the switch-on time of the heating system.

IN TERMS OF USED METHOD

Computer simulation of infrared radiant heating systems is tool, which could help to find critical nodes of the heating system and prevent problems with indoor environment in large spaces, heated with infrared radiant heating systems. This tool could be also used for optimisation of temperature distribution in halls and for appreciation of thermal comfort for occupants in halls. Using of the complex simulation secure the entire overview about the heated space. In terms of energy could optimised design to reduce investment costs and energy consumption to minimum.

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