MODELLING OF INDOOR ENVIRONMENT QUALITY IN SUSTAINABLE BUILDING

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Summary

Sustainable building philosophy focused on minimizing of energy use brings new problems in indoor quality-minimizing of ventilation increase danger of moulds and CO_2 concentration. Paper is focused on relation between building façade and operation in terms of heating and cooling energy consumption and indoor environment. There are discussed alternatives in typical, low-energy and passive houses building envelope solution standards. Evaluation of indoor environment and energy performance is based on computer simulation results, using ESP-r based models to quantify thermal comfort, energy consumption in office building.

Keywords: Sustainable building, low energy systems, modelling of IAQ, building performance

1 Introduction

Low-energy building heating and cooling design concept in climate conditions of Central Europe is based on minimizing energy consumption as one of the critical criterions in building design aiming to decrease total energy consumption and environmental pollution at the same time with preserving or improving indoor air quality. The main question in low energy architecture is not only a well insulated building envelope, but also the design and the control of heating and cooling system, which being energy distributors in the building are the main producers of the operational pollution. Heating/cooling system must cover transmission and ventilation heat losses/gains. Comparing with traditional buildings, where the main part of heat loss is transmission, the low-energy buildings are typical with reverse ratio of transmission and ventilation heat losses. There are several building elements, which are used to minimize energy consumption. Besides a well-insulated building envelope, there are elements like heat recovery, controlled air exchange rate, earth pre-heater, accumulation, solar energy utilization (PV and water systems), wind energy utilization and systems like warm-air heating, radiant heating and cooling.

Computer modeling and energy performance simulation as well as indoor environment simulation are not usually used at the first stage of architectural design process for common buildings. Usually an expert for energy use and environmental control is invited to participate the design process at the stage when the building shape and structure is practically fixed. All recommendations given by this expert, coming out from an energy and environmental performance analysis, have to be carried out in such a designed building. This implementation is mostly very inefficient and expensive due to the difficulties in making major changes in the building philosophy.

In our case, which is the subject of this paper, there was a very good co-operation between an architect and a specialist in building energy performance simulation. This could be a good example for a new approach to architectural design process. We hope that this case will help to answer the architect his usual question – "In which design stage it is the time to carry out an energy and environmental simulation and what can I expect from it?" The co-operation between the architect and the building energy specialist in our case started at the very beginning of the design process in finding conceptual solution of the building. In this phase, an energy and environmental analysis of various building concepts was carried out.

The aim of this paper is to investigate how the energy demand and indoor climate are affected by changing boundary conditions, it is trying to express the difference between traditional and low-energy architecture. It takes into consideration both the quality of the building envelope and the heating system. ESP-r, an energy simulation program, was used for this purpose.

Predicted mean vote (PMV), Percentage Dissatisfied (PPD) and cooling/heating loads are used as parameter indices for thermal comfort and energy consumption evaluation.

2 Problem description

The primary question, which origin this case study, was how to design low-energy sustainable office building. During a long discussion about using different low energy technologies (natural ventilation, solar chimney, heat storage) several questions like which U-value of the building envelope structures should be used, what kind of heating/cooling system should be designed and what level of indoor environment will be achieved using this system to design a low-energy office building with comfort indoor environment. Thinking of previous experience we accepted that in climate condition of Central Europe it is difficult to fulfill comfort requirements in an office building during summer period without an active cooling system. Therefore a concept of fan-coil heating/cooling system was accepted and simulation was focused on variation of U-value of the building envelope.

Tab. 1 Maximum values of overall heat transmission coefficient

Alternative	**U wall** [W/m^{2}K]	**U window** [W/m^{2}K]
Demanded (DEM)	0,38	1,7
Recommended (REC)	0,25	1,2
Low-energy (LE)	0,15	0,8

In terms of energy three main categories of buildings are taken into account according to Czech building regulations [1], where the maximum values of overall coefficient of heat transmission are set. Parameters of the constructions in mentioned categories are in **Tab. 1**.

3 Modeling and simulation

To evaluate annual energy consumption and indoor environment quality during the entire year we selected ESP-r [2] modeling, simulating and analyzing tool, which enables with adequate accuracy and sensitivity to obtain data to answer all of the questions from above.

3.1 Model

A typical part of the building was chosen for simulation purposes containing office room facing west and zone representing air-handling unit (AHU).

Office room has the following dimensions 5×9×3 m. Room has one exterior wall with a window (dimensions 5×1,6 m) facing west, as critical orientation for the cooling, resulting from pre-analysis. No heat flux through side internal walls, ceilings and floors is assumed. Building envelope properties are the subject of simulation alternatives and are selected as three options according to **Tab 1**.

AHU is single zone model with no heat flux through boundary structures and with defined air change rate.

Heating and cooling system was defined by heating capacity controlled in range 0-500 W, cooling capacity 0-5000 W in the office room and 0-10000 W for heating and cooling in the AHU. Control of the system is running as basic controller according to sensors, located in both of the zones sensing dry bulb temperature. Actuator representing heating/cooling system transmits energy as convection. Set point for heating is 20 °C; for cooling 26 °C. There is no humidity control considered.

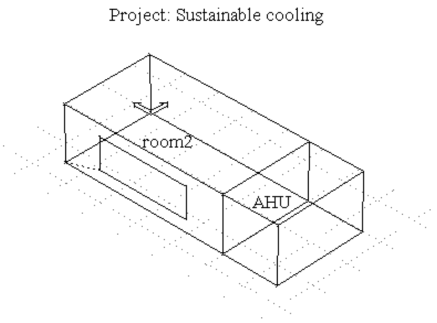


Fig. 1 ESP-r model

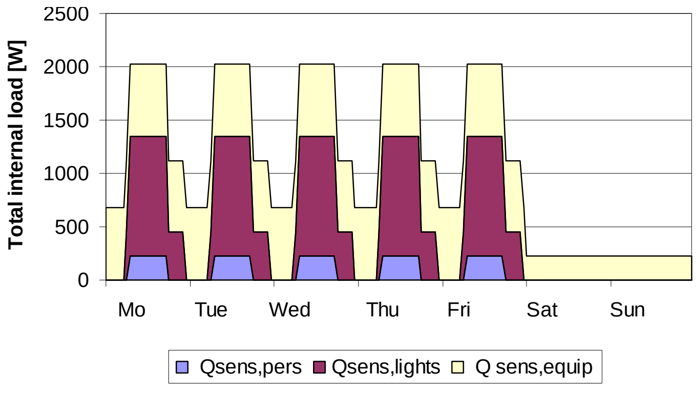


Fig. 2 Internal heat loads profile (sensible)

Ventilation system was modelled supposing air change rate during working hours using value of 0,7 ac/hr for office supplied by AHU besides the value of 0,3 ac/hr representing infiltration during non-working hours.

To get the knowledge about casual gains inside the building it is necessary to see the occupancy, equipment and lighting situation. Hours between 7 and 18 are considered to be working time. During this time the office is occupied, running computers and lights are on. During non working time there is no occupation, computers are in sleep mode and lights are on n dimmed mode only during working days 6-7 and 19-23 hours. According to [3] these occupancy produce 7,8 W/ m^2 (incl. sensible and latent heat), computers 15 W/m^2 (5 W/m^2 in the sleep mode) and lighting 25 W/m^2 (10 W/m^2 in the dimmed mode).

3.2 Simulation

In the simulation we created three alternatives of the model. The insulation thickness was changed in the simulation to reach different U-values entering the computation (**Tab. 1**).

The whole year period was studied using Prague (Czech Republic) climate files. Integrated building simulation was used, with time step 1 hour and initial period 3 days. During simulation, no major problems were detected by the program. The discussion about the results was focused on heating/cooling energy consumption. PMV and PPD parameters were used to evaluate thermal comfort.

3.3 Results

Temperature. In all three alternatives the temperature in office room was within the acceptable range. During working time, when the system was on, temperature did not exceed required boundaries. The results in a one year period obtained from the simulation are summarized in **Tab. 2**. Temperature ranges verify correct control of the heating/cooling system.

Heating and cooling system peak loads. During whole year operation of the system results summarized in the **Tab. 2** were calculated. Delivery of heating energy into the fan-coil located in the office room was needed only for DEM variation. In both other variations (REC,LE) was enough to supply air from AHU with temperature 20 °C to achieve required range of temperatures in the room (20-26 °C). Delivery of the peak cooling energy into the office room slightly rises with increasing thermal insulation of the façade, because of worse heat transfer during period, when indoor temperature is higher than outdoor temperature.

Tab. 2 Peak values

Alternative	$\Theta_{i,max}$	$\Theta_{i,min}$	$Q_{heat,max}$ [W] Room	$Q_{cool,max}$ [W] Room	$Q_{heat,max}$ [W] AHU	$Q_{cool,max}$[W] AHU
DEM	26	20	457	3278	878	0
REC	26	20.1	0	3292	865	0
LE	26	22.1	0	3308	867	0

Tab. 3 Energy delivered

Alternative	Heating q_h [kWh/a]	Cooling q_c [kWh/a]	Total primary $q_t = q_h \cdot \eta_h + q_c \cdot \eta_c$
DEM	539	5254	2701
REC	523	6312	3106
LE	523	7311	3505

Energy. Tab. 3 and **Fig. 3** and **4** show annual energy consumption for heating and cooling and summary heating and cooling energy consumption. The improving of the building envelope thermal properties in this case decreases obviously heating energy demand and so logically increases cooling energy demand. We can say taking into account significant internal heat gains that the total value of heating and cooling energy consumption is the lowest in the building with “demanded” envelope parameters contrary to all expectation rising of course from the “low-energy” building envelope solution.

For calculation of total primary energy we used fixed efficiencies of energy sources – for heating $\eta_h = 0.9$ and for cooling $\eta_c = 2.5$.

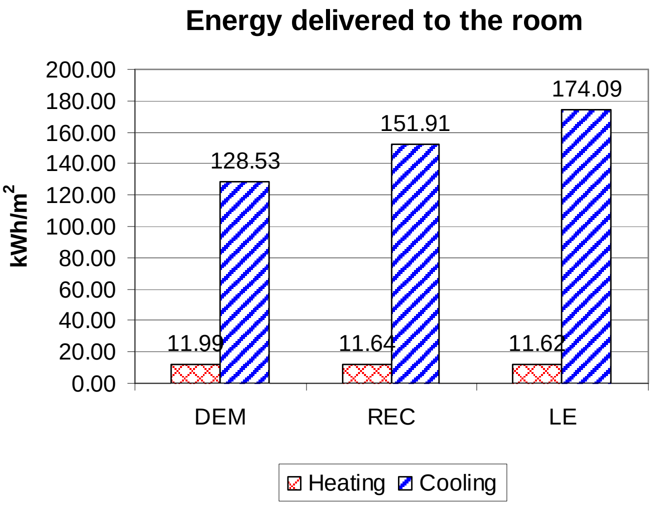


Fig. 3 Annual cooling and heating energy delivered to the room

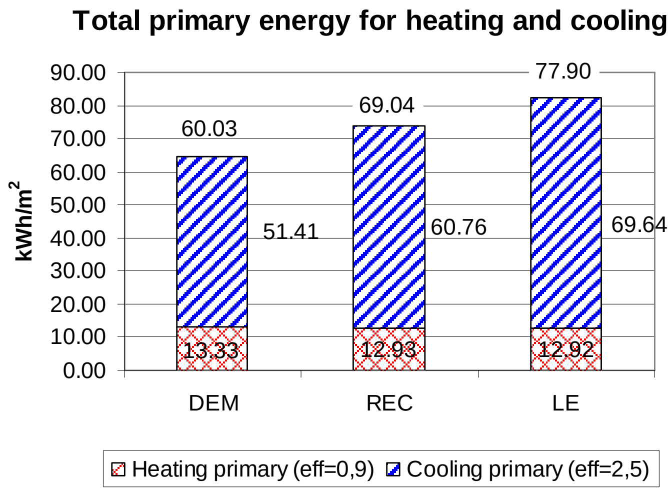


Fig. 4 Annual total primary cooling and heating energy consumption

Thermal comfort evaluation is based on PMV and PPD classification of heated/cooled spaces. PMV is defined by six thermal variables from indoor-air and human condition that is air temperature, air humidity, air velocity, mean radiant temperature, clothing insulation and human activity. The value of PMV index has range from −3 to +3, which corresponds to human sensation from cold to hot, respectively where the null value of PMV index means neutral to maintain the PMV at level 0 with a tolerance of ±0.5 to ensure a comfortable indoor climate [3]. The PPD index is a description of estimated thermal comfort and a function of four physical parameters: dry bulb temperature, mean radiant temperature, relative humidity and air velocity, and parameters connected to the occupant such as clothing level, metabolic rate and external work. **Fig. 7** summarize comfort evaluation during working time within a year. Comfort evaluation is based on activity level 1.2 MET with clothing level equal to 0,7 clo.

Variation DEM. In this case PMV index appeared from -0.5 to 1.5. Index PPD in 22.7 % of the time is up to 10 % which means that during this time the number of dissatisfied occupants will not exceed 10 %.

Variation REC. In this case PMV index appeared from 0.0 to 1.5. Index PPD in 9,6 % of the time is up to 10 % which means that during this time the number of dissatisfied occupants will not exceed 10 %.

Variation LE. In this case PMV index appeared from 0.0 to 1.5. Index PPD in 2,3 % of the time is up to 10 % which means that during this time the number of dissatisfied occupants will not exceed 10 %.

In all three cases there is no problem with heating, discomfort is caused due to cooling of the space.

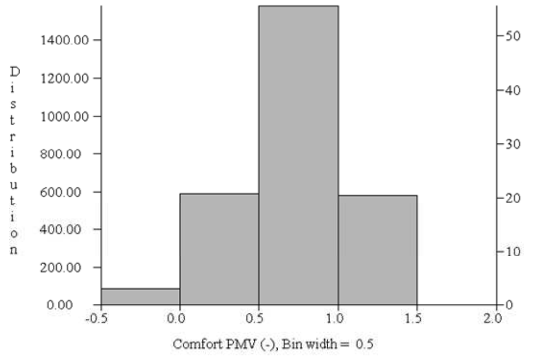
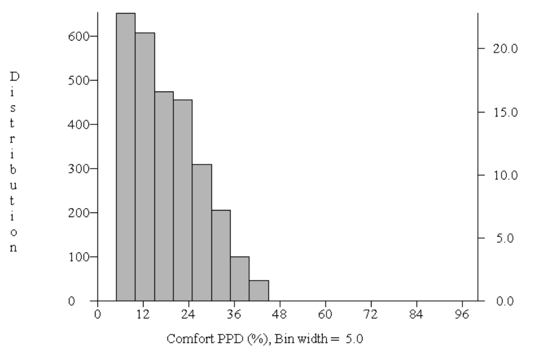
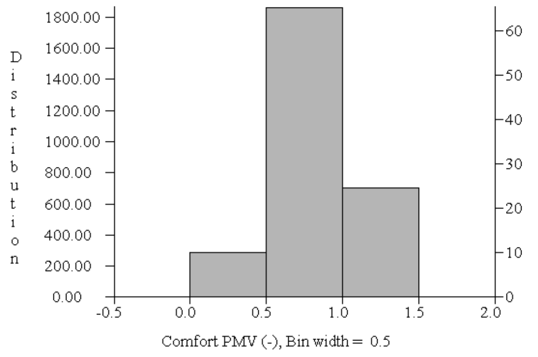
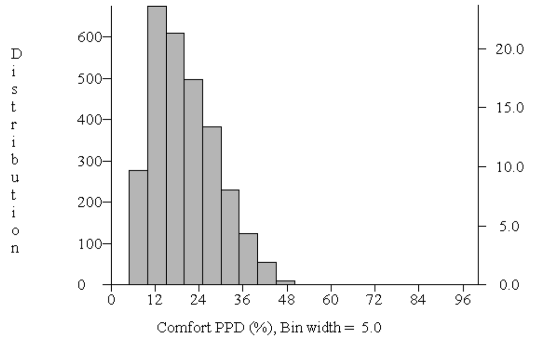
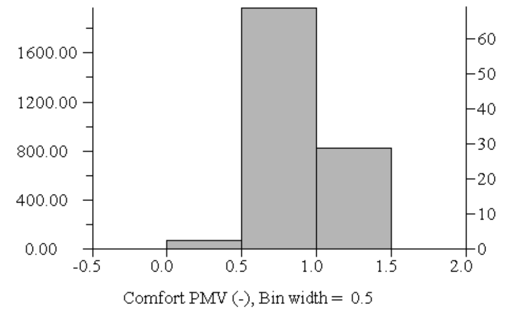
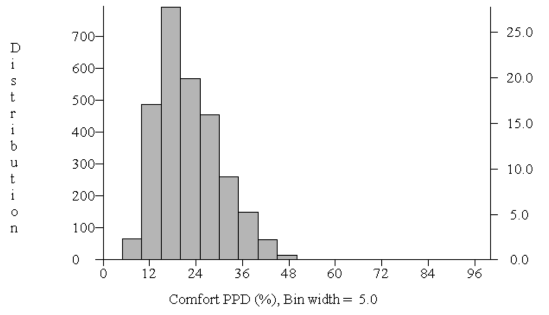
Alt	**PMV**	**PPD**
DEM		
REC		
LE		

Fig. 5 Annual evaluation of PMV and PPD

4 Conclusion

Presented case study has shown a possible utilization of integrated simulation supporting the early conceptual design phase. The recommendation based on this approach is to continue in designing alternative DEM- **demanded U-values**, which will give the best results in terms of energy consumption together with the best results in comfort evaluation. The reason, why the results of the thermal comfort evaluation are so unsatisfactory (most of working time is PMV > 0,5) is due to the relatively high summer temperature set point (+26 °C) in connection with settled clothing value and activity of the occupants.

This paper was supported by Research Plan CEZ MSM 6840770003.

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