Optimal properties of external building envelope for minimization of over heating

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Abstract. The article investigates the influence of different ventilation strategies on annual energy consumption and thermal comfort. The method proposed for the study is the analysis of the building model realized in the energy simulation software IDA Indoor Climate and Energy (IDA-ICE) 4.7 - a tool for dynamic simulation of thermal comfort, indoor air quality and energy consumption in buildings. The especial attention is paid to application of external shadings which is not popular in cold climate. Achieved results have shown operative temperature is below 26˚C.

1. Introduction

The construction of buildings with low energy consumption is regulated and promoted at the national level. The ultimate goal is to reduce the negative impact on the environment, control the effective consumption of energy and material resources, and create a comfortable environment for human’s life [1].

Designing energy efficient building it is important to find the balance between building thermal insulation level, type of ventilation systems and thermal comfort [2]. For example, increasing the thickness of thermal insulation layer and using the mechanical ventilation system with heat recovery significantly decreases energy consumption by about 45%, but there is a risk of overheating, which is needed to be prevented [3]. Extra thermal mass - latent heat - can have a negative impact on overall thermal comfort due to limited possibility for heat discharge [4] [5] [6]. According to the Energy Performance of Buildings Directive, the goal is to reduce the energy consumption for cooling the building and at the same time to improve the indoor climate and to prevent overheating [7] [8]. Recent studies [6,9] have shown that detailed analysis allows precise estimation of energy savings which provides correct estimation of economical benefits.

The purpose of this research is to investigate the influence of different ventilation strategies on annual energy consumption, indoor quality and thermal comfort.

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2. The new method, experimental results and discussion

The method proposed for the study is the analysis of the building model realized in the energy simulation software. Work done by [10,11] have proved that dynamic energy calculation can provide more reliable results. Computational analyses were carried out using the IDA Indoor Climate and Energy (IDA-ICE) 4.7 software - a tool for dynamic simulation of thermal comfort, indoor air quality and energy consumption in buildings. Accuracy of this simulation tool was studied in several reports, which conducted an empirical validation study of models in IDA-ICE, related to the thermal behaviour of buildings and HVAC equipment [3,12,13]. It was concluded that agreement between simulated and measured data was good and disagreements were similar to the measurement’s uncertainty. IDA-ICE was validated according to the EN 13791 [13] [14].

The analyzed building model was created by Autodesk Revit software and transferred to the simulation software in the IFC format. The climate data for current project calculation is used according to ASHRAE (American Society of Heating and Air-Conditioning Engineers) 2013 and wind profile according to ASHRAE 1993. The object of this case study is two-storey single family residential building. The compact heat pump (ground/water type) is chosen to provide heating and cooling. Heating power: 4.7kW (B0 / W35); COP 4.7 (B0 / W35). Class Seasonal Space Heating Energy Efficiency C A ++.

![Building model in IDA-ICE; Plan of the 1st floor; Plan of the 2nd floor.](image)

Table 1. Building data

| Type               | Value          |
|--------------------|----------------|
| Heated floor area  | 167.2 m²       |
| Model volume       | 416.3 m³       |
| Model area         | 88.1 m²        |
| Ground area        | 372.5 m²       |
| Window/Envelope    | 11.2 %         |
| Average U-value    | 0.1885 W/(m²K) |
| Envelope area per volume | 0.8947 m²/m³  |

Table 2 shows scenarios, which were simulated, analyzed and described for this case study.
| Type of ventilation system | CASE | Name of ventilation system in IDA-ICE | Description |
|---------------------------|------|-------------------------------------|-------------|
| Natural                   | 0    | Basis case                          | Windows are never opened. Ventilation system without heat exchange. Heat pump COP 4. |
|                           | 1    | Basis case + sun shading roof       | Sun shading roof on the first floor on facade “D”. Windows never opened. |
|                           | 1B   | Basis case + windows external shading | Windows external shading (drop arm awning) on facade “D”. Windows never opened. |
|                           | 1C   | Basis case + night ventilation (time schedule) | Night ventilation according to time schedule: four of six windows are opened in the summer period (1st. of June to 31st of August) from 23.00 till 1.00, during the heating period (from September to May) are closed. |
|                           | 1D   | Basis case + night ventilation (time schedule, PI PI (proportional-integral) temperature control) | If temperature sensors show necessity windows are opened according to time schedule in the summer period (1st. of June to 31st of August) from 23.00 till 1.00, during the heating period (from September to May) are closed. |
|                           | 1 AB | “0” + sun shading roof + windows external shading | Basic case added with sun shading roof on the first floor on facade “D” + windows external shading (drop arm awning) on facade “D” Windows never opened. |
|                           | 1 ABC | “0” + sun shading roof + windows external shading +night ventilation (time schedule) | Basic case added with sun shading roof on the first floor on facade “D” and windows external shading (drop arm awning) on facade “D”. Night ventilation according to time schedule: four of six windows are opened in the summer period (1st. of June to 31st of August) from 23.00 till 1.00, during the heating period (from September to May) are closed. |
|                           | 1 ABD | “0” + sun shading roof + windows external shading + night ventilation (PI sensors + time schedule) | Basic case added with sun shading roof on the first floor on facade “D” and windows external shading (drop arm awning) on facade “D”. If temperature sensors show necessity, windows are opened according to the time schedule in the summer period (1st. of June to 31st of August) from 23.00 till 1.00, during the heating period (from September to May) are closed. |
| Mechanic                  | 2    | “0” + ventilation heat recuperation 85% | |
|                           | 3    | “0” + operative temperature time schedule | |
In scenario “0”, basic building geometry is evaluated. Windows are never opened. Ventilation system works without heat exchange option. As it is seen on the Figure 2, operative temperature during summer time reaches 29˚C in rest area No. II and 33˚C in common space with kitchen zone No.I.

Fig. 2. (a, b) Scenario “0” Thermal comfort analysis a) common space with kitchen b) rest area

In scenario “1A”, basic building geometry is supplemented with additional roof above the windows of the 1st floor on the southern windowed facade (Figure 3) with an aim to lower operative temperature during summer period. Windows are never opened. Ventilation system works without heat exchange option.

Fig. 3(a, b). Scenario “1” Thermal comfort analysis a) common space with kitchen b) rest area

In scenario “1B”, the window external shading (drop arm awning) is installed on the southern windowed facade (Figure 4) to improve thermal comfort during summer period. Windows are never opened. Ventilation system works without heat exchange option. The operative temperature in common space with kitchen in period from July to August is below 26˚C, that is definitely positive result. In rest zone the temperature peaks of 29-29.5˚C are spotted in August and October.
Fig. 4. Building model with window external shading

In scenario “1C”, natural ventilation is organized according to the time schedule: four of six windows are opened from 11 pm till 1 am during the summer period (from June to August). During the heating period (from September to May) windows are closed. The operative temperature for this scenario in summer period is in the range of 26-28°C in common space with kitchen. As a positive result must be highlighted the fact of temperature range 22-26°C in summer period in rest area Nr. 205.

Summary Table 3 demonstrates comfort data for common space with kitchen: the best PPD value is achieved in Case studies 1A and ABD, thought the best PVM value is demonstrated in Case studies 1D. Such common option as natural ventilation organization according to time schedule if temperature exceed definite set point positively effects the comfort indicators, even without mechanical ventilation option.

Table 3. Summary table of comfort data for common space with kitchen

| Simulation case | Case 0 | Case 1A | Case 1B | Case 1C | Case 1D | Case 1AB | Case 1AMC | Case 1ABD | Case 2 |
|----------------|--------|---------|---------|---------|---------|---------|-----------|---------|--------|
| Achieved room Comfort category A and B, % of occupancy hour | 54% | 58% | 56% | 56% | 56% | 55% | 54% | 58% | 55% |
| Room temperature set point category | | | | | | | | | |
| Comfort category. A or I (best). h | 2459 | 2453 | 2365 | 3150 | 3104 | 2673 | 2378 | 3245 | 3942 |
| Comfort category. B or II (good). h | 5531 | 6150 | 5875 | 5553 | 5550 | 5830 | 5642 | 5311 | 5526 |
| Comfort category. C or III (acceptable). h | 6498 | 6645 | 6809 | 6193 | 6550 | 6303 | 6117 | 6817 | 6696 |
| Comfort category. D or IV (unacceptable). h | 486 | 288 | 124 | 740 | 983 | 831 | 816 | 16 | 267 |
| PPD, Predicted Percentage of Dissatisfied, %, mean | 27.64 | 29.45 | 27.87 | 26.19 | 24.55 | 26.69 | 30.49 | 29 | 26.6 |
| PPD, Predicted Percentage of Dissatisfied, %, min | 31.00 | 27.51 | 12.09 | 9.682 | 9.045 | 11.02 | 16.2 | 21.02 | 11.13 |
| PPD, Predicted Percentage of Dissatisfied, %, max | 43.07 | 43.39 | 45.81 | 43.08 | 42.92 | 44.72 | 45.35 | 43.31 | 43.21 |
| PPD, Predicted Percentage of Dissatisfied, %, range | -0.83 -0.7839 -0.9311 -0.8099 -0.6419 -0.9677 -0.9963 -0.8819 -0.7876 |
| PPD, % | 55% | 58% | 56% | 56% | 56% | 55% | 54% | 58% | 55% |

Reference for Thermal state of the body as a whole, A category (EN 15251)
PPD, Predicted Percentage of Dissatisfied, %. |
PPD, Predicted Percentage of Dissatisfied, %. | <5 %
| |
Reference for Thermal state of the body as a whole, B category (EN 15251)
PPD, Predicted Percentage of Dissatisfied, %. |
PPD, Predicted Percentage of Dissatisfied, %. | <10 %
| |
Reference for Thermal state of the body as a whole, C category (EN 15251)
PPD, Predicted Percentage of Dissatisfied, %. |
PPD, Predicted Percentage of Dissatisfied, %. | <15 %
| |
Reference for Thermal state of the body as a whole, D category (EN 15251)
PPD, Predicted Percentage of Dissatisfied, %. |
PPD, Predicted Percentage of Dissatisfied, %. | >15 %
| |
Table 4. Summary table of comfort data for rest zone

| Simulation case | Case 0 | Case 1A | Case 1B | Case 1C | Case 1D | Case 1AB | Case 1AIC | Case 1ABD |
|-----------------|-------|--------|--------|--------|--------|--------|--------|--------|
| Achieved room Comfort category | A or I (best) | A or I (good) | C or III (acceptable) | D or IV (Unacceptable) | 6.075 | 4.040 | 4.007 | 2.315 | 6.719 | 5.620 | 6.289 | 4.605 | 6.665 |
| PPD, Predicted Percentage of Dissatisfied, %, mean | 24.05 | 21.05 | 23.17 | 21.68 | 25.40 | 26.8 | 27.31 | 25.69 | 36.77 |
| PPD, Predicted Percentage of Dissatisfied, %, max | 7.616 | 6.129 | 5.971 | 6.057 | 7.47 | 8.346 | 5.31 | 8.189 | 7.577 |

For rest room, the best PPD value is achieved in Case studies 2. In this case mechanical ventilation using heat recovery significantly influences the comfort indicators. Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Most people will feel comfortable at temperature colloquially a range of temperatures around 20 to 22 °C, but this may vary greatly between individuals. The main factors influencing the thermal comfort are those that determine heat gain and loss, namely metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity. Psychological parameters, such as individual expectations, also affect thermal comfort. Maintaining the standard of thermal comfort for occupants of buildings is one of the important goals of HVAC design engineers.

The Predicted Mean Vote (PMV) model stands among the most recognized thermal comfort models. It was developed using principles of heat balance and experimental data collected in a controlled climate chamber under steady state conditions. The adaptive model, on the other hand, was developed based on hundreds of field studies with the idea that occupants dynamically interact with their environment. Occupants control their thermal environment by means of clothing, operable windows, fans, personal heaters, and sun shades. The quantity of different comfort categories hours was simulated for each scenario. Figure 5 demonstrates the example of thermal comfort graphics for scenarios “0”.

Fig. 5(a, b.) Scenario “0” Temperature analysis a) common space with kitchen (b) rest area

The contribution of Povl Ole Fanger to the research on thermal comfort still defines the state of the art in HVAC technology and the basis for international standardization. Figure 6
demonstrates the example of Fanger’s comfort graphics for scenarios “0”: the predicted percentage of dissatisfied (PPD) and predicted mean vote (PNV) data.

Fig. 6(a, b) Scenario “0” Comfort analysis a) common space with kitchen (b) rest area

3. Conclusion

Increasing the thickness of thermal insulation layer and using the mechanical ventilation system with heat recovery significantly decreases energy consumption by about 45%, but there is a risk of overheating, which is needed to be prevented. Modern energy efficient buildings require multidisciplinary approach to reach both overall energy efficiency and to ensure thermal comfort.

The best PPD value is achieved in Case studies 2: ventilation heat recuperation 85% with out windows opening. In this case mechanical ventilation using heat recovery significantly influences the comfort indicators. Situation can be significantly improved by installation of external shadings.

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