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The influence of a heating system control program and thermal mass of external walls on the internal comfort in the Polish climate

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Abstract

The main goal of this paper is to evaluate the influence of a heating system control program and thermal mass of the external envelope on the internal thermal comfort. The analogous influence was considered based on the final energy consumption for heating purposes. A building that was chosen for the purpose of the analysis is located in Warsaw. This building fulfils national requirements. To evaluate the problem, various programs for heating system control were applied: constant space temperature, and reduced space temperature. Besides that three kinds of external walls were chosen. To obtain the results the simulation program was applied.

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1. Introduction

Assessments of energy performance and indoor comfort are important indicators during design of public utility and residential buildings. Nevertheless, it is simulation tests that enable a dynamic analysis of key design parameters, such as indoor air temperature, operative temperature, energy demand for heating or cooling, and energy demand for driving auxiliary equipment. Although heat losses depend on thermal insulation of the envelope and air tightness, the variability of indoor temperature mainly relates to building dynamic properties.

Such an analysis is presented in the paper; it was performed with the aid of the DesignBuilder package [13], containing the EnergyPlus simulation software [14]. Simulation tests presented in the paper refer to an existing single-family house with a relatively small total area; the house can be considered as one that represents this class of size in Poland. Requirements concerning thermal insulation of the envelope were adapted to currently applicable legal requirements [9]. Four buildings featuring the same geometry and occupancy pattern but of different thermal mass were analysed. They have been equipped with a heating system that is typical in Poland: a pump and water-based system with convection heaters and a passive stack ventilation system.

A similar analysis was performed for different climatic conditions found in Italy [2]. With respect to energy performance, two building constructions were compared: an extremely “light” (gypsum-plaster sandwich filled by mineral fiber) and extremely “heavy” (plastered clay brick) ones. Heating and cooling needs for the buildings were taken into account. It was demonstrated that thermal capacity is certainly effective for energy saving.

The effect of thermal mass on space heating energy use and life cycle primary energy balances of a concrete- and a wood-frame building was analysed in [1]. It was shown that a concrete-frame building's space heating demand is not significantly lower than that of a wood-frame alternative. Depending on the thermal protection standard, the difference is: less than 1.0% (reference), 1.7% (current code), and 2.4% (passive standard).

The Swedish research [7] emphasized the possibility of reducing the energy demand for heating and cooling by applying specific materials which enable excess heat accumulation in the building structure. Furthermore, accumulation capabilities were found not to be large compared to the needs.

Even with a simplified building model [4], the effect of the thermal mass on the energy efficiency can be demonstrated. Basic elements of the proposed model are: an exterior wall, indoor air volume, and a thermally heavy inner wall. Research concerning cold-climate conditions showed that the thermal mass can decrease fluctuations in power drawn for heating, although in most analysed cases it has no contribution to the change in the energy demand for heating.

In Belgian conditions [8] the energy demand for heating in small residential buildings featuring a lightweight construction is 4,5% higher than in heavyweight buildings. On the other hand, however, the indoor comfort in lightweight buildings is 20.5% lower. It is an insulation level and glazing properties that have a larger effect on the energy efficiency and comfort.

As for office buildings, the research on the effect of suspended ceilings on energy performance and thermal comfort [3] showed that exposed concrete in the ceiling has an influence on the reduction and stabilization of indoor temperature.

An interesting solution presented in [6] consists in decreasing the peak energy demand for cooling in office buildings by applying thermally activated building systems (TABS). It was demonstrated that in Dutch conditions such a system makes it possible to reduce the energy demand for cooling by up to 50%.

The papers mentioned above showed the effect of heat capacity on indoor comfort conditions and on building energy efficiency.

2. Description of the building under consideration and its important parameters

As a result of political and economic changes, the number of construction projects in Poland has significantly increased in recent 20 years. Owing to economic conditions, very popular designs are small single-family houses, up to 150 m^2 in total area; hence, a two-storey residential building with a heating space area of 123.00 m^2 was analysed. The building is inhabited by four residents. The building is located in Warsaw, Poland (according to the Köppen climate classification: warm summer continental climate). According to data published by Eurostat, the European Union's statistical office, the number of heating degree-days in Poland is 3 615.77 (Sweden: 5 443.84; Czech

Republic: 3 570.64; Germany: 3 239.19; Denmark: 3 235.39; Netherlands: 2 726.59; Italy: 1 970.93) [15]. Assuming the base temperature as 24°C, the number of cooling degree-days for the Warszawa-Okęcie weather station is 95 (Torino-Caselle, IT: 106; Berlin-Tempelhof, DE: 53; Prague-Ruzyne, CZ: 37; Amsterdam-Airport Schiphol, NL: 14; Koebenhavn-Kastrup, DK: 5; Gothenburg, SE: 3) [12]. These data indicate that, compared to other Central Europe countries, Poland has unfavourable climatic conditions which result in higher energy demand for heating and cooling. In addition, resigning from traditional designs of masonry buildings made of clay brick and adapting lofts for residential purposes have in many cases contributed to decreasing indoor comfort parameters in summer. Hence, the application of cooling systems is often required. This is why it is so important to provide proper thermal protection of buildings and select appropriate dynamic properties of structures taking into account rational energy use for heating and cooling and protecting rooms from excess heating.

The higher requirements are reflected in current legal regulations [9]. Hence an assumption was made that the envelope elements meet the current requirements with respect to thermal insulation. The values of thermal transmittance of the building envelope elements are the following: external walls — 0.25 W/(m^2 K); ceiling over the top heated floor — 0.20 W/(m^2 K); ground floor slab — 0.30 W/(m^2 K); exterior door — 1.70 W/(m^2 K), and windows — 1.20 W/(m^2 K).

The results of the analysis are influenced not only by the building's dynamic properties but also by: outdoor climate parameters, required indoor temperature, and the program concerning the use and operation of electric appliances.

For assessing energy performance of buildings in Poland, meteorological data have been prepared; they are available at the Ministry of Infrastructure and Development's website [16]. Unfortunately, they are rather controversial to the extent relevant to solar radiation (discussing this is not within the scope of this paper); therefore, the Test Reference Year, supplied with the EnergyPlus simulation software [14] was used.

The schedule providing values of indoor heat gains was adopted from a document published by the National Energy Conservation Agency in Poland and describing a reference single-family house [5]: heat gains from lighting (5.0 W/m^2), from electrical equipment (3.14 W/m^2), and from occupants (50 W per occupant). This analysis considered variations in the internal heat gains as provided for in defined occupancy patterns.

Time-varying solar heat gains depend not only on the location and climate but also on the properties of transparent space-dividing elements used. One such property is a solar heat gain coefficient (*SHGC*). In the analysis a value of 0.6 was used, typical for windows available on the Polish market, featuring good thermal insulation, double panes and one argon-filled cavity.

As with majority of single-family houses in Poland, this building has passive stack ventilation. Ventilation air flow rate, 320 m^3/h under design conditions, was determined on the basis of hygiene requirements. An infiltration air flow rate was determined based on the building air tightness n_{50}=1 1/h. Hence, the design ventilation transfer coefficient is 119.0 W/K. The thermal performance of the conditioned space external envelope is expressed by the heat transmission coefficient [11] of 77.1 W/K.

The following building structures were considered: steel-reinforced concrete frame (building A), solid clay brick masonry (B), masonry with aerated concrete blocks (C), and wooden structure (D). Buildings A, B, and C have reinforced concrete floors, whereas building D has timber-framed floors. Heat capacity values were determined for these structures (Tab. 1).

Table 1. Internal heat capacity.

Parameter	Building A	Building B	Building C	Building D
Internal heat capacity, J/K	69 273 744.6	62 979 023.8	46 482 514.3	24 636 037.0
Internal heat capacity per heated unit area, J/K	563 201	512 025	377 907	200 293

3. Description of the heating system

It was assumed that a condensing combination boiler with annual average efficiency of 94% provides heat in the heating system. A pump and water-based upfeed system was used with design parameters 75°C/55°C (at the outdoor air temperature of -20°C). Rooms are equipped with convection heaters.

No cooling system is provided for the building. Two control options were analysed for each building (Tab. 2).

Table 2. Description of control options.

	Option I	Option II
Type of central heating control	Fixed setpoint control (temperature setpoint 20°C)	Overnight temperature drop by 2 K

4. Numerical simulation results

Simulations for the listed types of building structures with each of the two control options were performed. The simulation results included hourly values of operative temperature and the required capacity of the heat source (heating capacity). Then, the following values were calculated for the summer period: the number of hours when the limit indoor temperature of 26°C is exceeded; the mean operative temperature; and standard deviation of the operative temperature from the comfort temperature with respect to each building considered.

Running costs include the costs of gas, and power for driving the heating and domestic hot water pumps.

Results are listed in Tab. 3.

Table 3. Summary of results.

Description	Control option	Building A	Building B	Building C	Building D
Number of hours $\Theta_{op} > 26$°C	I, II	321	355	474	805
Mean operative temperature in the summer period	I, II	26.7	26.8	27.0	27.7
Standard deviation of operative temperature from comfort temperature in the summer period	I, II	0.69	0.77	0.99	1.72
Annual useful energy demand for heating and ventilation [kWh/year]	I II	9 070.51 8 805.10	9 039.34 8 792.59	9 067.79 8 833.39	9 242.49 9 139.85
Annual useful energy demand for heating and ventilation, *EU*, [kWh/(year m^2)]	I II	73.88 71.72	73.62 71.61	73.86 71.95	75.28 74.44
Annual final energy demand for heating and ventilation, *EF*, [kWh/(year m^2)]	I II	91.99 89.30	91.67 89.17	91.96 89.58	93.73 92.69
Annual primary energy demand for heating, ventilation and DHW supply, *EP* [kWh/(year m^2)]	I II	162.52 159.56	162.17 159.42	162.49 159.87	164.44 163.29
Cost [PLN]	I	3 836.67 (~922 EUR)	3 828.91 (~921 EUR)	3 835.99 (~922 EUR)	3 879.50 (~933 EUR)
	II	3 770.58 (~907 EUR)	3 767.46 (~906 EUR)	3 777.62 (~908 EUR)	3 853.94 (~927 EUR)

As the maximum operative temperature occurred on the 6th of July, Fig. 1 shows the temperature trend between the 4th (11.00 p.m.) and 7th of July (11.00 p.m.).

Fig. 1. Temperature trend between the 4th (11.00 p.m.) and 7th of July (11.00 p.m.).

5. Conclusions

- Four buildings having different dynamic properties were analysed. Other parameters relevant to the energy performance assessment were the same.
- Thermal performance of the envelope elements of the building A, B, C, and D meets current Polish regulations.
- According to regulatory requirements, the maximum annual primary energy demand for heating and ventilation for single-family buildings is 120 kWh/(m^2 year).
- In the summer period, the number of hours when the operative temperature is higher than 26°C depends on the building heat capacity. In this regard, the building with a very heavy structure is the most favourable. Certainly, the heating system control option can have no impact on these values.
- Indoor temperature is most stable in buildings with the largest heat capacity (A, B), and least stable in the one with the smallest heat capacity (D). This is evidenced by the values of standard deviation of operative temperature from comfort temperature in the summer period.
- In Poland’s climatic conditions, buildings with large heat capacity are the most favourable in terms of thermal comfort, as external air temperature in Poland throughout the year may vary from very low, -20°C, to very high, +35°C. Large heat capacity enables the reduction in the fluctuations of the internal temperature.

- A temperature decrease by 2 K in the heating period in all the cases considered resulted in a relatively small decrease in the effective energy demand for heating and ventilation (building A by 2.9%, B by 2.7%, C by 2.6%, and D by 1.1%).
- Based on the annual values of the useful energy demand for heating and ventilation, the buildings fall under the category of buildings with reasonable performance (EU <80 kWh/(m^2 year).
- The buildings under consideration fail to fulfill Polish requirements on energy performance. In all the cases, the calculated values of annual primary energy demand for heating and ventilation exceed 120 kWh/(m^2 year). The main reason for this is the energy demand for heating the ventilation air, since all the cases feature a passive stack ventilation system.
- The largest savings resulting from the overnight temperature drop by 2 K occur in the case of the building with the lowest internal heat capacity.
- The impact of the internal heat capacity on annual heating costs is negligible (the difference between the maximum and minimum values is about 1.1%).
- Heating costs per unit area amount to about 6 EUR per 1 m^2 of the building heated area.

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