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REDUCING ENERGY CONSUMPTION FOR HEATING SYSTEMS IN RESIDENTIAL BUILDINGS - CASE STUDY

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Abstract: *The article presents a case study of the energy performance of two types of heated living spaces, for the scenario in which the average indoor temperature is reduced by one degree Celsius. The obtained results are presented for different indoor temperatures and different thermal zones, estimating the average value for both an independent building and an apartment. The aim of the study is to evaluate the impact of reducing the average indoor temperature by one degree Celsius on the annual energy consumption for heating a residential building, so that the energy performance of the building improves without significantly affecting the comfort conditions for the building's occupants.*

Key words: *thermal comfort, indoor temperature, energy performance, residential buildings, energy use*

1. INTRODUCTION

The paper presents a case study of the change in energy consumption for heating a house and apartment when the average indoor temperature of the heated space is reduced by one degree Celsius.

Based on the national energy regulation [9] and the European directives on the energy performance of buildings [7], it is necessary to search for and continuously develop innovative methods to reduce the energy demand of buildings.

The focus of this study is on residential buildings, where, in order to improve consumption rates, different packages of specific measures can be applied to each building category. Applying these energy measures to both the building envelope and the utility systems serving the building can lead to increased thermal comfort.

A potential free intervention measure for existing buildings to reduce consumption, which could be available to the user, relates to the control of heating systems or the reduction of the number of operating hours of the heating system by lowering the average indoor temperature.

In residential buildings, especially in apartments that are not usually equipped with ventilation systems, lowering the indoor temperature is the only way to reduce consumption without cost, intervention, or modernization of the building systems or envelope, since heating systems are controlled by an indoor thermostat that maintains a temperature set by the user.

Thermal comfort can be considered from the point of view of thermal physiology, but also from the point of view of human adaptation by studying the dynamic relationship between people and their everyday environment [2]. The environmental conditions required for comfort are not the same for all people. There are six main factors that must be considered when defining conditions for thermal comfort: metabolic rate, clothing insulation, air temperature, radiant temperature, air velocity, and humidity [6].

Regarding the variability of indoor air temperature, the width of the comfort zone, when measured in purely physical terms, can be as much as ±2°C in a situation where there is no possibility of changing clothes or activity and where there is no air movement. In situations where these adjustment possibilities are available and appropriate, the comfort zone can be much wider [3].

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Previous field studies have found that for offices and schools, the acceptable temperature variation from day to day should not exceed +1 K. [4]

The indoor temperature of residential buildings for living spaces for people with sedentary occupations is between 20°C and 26°C [8].

Other studies have also shown that the best results are achieved when the average indoor temperature is in the range of 21-25°C [2].

In terms of energy savings, previous studies conducted for a group of office buildings have shown that lowering the thermostat heating set point by one degree would result in an average energy savings of 7.5% across all climates in the United States [1].

For office buildings equipped with the VAV system, lowering the heating set point from 21.1°C to 20°C could save an average of 34% of heating energy [5].

For residential buildings, especially for national climates, such studies do not exist and this aspect is the starting point of this study.

2. MATERIALS AND METHODS

For this particular energy study, two types of existing enclosed spaces were considered, namely a 45 m^2 one-bedroom apartment on the 1^{st} floor of a residential block with first floor and two upper floors, and a single-family house with first floor and attic.

The overview of the proposed apartment is shown in Figure 1.

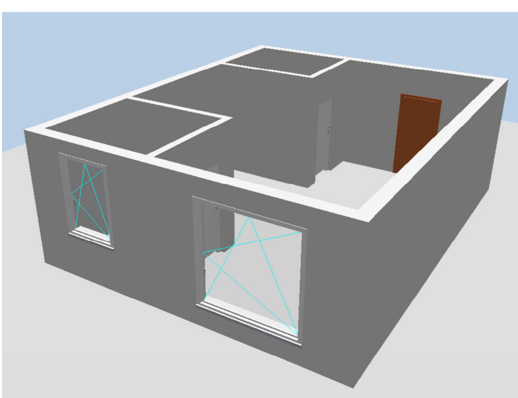

Fig. 1. Studio apartment, 45 square meters

The overview of the proposed two-story building or single-family house is shown in Figure 2.

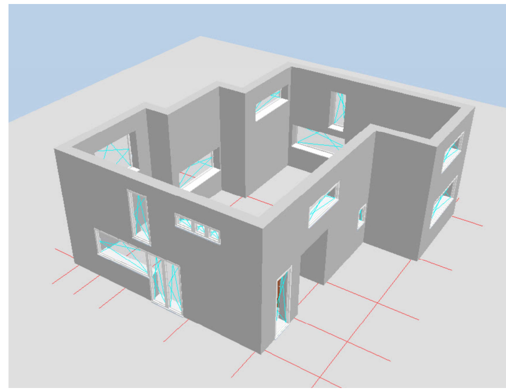

Fig. 2. Single-family house, 140 square meters

The building envelope differs for each type of space that was considered.

For the apartment, heat loss through an exterior wall and through an unheated stairwell wall was considered, while the remaining walls and ceilings were considered interior elements.

For the house, heat loss through an exterior wall, the floor slab, and the roof of the building were considered, with the second floor being an attic.

Also, the component layers and the specific thermal conductivity coefficient (λ) are given for each type of material through which heat transfer was considered.

For each type of apartment wall, the unidirectional thermal resistances were calculated according to the data presented in Tables 1÷2.

For the walls of the house, the unidirectional thermal resistances were calculated according to the data listed in Tables 3÷5.

Table 1

Thermal resistances for exterior wall – apartment

Layers	Depth [mm]	λ W/(m·K)	R m²K/W
Exterior			0.130
Thermal insulation plaster	10	0.060	0.167
Cellular polystyrene	50	0.044	1.136
Brick masonry with vertical holes	300	0.680	0.441
Cement mortar and lime	25	0.870	0.029
Interior			0.130
	385.0		R = 2.033

Unidirectional thermal resistance for exterior wall, R = 2.033 m²K/W.

Table 2

Thermal resistances for stairwell – apartment

Layers	Depth [mm]	λ W/(m·K)	R m²K/W
Exterior			0.083
Cement mortar and lime	15	0.870	0.017
Brick masonry with vertical holes	250	0.700	0.357
Cement mortar and lime	15	0.870	0.017
Interior			0.125
	280		R = 0.600

Unidirectional thermal resistance for unheated stairwell, R = 0.600 m²K/W.

Table 3

Thermal resistances for exterior wall – house

Layers	Depth [mm]	λ W/(m·K)	R m²K/W
Exterior			0.130
Thermal insulation plaster	10	0.060	0.167
Cellular polystyrene	100	0.044	2.273
Brick masonry with vertical holes	250	0.680	0.368
Cement mortar and lime	25	0.870	0.029
Interior			0.130
	385.0		R = 3.096

Unidirectional thermal resistance for exterior wall, R = 3.096 m²K/W.

Table 4

Thermal resistances for ground slab – house

Layers	Depth [mm]	λ W/(m·K)	R m²K/W
Exterior			0.000
Sand filling	200	0.580	0.345
Reinforced concrete	150	1.620	0.093
Cellular polyurethane	50	0.042	1.190
Concrete with natural aggregates	50	0.460	0.109
Interior			0.170
	450.0		R = 1.908

Unidirectional thermal resistance for ground slab, R = 1.908 m²K/W.

Table 5

Thermal resistances for the roof–house

Layers	Depth [mm]	λ W/(m·K)	R m²K/W
Exterior			0.040
Pine and fir along the fibers	24	0.350	0.069
Mineral wool mattresses	100	0.045	2.222
Pine and fir along the fibers	24	0.350	0.069
Plasterboard 1100	13	0.410	0.032
Interior			0.100
	161.0		R = 2.532

Unidirectional thermal resistance for the roof of the building, R = 2.532 m²K/W.

Unidirectional thermal resistance for the windows, R = 0.666 m²K/W for both types of spaces. Unidirectional thermal resistance for the doors was assumed to be R = 0.181 m²K/W for the apartment and R = 0.285 m²K/W for the house.

Climate zones

The two types of spaces considered, first the apartment and second the house, were calculated sequentially for different thermal zones, for four thermal zones with external calculation temperatures of -12°C, -15°C, -18°C and -21°C.

Operating plan and HVAC systems

Both types of spaces, i.e., the apartment and the house, were considered occupied 24 hours a day and the heat supply was considered continuous.

The proposed spaces are not equipped with other mechanical ventilation, cooling or air conditioning systems.

Calculation of energy requirements for space heating

The energy demand for the two building types was calculated sequentially for different indoor temperatures.

The calculation was performed for a single zone and the indoor temperature was considered as a weighted average temperature of all heated areas, based on the following relationship [10]:

$$\theta_i = \frac{\sum \theta_{ij} \cdot A_j}{\sum A_j} \quad [°C] \qquad (1)$$

where:

A_j - room area j having indoor temperature θ_{ij}

Monthly method

According to [11], for the monthly calculation method, the total energy consumption for heating was calculated with the following relation:

$$Q_{fh} = (Q_h - Q_{rhh} - Q_{rhw}) + Q_{th} \; [kWh/yr] \qquad (2)$$

where:

Q_h - the energy needed to heat the building, in kWh; Q_{rhh} - heat recovered from the heating system, in kWh; this component is a part of Q_{th}; Q_{rhw} - heat recovered from the hot water system used to heat the building, in kWh;

Q_{th} - total heat loss of the heating system, in kWh; these losses include the Q_{rhh} component.

Automated calculation software

The calculations were performed using AX3000 for Allplan (20201001) 64 bit V2021 specialized software developed for evaluating the energy performance of buildings in accordance with national energy performance calculation methods.

3. RESULTS

The determined results of energy consumption for the two types of buildings are designed as the authors' own contributions. In the following tables 6÷9 the values obtained for the dwelling are presented for different internal temperatures and for different thermal zones.

Table 6

Energy use for the apartment in thermal zone I

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	8329	-
24	7875	5.45%
23	7421	5.77%
22	6967	6.12%
21	6512	6.52%
20	6058	6.97%

For the apartment located in thermal zone I, the energy used for heating could be reduced with an average of 6.17 % per every decreased degree.

Table 7

Energy use for the apartment in thermal zone II

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	9039	-
24	8580	5.07%
23	8122	5.34%
22	7663	5.65%
21	7204	5.99%
20	6746	6.36%

For the apartment located in thermal zone II, the energy used for heating could be reduced with an average of 5.68 % per every decreased degree.

Table 8

Energy use for the apartment in thermal zone III

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	10777	-
24	10214	5.22%
23	9652	5.50%
22	9091	5.82%
21	8529	6.18%
20	7967	6.58%

For the apartment located in thermal zone III, the energy used for heating could be reduced with an average of 5.86 % per every decreased degree.

Table 9

Energy use for the apartment in thermal zone IV

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	12655	-
24	12036	4.89%
23	11417	5.14%
22	10797	5.42%
21	10178	5.73%
20	9607	5.62%

For the apartment located in thermal zone IV, the energy used for heating could be reduced with an average of 5.36 % per every decreased degree.

In the tables 10÷13 are presented the values obtained for the single-family house, for the same different internal temperatures and for the same different thermal zones as for the apartment case.

Table 10

Energy use for the house in thermal zone I

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	34134	
24	31396	8.02%
23	28729	8.49%
22	26248	8.64%
21	23850	9.13%
20	21651	9.22%

For the house located in thermal zone I, the energy used for heating could be reduced with an average of 8.70 % per every decreased degree.

Table 11

Energy use for the house in thermal zone II

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	38452	-
24	35678	7.21%
23	32861	7.90%
22	30242	7.97%
21	27889	7.78%
20	25698	7.86%

For the house located in thermal zone II, the energy used for heating could be reduced with an average of 7.74 % per every decreased degree.

Table 12

Energy use for the house in thermal zone III

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	45362	-
24	41927	7.57%
23	38661	7.79%
22	35790	7.43%
21	33019	7.74%
20	30248	8.39%

For the house located in thermal zone III, the energy used for heating could be reduced with an average of 7.78 % per every decreased degree.

Table 13

Energy use for the house in thermal zone IV

θ_i [°C]	Energy used for heating [kWh/yr]	Decrease in energy use [%]
25	53089	-
24	49389	6.97%
23	45751	7.37%
22	42186	7.79%
21	38750	8.15%
20	35690	7.90%

For the house located in thermal zone IV, the energy used for heating could be reduced with an average of 7.63 % per every decreased degree.

4. CONCLUSIONS

After analyzing the data resulting from the calculations made in the present study, the following conclusions can be drawn:

1. The best values in terms of energy performance were obtained for the warmest climate, or thermal zone I, where both proposed types of spaces had higher values for the reduction of thermal energy consumption.

2. In the case of the apartment, a decrease in the indoor temperature by 1°C could lead to an energy saving of about 6%; similarly, an increase in the indoor temperature by one degree Celsius leads to an increase in energy consumption to the same extent, the change in energy consumption being shown in Figure 3.

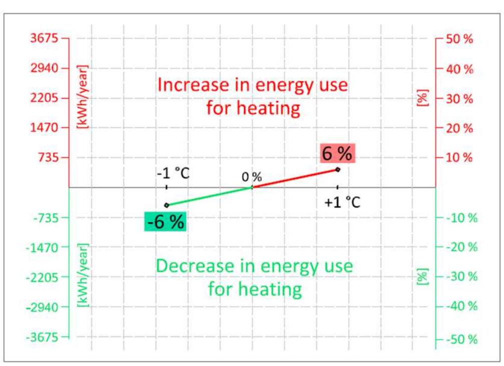

Fig. 3. Energy use variation at ±1°C for the apartment

3. In the case of the single-family house, lowering the indoor temperature by 1 °C could lead to an energy reduction of about 9%. Similarly, increasing the indoor temperature by one degree Celsius leads to an increase in energy consumption by the same amount, with the change in energy consumption shown in Figure 4.

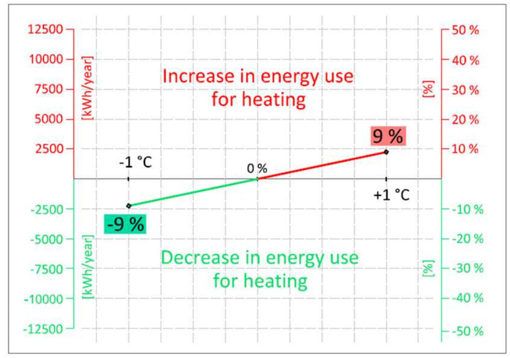

Fig. 4. Energy use variation at ±1°C for the house

4. For both types of proposed enclosed spaces, lowering the indoor temperature by 1°C, but still between the comfort temperatures accepted by the majority, i.e., not above 25°C and not below 21°C, could be a no-cost energy efficiency measure that would not significantly affect indoor comfort conditions because the building's occupants can adapt to this temperature difference in a relatively short time.

Energy savings could be achieved by lowering the temperature set point of the thermostat, which means reducing the operating hours of the heating system.

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REDUCEREA CONSUMULUI DE ENERGIE PENTRU SISTEMELE DE ÎNCĂLZIRE ÎN CLĂDIRI DE LOCUIT - STUDIU DE CAZ

Rezumat: *Articolul prezintă un studiu de caz al performanţei energetice a două tipuri de spaţii de locuit încălzite, pentru scenariul în care temperatura medie interioară este redusă cu un grad Celsius. Rezultatele obţinute sunt prezentate pentru diferite temperaturi interioare şi diferite zone termice, estimând valoarea medie atât pentru o clădire independentă, cât şi pentru un apartament. Scopul studiului este de a evalua impactul reducerii temperaturii medii interioare cu un grad Celsius asupra consumului anual de energie pentru încălzirea unei clădiri de locuit, astfel încât performanţa energetică a clădirii să se îmbunătăţească fără a afecta semnificativ condiţiile de confort pentru ocupanţii clădirii.*

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