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HEATING CEILING SYSTEM EFFICIENCY IN DIFFERENT CLIMATE ZONES

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Abstract
There are many benefits of building construction with prefabricated thermo active ceilings technology, and the most highlighted are: short lead time, ease of installation, low price, lack of taking up space in a room and additionally the possibility of working in heating and/or cooling mode. An analysis was carried out to illustrate the factors that influence the thermal output of a ceiling heating system in residential buildings located in 5 climate zones in Poland and 2 in Ukraine. The thermal loads were determined for the entire building, designed in accordance with the regulations in force in each country, for the flats and particular rooms (considering the heat exchange between the flats according to PN-EN 12831:2006). An average heating medium temperature of 34°C was assumed. The results were compared with the achievable heating capacity of the ceiling system, which results from the difference between the heating medium temperature and the indoor room temperature. It was investigated that the system achieves the calculated output in all climate zones in Poland, while it will not be sufficient in Ukraine. This is due to both less stringent building thermal protection regulations and different indoor design temperature values, resulting in a higher average temperature in the flat. When analysed on a room-by-room basis, it became apparent that in all considered locations there were rooms for which the heating capacity was insufficient. In the climate zones I to IV in Poland, the problem concerns only bathrooms, where in this case quite often the surface heating can be combined with a supplementary electric radiator. In the V climate zone in Poland and both in Ukraine, the solution to the power shortage under design conditions may be: building construction according to a higher energy standard, increasing the supply temperature (with the limitation of maximum ceiling surface temperature to 35°C for living spaces) or using additional heating elements not only in bathrooms. A novel part of the article discusses calculated power shortages in relation to climate change and the external design temperatures suggested by sources other than the standard.

Keywords: **Energy-saving technologies; Renewable energy sources; Residential building heating; OZC Software; Thermal performance of building.**

1. INTRODUCTION

The contemporary world gives the HVAC sector a number of challenges. The causes are the geopolitical situation, energy crisis and climate change, as well as the need to introduce the principles of sustainability as soon as possible. For many years, conventional heat sources have been losing relevance and are being replaced by renewable ones [1]. At the same time, heating systems that work well with them and provide a high level of comfort for users are being developed. The cost of constructing a heating system and its interference with the aesthetics of living spaces also can't be neglected. In this context, one of the interesting solutions is the prefabricated ceiling heating system which is a well-established technology used for more than a decade [2, 3]. This system has been used in many residential buildings, both multifamily and single-family dwellings, as well as public buildings

(schools, kindergartens) and is particularly recommended for areas where surface cooling is also planned [4, 5]. In Poland, this system is an excellent choice for buildings belonging to Social Housing Associations [6]. In this system heat is transfered to the room by means of long-wave infrared electromagnetic radiation (IR-C), causing the air to be heated indirectly by furniture and surfaces. Overall, there are many benefits of building construction with prefabrication technology integrated with a heating system, the most highlighted are: short lead time, ease of installation and low price [6, 7]. In addition, it takes no place in a room and also does not affect the plan of the rooms, creating one of the most developing solutions in recent years [8, 9]. The disadvantages of this system are: thermal comfort due to the inflow of heat from the ceiling which could be recognized as not demanded solution and the lower competitiveness on the market, which makes thermoactive ceiling still as the most expensive solution [8, 9].

Several important engineering details related to the construction of the thermoactive panels are worth attention. The multi-layer pipes 16 x 2 are integrated into the reinforced concrete ceiling. Each ceiling panel is individually designed and manufactured, not ready-made modules, according to a specific standard. Therefore, an approach to each building is individual and a solution is chosen in each case in terms of construction and heating and/or cooling capacity. Up to 8 running meters of pipes are installed per m^2 of ceiling, placed every 16 cm. The length of the pipe in the heating panel should not exceed 85 m (compared with under-floor heating $<$100 m). Generally, one room is considered to be one circuit and in the case of large rooms 2–3 circuits are used. No fittings are used in the concrete layer (floor, ceiling, walls), as the plasticity of the pipe allows it to be laid as designed. However, only between the ceiling panels are the pipes connected and then led to the manifold. The connections between the panels are not later accessible, as they are in the floors of the next store [4].

For reasons of human thermal comfort, the ceiling system requires a low temperature medium to maintain a ceiling surface temperature appropriate for the height of the room. In a room of 3 m high, the maximum temperature of the ceiling surface should not exceed 35°C. Any heat source that ensures a medium temperature below 38°C can be used for heating, however, its specific output is then limited. When the ceiling system is also used as a cooling one it may operate with a heat pump with a free-cooling set or a reversible one. For example, a brine/water heat pump serving as a heat source was selected and analysed for residential buildings with thermo active ceiling and low-temperature radiator systems in various climate zones [10]. In theory the supply temperature can be up to 55°C to achieve higher heating capacity, but in practice is not applied because of the thermal comfort conditions, the efficiency of some heat sources and energy savings tendencies [11]. Heat exchange by convection practically does not occur in this solution [4, 12, 13].

Heating systems are subject to legal requirements which, on the one hand, must ensure user thermal comfort and, on the other hand, energy efficiency. An adequate level of thermal comfort is provided by the design of indoor temperature values that should be maintained under certain outdoor conditions, whereas building thermal protection regulations set maximum thermal transmittance and maximum levels of annual energy consumption for energy efficiency. The still increasingly stringent regulations result in a reduction in the specific heat load of buildings. In addition, paradoxically, the warming of the climate seems to favour low-temperature heating systems, since both average and extreme temperature values are now higher than, for example, just 20 to 30 years ago. However, the designer is first and foremost obliged to comply with the applicable regulations when designing the systems.

The issue of evaluating the performance of a system with a heating ceiling is discussed in a novel way from two perspectives: in relation to current laws and regulations, and in relation to the assumptions of the method that oversizes the heating systems. The aim of this paper is to evaluate the thermal efficiency of a ceiling heating system that operates in different climate zones. An analysis was carried out including five temperature zones in Poland and two zones in Ukraine for a typical residential building. The heating capacities of all rooms were calculated to determine whether the system performs appropriately in all thermal conditions, or whether it needs adjustment and how, in order to ensure the required parameters.

2. MATERIALS AND METHODS

2.1. Climate zones in the context of the heating system design

For the purposes of heating system design, the countries specify climate zones and the characteristic outdoor (design) temperature values [14]. The territory



Figure 1.
The climate zones in Ukraine and Poland [15, 16, 19]

Table 1.
Mean and design temperature in the climate zones

Country		Ukraine		Poland				
Climate zone	acc.*	I	II	I	II	III	IV	V
	acc. ASHRAE	5A	5A	5A	5A	5A	6A	6A
City		Lviv	Odesse	Gdańsk	Wrocław	Warszawa	Białystok	Suwałki
Design air temperature [°C]	acc.*	-22	-19	-16	-18	-20	-22	-24
	acc. to ASHRAE	-17	-13.2	-15	-13.5	-15.5	-18.5	-19.1
Yearly mean air temperature [°C]	acc.*	8.8	11.8	7.7	7.9	7.6	6.9	5.5
	acc. to ASHRAE	8.5	11.2	7.9	9.6	9.0	7.3	7.1

of Ukraine is divided into 2 climate zones according to the DBNV.2.6-31 standard [15], in Poland there are five, given in the standard PN-EN 12831:2006 [16]. The climate zones of both countries are displayed in Fig. 1. Exemplary cities located in the considered climate zones were pointed out and presented in Table 1 together with the mean and design air temperature values. In the case of Poland, assigned outdoor air design temperature values were determined about 65 years ago [17]. Table 1 also presents the indications of the climate zones and design temperature values given by ASHRAE for the year 2021 [18]. Calculation conditions according to ASHRAE are determined for weather stations registered by the World Meteorological Organization and have long-term hourly or three-hourly observations with a minimum measurement period of at least 12 years [14]. When comparing the values from the literature sources, it is visible that design air temperature values vary greatly whereas yearly mean ones vary slightly.

2.2. Building characteristics in the context of heat loss calculations

A residential building belonging to Social Housing Associations, which provides affordable apartments with lifelong leases, is considered in the analysis. This is three floor building with an area of one floor equal to 637.4 m^2, without a basement and with two staircases. There are 13 flats on each floor, 7 in the left segment and 6 in the right one, so 39 flats are in total in the building. There are one-, two- and three-bedroom flats. The layout of the building was adopted on the basis of technical documentation and the model for heat loss calculations is shown in Fig. 2. The stairwells do not require a heating system, as they are heated by the gains from neighbouring rooms. The heated area is equal to 1912.3 m^2. The partition constructions were assumed so that the heat transfer coefficient values do not exceed the maximum values given in the standard [15] in the case of Ukraine and in the regulation [20] in the case of Poland. The minimum thermal insulation requirements for Poland are much stricter than for Ukraine, which is visible in Table 2 where the required values of the heat transfer coefficients are presented together with those assumed in the analysis.

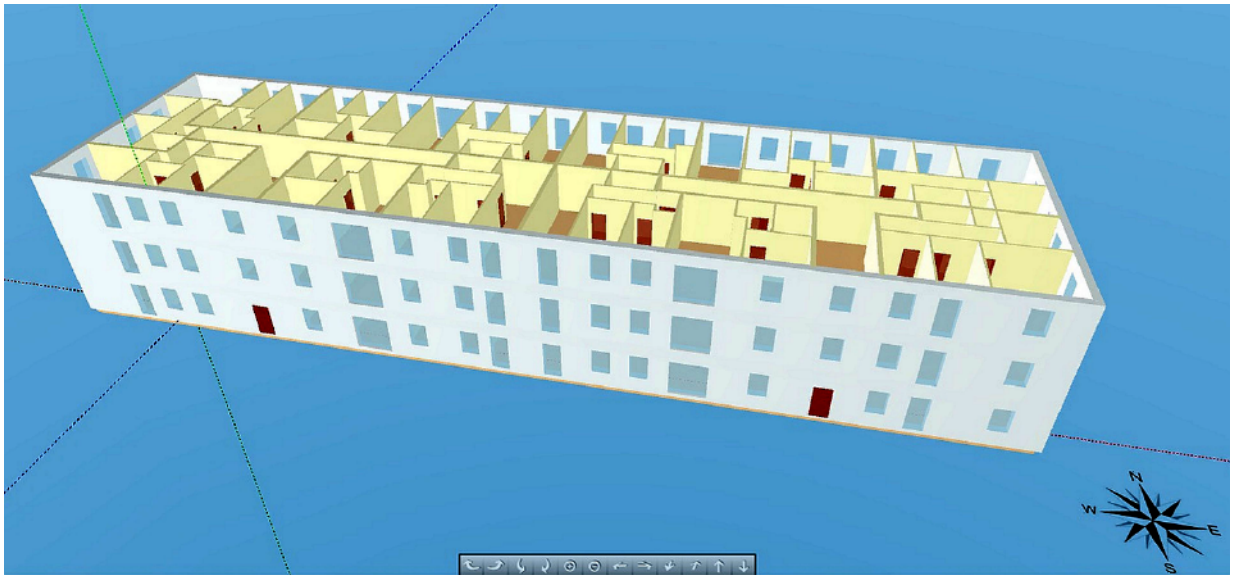


Figure 2.
The residential building's model

Table 2.
Heat transfer coefficients for building's envelopes U [W/(m^2·K)] [15, 20]

Building's envelope	The maximum values of heat transfer coefficient		Assumed values of heat transfer coefficient	
	Ukraine	Poland	Ukraine	Poland
Exterior walls	0.30	0.20	0.283	0.141
Flat roof above heated spaces	0.20	0.15	0.159	0.129
Floor on the ground	0.20	0.30	0.187	0.187
Flat roof over unheated attic	0.20	0.15	-	-
Flat roof over unheated basement	0.27	0.25	-	-
Exterior windows	1.33	0.90	1.100	0.760
Exterior doors	1.67	1.30	1.500	0.850

The indoor air temperature values according to the standards [15, 20] maintained by the heating system in the rooms are presented in Table 3.

Table 3.
The indoor air temperature values [15, 20]

Room	The indoor air temperature [°C]	
	Ukraine (Lviv)	Poland
Kitchen	19.5	20.0
Living room, bedroom, study room, toilet	22.0	20.0
Hall, utility room	19.5	20.0
Bathroom	25.0	24.0

2.3. Software

The heat loss for the residential building was calculated according to the EN 12831 standard [16] using the Audytor OZC 7.0 Pro software package. Heat demand is determined based on the introduced building model (Fig. 2) and climate data for the assumed location of the building (Tab. 1). For the calculation of spaces heat loads the heat exchange between units (flats) was considered, whereas heat load for the entire building was determined without this heat exchange. The package allows for estimating the heating demands of all rooms in the building and assessing if the amended parameters of the medium ensure the required needs.

2.4. Heating ceiling system

Based on the information provided in the manufacturer's brochures [4,21], the specific parameters of the ceiling panels are listed in the upper part of Table 4. The heating capacity given there is only an approximate value and is not suitable for direct use in heating system design or thermal performance assessment. To design and analyse radiant heating/cooling systems in detail, heat transfer coeffi-

cients are used [22]. The performance characteristic q_h of 1m^2 of thermo active ceiling panels was obtained at the RWTH Institute Aachen [21] based on EN 1264-2 [23]. It depends on the difference Δt_{av} between the average medium temperature (supply t_s and return t_r) and the temperature inside the room ti, which takes various values depending on the function of the room and is given by the formula:

$$q_h = 4.64 \cdot \Delta t_{av}, \quad (1)$$

where:

$$\Delta t_{av} = (t_s + t_r)/2 - t_i \quad (2)$$

In the lower part of Table 4 is given the ceiling heating capacity depending on Δt_{av} and its thermal performance qh for the indoor air temperature values (Table 3) valid in both countries and assuming a medium temperature of 35/33°C.

Table 4.
The technical data of ceiling panels [4, 21]

Parameter	Data
Heating capacity	at 15 K temperature difference approx. 54 W/m^2
Thermal conductivity λ_R	1.25 W/(m·K)
Ceiling thickness	20 cm
Element width	224.5 cm
Thermal performance t_s=35°C, t_r=33°C	Ukraine: t_i=19.5°C; q_h = 67.3 W/m^2 t_i=22.0°C; q_h = 55.7 W/m^2 t_i=25.0°C; q_h = 41.8 W/m^2
	Poland: t_i=20.0°C; q_h = 65.0 W/m^2 Poland: t_i=24.0°C; q_h = 46.4 W/m^2

2.5. Research procedure

The data presented in previous sections were used to perform the calculations. Research was carried out according to the procedure shown in Figure 3.

3. RESULTS AND DISCUSSION

3.1. Heat load of the building

The heat load of the residential building, calculated according to the requirements valid in the countries, in all climate zones, is shown in Table 5. In both climate zones in Ukraine, the heat load of the building is higher than in a building located in Poland (regardless of climate zone). Furthermore, in the I climate zone in Ukraine and in the IV in Poland the heat losses differ significantly, although the design temperature values are the same (Table 1). This is caused by both: the weaker insulation of the building partitions and the higher mean indoor air temperature in the apartments in Ukraine. It is worth noticing, that the reduction of the indoor temperature setpoint by 1°C in each room could reduce the heat load demand and energy consumption even by 16% [24].

The specific heat load was calculated as the mean value for the entire building and is also displayed in Table 5. When comparing those values with the ther-

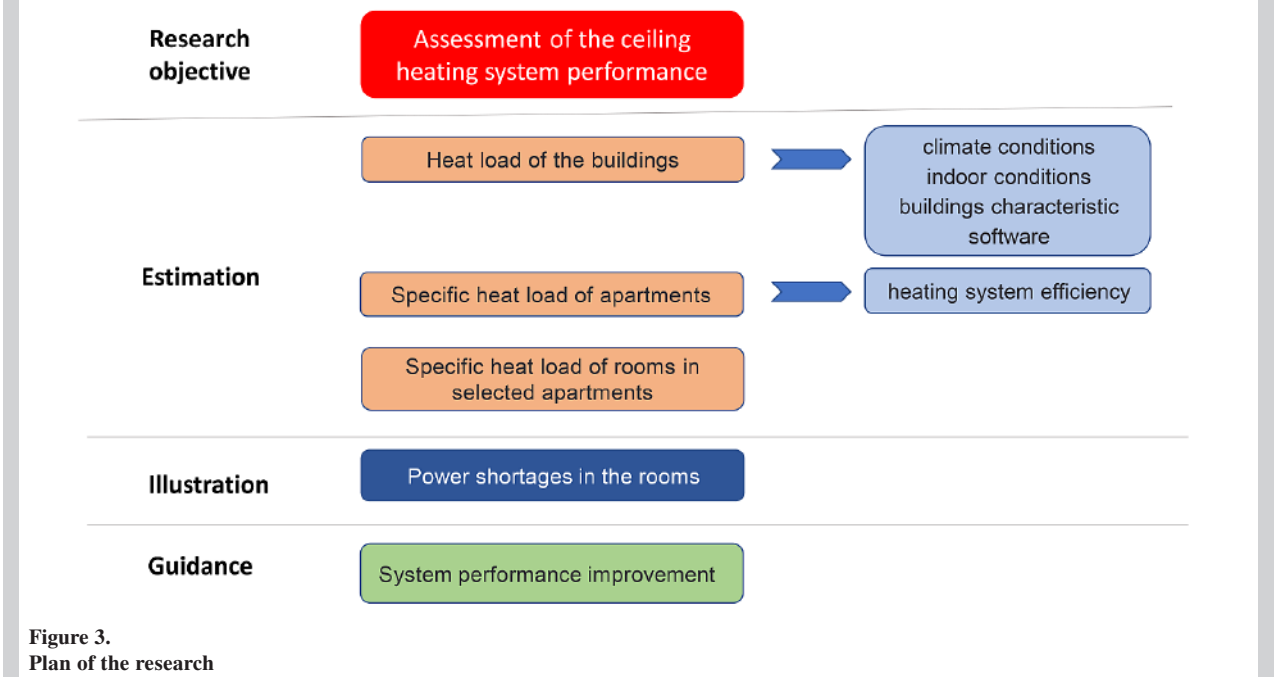


Figure 3.
Plan of the research

Table 5.
Heat load of the building

Country	Ukraine		Poland				
Climate zone	I	II	I	II	III	IV	V
Heat load [kW]	90.0	83.4	65.6	69.0	72.6	76.2	79.9
Specific heat load [W/m^2]	47.1	43.6	34.3	36.1	38.0	39.8	41.8

Table 6.
Specific heat load of all apartments in various climate zones

Country				Ukraine				Poland						
		No	A_h	Θ_{int}	I	II	q_h	Θ_{int}	I	II	III	IV	V	qh
		-	m^2	°C	W/m^2			°C	W/m^2					
Segment A	Ground floor	A10	35.0	21.5	60.3	54.5	58.0	20.6	47.4	49.1	51.3	53.9	57.1	62.2
		A11	43.0	21.7	68.8	62.4	57.1	20.4	51.4	53.4	55.9	58.7	62.1	63.1
		A12	48.6	21.3	68.3	61.5	58.9	20.4	51.9	53.9	56.3	59.2	62.7	63.1
		A13	35.0	21.5	56.0	49.9	58.0	20.5	45.3	46.7	48.8	51.2	54.5	62.6
		A14	67.7	21.5	52.8	47.4	58.0	20.4	42.0	43.5	45.4	47.7	50.7	63.1
		A15	49.3	21.3	53.0	47.0	58.9	20.3	43.1	44.5	46.5	48.8	52.0	63.6
		A16	46.6	21.4	53.0	47.3	58.5	20.4	42.7	44.1	46.0	48.4	51.4	63.1
	Floor I	A20	35.0	21.5	55.2	49.6	58.0	20.6	43.5	44.9	46.8	49.1	52.2	62.2
		A21	43.0	21.7	59.3	53.5	57.1	20.4	44.1	45.7	47.7	50.1	53.2	63.1
		A22	48.6	21.3	58.8	52.6	58.9	20.4	44.5	46.1	48.1	50.6	53.7	63.1
		A23	35.0	21.5	52.8	46.8	58.0	20.5	43.0	44.2	46.1	48.4	51.6	62.6
		A24	67.7	21.5	49.3	43.9	58.0	20.4	39.4	40.7	42.4	44.6	47.5	63.1
		A25	49.3	21.3	49.4	43.5	58.9	20.3	40.4	41.6	43.4	45.6	48.7	63.6
		A26	46.6	21.4	64.2	43.5	58.5	20.4	39.8	41.0	42.7	44.9	47.9	63.1
	Floor II	A30	35.0	21.5	61.3	56.0	58.0	20.6	46.5	48.3	50.5	53.1	56.1	62.2
		A31	43.0	21.7	66.4	60.8	57.1	20.4	47.7	49.7	52.1	54.7	57.7	63.1
		A32	48.6	21.3	65.9	59.9	58.9	20.4	48.1	50.2	52.5	55.2	58.3	63.1
		A33	35.0	21.5	58.6	52.9	58.0	20.5	45.7	47.4	49.6	52.1	55.2	62.6
		A34	67.7	21.5	55.1	50.0	58.0	20.4	42.2	43.9	45.9	48.3	51.1	63.1
		A35	49.3	21.3	55.3	49.7	58.9	20.3	43.3	44.9	47.0	49.4	52.3	63.6
		A36	46.6	21.4	55.1	49.8	58.5	20.4	42.7	44.3	46.4	48.7	51.6	63.1
Segment B	Ground floor	A50	35.0	21.6	60.8	54.9	57.5	20.6	47.5	49.2	51.4	54.0	57.3	62.2
		A51	46.7	21.4	53.1	47.3	58.5	20.4	42.7	44.1	46.1	48.4	51.4	63.1
		A52	49.1	21.3	51.4	45.7	58.9	20.3	41.7	43.0	44.9	47.2	50.3	63.6
		A53	67.8	21.5	52.2	46.9	58.0	20.4	41.3	42.8	44.7	47.0	49.9	63.1
		A54	58.3	21.4	62.2	56.2	58.5	20.3	47.3	49.1	51.4	54.0	57.4	63.6
		A55	55.3	21.5	65.0	59.0	58.0	20.3	48.8	50.7	53.0	55.7	59.2	63.6
	Floor I	A60	35.0	21.6	55.6	50.0	57.5	20.6	43.6	45.0	46.9	49.3	52.4	62.2
		A61	46.7	21.4	49.2	43.6	58.5	20.4	39.8	41.0	42.8	45.0	47.9	63.1
		A62	49.1	21.3	47.8	42.2	58.9	20.3	39.0	40.2	41.9	44.0	46.9	63.6
		A63	67.8	21.5	48.7	43.5	58.0	20.4	38.8	40.0	41.8	43.9	46.7	63.1
		A64	58.3	21.4	54.2	48.6	58.5	20.3	41.1	42.6	44.5	46.8	49.6	63.6
		A65	55.3	21.5	56.5	51.0	58.0	20.3	42.2	43.7	45.7	48.0	50.9	63.6
	Floor II	A70	35.0	21.6	61.7	56.4	57.5	20.6	46.6	48.4	50.7	53.2	56.2	62.2
		A71	46.7	21.4	55.1	49.8	58.5	20.4	42.7	44.4	46.4	48.7	51.6	63.1
		A72	49.1	21.3	53.6	48.3	58.9	20.3	41.8	43.4	45.4	47.7	50.6	63.6
		A73	67.8	21.5	54.5	49.6	58.0	20.4	41.6	43.2	45.3	47.6	50.3	63.1
		A74	58.3	21.4	61.0	55.6	58.5	20.3	44.6	46.8	49.0	51.5	54.3	63.6
		A75	55.3	21.5	63.4	58.1	58.0	20.3	45.7	48.0	50.3	52.8	55.7	63.6

mal performance given in Table 4 it seems that in the case of Poland, the thermal performance should be sufficient in all climate zones. However, in Ukraine, the system may be deficient because the thermal performance of the ceiling heating system in rooms with indoor temperature +25°C is lower than the specific heat load.

3.2. The heat load of apartments

For particular apartments in the residential building, the specific heat demand given in [W/m^2] was evaluated and compared with the specific heat output q_h of the ceiling heating system which was calculated according to formula (1) with respect to the mean

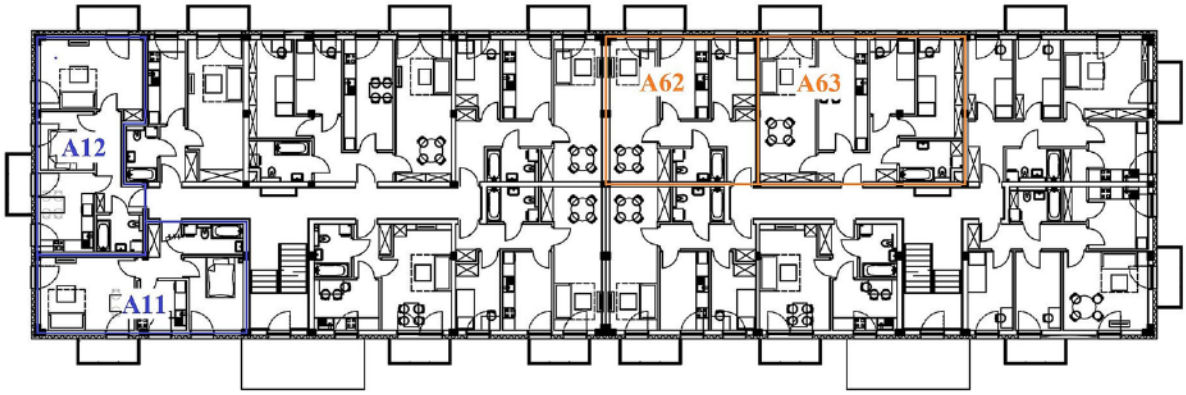


Figure 4.
Apartments A11, A12, A62 and A63 shown on building plan

indoor temperature Θ_{int} in the apartment. Outcomes are presented in Table 6 where: No is the number of flats, A_h is the area of flat [m^2], and I, II, III, IV and V are climate zones.

The values in Table 6 highlighted in green show the apartments with the lowest heat load, while the red colour indicates the apartments in which the ceiling heating efficiency is not sufficient to maintain the inner conditions required when the heating medium temperature values are equal to 35/33°C.

The results of the calculated heat demand for individual apartments in Ukraine indicate that 15 apartments in zone I and 6 in zone II are deficient in heat demand. In Poland, the ceiling system heating capacity is sufficient to meet the average heating demand in all apartments.

In Ukraine, apartment A62 (climate zone II) was identified as the one with the lowest heat load and A11 (climate zone I) as the one with the highest heat load. In Poland, apartments A63 (I climate zone) and A12 (V climate zone) were identified as those with the lowest and highest heat load, respectively. It is interesting that the apartments are not located in the same place in the building layout in both countries. It is caused by the differences in mean design indoor temperature Θ_{int} shown in Table 6.

The apartments A11 and A12 with the highest heat loss are located on the ground floor of the building while A62 and A63 are on the floor I. They are shown on the repeated floor plan in blue and orange in Fig. 4.

The thermal power shortages in apartment A11 in Ukraine in both climate zones are significant and cannot be omitted. Raising the medium temperature allows the heating capacity of the ceiling panels to increase. The minimum temperature of the medium, which allows the heat loss to be covered, was determined based on the relationship (2) and knowing the calculated heat load of the apartment from Table 6. The results of the estimation are shown in Table 7. In the case of the I climate zone, the minimum supply temperature of the medium must be increased by 3°C and is established at 38/36°C. For the II climate zone, the minimum supply temperature of the medium should be 1°C higher.

Table 7.
Minimum temperature of supply medium

Country: Ukraine, flat A11 / 43.0 m^2 / ground floor, Θ_{int} = 21.7°C		
Climate zone	I	II
Specific heat load of flat [W/m^2]	68.8	62.4
Medium supply temperature [°C]	38/36	36/34

3.3. Heat load of rooms in apartments

In the next step, the heat demand in the individual rooms was analysed to verify if even though the results in Table 6 suggest that in Poland the amount of heat delivered to all apartments would be sufficient, the thermal performance of the ceiling heating will be high enough to cover the heat demand in all rooms. Detailed analysis showed that in certain cases power shortages in the rooms can be noticed. It refers to, for example, bathrooms in all buildings in five climate zones. In the V climate zone, there are also thermal power shortages in the kitchen and living room. In zone IV, the problem only affected the bathroom, and in the other two rooms, the heat demand was only negligibly higher (< 20 W and < 3%) than the amount of heat supplied by the ceiling heating.

The layouts of the apartments with the highest and lowest heat demand (A11, A62, A12 A63) with the

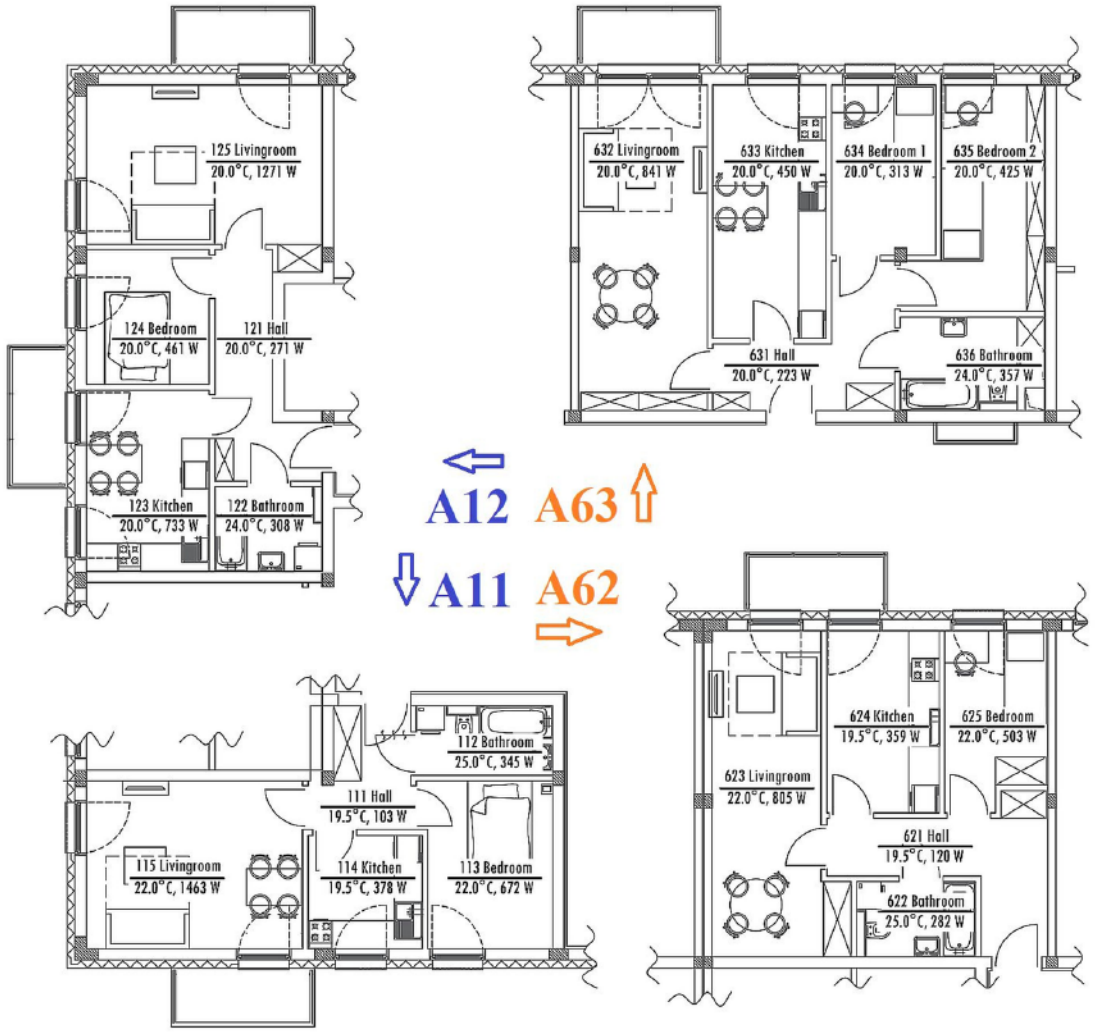


Figure 5.
The layouts and heat load of flats: A12, A63 in Poland and A11, A62 in Ukraine

thermal loads ϕ_{HL} and the indoor design temperature values ti are shown in Fig. 5. Table 8 presents the values of the specific heat loads of the rooms q_{HL} and the capacities of the heating system q_h, as well as the thermal power shortages ΔQ.

In Fig. 6 the percentage values of thermal power shortages in the best and worst case apartments, according to Table 8, are given and illustrated by shadings. These illustrations and Table 8 allow to recognise in detail the differences between apartments in particular countries and climate zones. In Ukraine, in zone I, rooms with a required temperature of 22.0°C had insufficient ceiling performance up to 524 W (Table 8). In the climate zone with a temperature of -19°C, in apartment A62, insufficient heat will be delivered to the bathroom and bedroom. The shadiness in Figure 6 highlighted that the heating system is the most insufficient in the bathrooms due to the highest values of the required indoor temperature.

In apartment A11, in the living room and bathroom, the values of the heat load are higher than the average value in the entire apartment (Table 6). The necessary medium temperature should be 42/40°C to cover heat loss in these rooms, which is not allowed because the maximum temperature of the ceiling surface will exceed 35°C. In apartment A12 with the highest heat loss, in the V climate zone in Poland, to provide sufficient heat to the living room and kitchen, the medium supply temperature should be 36/34°C, while the heat losses in the bathroom need the delivery of the medium with a temperature too high for the system, which is 40/38°C.

Table 8.
Heat loads of the rooms in selected apartments

App.	Room	Name	t_i, °C	A_h, m^2	ϕ_{HL}, W	q_{HL}, W/m^2	q_h, W/m^2	ΔQ, W
the best case in II climate zone	621	Hall	19.5	9.3	120	12.9	67.3	
	623	Living room	22.0	18.1	805	44.4	55.7	
	624	Kitchen	19.5	9.4	359	38.2	67.3	
	625	Bedroom	22.0	8.0	503	63.1	55.7	-59
	622	Bathroom	25.0	4.3	282	65.9	41.8	-103
the worst case in Ukraine A11 I climate zone	111	Hall	19.5	5.0	103	20.6	67.3	
	115	Living room	22.0	16.9	1463	86.8	55.7	-524
	114	Kitchen	19.5	6.1	378	61.7	67.3	
	113	Bedroom	22.0	10.3	672	65.4	55.7	-100
	112	Bathroom	25.0	4.8	345	72.2	41.8	-145
the best case in Poland A63 I climate zone	631	Hall	20.0	8.3	223	26.9	65.0	
	632	Living room	20.0	19.5	841	43.2	65.0	
	633	Kitchen	20.0	13.4	450	33.5	65.0	
	634	Bedroom 1	20.0	8.1	313	38.8	65.0	
	635	Bedroom 2	20.0	12.0	425	35.4	65.0	
	636	Bathroom	24.0	6.5	357	54.9	46.4	-55
the worst case in Poland A12 V climate zone	121	Hall	20.0	7.6	271	35.5	65.0	
	125	Living room	20.0	18.2	1271	69.7	65.0	-86
	123	Kitchen	20.0	10.6	733	69.2	65.0	-45
	124	Bedroom	20.0	7.7	461	59.9	65.0	
	122	Bathroom	24.0	4.4	308	70.0	46.4	-104



Figure 6.
Illustration of thermal power shortages in flats A12, A11, A63 and A62

When considering performance shortages of ceiling heating systems, it should be noted that heating systems are generally sized with a thermal power surplus resulting from the design assumptions discussed earlier. Thermal power is increased due to heat exchange between apartments, as required by standard PN-EN 12831 (assuming that adjacent apartments may periodically have reduced temperatures due to, for example, longer absences of tenants). Additionally, the outdoor design temperature values (Table 1) are very low compared to the ASHRAE data. Such low temperatures occur extremely rarely, only for a few hours, during the heating season, and the power calculations do not consider either internal and external heat gains or the thermal accumulation of the building.

Oversized heating systems do not operate efficiently, they require larger and/or additional heat sources, increasing the negative impact on the environment. Systems should operate efficiently, according to actual heat needs. The ongoing revision of the EU Building Efficiency Directive [25] will also force changes to national regulations. This creates an opportunity and space for the design of the heating system methodology to be revised and upgraded according to climate changes and conditions related to room usage.

3.4. Guidance in case of insufficient heating system performance

When designing the heating system for the building according to the requirements given in Sections 2.1 and 2.2 certain thermal power shortages in rooms are negligible and may be omitted. However, when the heating ceiling system does not meet the heating demands, specific solutions can be proposed:

- designing the building envelope (walls, floor on the ground, roof and windows) with reduced heat transfer coefficients, and elimination of thermal bridges,
- ensuring high building air tightness for ventilation heat loss decrease,
- use of additional heating elements, e.g. electric heaters in bathrooms,
- implementation of additional heating elements e.g. decorative heating mats (pieces of art [26]) in rooms,
- raising the medium temperature by 3–4°C for the heating output increase, guaranteeing the thermal comfort of the inhabitants, i.e. not exceeding the ceiling surface temperature of 35°C.

In existing buildings, while planning a deep thermomodernisation process [27], the ceiling system will have the possibility to be also implemented because the heat demand would be reduced by improving the performance of the building envelope and reducing the heat transfer coefficients. Furthermore, during this process ensuring proper air tightness of the building will be significant because leaky windows cause higher air velocity in the rooms causing thermal discomfort for the residents [28, 29].

4. CONCLUSIONS

Many profits of building construction with prefabrication technology integrated with the heating system made it a preferable solution for various buildings. Analysis of the efficiency of the heating ceiling showed the significant importance of the insulation of the building envelope, which influences the heat transfer coefficients. In Ukraine, their higher values made it impossible for heat losses to be covered by the ceiling in many apartments. Furthermore, the analysis showed that it is extremely significant to check in detail the ceiling performance in each room in the building because although the results of the calculations assuming an average temperature in the apartment showed that the ceiling performance is sufficient, the calculations for each room separately showed that in all cases the bathrooms are underheated, causes from 15.5 to 42.1% of the power shortage. In these rooms, the installation of an additional heating device is required or the increase of the medium temperature by 3–4°C. However, it is highlighted that widely practised methods to calculate heat load cause the system oversize and that's why certain of the thermal power shortages in rooms are negligible and may be omitted. The ongoing revision of the EU regulations will create opportunities to revise and update the design methods of heating systems in accordance with climate changes and conditions related to room use.

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