THERMAL COMFORT AND ENERGY PERFORMANCE OF RESIDENTIAL BUILDINGS IN RUSSIA

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ABSTRACT

Currently, around 50% of the Russian housing stock needs renovation. Although the annual energy consumption for residential buildings in Russia seems to be within the recommend good practice ranges, they may not provide a thermally comfortable environment for their occupants, due to the significantly lower heating set points compared to the UK. This paper investigates the current conditions and methods to improve energy performance and thermal comfort in residential buildings in Russia. Dynamic thermal simulations are conducted using IES(VE) to assess thermal comfort and energy performance in a multi-story residential case study building. CIBSE TM59 and PMV assessment methods were used to investigate the thermal comfort conditions during summer and winter, respectively. Different combination scenarios for heating setpoints, external shading strategies and refurbishment strategies were considered to assess the effects of these strategies on energy and comfort in the building. The results reveal that energy consumption was significantly reduced by over 94% for the high-performing refurbishment strategies, while thermal comfort was marginally improved.

Keywords: Residential Buildings, Retrofit, Energy Performance, Thermal Comfort, Russia.

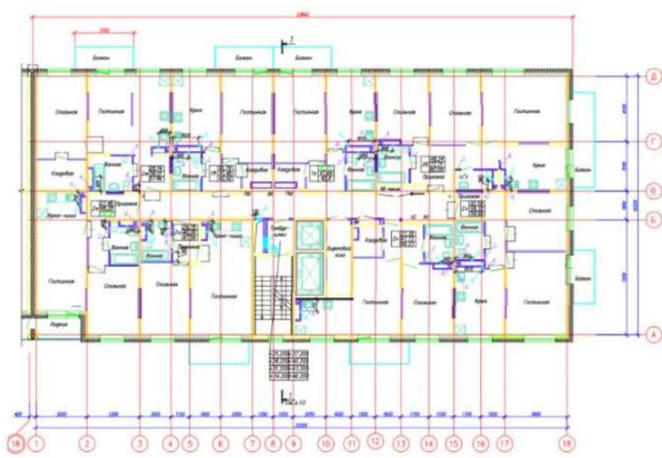
INTRODUCTION AND RESEARCH CONTEXT

According to (С.В. Корниенко, 2018), currently, 50% of the Russian housing stock is in need of renovation, this is because the housing percentage was constructed during an industrial era, where thermal comfort in buildings wasn't the main focus, leading to the currently unsatisfactory Russian housing stock. During the Soviet Union, the main construction method was masonry, or precast concrete panels with no insulation (Satu Paiho Å. H., 2013). Currently, modern construction still practices the use of precast concrete panels with either an exterior concrete surface or ceramic tiles with little or no insulation (Satu Paiho Å. H., 2013). This method of construction leads to poor thermal insulation which does not meet modern standards (Satu Paiho Å. H., 2013). The poor construction is one of the reasons why Russian construction is unable to reach its full energy potential. Additionally, the ineffective energy infrastructure, does not adequately meet the requirements of the long heating season (Satu Paiho Å. H., 2013), which degrades the energy efficiency even more. According to (Satu Paiho I. P., 2015), 60% of Russian multi-family apartment buildings require renovations or repairs, and this is rising to 93-95% in apartments less than 25 years old. The lack of renovation is also affecting the residential buildings and their compliance with modern standard requirements for the thermal insulation of the building envelope, which have been increasing since 2000 (Modin, 2020). Russia is considered to have a big potential for energy conservation; however, due to the knowledge gap and the rather old infrastructures, 40-45% of the consumed energy is related to household needs, 10% of which is wasted. Other sources indicate that, compared to other developed countries that use half of the energy construction, Russian buildings account for 38% of the primary energy consumption (Bashmakov, 2017); (A I Gabitov, 2019). According to, (Sirvio Anu, 2015) and (Modin, 2020) the main source of energy and heat losses are related to the outer walls, windows, air leakage through joints, holes, and ducts. Therefore, to reduce the share of heat losses, some design changes should be considered; including insulation of walls from the outside, replacement of low-performing windows and doors, and thermal insulation of structural elements (Modin, 2020). When it comes to climates, such as in Russia, breathable insulation such as mineral wool is recommended (Modin, 2020). A few solutions that could be applied to improve energy efficiency in residential buildings, include the improvement of space heating, water heating, improvement of water delivery systems, increased thermal resistance of building envelopes, using Low-E coated windows, reduced air infiltration, optimized fuel and energy consumption (T Lychuk, 2012) and (Korniyenko, 2018).

According to (A I Gabitov, 2019) Russia, for the second half of the 20th, century, has annually used 350-380 kWh/m^2 purely for heating residential buildings, which is 5-7 times higher compared to other European counties. Other sources indicate that the heating energy consumption during heating seasons in old buildings is 150-200 kW/m^2, (С.В. Корниенко, 2018). Retrofitting these buildings would decrease energy consumption by half. During the initial analysis, a major gap in the knowledge was identified in terms of thermal comfort, energy efficiency benchmarks, and the internal comfortable temperatures in buildings. To this end, this paper aims to assess the current conditions of the residential buildings in Russia, based on an existing case study. The assessment will be undertaken using existing Russian data, with the aim of using a parametric design method where four main scenarios are simulated and analysed including insulation, infiltration rates and shading strategies to understand how thermal comfort and energy consumption are influenced by these.

RESEACRH METHODOLOGY

Dynamic thermal simulations are done in IES(VE) to assess comfort and energy performance in a case study residential building in Kazan, Russia (Figures 1 &2). The current and optimal U-Values for the Russian construction as well as the UK (CIBSE Guide A) (CIBSE, 2021) and Russian set points are used. Thermal comfort assessment will be based on CIBSE TM59 (TM59, 2017) for the summer period (Table 1), and PMV for the winter period, to understand the current thermal comfort and energy consumption conditions in Russia.



Four main fabric scenarios are considered, aiming to understand how different u-values, setpoints and air change rates affect the thermal comfort and energy consumption as follows.
Building Fabric:

- The scenarios will be: Base Case (worst scenario),
- Basic Renovation Case,
- Improved Case and Passive house case (best scenario).
- Passive house
- Shading on south facade:
- No shading
- 0.5m
- 1m.

Heating set points (CIBSE, 2021) as shown in Table 2:

- Russia
- UK

A total of 24 combination scenarios therefore are simulated for four different fabric standards, two types of shading systems on the south façade and two heating set points.

Table 1: Criteria for TM59 (CIBSE TM59 2017)

Naturally ventilated dwellings	Criteria 1	Criteria 2
Location	Living rooms, Kitchen, bedroom	Bedroom
Degree	time greater or equal to 1	not exceed 26
Action		Sleeping
Time	May to September	10PM to 7AM
Percentage	no more than 3% occupier hours	no more 1% of annual hours

Table 2: Building Fabric Data for simulation

Building Fabric			
	Wall W/m2 K	Window W/m2 K	Air Change n50 (1/h)
Base Case	1.1	2.9	0.325
Basic Renovation Case	0.5	1.85	0.2
Improved Renovation Case	0.32	1.5	0.1
Passive House Case	0.1	0.8	0.05
Heating setpoints			
Russian Scenario	16 °C		
UK Scenario	18°C Bed- 22.5°C Living - 18 °C Kitchen		
Shading			
Shading 1	No Shading		
Shading 2	0.5 Meter		
Shading 3	1 Meter		

The occupancy levels were taken from the TM59 template (Table 3). For the PMV assessments, the heating system was considered to be on from October to March and off from April to September. Also for the TM59 thermal comfort assessments during summer time the heating was off during the summer period from April to September (TM59, 2017). Additionally, during summer time a window opening schedule was applied to open the windows every time the temperature in the room exceeded 22 C to meet the TM59 Criteria.

Table 3: Occupancy Profiles (CIBSE TM59 2017)

Occupancy Profiles	
Unit/room type	Occupancy
Studio	2 People at all times
1-Bedroom: Living room /Kitchen	1 Person from 9am to 10 pm
1-Bedroom: Living room	1 Person at 75% gains from 9am to 10 pm
1-Bedroom: Kitchen	1 Person at 25% gains from 9am to 10 pm
2-Bedroom: Living room	2 Person at 75% gains from 9am to 10 pm
2-Bedroom: Kitchen	2 Person at 25% gains from 9am to 10 pm
Double Bedroom	2 Person at 70% gains from 11pm to 8 am
	2 People at full gains from 8am to 9am from 10pm to 11pm
	1 person at full gain in the bedroom from 9am to 10pm

DATA ANALYSIS AND DISCUSSION

The results are reported for Flat 1 (64.9644 m2) located on the first floor with two bedrooms, a living room and an open kitchen. The results are divided into 3 parts for the PMV and TM59 for thermal comfort and the overall Energy consumption of the case study building.

PMV Thermal Comfort (winter time)

Figure 3 shows the PMV results for the Base Case scenario, where thermal comfort has been achieved during the winter period in the bedroom but not for the open plan for the UK set points whereas for the Russian heating set point the temperatures are significantly lower resulting in thermal discomfort. Additionally, in Figure 3 it can also be noticed that the 0.5m or the 1m shading does not have a meaningful effect on the PMV results. Additionally, after careful analysis, it is noticed , that in April and October, before the season change, temperatures decrease significantly in April resulting in a PMV between 0.4 and -0.4. In figure 4, where the condition of the external envelop was improved it is noticeable that the PMV in the UK and Russia cases, has improved, making the rooms thermally comfortable. Compared to the previous results, Figure 5 has significantly improved the results, with the improved case the rooms are fully meeting PMV reaching 0.5 results in the UK case where the set point is higher. Figure 6 shows the Passive House case, where the thermal comfort is comfortable in both Russian and UK case point cases, the reason is due to the high insulated envelope, which offers a very comfortable building during the winter period. In all figures, it is noticeable that at the end of the winter season, April tends to be overheated, especially in the passive house case (Figure 6) the rooms are reached a 1.0 PMV in the UK case and a 0.6 for the Russian setpoint case. Implying that the heating should be closed at the begging of April to keep the building thermally comfortable. Overall, not even one of the four fabric scenarios has been majorly affected by shading.

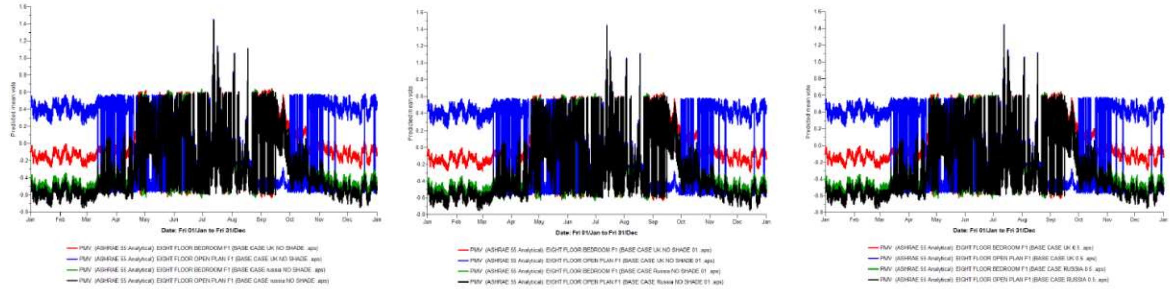


Figure 3: PMV results BASE case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

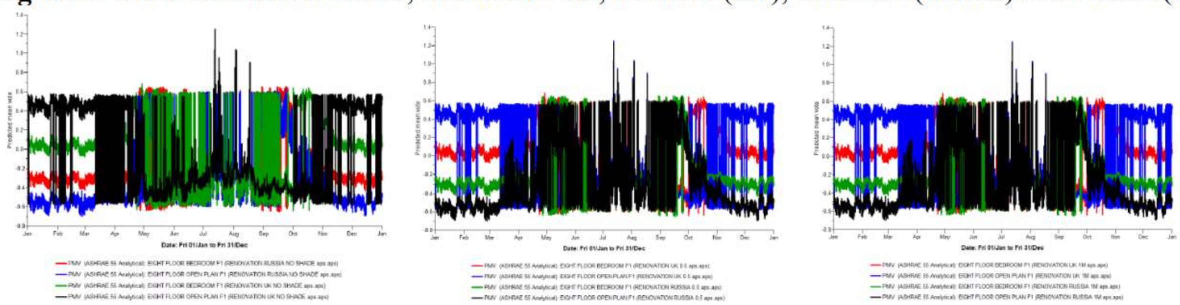


Figure 4: PMV results BASIC RENOVATION case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

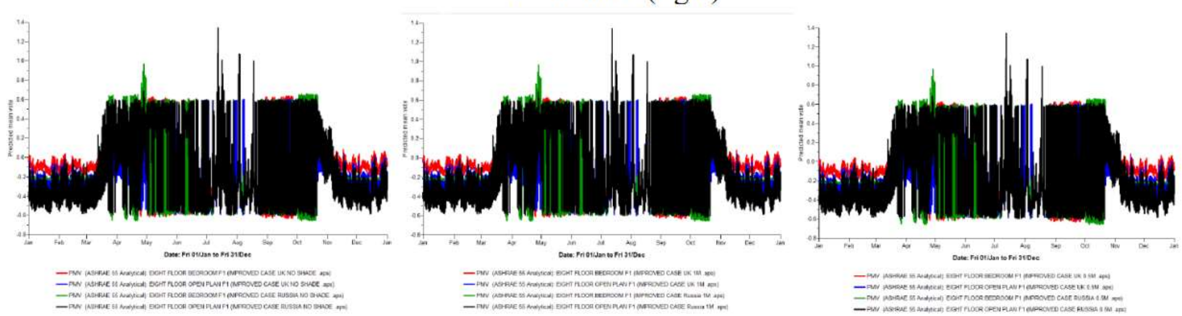


Figure 5: PMV results IMPROVED case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

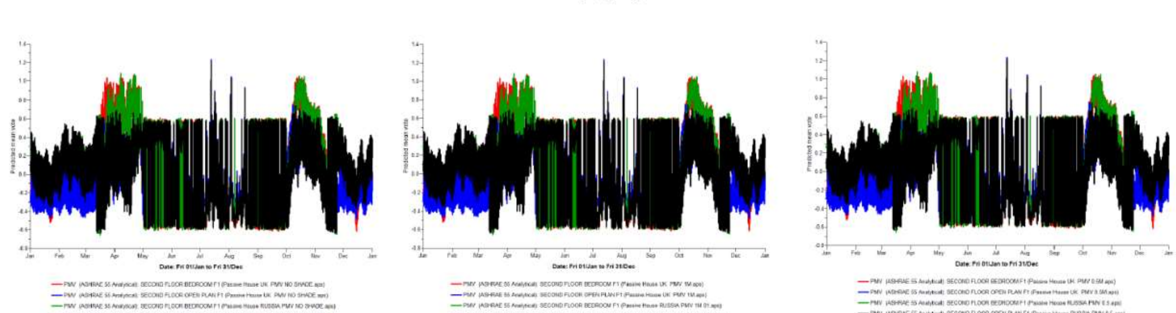


Figure 6: PMV results PASSIVE HOUSE case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

Table 4, shows the percentage of occupied hours when PMV was met during winter in Fat 1. II. This shows that the this flat has passed PMV requirements in all four scenarios with an average of 80.12%

for the UK and 71.61% for the Russian setpoint. As expected in the Russian case, where the set point is lower, PMV is less achieved compared to the higher set points used in the UK. For the base case scenario, thermal comfort conditions in the Russian case are below 55% and 78% for the open plan and bedrooms respectively, demonstrating the excessive thermal discomfort during winter. When the construction was poorer and with a better set point, the building reached a higher thermal comfort during winter. For the improved case and passive house cases the results improved significantly; however, for the basic renovation thermal comfort deteriorated. The latter requires more investigation to identify the reasons.

Table 4: UK % Occupied hours meeting PMV

	UK Setpoint%	Russia Setpoint%
Base Case % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	74.8	53.8
First Floor Bedroom F1	86.5	77.7
Basic Renovation % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	71.7	56.9
First Floor Bedroom F1	81.5	83
Improved Case % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	84.9	76.9
First Floor Bedroom F1	81.1	78.5
Passive House Case % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	94.8	77.6
First Floor Bedroom F1	65.7	68.5

Energy Consumption

The annual energy consumption has been assessed based on four different fabric scenarios each having different U-values for the external envelope of the building and different air change rates. Table 5 shows the final results representing how much energy has been used annually for the Russian and the UK setpoints. The results show that the annual energy consumption is reduced in every scenario in the Russian case; going down from 124.2193 MW/h with the base case scenario, which has the worse construction, to 4.4598 MW/h with the passive house. This is a reduction of over 94% in energy consumption. The addition of shading did not have a meaningful influence on energy consumption.

Similar to the Russian case, the energy consumption for the UK condition is reduced for the improved fabrics. Another comparison that can be observed is in the UK scenario the energy levels tend to be four times higher compared to the Russian data results, this is caused by the higher sets points used in the UK which will lead to higher consumption of energy to heat the room and reach a thermally comfortable room.

Table 5: Total Annual Energy Consumption

	Total Nat. Gas (MWh)	KW.h.m-2
Base Case -Russia	124.2193	75.02
Base Case -UK	168.7592	101.92
Basic Renovation -Russia	58.6319	35.44
Basic Renovation -UK	90.2058	54.48
Improved Case -Russia	28.0184	16.92
Improved Case -UK	59.3530	35.84
Passive House Case -Russia	4.4598	2.69
Passive House Case -UK	13.3217	8.24

The UK residential energy benchmarks (CIBSE GUIDE F, Table 20.1), identifies an energy consumption of 247 (kW·h·m–2) as the good practice and 417 (kW·h·m–2) as the typical practice. Table 5 shows that the UK benchmarks are met in all four scenarios, for both the UK and the Russian setpoints. Given that the simulations are based on the analysis of an intermediate floor, since the assessed flats are generally exposed to external weather conditions on one or two sides, the average energy consumption per square meter of the flats is meeting the benchmarks and in fact significantly lower than the UK benchmarks. It should also be noted that the lower energy consumption in Russia is due to the lower heating setpoints compared to the UK.

Adaptive TM59 Thermal Comfort (summertime)

Figures 7,8,9,10 illustrate the operative temperatures achieved in Flat 1. The results show that Flat 1 is passing the criteria set by CIBSE TM59 because the temperatures did not exceed the maximum of 26 degrees. These results show that the construction and the different U-values and air change rates as well as the addition of a shading system do not significantly influence thermal comfort in the building during summertime. For improved construction types, the lowest temperature that Flat 1 is between 19-20 degrees, in comparison with Figure 8, where the temperature can go as low as 16 in May. The 5 C degrees difference may be due to the construction of the building which has been significantly improved in the Passive House scenario.

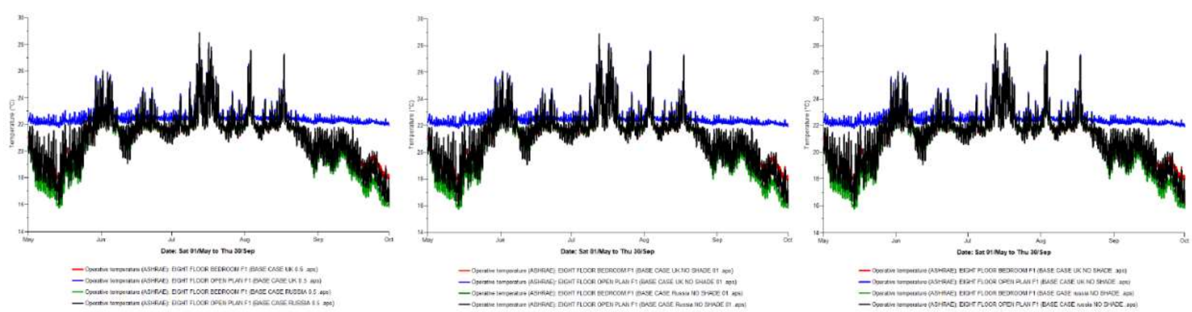


Figure 7: Operative Temperature Base Case Russia + UK 1/0.5m and NO shade Flat 1

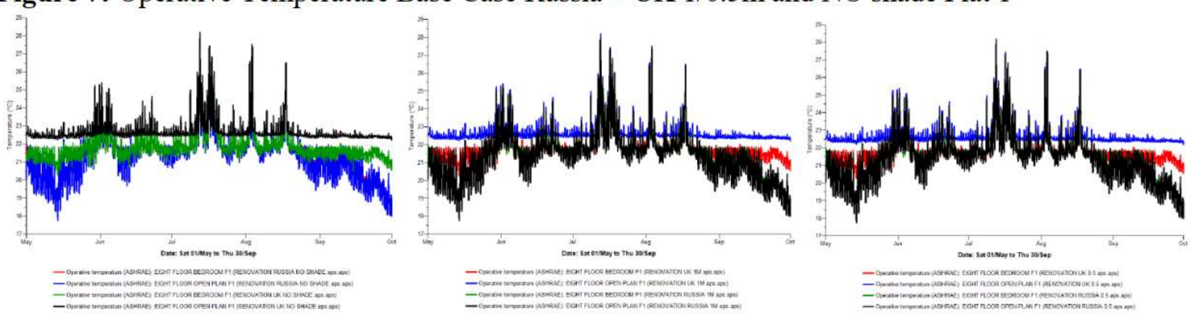


Figure 8: Operative Temperature Basic Renovation Case Russia + UK 1/0.5m and NO shade Flat 1

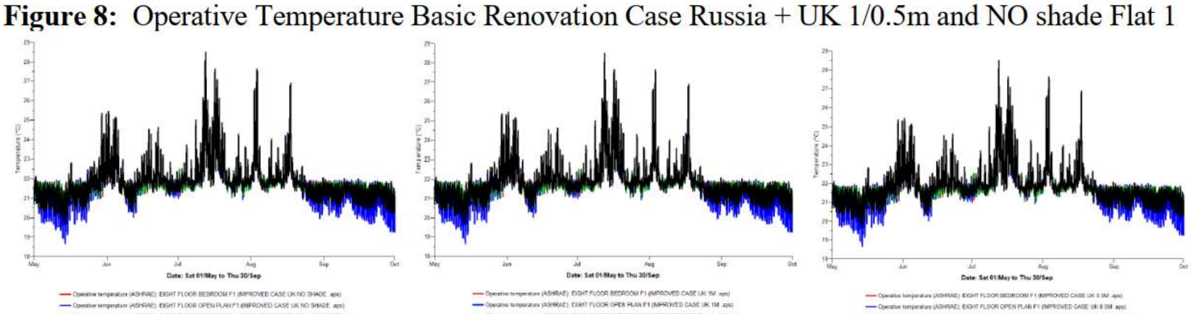


Figure 9: Operative Temperature Improved Case Russia + UK 1/0.5m and NO shade Flat 1

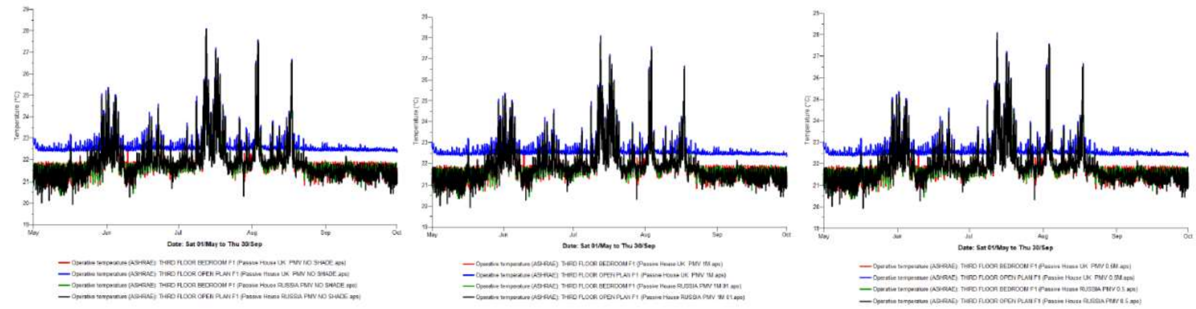


Figure 10: Operative Temperature Passive House Case Russia + UK 1/0.5m and NO shade Flat 1

DISCUSSION

Overall, the PMV results show a major difference between the Base Case and the Passive House scenarios, implying that the differences in U-values have a major impact on thermal comfort during winter. Generally, the PMV results indicate that thermal comfort has been achieved at 76% on average in all 24 scenarios. On the other hand, CIBSE TM59 requirements have been successfully achieved during the summertime. This implies that the comfort conditions have not been influenced by the construction of the building; however, improved construction has been effective in keeping the temperatures high during the winter to summer transition. As for the operative temperature, PMV has not been affected by the addition of shading. The reason for this may be due to the building orientates (west and east) and the size of the glazing/windows. In terms of the energy consumption of the building, assessed and compared against the UK's benchmarks for residential buildings, the UK and Russian scenarios successfully meet the benchmarks. While the benchmarks are met, it is noticeable that energy consumption in Russia has reduced by over 94% for the passive house condition compared to the base case. For the UK case with higher heating setpoints, the improvement has been over 92%. This indicates a significant potential for energy saving if the existing buildings in Russia are retrofitted to the passive house standards.

CONCLUSION

This paper analysed energy performance and thermal comfort in a typical multi-story case study building in Russia. A discrete amount of information concerning energy consumption and construction methods gives a clear understanding of how Russia is approaching industry development and the new sustainable implementations required worldwide. This said, despite meeting the UK benchmarks in terms of energy performance, the current situation (lower heating set points and defective construction methods) means that thermal comfort is dramatically failing in many residential buildings particularly during winter making them too cold. This could affect the health and well-being of the occupants of these buildings in the long term. The effects of different U-Values, airtightness, shading and heating setpoints were assessed in 24 different combination scenarios. The results showed that thermal comfort was marginally affected by the construction type and shading. In contrast, there was a strong correlation between energy consumption, the building fabric quality (in terms of U-Values and airtightness) and the different heating setpoints. These had a significant impact on the annual energy consumption resulting in a reduction of over 94% for energy consumption in the passive house case. Retrofitting the existing buildings to achieve higher energy efficiency standards could therefore significantly reduce energy consumption and Green House Gas emissions in Russia. Additionally, a better-insulated envelope would result in a thermally comfortable space for the occupants by keeping the heat inside. This said the current internal temperature norms of 16 C in Russian residential buildings is open to question as to whether this could achieve a thermally comfortable space without affecting the occupants' health and wellbeing. More research is required on the effects of various issues such as the inefficient infrastructure and various retrofitting strategies on energy performance in Russian buildings.

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