The Effects of Windows and Reduced Night Temperature on the Heating Energy Demand in Different Regions of Russia

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Abstract. An energetic model of a typical log home was placed in ten different regions of Russia and examined the yearly heating energy demand. The building was supplied with three different types of windows to demonstrate the effect of windows on the heating energy demand. In a 108 m^2 building, changing the 3.5 W/m^2K thermal insulation capacity windows to 1.4 W/m^2K and 0.7 W/m^2K windows caused an energy saving of 11.9% and 15.9% heating energy respectively. In a heated space reducing the night temperature by 2 degrees Celsius can result in only a 2.7% (1 865 kWh) saving in the colder Magadan region, while in the Mediterranean Krasnodar, there was a 4.48% (1 151 kWh) saving of the net heating energy amount. Calculations estimated that Russia possesses a very significant heating potential savings.

1. Introduction

Because of their large number and significant energy use, residential buildings are responsible for a high proportion of all utilized energy. Residential buildings consume 30-45% of all utilized energy. This value differs from country to country depending on climate conditions, and the thermal properties of buildings [1, 2]. Due to the high energy proportion and inefficient utilization, the energy saving potential is high mainly due to the thermal properties of buildings [3-6]. When building and retrofitting houses, with higher energetic requirements, the main goal is to improve thermal insulation and to increase energy efficiency, to reduce energy consumption. These modifications are important both for the environment and operation cost-efficiency, which is proved by several studies [7-10].

During the determination of the thermal characteristics of a building, special attention must be given to the windows, because their heat loss can significantly surpass that of other building parts. Several investigations emphasize the importance of the windows in the heat loss of buildings and the opportunity to harness solar gaining [11, 12]. Grynning et al. [13] determined that the possible heat loss ratio related to the windows can be over 40% according to the actual Norwegian regulation [14]. The optimal thermal parameters of windows are influenced by their size and orientation and annual heating-cooling energy demand which connects directly to the climatic conditions as Jber and Ajib determined [15].

Besides the thermal parameters of buildings, the geographical location and position play a very important role determining the heating-cooling energy. The same building requires different amounts of energy in different weather and orientation conditions to provide the same inner circumstances. The Russian Federation is the biggest country in the world. It stretches from Eastern Europe to the northern

Pacific Ocean. There are many types of climate in its 17 125 187 km^2 area. Mostly the continental features dominate, but near the Arctic circle the climate is subarctic, and subtropical climates can also be found near the Black and Caspian Seas.
The great majority of residential houses in rural areas of Russia are wooden houses [16, 17]. They have a centuries old tradition to build log homes, which are an advantageous solution in local conditions. Good quality wood as building material has always been available in great amount and so far the 18-25 cm thick log wall could satisfy the regulations [18]. The regulations set recommendations for “low-rise” buildings which includes the individual residential buildings, but does not determine the minimal thermal resistance of the wall structure.
The three main goals of the present research are: (1) determination of heat energy demand of the same building in ten Russian cities with different climates, (2) determination of the role of windows with three different insulation levels regarding the heat energy demand of an average Russian log house, (3) determining the available energy saving by reducing the building’s inner temperature at night in theses ten regions.

2. Materials and methods

The heat energy model of a typical Russian log building was built with the help of Finite Element Model simulation. Then the building’s virtual energetics model was placed into different regions of Russia and an energetics simulation was run to determine the heating energy demand. Although the solar gaining and wind have also significant effects on the heating demand, the necessary local data on sunshine and wind data was not available. That is why the orientation of the building was not considered in the calculations in other words it was the same in all cases. The heated area in two floors totals 108 m^2 with an almost square ground plan. The building stands on concrete point foundations. The layer order of the walls, roof, ceiling, floor is shown in Table 1.

Table 1. Layers of the building.

No.	Floor		Ceiling		Roof		Side wall	
	Thickness [mm]	Name	Thickness [mm]	Name	Thickness [mm]	Name	Thickness [mm]	Name
1	40	sawnwood	40	sawnwood	0.7	metal tile	200	log beams
2	1	water insulation	200 x 50	beam frame	25	purlin		
3	200x 50	beam frame	150	rockwool thermal insulation	25	counter batten		
	200	rockwool thermal insulation	1	vapor barrier	2	water insulation		
4	25	lower floor boards	20	final decking	200	rafter		
5	25	lath frame			150	thermal insulation		
6		air gap			1	vapor barrier		
7		soil			25	purlin		

The biggest proportion of the wall is made of a simple laminated 200 mm thick log, whose U value is 0.5 W/m^{2}K the thermal conductivity of coniferous wood material is 0.11 W/mK and the inner surface coefficient of heat transmission is 1/24 while the outer is 1/8. The virtual thermodynamic model of the building was created in WinWatt software (http://www.bausoft.hu) based on the data of Table 1. The characteristic values of each building part were chosen from the database of the software, which provides up-to-date data for big amounts of building material. The model was run with windows having three different thermal insulation capacity having unified thermal conductivity („U" value) of 3.5 W/m^{2}K, 1.4 W/m^{2}K and 0.7 W/m^{2}K. These values include the thermal parameters of the glass and frame weighting in proportion of the surface. Total surface of windows was 18 square meter including the frames. The thermal finite element model made it possible to calculate the current heat loss of the building for every temperature difference between indoors and outdoors.

The yearly heat energy demand was integrated from the hourly data of the inner and outer temperature difference with the help of a program made for this purpose (EnergiKalk software) [19]. The program allows us to determine the energy demand of the same building in different climatic conditions. and counts the heat energy consumption for a given period using the weather data for the given city and the inner temperature for the building. With the difference of the building's inner and the outer temperature, there is a specified heat energy demand. The energy demand of the house for a given period of the year is derived by integrating this hourly data. The yearly energy demand in the first case was determined with an inner temperature of 20 degree Celsius. In the second case, the temperature was lowered to 18 degrees between 10 pm and 6 am thus reducing the difference of the inner and outer temperature and consequently the heat loss. The calculated energy demand results the net energy needs of the building.

The chosen cities for modeling are Archangelsk, Chelyabinsk, Irkutsk, Krasnodar, Krasnoyarsk, Magadan, Moscow, Omsk, St. Petersburg and Vladivostok (Figure 1). The building had been investigated can be built legally any types of windows mentioned in this article which mean that all of them meet the official regulations. Near each of these cities there is a civil airport whose weather data between 01/01/2014 and 31/12/2014 were used during modeling [rp5.ru]. The exactness of the data was checked with the help of other weather stations and found that the data are identical.

Figure 1. The location of the cities studied.

Although in some of the cities the outdoor temperature hardly reaches the indoor temperature, in several other locations the temperature far exceeds the indoor temperature of 20 degrees. In this case cooling energy would be needed to keep the buildings inner temperature. The climate conditions of Russia require cooling for only a short period therefore the air conditioning systems generally are not used. Therefore during modelling was not calculate the demand for cooling energy. Table 2 presents the location and temperature data of cities.

The biggest yearly fluctuation of temperature is in Krasnoyarsk, the lowest yearly average temperature is in Magadan, the highest is in Krasnodar. The number of heating hours was the highest in Magadan and the lowest was in Krasnodar. Despite its northern location, Archangelsk is not the coldest due to the equalizing effect of the sea. In most cities the continental effect prevails on different scales. The number of heating hours is affected by several factors besides geographical location, such as sea currents, wind conditions and elevation and the terrain. The result is that the northernmost city has not got the coldest average temperature. In Russia's continental territories the number of heating hours is approximately the same although the minimum and maximum temperature values are different. It was determined the amount of the hourly temperature differences in the heating temperature of each region by the number of heating degree hours.

Table 2. Geographical data of the cities and extreme temperatures in 2014.

Town	North latitude	East longitude	Mean-temperature (℃)	Maximum temperature (℃)	Minimum temperature (℃)	Number of heating hours*
Archangelsk	64.55	40.56	2.4	32	-30	8246
Chelyabinsk	55.16	61.44	2.9	32	-35	7877
Irkutsk	52.29	104.31	1.0	31	-34	7926
Krasnodar	45.03	38.97	12.6	37	-17	6125
Krasnoyarsk	56.02	92.89	1.3	35	-35	7927
Magadan	59.57	150.8	-4.2	27	-45	8627
Moscow	55.76	37.62	6.4	33	-26	7592
Omsk	54.98	73.37	2.1	35	-35	7707
St. Petersburg	59.93	30.34	6.6	33	-22	7808
Vladivostok	43.13	131.9	5.4	32	-29	7258

* Number of heating hours if the inner temperature is 20 ℃

3. Results and discussion

With the help of the EnergiKalk software, were calculated the yearly heating energy demand for the three types of windows and for two kinds of daily temperature rhythms in each of ten cities (Table 3). The table shows the yearly heating degree hours in both the 20 degrees and the lowered 18 degrees Celsius night temperature.

Table 3. Energy demands.

City	Heating degree hours constant 20 ℃ (h ℃)	Heating degree hours 18 ℃ at night and 20 ℃ by day (h ℃)	Energy demand constant 20 ℃ (kWh/year)			Energy demand 18 ℃ at night and 20 ℃ by day (kWh/year)		
			3.5 W/m^{2}K	1.4 W/m^{2}K	0.7 W/m^{2}K	3.5 W/m^{2}K	1.4 W/m^{2}K	0.7 W/m^{2}K
Archangelsk	155 599	150 633	51 534	45 390	43 336	49 671	43 749	41 769
Chelyabinsk	152 980	148 560	50 396	44 386	42 379	48 724	42 914	40 973
Irkutsk	169 550	165 361	55 775	49 123	46 904	54 217	47 751	45 593
Krasnodar	77 357	74 183	25 710	22 645	21 618	24 559	21 632	20 651
Krasnoyarsk	167 009	162 086	55 077	48 509	46 317	53 205	46 861	44 743
Magadan	212 417	206 759	69 850	61 517	58 739	67 985	59 876	57 171
Moscow	124 180	119 457	41 141	36 236	34 597	39 400	34 703	33 132
Omsk	161 330	156 464	53 003	46 681	44 573	51 198	45 092	43 055
St. Petersburg	120 797	116 254	40 211	35 416	33 813	38 539	33 945	32 407
Vladivostok	132 475	129 008	43 510	38 322	36 590	42 219	37 186	35 504

(1) According to the calculations, the amount of heating energy is not related to the number of heating hours, but to the heating degree hours. Magadan has the highest energy demand and the number of heating hours; these values are the lowest in Krasnodar. In Archangelsk the heating degree hours are not the highest despite the high number of heating hours. Irkutsk, Krasnoyarsk and Omsk have a higher energy demand because of the greater number of heating degree hours. The reason is that although the temperature is permanently under the given value, the minimum and average temperatures are higher than in the middle part of the country, where the temperature could be much lower during a shorter heating period.

The energy consumption of a building in the Moscow region with 1.4 W/m^2K type windows is 335 kWh/m^2 per year (Table 3). This data is a good agreement with the calculation have been done in the GWD Engineering 2017 system (gwde.ru) which is about 298 kWh/m^2 per year [20].

(2) The different energy requirements from using different types of windows can be compared because the configuration and orientation of the house is constant. The window with the lowest insulation capacity and 3.5 W/m^2K thermal conductivity accepted as a basis. The 1.4 W/m^2K thermal insulation window saved 11.9%, and the 0.7 W/m^2K window saved an additional 4.0% compared to the initial value. In the coldest Magadan area, modern windows (U=0.7 W/m^2K) save 11 MWh energy annually compared to the 3.5 W/m^2K windows. In Krasnodar, where the energy demand is the smallest, the saving is still 4 MWh. The results show the building's energy demand by measuring heating degree hours with the different types of windows. Changing the windows from type 1.4 W/m^2K to type 0.7 W/m^2K produced much less (~4%) energy savings.

(3) If the temperature is reduced from 20 ℃ to 18 ℃ between 10 pm and 6 am, energy use can be reduced by as much as 4.5% depending on weather conditions characteristic of the area (Table 4). By reducing the inner temperature the heating degree hours are reduced as well, because the night temperature difference will be lower (Table 4).

Table 4. Heating energy saving by reduced night temperature.

City	Energy saving 18 ℃ at night and 20 ℃ by day [kWh/year]			Energy saving [%]	Decrease of heating degree hours [%]
	3.5 (W/m^2K)	1.4 (W/m^2K)	0.7 (W/m^2K)		
Archangelsk	1 863	1 641	1 567	3.62	3.19
Chelyabinsk	1 671	1 471	1 406	3.32	2.89
Irkutsk	1 558	1 372	1 311	2.79	2.47
Krasnodar	1 151	1 013	968	4.48	4.10
Krasnoyarsk	1 872	1 648	1 574	3.40	2.95
Magadan	1 865	1 641	1 567	2.67	2.66
Moscow	1 741	1 533	1 464	4.23	3.80
Omsk	1 805	1 589	1 518	3.41	3.02
St. Petersburg	1 673	1 472	1 406	4.16	3.76
Vladivostok	1 291	1 136	1 085	2.97	2.62

The saving in Magadan with the highest heating demand is 1 865 kWh, (2.67%). In Krasnodar it is 1 151 kWh, (4.48%) of the energy using the 3.5 W/m^2K windows. The energy saving in Magadan is almost one and a half times as much as in Krasnodar in absolute value. However, it indicates a smaller proportion. The amount of savings is mostly connected to the whole amount of energy needed for heating. Where the heating energy demand is bigger, more energy can be saved by lowering the inner temperature at night. The percentage of energy saved is the same with the better insulated windows, although its absolute quantity is lower.

4. Conclusions

Cities in the warmest areas require heating in 70% of the year while city in the coldest places need heating for more than 98% of the year. Due to the long heating period, a smaller improvement of insulation saves a large amount of energy. Therefore using windows with lower thermal conductivity and lowering the temperature at night reduces heating energy 20% in most areas of Russia. Windows play a significant role in the amount of heat building needs. Compared to the two times one layer glazing (3.5 W/m^2K), the windows with thermal insulation glazing and a low emission coating and argon gas filling (1.4 W/m^2K) can produce significant savings. The windows with three layers of glazing and excellent insulation (0.7 W/m^2K) can reduce a building's whole heating energy demand by almost one sixth. That is a really significant result if the low surface are of the windows is taken into account.

Reducing the night temperature 2 ℃ can save 2.67% to 4.48% of the required energy depending on the heating demand and the region. This type of energy saving can be realized without investment.

At present the rural regions of the country mostly heat with wood, a fuel that is abundantly available everywhere in the country. Since Russia has plenty of fossil energy sources compared to the western countries, there is less pressure to use energy efficiently. This is reflected in the regulations for thermal characteristics of buildings. Nationwide Russia has a very significant potential to save energy and carbon dioxide. The key to this is to raise the standards for the energetics of buildings and to retrofit buildings.

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