WEB OF SCIENTIST: INTERNATIONAL SCIENTIFIC RESEARCH JOURNAL
ISSN: 2776-0979, Volume 4, Issue 6, June, 2023

DETERMINATION OF THE OPTIMUM INSULATION THICKNESS FOR DIFFERENT ORIENTATIONS OF EXTERNAL WALLS OF A RESIDENTIAL BUILDING IN TASHKENT, UZBEKISTAN

ОПРЕДЕЛЕНИЕ ОПТИМАЛЬНОЙ ТОЛЩИНЫ УТЕПЛИТЕЛЯ ДЛЯ РАЗЛИЧНЫХ ОРИЕНТАЦИЙ НАРУЖНЫХ СТЕН ЖИЛОГО ДОМА В ТАШКЕНТЕ, УЗБЕКИСТАН

Abdullaev Nodirbek Azatvay Ogli,
Bo'riyev Elbek
Tashkent State Technical University, Energy Faculty,
Universitetskaya 2, 100095, Tashkent, Uzbekistan

Abstract:
Annual heating and cooling transmission loads are being calculated based on transient heat flow through the external walls and by using hourly climatic data. Additionally, we performed a financial analysis based on the Life Cycle Savings (LCS) method, for each wall configuration and orientation, as well as for various thicknesses of insulation material. Depending on the wall type and orientation, the optimum insulation thickness was found to be between 3.75 cm and 11.0 cm.

Аннотация:
Рассчитываются годовые нагрузки по передаче тепла и холода на основе нестационарного теплового потока через наружные стены и с использованием почасовых климатических данных. Кроме того, мы провели финансовый анализ на основе метода экономии жизненного цикла (LCS) для каждой конфигурации и ориентации стен, а также для различной толщины изоляционного материала. В зависимости от типа и ориентации стены оптимальная толщина изоляции составляет от 3,75 см до 11,0 см.

Keywords : cooling load, heating load, life cycle saving, optimum insulation thickness, transient simulation

Ключевые слова: холодильная нагрузка, тепловая нагрузка, экономия жизненного цикла, оптимальная толщина изоляции, моделирование переходных процессов.

WEB OF SCIENTIST: INTERNATIONAL SCIENTIFIC RESEARCH JOURNAL
ISSN: 2776-0979, Volume 4, Issue 6, June, 2023

Introduction

Uzbekistan's energy sector is currently undergoing a large-scale transition. In order to implement comprehensive measures to deepen structural reforms, the government of Uzbekistan has adopted a wide range of strategies and laws related to energy, which include among others, the widespread introduction of energy-saving in residential sector. However, it is known that the Europe and Central Asia regions are the most energy intensive in the world, with experts concurring that improvements in energy efficiency are an economic and environmental imperative [1]. The major difference between these two regions, however, is that the high residential energy consumption in Europe is mainly attributed to the advanced economy of the region, with households having a large area and using a large number of electric appliances [2]. On the contrary, the economy of the Central Asia region is significantly inferior, yet the residential energy consumption per capita surpasses that of European countries [2, 3]. The high residential energy consumption in the region is primarily attributed to the very low cost of energy, which does not offer an incentive for energy saving measures and practices.

The share of Uzbekistan's residential sector in relation to the country's total energy consumption particular is amongst the highest in the world, with the most recent available data showing that it surpasses every other country in the Europe and Central Asia regions [2, 4]. The energy consumption of residential buildings in Uzbekistan is estimated at 200% to 250% higher than that of developed countries, meaning that there is great potential for energy saving measures and practices [5]. Specific energy consumption per m2 of living area in Uzbekistan is 423 kWh per year [5] and is closest to the relevant figures in Russia and the U.S., i.e. countries differing substantially in terms of climate, development level, and housing amenities. Additionally, two thirds of residential energy consumption are related to space heating [2].

Until recently, the very low energy prices in Uzbekistan made the introduction of energy saving measures on buildings entirely financially unappealing, as the cost of the investment greatly surpassed the cost of energy and there were no government subsidies to promote such practices. However, energy prices in Uzbekistan have been increasing at a rapid pace during the past few years. With the price of natural gas jumping from 0.03599€ in September 2013 [6] to 0.06337€ in October 2016 [7], the application of insulation on buildings is becoming an appealing option even without government subsidies. The high energy consumption in the residential sector in Uzbekistan [8], combined with annual population growth, has a great energy saving

potential. The application of adequate insulation thickness on external walls, is one of the main measures to drastically reduce energy consumption and CO_2 emissions. Several studies have been performed on the subject of optimum insulation thickness, each taking a different approach for the calculation of the thermal performance of the wall. Some are based on the Degree-Days concept [9-17], while others use numerical [18-22] or analytical methods [23-25] for transient heat flow through the walls of the building. Generally, the results and conclusions from these studies are site specific and applicable only to local climatic conditions, financial parameters, as well as construction and insulation materials. For instance, Bolattürk [12] studied the optimum insulation thickness of building walls using the degree-hour method, depending on the annual cooling and heating loads, for different base temperatures of various cities within the first climatic zone of Turkey. Al-Sanea et al. [19] used a dynamic time-dependent model based on the finite-volume implicit method to compute the annual transmission losses through the wall under steady-periodic conditions for climatic conditions of Riyadh. Daouas [23] used an analytical method to calculate the optimum insulation thickness of walls for different orientations in the Tunisian climate. In addition, a methodology has been developed for the optimization of thermal insulation solutions, based on the primary energy consumption, environmental impact and the financial cost of building elements and materials [26, 27].
This paper investigates the financial optimal insulation thickness for the two most commonly used building insulations materials in Tashkent, Uzbekistan: expanded polystyrene and mineral wool. The intention of the authors is to identify the financially optimal insulation thickness for the three most common wall topologies in the country and for the four different orientations of a building. The optimisation methodology uses the transient building simulation program TRNSYS [28] and the Life Cycle Savings (LCS) analysis. Our approach is using hourly climatic data and takes into account the cooling and heating transmission load.

Materials and Methodology

For the present study the city of Tashkent (41° 16' N, 69° 13' E) has been selected because of its location, size, and climatic likeness with most of the densely populated Central Asia regions. With 2.4 million inhabitants, Tashkent is the capital of Uzbekistan and features a Mediterranean climate with strong continental climate influences.
The most common and widely used wall topologies for the construction of external walls in Tashkent are described below. The thermal behavior of each topology is

studied for two insulation materials of various thicknesses and different orientations with respect to cooling and heating transmission load. The following three different configurations of external walls have been selected and also are graphically displayed in Fig. 1.

For all configurations, the assumed thickness of both the interior and the exterior plaster is 2.5 cm each. Also, the thermal insulation materials that can be effectively applied are those of expanded polystyrene (XPD) and mineral wool (MW) of different thicknesses. The values of thermophysical properties of each material used for the simulation have been derived from the database available in [28] and from [27, 29], while they are shown in Table 1. The conduction heat transfer is being treated as one-dimensional and the thermophysical properties of building materials are independent of their temperature.

Using the aforementioned data, we performed a transient simulation of the external walls for each of the three most common wall configurations in the region and for all four possible orientations (north, west, east, and south), followed by a financial analysis that identifies the optimum insulation thickness for each wall type and orientation. The financial analysis is then expanded to determine the payback period of the optimal solutions.

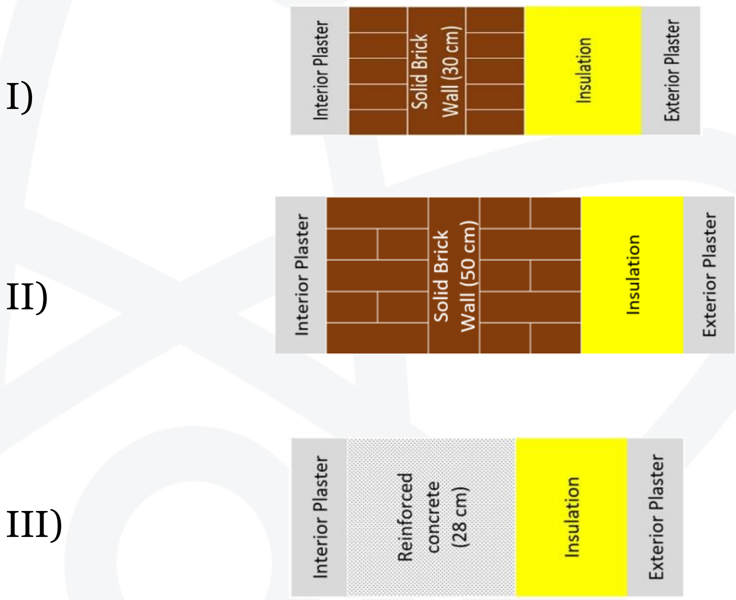

Figure 1. Examined wall configurations. From top to bottom (not in scale): I) interior plaster, 30 cm solid brick, insulation material and exterior plaster, II) interior plaster, 50 cm solid brick, insulation material and exterior plaster, and III) interior plaster, 28 cm reinforced concrete, insulation material, and exterior plaster.

Table 1. Thermophysical properties of building materials used
(λ: coefficient of thermal conductivity, ρ: density, cp : specific heat)

Material	λ (W/mK)	ρ (kg/m3)	c_p (kJ/kgK)
Plaster	0.87	1800	1
Solid brick	0.68	1500	1
Reinforced concrete	2.2	2400	0.84
Expanded Polystyrene	0.036	20	1.45
Mineral wool	0.04	55	0.84

The methodology followed is a partial version of the proven approach that the research team has used in previous studies, which has been adapted to the specific requirements and parameters of this particular study [30, 31].
The heat transfer function method is one of the most accurate methods for the calculation of a time-variable heat load. It has been experimentally validated and adopted by ASHRAE [32, 33]. The heat transfer function method has been used to calculate the heat fluxes (W/m²) to the wall at its both sides, external and indoor. [34]. Moreover, this method considers not only the position of the insulation within the wall but also the material's thermal mass, which plays a key role in temperature stability. For the outside surface temperature, we used a model that takes into account the combined effect of the incident solar irradiance, outdoor air temperature, and convective heat exchange with the outdoor air. This temperature is being referred to as the sol-air temperature ($T_{sol-air}$) in scientific literature [32].

$$T_{sol-air} = T_{\alpha} + \frac{\alpha I_T}{h_{o,c}} - \frac{\varepsilon \Delta R}{h_{o,c}} \qquad (1)$$

where T_{α} is the outdoor air temperature, α is the solar absorptance of the outside surface, I_T is total solar irradiance incident on the surface (W/m²), $h_{o,c}$ is the combined convective and radiative heat transfer coefficient on the outside surface (W/m²K), ε is the hemispherical emittance of the surface and ΔR is the difference between the longwave radiation incident on the surface from the sky and surroundings and the radiation emitted by a blackbody at outdoor air temperature (W/m²). For vertical surfaces, the radiant heat loss to the sky counteracts the heat gain from the ground, therefore the value of ΔR is zero. The $\alpha / h_{o,c}$ ratio was taken equal to 0.026, as recommended for light colored surfaces [32].

Regarding the inside surfaces of the wall, there are several formulas in literature for the calculation of the convective heat transfer coefficient. It is known that these formulas display deviations because the flow characteristics, local geometry, and specific conditions under which they have been derived differ from case to case [35, 36]. In this work we used the following formula for the calculation of the heat transfer coefficient on the inside surface of the wall (hi) (as suggested in [32, 37] and cited in [38]):

$$hi = 1.31(Ts,i - Ti)^{1/3} \qquad (2)$$

where: Ti is the inside air temperature. The in-build air dry bulb temperatures used to set the need for heating and cooling were at 20 °C and 26 °C respectively, which are reasonable values that will not lead to the overestimation or underestimation of the annual energy use.

We calculated the incident total solar irradiance on the external surface of the wall by using the solar radiation data for the city of Tashkent-Uzbekistan and the well-known equations from solar geometry [39]. Thus, at each time step, the solar incidence angle and the solar zenith angle were being calculated from the solar position coordinates, namely from the solar altitude angle, solar azimuth angle, surface orientation, and slope. Then, in order to determine the heat flux on the external wall, the aforementioned equations were used in conjunction with the appropriate parameters and the hourly weather data. The integration of the resulting heat flux during a time period determines the heating or cooling load for that period.

For the determination of the most profitable thickness of insulation for each type of wall, a simple economic analysis based on the Life Cycle Savings (LCS) method has been performed. This method is widely applied for determining energy systems economics. This method can also be used to find the economically optimum design of a given system. The estimation requires the synthesis of both the energy performance results and a number of economic parameters. Required energy performance data have been calculated using the aforementioned simulation model. The set of assumed economic parameters are shown in Table 2 and were obtained from the manufacturers of the insulation materials, the Electricity Authority of Tashkent and one of the banks operating in Tashkent.

The two energy systems compared in this study is a conventional heating and cooling system with and without insulated walls. The fuel and electricity costs are being considered for each case and compared to each other. The conventional heating and cooling systems are assumed to be a gas-fired boiler and an electric heat pump respectively. The Net Present Value (NPV) is being used to perform a comparative economic analysis for a 30-year period.

Table 2. Economic parameters

Parameter	Value
Insulation cost	XPD: 124 €/m3
MW: 60 €/m3	
Domestic electricity price	0.0425 €/kWh
Cost of heating energy	0.00577 €/kWh
Domestic electricity inflation rate	17.8 %
Heating gas price inflation rate	17.8 %
Bank loan interest rate	14 %
Loan lifetime	10 years
Economic analysis	30 years
Discount rate	12 %
COP	3
Furnace efficiency	0.85

The payback period can be defined in many ways [40]. In the present work, it is being calculated using its discounted form including the time value of money and hence is more reliable for finding the payback period. In this case, it is the time required for the discounted cumulative energy savings to equal the initial investment cost.

The NPV for the different types of walls, insulation thicknesses, and orientations is being calculated with the help of a spreadsheet which can be used to calculate and ultimately compare their economic viabilities under multiple economic parameters, as long as the annual heating and cooling load has been calculated. If the NPV is positive, then, on the basis of the anticipated costs and savings, the investment is economically viable and the highest figure of NPV corresponds to the optimal insulation thickness.

Results and Discussion

The results of the simulation are being presented in the diagrams of Fig. 2-5 and as can be seen, when the thickness of the insulation is increased, the heating and cooling load per square meter of the wall area respectively decreases, for different orientations and for three types of walls and two insulation materials examined.

These results are described and explained in detail below, for each of the diagrams obtained.

Figures 2 and 3 relate to heating transmission load and show that the north facing wall has the highest heating transmission load, regardless of the type of wall, due to the negligible solar heat gain during the heating period. In contrast, the south facing wall has the lowest heating load per unit area of the wall than all other orientations because of the high solar heat gain, which is due to the effect that during the winter months the sun rises and sets to the south of east-west line, therefore this surface is exposed more hours to solar radiation. In conclusion, the south facing wall seems to be the most advantageous when compared to any other wall type and orientation.

During the cooling season (Figs. 4 and 5), the thermal behavior of the walls alters as the west facing wall has the highest cooling load while north the smallest. The thermal behavior of the west facing wall is the result of the high temperature on its external surface which, in relation with inside surface temperature, drives the heat gain mechanism. The high ambient temperatures early in the summer evenings give the high values on the outside surface of this wall, according to the definition of sol–air temperature which is used in the simulation.

The low cooling load of the north oriented wall is due to the fact that during the summer months, because of the longer day length, the solar irradiance falls on this surface for a few hours, mainly in early morning and late afternoon, when its intensity is quite low compared to all other orientations. Similar results are obtained in literature [19, 23, 41], although they have been derived from different assumptions and climatic conditions.

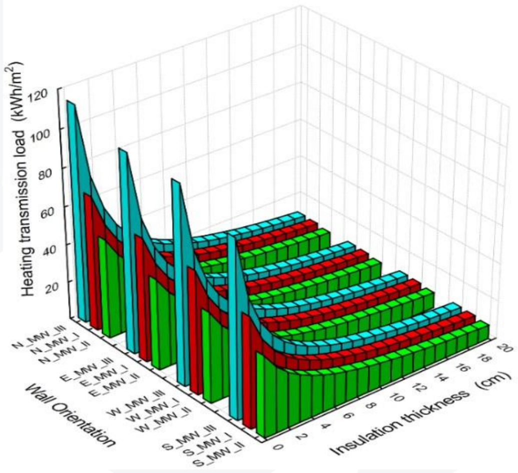

Figure 2 Heating transmission load for all wall configurations and orientations with mineral wool as the insulation material.

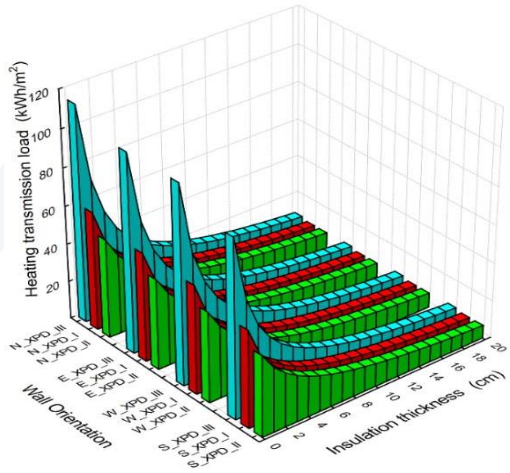

Figure 3. Heating transmission load for all wall configurations and orientations with expanded polystyrene as the insulation material.

ISSN: 2776-0979, Volume 4, Issue 6, June, 2023

Figures 2-3 and 4-5 refer to the heating and cooling load respectively and show that the wall type II (figure 1) has the lowest energy load per unit area of the wall, followed by the wall type I and then comes the wall type III. This result is independent of the insulation material used and is due to composition and its thermal conductivity value (Table 1). It should also be noticed that the starting point of the heating and cooling transmission loads corresponds to zero insulation thickness, referring to uninsulated walls, and thus the initial values are respectively identical.

Figures 6 and 7 present the results of the economic analysis for the mineral wool (MW) and expanded polystyrene (XPD) respectively. As the insulation thickness increases all curves initially display increasing NPVs, but the increasing rate declines as the insulation thickness increases, until it reaches a maximum point which denotes the optimum insulation thickness.

After the optimum point, a further increase of the insulation thickness continues to increase the fuel savings but the NPV decreases due to the rising cost of the intervention. The wall type III on north orientation and regardless of the insulation material used, has the greatest economic benefit compared to the corresponding wall types of different orientations and for all thicknesses of insulation studied. This is justified by the effect of the high heating load imposed by the wall and the system used to meet it, which in this study it is assumed to be a gas-fired boiler. Thus, in accordance with the above, the classification of the walls with respect to economic benefit (Fig. 6) resembles the classification for the heating load (Fig.2-3) but differs from that of the cooling load (Fig. 4-5).

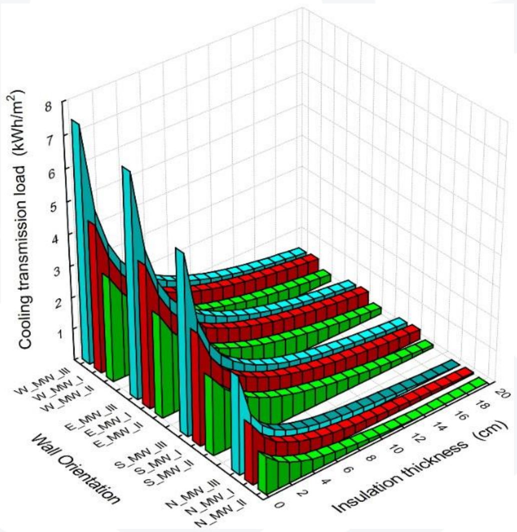

Figure 4. Cooling transmission load for all wall configurations and orientations with mineral wool as the insulation material.

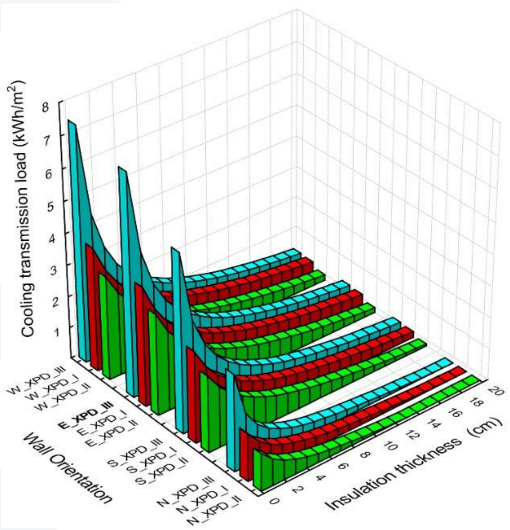

Figure 5. Cooling transmission load for all wall configurations and orientations with expanded polystyrene as the insulation material.

Furthermore, the wall with mineral wool (MW) displays the greatest economic benefit compared to the expanded polystyrene, for all orientations and insulation thicknesses studied. As can be seen in Figures 2 and 3, the use of expanded polystyrene in all three types of walls, and for all orientations and insulation thicknesses studied, presents a smaller heating load compared with the mineral wool. However, from the corresponding diagrams of the economic analysis (Fig. 6-7), the use of mineral wool presents greater economic benefits compared with the expanded polystyrene. This result is explained by the fact that expanded polystyrene has a higher cost compared to the mineral wool (Table 2). The wall type, optimum insulation thickness, NPV and payback period, for the two insulation materials and all orientations are tabulated in Table 3. The wall with the highest financial benefit has the smallest payback period when compared to all other orientations. From Table 3 and Fig. 8, it can be seen that the wall with mineral wool as insulation material, displays the shorter payback period for all orientations, regardless of its type. In addition, the south-facing wall has the smallest optimum insulation thickness and economic benefit, but also the longest payback period when compared to the other orientations. The results are within the range of similar estimates in literature [19, 23, 42, 43], despite the fact that they had been calculated by using a different methodology and climatic conditions. The optimum choice among the various orientations would be the one displaying the greatest monetary gains and/or the shortest payback period.

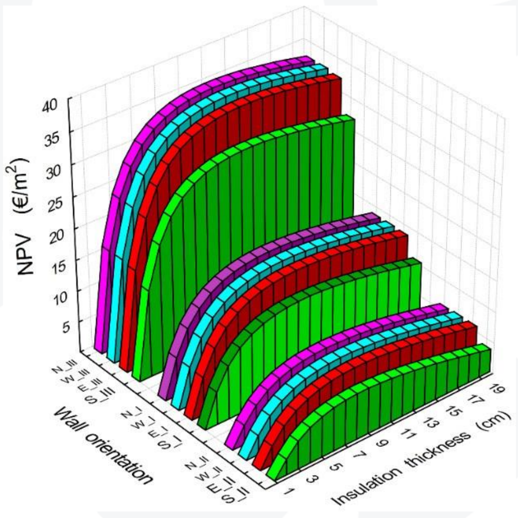

Figure 6. Economic analysis for all wall configurations and orientations with mineral wool as the insulation material

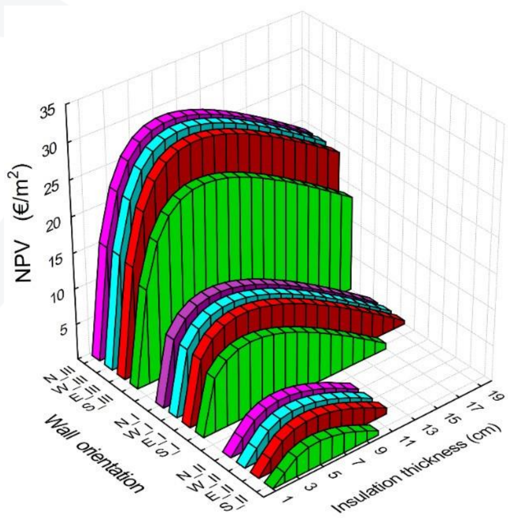

Figure 7. Economic analysis for all wall configurations and orientations with expanded polystyrene as the insulation material.

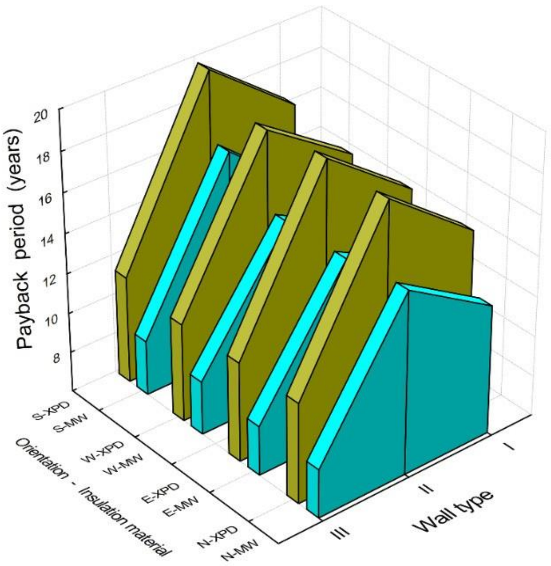

Figure 8. Payback period for all wall configurations and orientations, for both of the studied insulation materials.

Table 3. Optimum insulation thickness, NPV and payback period for all wall types, insulation materials and orientations

Orientation	Wall Type (Fig. 1)	Insulation material	Optimum insulation thickness (cm)	NPV (€/m2)	Payback period (years)
South	I	XPD	4.97	10.33	16.39
	I	MW	8.5	14.28	12.72
	II	XPD	3.75	4.76	19.79
	II	MW	8.0	7.50	16.38
	III	XPD	5.87	25.51	11.33
	III	MW	9.5	30.16	8.72
East	I	XPD	5.5	12.53	15.69
	I	MW	9.5	16.87	12.47
	II	XPD	4.5	6.04	18.96
	II	MW	8.0	9.73	14.75
	III	XPD	6.47	29.82	10.96
	III	MW	10.47	34.89	8.47
West	I	XPD	5.5	12.64	15.64
	I	MW	9.5	16.98	12.42
	II	XPD	4.37	6.08	18.57
	II	MW	8.0	9.77	14.72
	III	XPD	6.5	30.18	10.89
	III	MW	11.0	35.24	8.66
North	I	XPD	5.25	12.72	15.47
	I	MW	9.5	17.04	12.42
	II	XPD	4.25	6.16	18.83
	II	MW	8.0	9.79	15.14
	III	XPD	6.5	30.28	11.02
	III	MW	10.5	35.30	8.43

The U-value corresponding to the optimum insulation thicknesses for all wall types, insulation materials, and orientations is ranging between 0.314 W/m2K and 0.503 W/m2K, which is lower than the maximum permitted by the prevailing regulation [44] in Uzbekistan (0.75 W/m2K for vertical walls).

It is well known that one of the most efficient measures to reduce the thermal losses of the building envelope and, consequently, the CO_2 emissions from heating/cooling equipment, is the insulation of the external walls [45, 46]. With the proper selection of wall type, insulation material, and insulation thickness for each orientation, annual energy for heating/cooling system and CO_2 emissions can be significantly reduced, thus contributing to the concept of the “Green” Building [47]. Along with these measures, the large consumption of natural gas for space heating in Uzbekistan should be significantly reduced [48]. Given that Uzbekistan has a high solar potential [49], the used methodology which takes into account, among other parameters, the solar irradiance on the walls of different orientations, will be useful for energy saving studies in the building sector.

Conclusions

The economically optimum insulation thickness for the external walls of a residential building in Tashkent, Uzbekistan, has been determined by taking into account their construction, orientation, and different insulation materials.

For all wall types and insulation thicknesses examined, the north-facing wall with mineral wool as insulation material has the highest heating transmission load per unit area and the lowest cooling load per unit area than all other orientations. The south oriented wall with expanded polystyrene as insulation material has the lowest heating load per unit area and for all insulation thicknesses, in comparison to any other orientation and type of wall. In contrast, the west oriented wall with mineral wool as insulation material has the highest cooling load per unit area of any wall type and orientation.

The optimum insulation thickness for any type of wall and orientation was found to be between 3.75 cm and 11.0 cm. Generally, the installation of insulation to the exterior walls of a residential building in Tashkent proved to be a profitable investment since for all combinations studied the resulting net present value is positive, despite the low prices for heating and cooling energy. However, the north-facing walls of three wall types offer the greatest economic benefit compared to the corresponding walls of different orientation, regardless of the insulation thickness. Thus, it can be concluded that the wall with the largest heating load yields the greatest potential for economic benefits and has the shortest payback period, which in the present study is the north-facing wall of wall type III, with mineral wool as insulation material.

Finally, under the current economic circumstances that create the parameters considered in this paper, the implementation of adequate insulation on external walls of residential buildings appears to be a cost-effective energy conservation measure, for any type of wall and orientation studied and, in the case of Uzbekistan, could trigger great national energy savings and reduction of CO2 emissions.

References

1. A. Olivier, L. C. Ruggeri, and C. P. Trimble, "Balancing Act: Helping Households Cope with Rising Energy Prices in Europe and Central Asia," The World Bank, 2013.
2. M. Kenisarin and K. Kenisarina, "Energy saving potential in the residential sector of Uzbekistan," Energy, 32, pp. 1319-1325, 2007.
3. International Energy Agency. (2017, August 12). World Energy Statistics and Balances. Available: https://www.iea.org/statistics/relateddatabases/worldenergystatisticsandbalances/
4. Center for Economic Research, "Energy efficiency of buildings in Uzbekistan: energy saving capacity, direction of reforms and expected effects", Tashkent, Uzbekistan, 2015.
5. K. Usmanov, "Promoting Energy Efficiency in buildings in Uzbekistan," United Nations Development Programme in Uzbekistan, 20-21 April 2015.
6. Ministry of Finance of the Republic of Uzbekistan, "Registry No. 19-03-22-05-RUz-112-2013," Tashkent, Uzbekistan, 2013.
7. Ministry of Finance of the Republic of Uzbekistan, "Registry No. 19-03-22-06-РУз-55-2016," Tashkent, Uzbekistan, 2016.
8. Copenhagen Centre on Energy Efficiency, "Accelerating Energy Efficiency: Initiatives and Opportunities - Eastern Europe, the Caucasus and Central Asia," Copenhagen, Denmark 2015.
9. A. Hasan, "Optimizing insulation thickness for buildings using life cycle cost," Applied energy, 63, pp. 115- 124, 1999.
10. K. Çomaklı and B. Yüksel, "Optimum insulation thickness of external walls for energy saving," Applied thermal engineering, 23, pp. 473-479, 2003.
11. Ö. A. Dombaycı, M. Gölcü, and Y. Pancar, "Optimization of insulation thickness for external walls using different energy-sources," Applied Energy, 83, pp. 921-928, 2006.

12. A. Bolattürk, "Determination of optimum insulation thickness for building walls with respect to various fuels and climate zones in Turkey," Applied thermal engineering, 26, pp. 1301-1309, 2006.
13. A. Ucar and F. Balo, "Determination of the energy savings and the optimum insulation thickness in the four different insulated exterior walls," Renewable Energy, 35, pp. 88-94, 2010.
14. N. Sisman, E. Kahya, N. Aras, and H. Aras, "Determination of optimum insulation thicknesses of the external walls and roof (ceiling) for Turkey's different degree-day regions," Energy Policy, 35, pp. 5151-5155, 2007.
15. H. T. Ozkahraman and A. Bolatturk, "The use of tuff stone cladding in buildings for energy conservation," Construction and Building Materials, 20, pp. 435-440, 2006.
16. O. Kaynakli, "A study on residential heating energy requirement and optimum insulation thickness," Renewable Energy, 33, pp. 1164-1172, 2008.
17. B. B. Ekici, A. A. Gulten, and U. T. Aksoy, "A study on the optimum insulation thicknesses of various types of external walls with respect to different materials, fuels and climate zones in Turkey," Applied Energy, 92, pp. 211-217, 2012.
18. M. Ozel, "Effect of insulation location on dynamic heat-transfer characteristics of building external walls and optimization of insulation thickness," Energy and Buildings, 72, pp. 288-295, 2014.
19. S. Al-Sanea and M. Zedan, "Optimum insulation thickness for building walls in a hot-dry climate," International Journal of Ambient Energy, 23, pp. 115-126, 2002.
20. A. Ucar and F. Balo, "Effect of fuel type on the optimum thickness of selected insulation materials for the four different climatic regions of Turkey," Applied Energy, 86, pp. 730-736, 2009.
21. X. Kong, S. Lu, Y. Li, J. Huang, and S. Liu, "Numerical study on the thermal performance of building wall and roof incorporating phase change material panel for passive cooling application," Energy and Buildings, 81, pp. 404-415, 2014.
22. J. S. Carlos, "Simulation assessment of living wall thermal performance in winter in the climate of Portugal," in Building simulation, 2015, pp. 3-11.
23. N. Daouas, "A study on optimum insulation thickness in walls and energy savings in Tunisian buildings based on analytical calculation of cooling and heating transmission loads," Applied Energy, 88, pp. 156-164, 2011.
24. N. Daouas, Z. Hassen, and H. B. Aissia, "Analytical periodic solution for the study of thermal performance and optimum insulation thickness of building walls in Tunisia," Applied thermal engineering, 30, pp. 319-326, 2010.
25. I. Susorova, M. Angulo, P. Bahrami, and B. Stephens, "A model of vegetated

exterior facades for evaluation of wall thermal performance," Building and Environment, 67, pp. 1-13, 2013.

26. D. Anastaselos, S. Oxizidis, and A. M. Papadopoulos, "Energy, environmental and economic optimization of thermal insulation solutions by means of an integrated decision support system," Energy and Buildings, 43, pp. 686-694, 2011.
27. D. Anastaselos, E. Giama, and A. M. Papadopoulos, "An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions," Energy and Buildings, 41, pp. 1165-1171, 2009.
28. "TRNSYS 16 - A TRansient SYstem Simulation Program," ed, 2006.
29. Technical Instruction 20701-2/2010, Technical Chamber of Greece, 2010.
30. I. Axaopoulos, P. Axaopoulos, G. Panayiotou, S. Kalogirou, and J. Gelegenis, "Optimal economic thickness of various insulation materials for different orientations of external walls considering the wind characteristics," Energy, 90, pp. 939-952, 2015.
31. P. Axaopoulos, P. Panagakis, and I. Axaopoulos, "Effect of wall orientation on the optimum insulation thickness of a growing-finishing piggery building," Energy and Buildings, 84, pp. 403-411, 2014.
32. ASHRAE, ASHRAE Handbook of Fundamentals: Mar Lin Book Company, 1974.
33. C. Giaconia and A. Orioli, "On the reliability of ASHRAE conduction transfer function coefficients of walls," Applied thermal engineering, 20, pp. 21-47, 2000.
34. D. G. Stephenson and G. Mitalas, "Calculation of heat conduction transfer functions for multi-layers slabs," Air Cond. Engrs. Trans;(United States), 77, 1971.
35. A.-J. N. Khalifa, "Natural convective heat transfer coefficient–a review: II. Surfaces in two-and three- dimensional enclosures," Energy Conversion and Management, 42, pp. 505-517, 2001.
36. T. Defraeye, B. Blocken, and J. Carmeliet, "Convective heat transfer coefficients for exterior building surfaces: Existing correlations and CFD modelling," Energy Conversion and Management, 52, pp. 512-522, 2011.
37. W. H. Mcadams, Heat Transmission: 3d Ed: McGraw-Hill, 1954.
38. A. K. Athienitis, Thermal analysis and design of passive solar buildings: Routledge, 2013.
39. P. J. Axaopoulos, "Basic principles of solar geometry," in Solar thermal conversion, P. J. Axaopoulos, Ed., Athens, Greece: Simmetria, 2011.
40. J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes. New York: John Wiley & Sons Inc, 2006.

41. M. Ozel, "Determination of optimum insulation thickness based on cooling transmission load for building walls in a hot climate," Energy conversion and management, 66, pp. 106-114, 2013.
42. J. Yu, C. Yang, L. Tian, and D. Liao, "A study on optimum insulation thicknesses of external walls in hot summer and cold winter zone of China," applied energy, 86, pp. 2520-2529, 2009.
43. A. Halimova, M. Nürenberga, D. Müllera, J. Akhatovb, and Z. Iskandarovc, "Multi-Objective Optimization of Complex Measures on Supplying Energy to Rural Residential Buildings in Uzbekistan using Renewable Energy Sources" ISSN 0003-701X, Applied Solar Energy, 2020, Vol. 56, No. 2, pp. 137–148. © Allerton Press, Inc., 2020.
44. F. Liu and R. W. Tromop, "Uzbekistan - Scaling up energy efficiency in buildings: short-to-medium-term priorities and recommended actions (English)," The World Bank, Energy and Extractives Global Practice, Europe and Central Asia Region, 2016.
45. CA Balaras, AG Gaglia, E Georgopoulou, et al., "European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings," Building and Environment, 42(3): 1298–1314, 2007.
46. AM Papadopoulos, TG Theodosiou, KD Karatzas, "Feasibility of energy saving renovation measures in urban buildings: the impact of energy prices and the acceptable payback time criterio" Energy Build, 34(5), 455–66, 2002.
47. Definition of Green Building. https://archive.epa.gov/greenbuilding/web/html/about.html
48. Murat Kenisarina and Kamola Kenisarina, "Energy saving potential in the residential sector of Uzbekistan" Energy 32 (2007) 1319–1325.
49. E. Yu. Rakhimova, Sh. E. Sadullaevaa, Yu. G. Kolomietsb, Kh. K. Tashmatovc, and N. O. Usmonov, "Analysis of the Solar Energy Potential of the Republic of Uzbekistan " ISSN 0003-701X, Applied Solar Energy, 2017, Vol. 53, No. 4, pp. 344–346. © Allerton Press, Inc., 2017.