Determination of optimal thermal insulation layer thickness of outer structures of buildings according to the load of heating and cooling system

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Abstract - One of the key energy efficiency measures in residential buildings is to reduce the load on heating and cooling when in outer structures such as walls and ceiling a thermal insulation material is included in order to reduce the losses caused by heating and cooling, air and moisture penetration. It depends on the climate zone of the building, structural construction, heat and cold sources, prices for fuel and electricity in that region. It can be different in every specific case, so it is of high necessity to determine the optimal thickness of the used thermal insulation, the location of the installation. Below are the features and the need to introduce thermal insulation in newly constructed and operated buildings. The influence of the presence of thermal insulation in the construction industry on the cold load necessary for cooling and the pattern of changes in the cost with and without the presence of thermal insulation was investigated.

Introduction
About 35-40% of the world's total fuel is used in various types of buildings for the purpose of microclimate ensuring. In many settlements of Armenia, during the winter season, using traditional and non-traditional sources of heat, in conditions of low seasonal outdoor temperatures, significant amounts of natural gas are spent on heating buildings. As a result of raising the standard of living of the population, local or central-local air conditioners are widely used, mainly using low-temperature thermal potential of outdoor air, providing heating for individual buildings in high-rise and low-rise buildings, as well as hot water during the summer and transition periods. As a result, mainly using small electric household air conditioning, it becomes possible to ensure the load. This questions are considered in [2]:

The above mentioned shows that values of $R_{10}$ are rising in accordance with the increase of D, consequently the longer the heating season and the lower the outdoor temperature is, the greater is the need for thermal insulation of external structures with high-thickness thermal insulation materials and good thermal properties, oriented mainly to the thermal load during the heating season: However, the effect of insulation on the change in cold load during the cooling season is not taken into account, while the cost of cold is significantly higher and can significantly affect the energy performance of the district heating system.
The method of calculation
According to the above-mentioned the main purpose of this article has been figured out, namely to determine the optimal thickness of the insulation layer and the place of installation of structures under the influence of climatic zones and various factors according to energy performance, type of heat source and its energy efficiency. One of the possible options to reduce fuel consumption and energy for buildings is the option to improve the thermal performance of building structures using insulating materials.

These kind of We have been dealing with such research in the Soviet era, but the extremely low cost of fuel and its "inexhaustible" dimensions were preconditions for postponement of such measures. In the future, the results of other studies remained incomplete.

The optimum thickness of the thermo-technical properties and the thermal insulation materials were determined based on the minimum annual costs in case of $3_{\text{ter.ins.}}^\text{aver.seas} \rightarrow \text{min}$, in case of the given climatic conditions, the actual construction of the building, in accordance with the type of heat and cold supply system, the availability and price of insulating material on the market, fuel cost. Numerous studies have shown that they are incomplete because they do not take into account cooling problems, therefore the following phrase is proposed:

$$3_{\text{ter.ins.}}^\text{aver.seas} = \left((E_{\text{hit.seas.}} + k_{\text{hit.seas.}}), K_{\text{hit.seas.}}, (E_{\text{boil.}} + k_{\text{boil.}}), K_{\text{boil.}}, (E_{\text{tem.net.w.}} + k_{\text{tem.net.w.}}), K_{\text{tem.net.w.}} \right) +$$

$$(E_{\text{sour.cold}} + k_{\text{sour.cold}}), K_{\text{sour.cold}}, (E_{\text{HCS}} + k_{\text{HCS}}), K_{\text{HCS}}) + c_{\text{fuel}} \sum V_{\text{aver.seas}} + c_{\text{el.m.}} \sum N_{\text{aver.seas}}.$$

$/\text{years}$,

$K_{\text{hit.dev.}}, K_{\text{boil.}}, K_{\text{tem.net.w.}}, K_{\text{sour.cold}}, K_{\text{HCS}}$. Each of the capital investments can be determined by the technical project cost estimates or specific investments, unless there is any actual value thereof. $E_{\text{hit.seas.}}, E_{\text{boil.}}, E_{\text{tem.net.w.}}, E_{\text{sour.cold}}, E_{\text{HCS}}$ are normative factors of heating device, thermal insulation material, boiler, source of cold and heat and cold supply system that depend on their service life and can be 20, 25, 15 and 20 years, respectively.

$k_{\text{hit.seas.}}, k_{\text{boil.}}, k_{\text{tem.net.w.}}, k_{\text{sour.cold}}, k_{\text{HCS}}$ are the values that characterize the costs of restoring the materials, equipment and systems and constitute certain percent of the normative factors:

$K_{\text{hit.seas.}}, K_{\text{boil.}}, K_{\text{tem.net.w.}}, K_{\text{sour.cold}}, K_{\text{HCS}}$. Each of these investments decreases as the heat and cooling load decreases due to thermal insulation, as the heat exchangers of heating / cooling devices, boilers and cold sources, cold and heat supply system connections, heat networks, valves and pump performance are significantly reduced. $K_{\text{tem.net.w.}}$ Value however increases according to the thickness and type of heat insulation. Operating costs are attributable to actual fuel $c_{\text{fuel}} \sum V_{\text{aver.seas}}$ and electricity. $c_{\text{el.m.}} \sum N_{\text{aver.seas}}$ costs to meet heat and cold supply system requirements. They are significantly reduced as a result of insulation of the external structure, since heat losses, heat generation values, as well as the load on heating and cooling are so small that their seasonal costs are low. $\sum V_{\text{fuel}}$ of the fuel in the boiler, $\sum N_{\text{el.m.}}$ of electricity in refrigerating machine, electric pumps.

With the help of the 1st formula the necessary calculations were made for the building of the A-541 series in Yerevan, when the heating and cooling of the building were performed, and the thermal insulation material was made of foam plastic, $\lambda = 0.041 \text{ Watt/m} \cdot \text{temp}$. External wall structures with structural dimensions of individual layers and heat transfer coefficients without an insulating layer, which are shown in [2].

Similarly, the costs of operating the system, such as the fuel consumed in the boiler, the
compressor of the refrigeration compressor and the condenser, the electricity consumed in the electric motors of the pump that provides the thermal circuit. To determine the fuel equivalent of comparable options, we calculate fuel consumption for electricity generation in the equivalent of 1 kWh in natural gas equivalent of 0.35 m\(^3\) gas / kWh. The cost of fuel for comparable options was determined based on the assumption and possible changes in the cost of fuel used for small and medium-sized consumers - $200, $250 and $300/1000 m\(^3\). (currently it is 290).

**Optimal thickness determination in winter season and results analysis**

According to the method described above, the calculation of the above mentioned building has been carried out, the results of which are given in Pic. 2. Also the pattern of changes in the cost of building insulation for different types of boilers and thermal efficiency coefficients in the absence of insulation has been presented. It is clear from Pic. 2a that in the case of \(\delta_{\text{Li}} = 0\) the costs are significantly higher than the insulation. The higher the coefficient of thermal efficiency of the boiler, the lower the cost and the reduced coefficient of thermal efficiency from 0.92 to 0.88, which leads to an increase of 4%. In the case of the value of \(\delta_{\text{Li}} = 0.2\) m of insulator the change in the use of heat does not have a significant impact on costs, but they are reduced by 1.85 times compared with thermal insulation.[2]

This will be conditioned not only by a result of thermal transfer, but due to the reduction of losses in the wall as a result of air and moisture penetration processes which will be significantly reduced in case of thermal insulation. Additionally, in case of isolation, the wall decreases the risk of dew point and condensate, with some changes in the temperature field occurring there. Therefore, there is a need to determine the place of installation of the insulator. Taking into consideration [13, 14], appropriate studies have been carried out, which led to the fact that as a result of the penetration of air and steam into the protective sheath, heat losses increase by 8-13%, which requires compensation for an additional insulating layer. In this case the optimal thickness of the thermal insulation layer will be \(\delta_{\text{opt}} = 0.18\) m. The calculations for other settlements in Armenia have shown that the value of depends heavily on the climatic conditions, and the insulation of the structure is necessary after certain values of the wall heat transfer coefficient.

**Wall structure humidity analysis**

It should be noted that after the heat engineering and economic calculations of construction, the cost of \(\delta_{\text{opt}}\) should be determined in accordance with the humidity of the condensate zone to determine the likely range of condensate. For such areas, it is necessary to use not the calculation parameters of this climatic zone, but the monthly average temperature \(t_{\text{av},\text{mon}}\) and relative humidity \(\varphi_{\text{av},\text{mon}}\) of the coldest month. Such a change is due to the calculated winter period of temperature maintenance, which is different and very short in different climatic zones of Armenia. In particular, it's 10 days for Yerevan, 15 hours for Vendor and so on. During this time, under conditions of low intensity of water vapor flow, the construction will be in good condition will not be compromised its preservation. The possible range of condensate generation, in its turn, depends on the application of the insulating layer. It is usually assumed that it is placed outside the building so that the remaining layers are at positive temperatures, but in this case there is also insulation moisture, so it will have a partial loss of its thermal properties. In the case of buildings in operation, thermal insulation is technically difficult from the outside, and in some cases this is done indoors. The latter is clearly seen from the results of calculations for the above mentioned constructions.[2]

External building structures of new buildings should be designed in such a way that they have the optimal thickness of the heat seal layer corresponding to the climate zone and heat source. In order to reduce the effect of air permeability and vapor permeability, it is required to provide an evaporative layer after isolation in a constriction. It is most appropriate to place it in the center of the building, since it will avoid moisture insulation, if it has such a feature. No moisturizing material, for example,
foam resistant, does not need it, although it is a fire hazard. But when it is in the center of the building, it will be less dangerous. As a result of research, the design can be changed and presented as follows: [2]

The above refers to the processes occurring during the heating season, but the presence of insulation also contributes to the microclimatic conditions during the cooling season of the building. For Armenia, this is not an urgent problem for many residents, but for some of the population, as well as in developed countries, it is necessary to provide favorable conditions for the cooling season. During the calculations of the cooling load this season, we found it appropriate to take the air temperature \( t_{\text{ind,air}} = 24^\circ C \) in the room, then for different months of the season, heat exchangers with external building structures were calculated and the cold load was determined. As a cold source, a refrigeration unit was selected in which a supply of chilled water was pumped through a circulation pump to provide an integrated heating system for heating / cooling devices. Both the diameter of the internal network piping and the heat exchange surfaces of the heating / cooling devices were calculated for two seasons, and the largest of them was chosen as the defining area.

**Thermal insulation influence on cooling load**

External walls with ceiling structures, ceiling thermostats strictly depend on the type and thickness of the insulation material used in them, the air temperature at the site and the air temperature inside. Since the first of these can be changed during the months of the cooling season, it has changed in the computer-aided computing program, and the internal air has been maintained for the season and days. The building was located in Yerevan, therefore the climatic conditions were adopted: Polyfoam was used as a thermal insulation material for building structures considered in the course of calculations. Pic. 1 shows that the temperature in the climatic conditions of the city of Yerevan during the specified period and in the thickness of the insulation, along with the increase in thickness, decreases from 8.6 to 9.3% (except for June, when the temperature and solar radiation flows, compared to the contrast). This will mean that, as a result of thermal insulation, the average energy efficiency of the building’s cooling system will increase about 9.0%.

![Figure 1](image1.png)

**Figure 1.** A and B. Heat emission of residential building expressed by Watt/m \( ^\circ \text{C} \) and % (B) heat transfer ratio without heat insulation in the given month and given thickness of heat insulation layer in the climate conditions of Yerevan during the various months of the cooling season from May to September when foam plastic was applied for the purpose of insulation of external construction \( \lambda_{\text{opt}} = 0.041 \text{Wt} / \text{m}^\circ \text{C} \), and the thickness changed from \( \delta_{\text{opt}} = 0.00 \) to 0.05 m.

Since the thickness of the insulation for the heating season, according to the above calculations, was. \( \delta_{\text{opt}} = 0.15 \) m, it is necessary to compare the results obtained under these conditions. They are presented in Figure 1

As a result, the average energy efficiency of the building’s cooling system increased by 19.0%.
However, as is the case with the heating system, in this case there is no need to compare with the economic performance of cooling systems without thermal insulation, but with more concise characteristics, since the overall indicators have already been taken into account for the heating system. This will mean that only the economic performance of cooling systems should be taken into account without the cost of insulation and unloading. These include major investments in the source of cold, as well as the cost of electricity consumed by electric motors for the required cooling efficiency. Let's look at their solution.

![Figure 2. Heat emission of residential building expressed by Watt/m°C and %, in the climate conditions of Yerevan during the various months of the cooling when foam plastic was applied for the purpose of insulation of external construction $\lambda_{t,i}^{f,pl} = 0.041 \text{ Wt/m°C}$, and the thickness changed from $\delta_{t,i}^{f,pl} = 0.00$ to $0.05 \text{ m.}$](image)

If the external building constructions of the building are not thermal insulated, we will have the following: When calculating the refrigeration apparatus, we recognized that it serves as a working body for $R-22$, evaporation temperature in the cooling zone of the cooling system at a temperature of $5/12^\circ \text{C}$ will be $t_k^{CM} = t_{w_2}^a C$ , but condensation will be $t_k^{CM} = t_{w_4}^{hash} - \Delta t_{od} = 35 - (7 - 15^\circ \text{C}) = 50^\circ \text{C}$:

Under these conditions, according to [19], when the installed cold demand of a building is $20\%$ of the reserve capacity, that is, $64 \text{ kW}$, then the refrigeration compressor can serve a $4G-30.2-40P$ semi-winding compact compressor, whose electrical power is $21 \text{ kW}$ in cold and temperature it will consume $49,027.34 \text{ kWh}$ during different months of the cooling season, different condensation temperatures and cold needs.

When the external building constructions of the building are thermally insulated $\delta_{t,i}^{f,pl} = 0.15 \text{ m}$, we will have the following results: Approximate cold need of the building will decrease and amount to $53.4 \text{ kW}$. In the above-mentioned temperature conditions, the $4H-25.2-40P$ compressor will now require an electric motor with an electric current of $17.68 \text{ kW}$ at current needs and temperature conditions. As a result of thermal insulation, we will have a decrease in power of electric motors by $18.8\%$: During the months of the cooling season, it will consume $40,554.9 \text{ kWh}$ / compaction. or $20.9\%$ less electricity than the previous: This will mean that as a result of the thermal insulation, the power consumption of the system is reduced for the cooling mode, so this option is the most suitable.

$$
\begin{align*}
\delta_{t,i}^{f,pl} &= k_{SM} \cdot \left( E_{n_{zi}}^{hinn,miq} + k_{zv,miq} \right) + C_{SM}^{f,me} = 400 \cdot 64 \cdot 1.3 \cdot 0.083 + 49027.34 \cdot 0.3 \cdot 200/1000 = 5703.6 \\
\delta_{t,i}^{f,pl} &= k_{SM} \cdot \left( E_{n_{zi}}^{hinn,miq} + k_{zv,miq} \right) + C_{SM}^{f,me} = 400 \cdot 53.8 \cdot 1.3 \cdot 0.083 + 40554.9 \cdot 0.3 \cdot 200/1000 = 4755
\end{align*}
$$

As a result, due to the heat recovery of the external structure of the building, the costs will be...
reduced by 19.9%. The distributed cold cost will be proportional to the comparable options:

\[
\sum_{\text{maj}} Q^{\text{pl, plf}}_{\Delta t_i, b, \text{berv, cahs, berv}} = 27.91 \cdot 744 + 44.5 \cdot 720 + 50.77 \cdot 744 + 53.35 \cdot 744 + 37.6 \cdot 720 = 157342.3
\]

\[
\sum_{\text{maj}} Q^{\text{pl, opt}}_{\Delta t_i, b, \text{berv, cahs, berv}} = 23.55 \cdot 744 + 37.4 \cdot 720 + 42.74 \cdot 744 + 44.8 \cdot 744 + 31.5 \cdot 720 = 131708.4
\]

\[
\sum_{\text{maj}} Q^{\text{opt, cahs, berv, berv}} = 5703.6/157342.3 = 0.0363, \sum_{\text{maj}} Q^{\text{opt, cahs, berv, berv}} = 4755/131708.4 = 0.0361,
\]

As a result for comparable options, a decrease in seasonal expenses by 19.5% is reduced by 0.55%.

Summary
- In determining the optimal thickness of the heat insulation, the type of heat source, type of heating device, the features of heat and cold supply system should be taken into consideration.

  - In the case of $\Delta t_i = 0.00$ to 0.05 m thickness of the thermal insulation layer in climate conditions of Yerevan for the time period of May–September the cooling load of the building is reduced by 9%, therefore in the case of $\Delta t_{i, \text{opt}} = 0.15$ m optimal thickness by 19%.

  - In the case of thermal insulation thickness of 0.55%, $\Delta t_{i, \text{opt}} = 0.15$ m, the cost of cold cooling the building was 19.5%, while the cost of the system decreased by 19.9%, and the specific value was 0.55%.

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