## SCIENTIFIC RESEARCH

**УДК 69.003.12**

# STUDY OF SHELL FOR ENERGY EFFICIENT OF SUSTAINABLE LOW-RISE BUILDING

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**Abstract.** The article presents the results of study the shell for energy-efficient environmental low-rise residential building, corresponding to the criteria of sustainable development in construction. ***Purpose***. The purpose of the presented research is providing a study of parameters for shell of energy-efficient environmental low-rise buildings. ***Methodology***. Research is carried out on the basis of an improved method for calculating the thermal characteristics of the external walling, as well as physical heat transfer simulation. ***Conclusion*.**The ratio between the thickness of external walling and the proportion of heat loss through them was determined, and also the heat loss through thermal "bridges" was studied. ***Originality.*** The limits for the optimum thickness of the external walling of ecological materials was analyzed, and it was offered solution for minimization of heat loss through the nodes of shell. ***Practical value.***Recommendations are worked out on constructing of thermal shell at planning of energy-efficient low-rise residential buildings.

**Keywords:** *energy efficiency in construction; sustainable development; sustainable building; thermal shell of the building; reduced resistance to heat transfer*

# ВИВЧЕННЯ ОБОЛОНКИ ЕНЕРГОЕФЕКТИВНОЇ ЕКОЛОГІЧНОЇ МАЛОПОВЕРХОВОЇ БУДІВЛІ

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**Анотація.** У статті представлені результати дослідження оболонки енергоефективного екологічного малоповерхового житлового будинку, відповідає критеріям сталого розвитку в будівництві. ***Мета.*** вивчення необхідних параметрів оболонки енергоефективного екологічного малоповерхового будівлі. ***Методика.***

Дослідження виконані на основі на основі вдосконаленого методу розрахунку теплотехнічних характеристик зовнішніх огороджувальних конструкцій, а також фізичного моделювання теплопередачі. ***Результати.*** Визначено співвідношення між товщиною зовнішніх огороджувальних конструкцій і часткою теплових втрат через них, а також втрати тепла через термічні «мости». ***Наукова новизна***. Встановлена межа оптимальної товщини зовнішніх огороджувальних конструкцій з екологічних матеріалів, запропоновано оптимальні конструктивні рішення вузлів сполучення конструкцій будівлі з теплової оболонкою. ***Практична значимість***. Розроблено рекомендації щодо конструювання теплової оболонки при проектуванні енергоефективних малоповерхових житлових будинків.

**Ключові слова:** *енергоефективність в будівництві; сталий розвиток; екологічна будівля; теплова оболонка будівлі; приведений опір теплопередачі*

# ИЗУЧЕНИЕ ОБОЛОЧКИ ЭНЕРГОЭФФЕКТИВНОГО ЭКОЛОГИЧЕСКОГО МАЛОЭТАЖНОГО ЗДАНИЯ

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***Аннотация.*** В статье представлены результаты исследования оболочки энергоэффективного экологического малоэтажного жилого здания, соответствующего критериям устойчивого развития в строительстве. ***Цель.*** Изучение необходимых параметров оболочки энергоэффективного экологического малоэтажного здания. ***Методика.*** Исследования выполнены на основе усовершенствованного метода расчета теплотехнических характеристик внешних ограждающих конструкций, а также физического моделирования теплопередачи. ***Результаты***. Определены соотношение между толщиной внешних ограждающих конструкций и долей тепловых потерь через них, а также потери тепла через термические «мосты». ***Научная новизна***. Установлен предел оптимальной толщины внешних ограждающих конструкций из экологических материалов, предложены оптимальные конструктивные решения узлов сопряжения конструкций здания с тепловой оболочкой. ***Практическая значимость.*** Разработаны рекомендации по конструированию тепловой оболочки при проектировании энергоэффективных малоэтажных жилых зданий.

**Ключевые слова:** *энергоэффективность в строительстве; устойчивое развитие; экологическое здание; тепловая оболочка здания; приведенное сопротивление теплопередачи*

**Introduction.** In recent years, the issues of energy saving and energy efficiency policies have acquired special urgency in Europe and are directly linked not only with global environmental problems, but also with energy security.

Scientists and experts in numerous seminars and conferences, both national and international levels, are actively discussing various aspects of the energy-efficiency problem. The latest among these activities was the Climate Conference in Paris in 2015 (COP21), the results of which have been adopted by a number of solutions to reduce greenhouse gas emissions (GHE), the main cause of which is the production of oil and gas - the most common source of energy.

Buildings and communal services is one of the most energy-intensive sectors of the economy. In Ukraine and the countries of the European Union from 30 to 40% of total energy, consumption is spending in the operation of the building complex. However, the structure of these costs is fundamentally different in our country. In developed countries, a significant part of the energy is spending on ensuring the comfort of human life - a sub-holding of the normal temperature, both in winter and in the warmer months, to work appliances. In our country, the vast majority of energy is spending only for space heating at a low level to ensure comfortable heat and humidity parameters.

The economic crisis, increasing energy prices, irreversible environmental degradation of the planet make people to create new construction projects that would be economically viable in their construction, operation, utilization, and create a comfortable environment for human habitation, and were established in accordance with the concept of sustainable development.

There is a high cost of engineering equipment for the use of renewable energy sources on the market of Ukraine.Moreover,by the results of previous studies it has quite a long payback period.[1]That`s why for the wider dissemination of energy-efficient building at the national level, it is necessary to examine the best possible optimization of the thermal performance for the building shell. Itmay permit to achieve a high level of energy efficiency only through the efficient solutions of exterior building`s walling. In addition, the use of local organic materials from renewable resources is an opportunity to reduce costs and expenses of energy at the stage of construction of the building and its recycling.

**Research purpose.** The aim of the presented research is providing a study of parameters for shell of energy-efficient environmental low-rise building.

In accordance with this aim the following specific objectives were formulated:

- providing the analysis of possible optimization the thickness of the shell for energy-efficient environmental low-rise building;
- evacuation of modeling study of the heat loss through thermal "bridges" to minimize their effect to the energy-efficiency of the building shell;
- propose the recommendations for constructing of thermal shell at planning of energy-efficient low-rise residential building.

**Methodology.** The main arguments in the article are developed by applying an improved method for calculating the thermal characteristics of the external walling, as well as physical heat transfer simulation.

**Conclusion.** Energy-efficient building includes a set of architectural planning, design and engineering solutions that meet the goals to ensure a comfortable microclimate and minimal energy consumption in the building premises.

**The architectural and planning solution** includes: correct orientation of the building, compactness of the building, lack of jetties, zoning of the internal spaces, presence of elements of the summer sun protection as an independent structure, well-isolated thermal shell of the building, use of the terrain and vegetation.

**The design solution** includes the creation of a continuous shell of a building with high thermal insulation, with thermal "bridge" which are absent or reduced to a minimum.

For energy-efficient buildings is preferable to frame technology unit wall using environmentally friendly natural materials such as wood, soil-concrete. Eco-friendly, energy-efficient thermal shell is formed by filling the space between the uprights with environmental organic insolation material - cereal straw, hemp or flax fire, cane chaff and others.

The tightness of the thermal shell is provided: inside –by device protective layers of vapor barrier, thermal capacitance designs of soil-concrete blocks or bricks and plaster; outside –by device protective layers of wind-protection and facade decoration.

**The engineering solutions** include different systems such as heat pumps, solar and geothermal collectors, solar panels, wind turbines, etc.

**Study of shell thickness for energy-efficient sustainable building.** Designing of the heat-insulating shell for building on thermotechnical parameters of its elements includes a number of conditions [2]:

$$R_{\Sigma пр} \geq R_{q\min}, \quad (1)$$

where $R_{\Sigma пр}$ – reduced R-value, $m^2K/W$;

$R_{q\min}$ – the minimum acceptable value of resistance of heat transfer.

From the point of view of energy efficiency, the rational design of heat-insulating building envelope requires that all non-transparent fence to have the same resistance to heat transfer, which is achieved by appropriate selection of the thickness of the insulation. We assume that the heat transfer resistance of the attic and basement floors equal to the resistance to heat transfer of walls, which in turn is determined by the formula (2).

Fig. 1 shows the dependence of the reduced thermal resistance $R_{\Sigma пр}$ of the thickness of insulation $\delta_2$.

The relationship is nonlinear: with an increase $\delta_2$ in the growth rate $R_{\Sigma пр}$ decreases significantly. This is due to the heat of the cost through a translucent fencing. The dimensionless fraction of heat loss through the opaque $\overline{q}_{нп}$ and translucent $\overline{q}_{сп}$ building shell are:

$$\overline{q}_{нп} = \frac{F_{нп}}{R_{нп}}\left(\frac{F_{нп}}{R_{нп}} + \frac{F_{сп}}{R_{сп}}\right)^{-1}, \quad \overline{q}_{сп} = \frac{F_{сп}}{R_{сп}}\left(\frac{F_{нп}}{R_{нп}} + \frac{F_{сп}}{R_{сп}}\right)^{-1}.$$

Fig. 2 shows the dependence $\overline{q}_{нп}$, $\overline{q}_{сп}$ of the insulation thickness $\delta_2$.

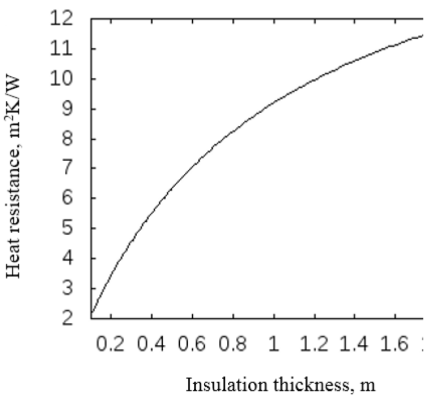



*Fig. 1. The normalized thermal resistance*

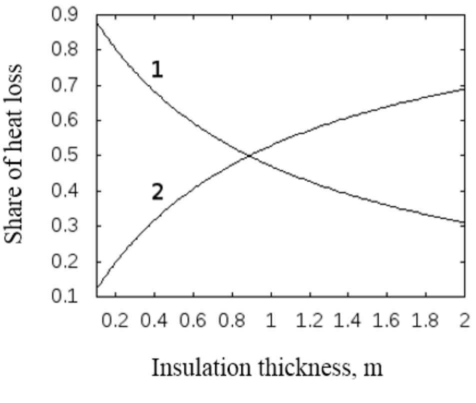



*Fig. 2. Rates of the heat flow throw opaque (1) and translucent (2) fences*

Analysis of the results shows that a relatively small thickness of the insulation (0.3-0.4m) when given thermal resistance $R_{\Sigma пр}$ close to the minimum value $R_{q\min}$, the vast majority of the costs of heat occurs through the opaque part of the outer fence. In this case, increasing the thickness of the insulation can significantly enhance $R_{\Sigma пр}$ and improve the energy efficiency of the house. When the insulation thickness is greater than 1m, the bulk of spending is on heat translucent enclosures and therefore an increase in the thickness of insulation does not result in a significant increase $R_{\Sigma пр}$. In this case, to improve energy efficiency of building, you must first increase the thermal resistance of translucent enclosures.

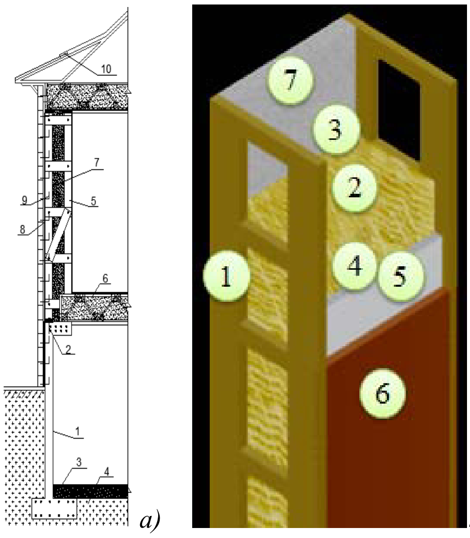
**Studies of heat loss through the nodes for environmental building shell.** Calculations of heat loss through the shell of building were carried out according to the procedure laid down in the normative document [3].Study of structural coupling nodes, where the formation of cold bridge is possible was realized using Elcut software package. [4] Analysis was provided for the building with the following design solution.

The design concept of the house - a wooden frame. Exterior walls are three-dimensional frame structure prefabricated, which consists of wooden pillars of the "ladder" shape in increments of 500 mm, filled with insulating material of hemp. The thickness of the wall fence - 500 mm. Interior and exterior walls - brick 120 mm.

Overlap the floor, overlapping the attic floor and the truss is wooden trusses 500 mm with fastening elements to the wall frame on metal toothed plates. Thermal insulation and sound insulation design provides cross-farm filling space in the same insulating material as the house walls. The height of the truss ceiling - 600 mm, roof trusses - 500 mm. On the outer and inner sides protecting load-bearing structures are sheathed film for hydro and wind protection and sheathed OSB plate 20 mm thick.Coverage of the roof - slabs of reeds.

Windows and doors - made of metal or wood with glass. Glazing - triple with low-emissivity coated glass and filled with an inert gas. Thermal resistance of glass Rpr = 0.85 m2 · K / W [5].

Figure 3 shows the general construction-planning solution of energy-efficient low-rise building. We investigated the window to the wall interface assembly (node) - determined the optimal location of the windows on the width of the wall (Fig.4)




a) b)

*Рис. 4. Construction of low-storey building:*
*a) a vertical section through the outer wall:*
*1 - foundation; 2 anchor for fastening the frame to the foundation; 3 - technical underground floor;*
*4 - waterproofing and protection antiradon barrier;*
*5 - wooden frame "ladder" type;*
*6 - farm overlap; 7 - thermal insulation;*
*8, 9 - frame elementss; 10 - roofing;*
*b) Wall construction:*
*1 - Front wooden frame 2 - thermal insulation, vapor barrier 3 and 4 - windscreen;*
*5 – base net, 6 - clay plaster, 7 - internal finishing*

For determination the location of the window frame of rational thickness of the outer wall of heat engineering calculations were made for the following options:

1. Scheme 0 (standart): framing the window opening - cement - sand mortar, the location of the window frame - in the middle.
2. Scheme 1 (-200_utepl): insulation thickness of 40 mm from the negative temperature, insulation thickness of 20 mm from the zero temperature, the window frame is shifted by 200 mm from the central position in the direction of the minus temperature.
3. Scheme 2 (-150_utepl): thickness of insulation is identical, the window frame is shifted by 150 mm from the central position in the direction of the minus temperature.
4. Scheme 3 (centr_utepl): thickness of insulation is identical, the location of the window frame - in the middle.
5. Scheme 4 (+ 150_utepl): thickness of insulation is identical, the window frame is shifted by 150 mm from the central position towards the positive temperature.
6. Scheme 5 (+ 200_utepl): thickness of insulation is identical, the window frame is shifted by 200 mm from the central position towards the positive temperature.

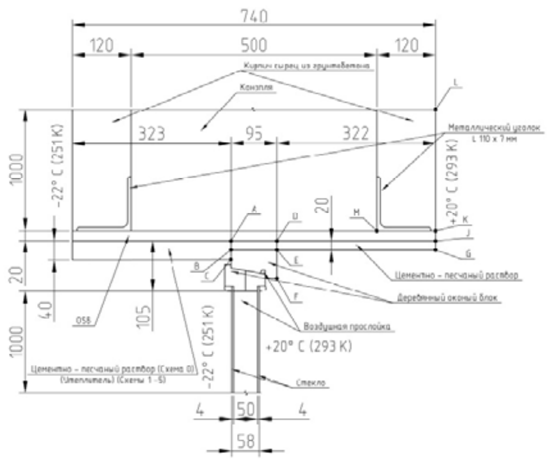
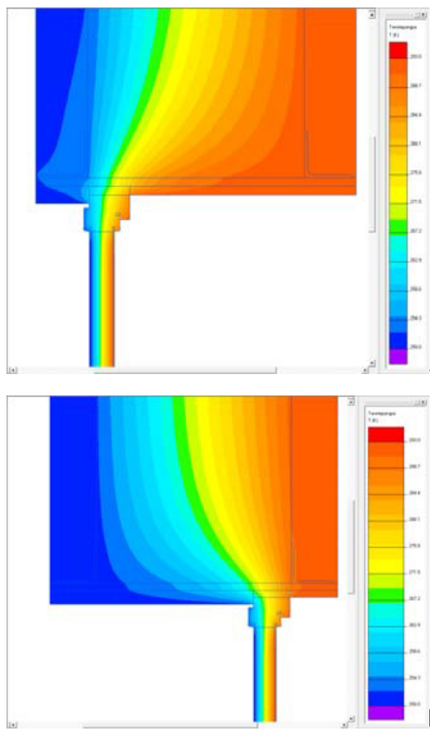



*Рис.4. Structural decision of node interface of window with a wall*



a)

b)

*Fig. 5. Temperature field for variants:*
*a) Schema 1 (-200_utepl); б) Schema 5 (+200_utepl)*

The criterion for evaluating the rational arrangement of the window frame were the heat flux passing through the segment and LG teperatury value at characteristic points: A, B, C, D, E, F, G, J, K, L and M.

The calculation results are shown in Fig. 5 and Table.1.

The calculation results indicate that the optimal location of the window at this constructive solution is the central location of the window on the wall thickness (Figure 1), since the total heat flow through the interface "wall-box" unit is minimal - 5.7 W (Table 1.).

*Table 1*

***Thermal characteristics of the host interface options "window-wall"***

| № Schema | The temperature in the characteristic points of the structure, °C | | | The heat flow through the segment EGJKL, W |
|---|---|---|---|---|
| | E | G | L | |
| 0 | 15,27 | 19,85 | 19,46 | 7,50 |
| 1 | 13,48 | 19,99 | 19,47 | 5,70 |
| 2 | 14,08 | 19,99 | 19,47 | 6,06 |
| 3 | 14,55 | 19,98 | 19,46 | 6,41 |
| 4 | 15,10 | 19,95 | 19,45 | 6,17 |
| 5 | 15,76 | 19,93 | 19,45 | 6,80 |
| | | | | |

In order to select a rational constructive solution for low-rise residential buildings we considered two options of nodal connection with the foundation of the building and outer wall. The node "wall-foundation" is the most vulnerable point in the thermal shell of the building, since it is possible the formation of "bridges". *Option one* - heat insulation of the basement of the building from the outside; *second option* - the outer wall of the building is insulated from the inside from the base (floor) insulation foam glass.

For the considered node interface options "foundation-wall" it was obtained values of heat flux passing through the connection node, the temperature differential across the inner surface of the coupling assembly designs and linear heat-transfer coefficient.

Constructive unit solution pairing options "wall-foundation" and the results of the calculations are presented in Table. 2.

Analysis of the results of the calculation shows that the option 2 is more efficient in terms of thermal performance.It`s linear coefficient of heat transfer is in 37.5% lower compared with the option 1. Moreover,the value of the temperature drop at the inner surface of the node option 1 does not satisfy the requirements of [6].

**Originality and Practical value.** The study analysed the problem constructive elements of shell to make rational design of energy-efficient environmental low-rise building.

The limits for the optimum thickness of the external walling of ecological materials was provided, and it was offered solution for interface design of building structures with a thermal jacket.

Recommendations are worked out on constructing of thermal shell at planning of energy-efficient low-rise buildings and outlined in the conclusions.

**Conclusions.**

1. For the wider dissemination of energy-efficient building at the national level, it is necessary to examine the best possible optimization of the thermal performance for the building shell. It may permit to achieve a high level of energy efficiency only through the efficient solutions of exterior building`s walling without expensive engineering equipment.

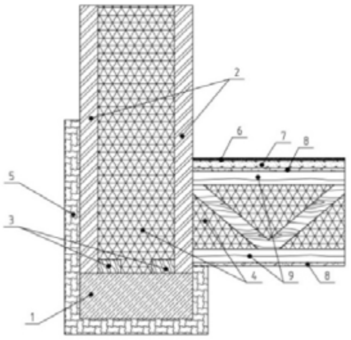
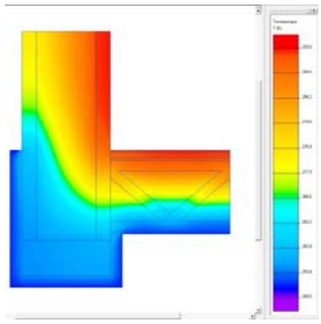
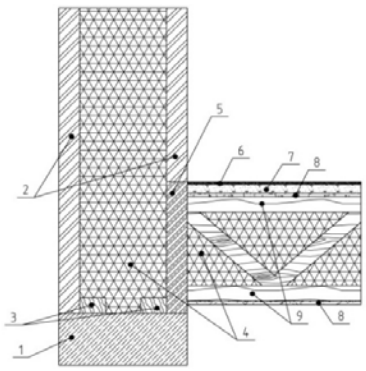
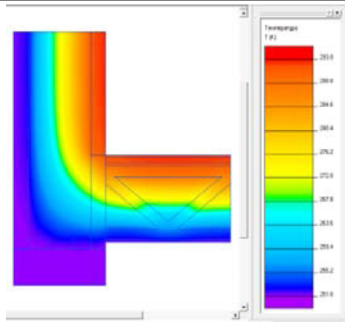
2. When the thickness of the insulation exceeds 1m, the bulk of the heat loss falls on translucent enclosures and therefore increasing the thickness of insulation does not result in significant growth. In this case, for energy efficiency the heat resistance of translucent enclosures should be increased.

3. The calculation results indicate that the optimal location of the window at this constructive solution is the central location of the window on the wall thickness.

4. Analysis of the results of the calculation shows that the option when outer wall of the building is insulated from the inside with foam glass is more efficient in terms of thermal performance. It`s linear coefficient of heat transfer is in 37.5% lower compared with the option when heat insulation of the basement of the building is realized from the outside with mineral wool.

*Table 2*

***The Structural decision and heating engineering descriptions of variants knot of interface "wall-foundation"***

| Constructive decision of node "wall - foundation" | Description of constructive element | Thermal performance of node "wall - foundation" |
|---|---|---|
| Option 1 - building foundation insulation from the outside | | |
|  | 1.concrete foundation<br>2.soil-concrete<br>3.wooden bar<br>4.insulation - hemp<br>5.Insulation - mineral wool<br>6 Ceramic tiles<br>7 Fibrous concrete<br>8 OSB plate<br>9 Wood Farm | <br>Linear heat transfer coefficient :<br>k= 0.08 W/mK.<br>The temperature drop across the inner surface of the structure: $\Delta t_{cr} = 3K$ . |
| Option 2 - thermal insulation on the inside of the glass foam insulation | | |
|  | 1.concrete foundation<br>2.soil-concrete<br>3.wooden bar<br>4.insulation - hemp<br>5.Insulation – foam glass<br>6 Ceramic tiles<br>7 Fibrous concrete<br>8 OSB plate<br>9 Wood Farm | <br>Linear heat transfer coefficient :<br>k= 0.05 W/mK.<br>The temperature drop across the inner surface of the structure : $\Delta t_{cr} = 2K$ . |

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Надійшла до редколегії: 11.01.2016 р. Прийнята до друку: 16.01.2016 р.