

## APPLICATION OF CORK AS AN ECOLOGICAL MATERIAL IN THERMAL INSULATION OF BUILDINGS

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### Abstract

In this paper, the possibility of using an environmentally friendly material - cork as a thermal insulation material for buildings will be pointed out. In today's world, energy efficiency and ecology are two of the most important problems facing our society. The great and growing need of society for construction and housing has raised the need for the use of innovative building materials in order to preserve the environment, reduce operating costs, i.e., life in them.

The need for energy is increasing, with the energy becoming more expensive and there is less and less conventional energy, energy crises are becoming more frequent, and the environment is becoming more polluted. Therefore, there is a need to reduce energy consumption and find ways to generate energy that are sustainable and environmentally friendly.

Energy efficient and environmentally friendly thermal insulation materials play a key role in reducing energy consumption and solving climate changes. The most energy-efficient and environmentally friendly insulation materials are those made from renewable or recycled resources, they have low built-in energy and a long lifespan.

KEYWORDS: Energy efficiency, insulation materials, ecology, energy.

### Introduction

Energy efficiency is the sum of planned and implemented measures, the ultimate goal of which is to use the minimum possible amount of energy so that the level of comfort and living conditions are not impaired. In essence, energy efficiency means the use of less energy (energy products) to perform the same work with the same comfort.

The role of energy efficiency is very important, both from the point of view of economic development, and in relation to solving many important environmental issues such as climate changes.

The energy efficiency of buildings depends on the thermal properties of its envelope, the characteristics of the energy systems in it, but also on the climatic conditions of the area where the building is located.

Buildings are the largest single consumers of energy, with a tendency to increase in line with rising population standards. In addition, buildings are major polluters of the environment, and that is precisely why energy efficiency in buildings is the area that has the greatest potential for reducing energy consumption and reducing environmental pollution.

In the European Union, around 26% of energy is consumed in the building industry, while in Serbia, it is around 35% of the total energy consumption [5], [7]. The trend must be stopped as much as possible with the use of environmentally friendly insulation materials.

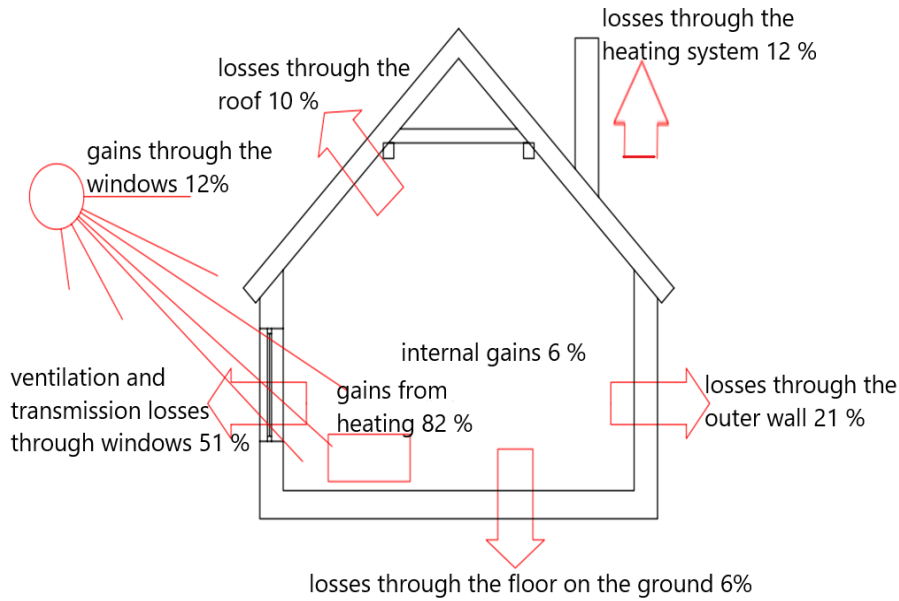


Figure 1. Heat losses and gains in the facility during the heating season [8]

The most important measure that can be used to improve the energy efficiency of buildings is the application of adequate thermal insulation materials. Furthermore, the shape of the building, thermal bridges as well as the building shape factor play an important role.

$$F_o = \frac{A}{V_e} [m^{-1}]$$

Where:  $F_o$ - shape factor,  $A$  – usable area [ $m^2$ ],  $V_e$  – heated volume [ $m^3$ ].

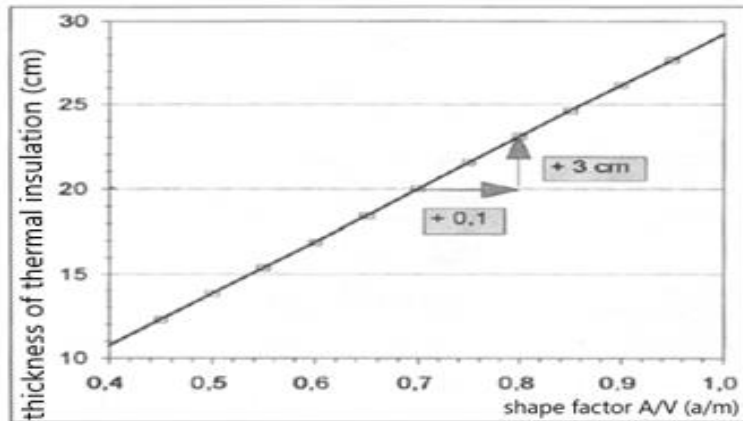


Figure 2. Dependence of the shape factor and thermal insulation thickness [12]

We can see that with an increase in the shape parameter by 0.1, the thickness of the thermal insulation that we will install for the walls of the building should be increased by a whole 3 cm (EPS).

## In general about cork

Some insulation materials are made from non-renewable resources, and the process of production and use can create harmful environmental consequences. The selection of natural insulation material is important in order to reduce the negative impact on the environment.

The concept of ecological and energy-efficient construction is a future concept that will be necessary if we want to preserve the planet and the environment for future generations. The use of cork as thermal insulation helps to create a healthier and more sustainable future, reducing the harmful impact of construction on the environment. The use of expanded cork, as well as cork as a whole, can definitely help us in this.

Cork (*Quercus suber*) is a completely renewable, natural material, obtained from the bark of the cork oak tree, which grows in Spain, Portugal, Italy, France, Algeria, Tunisia and Morocco. It can be said that it is an exceptional material in terms of ecology. Scraping off the outer layer of dead bark does not damage the tree itself, so the cork layers can be scraped from the same tree every 9 to 15 years, and it still continues to grow. [12]

The microstructure of cork contains a large number of cells, about  $40 \times 10^6 / \text{cm}^3$ , and about 50% of these cells are made up of air. This structure gives cork exceptional lightness, making it a good sound and heat insulator. Cork is a naturally elastic material, which means it can absorb shock and pressure. This property makes cork comfortable to walk on and stand on, and is often used in flooring to provide comfort. It has a low thermal conductivity, which means it makes it difficult for heat to pass through. This property contributes to thermal insulation.

In short, cork combines its microstructural features, elasticity and other characteristics to provide good sound and thermal insulation, with the addition of comfort for walking and standing. This makes it a popular material in various industrial sectors.

This type of oak is the only tree that is able to develop normally and live without its "coat", i.e. its bark, often for over 200 years. Even more interesting is that the bark is removed from the tree every 9 to 15 years - the period it takes to fully regenerate. The life cycle of cork as a raw material begins with the extraction of cork oak bark. Harvesting takes place during the most active phase of cork growth, from mid-May or early June to mid- or late August.

It takes almost 25 years for a cork oak trunk to start producing cork. Each trunk must reach a circumference of about 70 cm at a height of 1.30 m above ground level.

The first harvest, which produces cork of a very irregular structure is too hard to be easily processed. The second harvest produces a material with a regular structure, less hard - this is known as secondary cork. It is from the third and subsequent harvests that the cork with the best properties or reproduction cork is obtained. Throughout the process, it is absolutely crucial to take all necessary precautions to avoid damaging the trees, damaged cork oak can no longer be used for corking. For this reason, harvesting is done only by highly qualified experts. At the end of the harvesting process, each tree is marked with the last number of the year in which the harvesting was done, so that it is possible to know when the procedure will be repeated. [19]



Figure 3. Removing the bark of the cork oak tree      Figure 4. - Bark of the cork oak

Cork for insulation is produced by grinding the peeled bark into granulate, which is then treated with hot steam. They are then pressed into planks and boards, which causes the cork to expand. Then the suberin, which is in the composition of cork, is activated and as a natural binder joins the granules and thus cork blocks are formed. Therefore, no other binders or chemicals are used in the production of cork for insulation, nor is anything disposed of as waste because everything is returned to the production cycle. Almost all parts that remain in the production itself can be used further. For example, producers use small scraps of bark for the so-called pressed cork. Cork can be mixed with recycled rubber granulate, which gives a special structure to the floors.



Figure 5. Cork roll with recycled rubber granulate



Figure 6. External insulation made of cork

Table 1. Comparative view of the coefficients of different thermal insulation materials, [3]

Naziv termoizolacionog materijala	Koeficijent toplotne provodljivosti $\lambda$ (W/mK)	Gustina $\rho$ (kg/m <sup>3</sup> )
pluta	0,041-0,044	120-160
expanded polystyrene (EPS)	0,041	15-30
extruded polystyrene (HPS)	0,035-0,038	33
mineral wool	0,032-0,039	14-180
cellulose fibers	0,04	80
Sheep's wool	0,04	20
wood	0,14-0,21	500-800
concrete	0,93-2,33	1800-2500
steel	53,5	7800

Table 1 shows that the coefficient of thermal conductivity of cork is approximately the same as the coefficients of thermal conductivity of traditional thermal insulation materials.

Due to its relatively high density, cork insulation is ideal for areas where the insulation is subjected to high pressure loads. It is resistant to different weather conditions. Examples of cork insulation are: internal/external wall insulation, roof insulation, ceiling insulation, cavity insulation, floor insulation, and indoor sound/heat insulation.



Figure 7. Cork as the final layer of the floor



Figure 8. Cork as a decorative interior

Since cork has a strong sound absorbing effect, it is often used to insulate ceilings and floors, where it protects against impact noise.

It is not recommended to install cork in bathrooms and similar rooms where there is a lot of moisture, because cork, although resistant to moisture, can be damaged over time after years of exposure to large amounts of moisture.

Cork can be easily installed with or without gluing, and the finish of the surface layer allows for easy maintenance and cleaning. Cork floors are also suitable for installation on a base with underfloor heating. The lifespan is several decades.

Cork is known not only as an excellent sound and thermal insulator, but also as a material that can also be a decorative wall covering that will offer the space a real cosiness and warmth, as well as a modern and sophisticated design.

In the case of wall coverings, the original appearance of cork can be kept or it can be repainted if the panels have not already been factory processed, i.e. waxed or varnished. It is also a perfect decoration when it comes to office or work spaces.

Table 2. Advantages and disadvantages of cork [12]

Advantages of cork	Disadvantages of cork
Environmentally friendly, cork is a natural material obtained from the bark of the cork tree, thus reducing the need to use resources such as plastic or other artificial materials.	High cost, the process of producing cork can be expensive, which can result in higher prices.
It is an exceptional thermal insulator; it can have unchanged thermal performance for up to 50 years.	Limited availability, the possibility of reusing bark every 9 to 15 years.
It does not retain dust nor does it cause allergic reactions in children or adults,	Limited strength, although cork is elastic, so minor damage, such as those caused by a tool or knife, will "heal", major damage will have to be repaired by replacing damaged boards.
It has anti-allergic properties, cork is naturally resistant to dust, mites and other allergens, making it a good solution for people with allergies.	
It allows steam and air to pass through.	Sensitive to UV radiation, it can change colour and texture under the influence of long-term exposure to sunlight.
It is easy to cut and shape, therefore easy to install.	
It is resistant to atmospheric effects	Cork can absorb moisture, so it can become deformed or damaged if exposed to water or wet conditions for long periods of time.
It burns hard	
It has exceptional vibration resistance	

### Numerical implementation

The calculation of the required amount of energy for heating for the existing building was carried out, and then the energy reconstruction was performed using cork. The calculation was made according to the Rulebook on Energy Reconstruction of Buildings. [3]

The necessary amount of heat for heating is supplied to the room in order to maintain the desired temperature of the indoor air. That amount of heat is called heat losses in the terminology used in the practice of thermo-technical engineers.

The heat transfer coefficient of the building element,  $U$  [ $W/(m^2 \cdot K)$ ], is calculated, in the general case, for the construction element.

$$U = \frac{1}{R_{si} + \sum \frac{d}{\lambda} + R_{se}}$$

where:  $d$  is material thickness (m),  $\lambda$  is thermal conductivity coefficient ( $W/(m \cdot K)$ ),  $R_{si}$  is resistance to the heat transfer, internal ( $m^2 \cdot K/W$ ),  $R_{se}$  is resistance to the heat transfer, external ( $m^2 \cdot K/W$ )

Table 3. Data on the facility

Facility type	New construction
Elevation	500 [m]
Construction year	2022
Location	Tutin, Serbia
External design temperatures $\theta_e$	-23.7 [°C]
Internal design temperatures $\theta_i$	+22.0 [°C]
Average temperatures for the heating period $\theta_{H,mn}$	+4.6 [°C]
Number of heating days HD	220
Number degree days HDD	3371
Number of wetting days	60
Number of drying days	90

Wall thermal calculation (before additional thermal insulation)

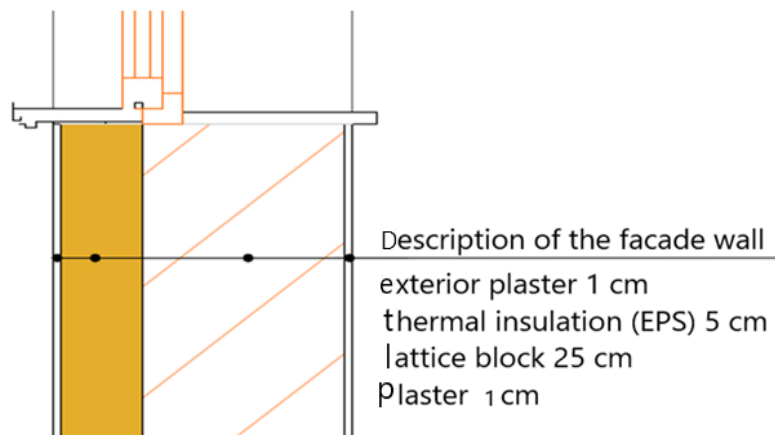


Figure 9. Wall cross-section

$$U = 0.493 \frac{W}{m^2 \cdot ^\circ C}, \quad U_{max} = 0.3 \frac{W}{(m^2 \cdot ^\circ C)}$$

$U > U_{max}$ , the wall does not meet the prescribed value, additional thermal insulation is required.

Then, the calculation of the passage of heat through the complete wall was made and the cross-section of it was drawn.

Table 4. Thermal characteristics of wall layers

slojevi	$\lambda$	$d$	$R = \frac{d}{\lambda}$	$h_i = \frac{1}{R}$
plaster	1.40	0.01	7,14	0,14
EPS	0.035	0.05	1.42	0.70
lattice block	0.61	0.25	0.41	2.44
plaster	0.85	0.01	0.01	85.0
cork	0,041	0,08	1,95	0,51

where: R is the resistance to heat transfer ( $m^2 \cdot K/W$ ),  $h_i$ - heat transfer coefficient, internal ( $W/(m^2 \cdot K)$ )

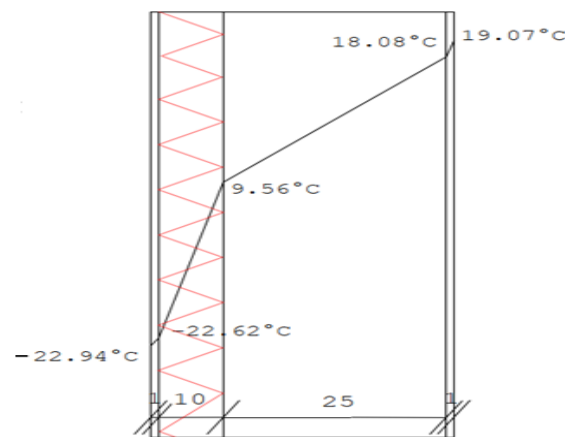


Figure 10. Display of heat loss through the wall layers

Table 5. Dew point temperature depending on air humidity and air temperature,[3]

$\theta_i$ [°C]	$\theta_s$											
	$\varphi_i$ [%]											
	30	35	40	45	50	55	60	65	70	75	80	85
23	4.5	6.7	8.7	10.4	12.0	13.5	14.8	16.1	17.2	18.3	19.4	20.3
22	3.6	5.9	7.8	9.5	11.1	12.5	13.9	15.1	16.3	17.4	18.4	19.4
21	2.8	5.0	6.9	8.6	10.2	11.6	12.9	14.2	15.3	16.4	17.4	18.4
20	1.9	4.1	6.0	7.7	9.3	10.7	12.0	13.2	14.4	15.4	16.4	17.4

Based on Table 5, we conclude that the dew point temperature at a relative humidity of 65% and an internal air temperature of 22°C is 15.1 °C and is located in the thermal insulation layer.

Transmission heat losses through the wall are:

$$Q_{T,wall} = F_{xi} \cdot U_z \cdot A_{z,neto}, \quad Q_{T,zid} = 51.74 \frac{W}{^\circ C}$$

where:  $Q_T$  is the quantity of transmission heat (J),  $Q_V$  is the quantity of ventilation heat (J),  $F_{xi}$  - temperature correction factor,  $A$  is the element surfaces ( $m^2$ )

**Thermal calculation of interstorey ceiling construction**

The ceiling construction of the building was adopted to be EIC (easy install ceiling) (16+4cm) with 10cm of glass wool thermal insulation.

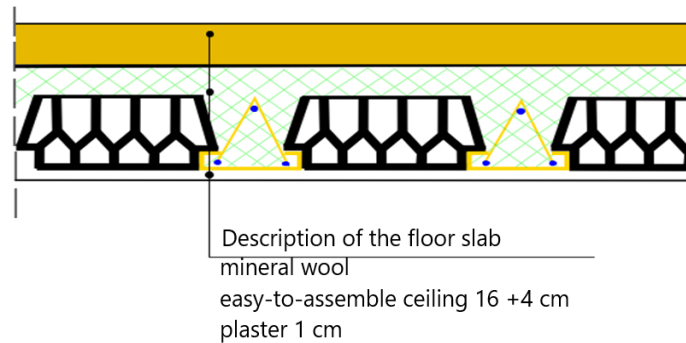


Figure 11. Interstorey construction of the ceiling

$$U = 0.240 \frac{W}{m^2K}, U_{max} = 0.3 \frac{W}{m^2 \text{ } ^\circ C}$$

$U < U_{max}$ , complies with the Regulations, there is no need for additional thermal insulation.

$$Q_{T,ceilling} = 30.33 \frac{W}{^\circ C}$$

**Thermal calculation of floor construction on the ground**

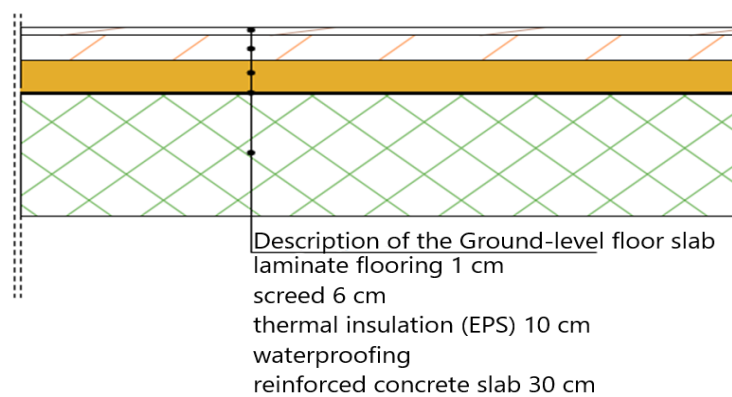


Figure 12. Detail of floor panel

$$U = 0.305 \frac{W}{m^2^\circ C}, U_{max} = 0.4 \frac{W}{m^2 \text{ } ^\circ C}, U < U_{max}, Q_{T,slab} = 28.91 \frac{W}{^\circ C}$$

**Thermal calculation of transparent surfaces**

$$U_{window}^{wi} = \frac{A_{gi} \cdot U_{gi} + A_{fi} \cdot U_{fi} + \varphi_g \cdot l_{gi}}{A_{gi} + A_{fi}}$$

$U_{window}^{w1} < U_{max}$ , meets the standards, there is no need for additional thermal insulation.

$$Q_{t,window} = 41.58 \frac{W}{\text{°C}}$$

Calculation of the coefficient of heat transfer and heat loss for the entire surface of the ground floor wall (including windows):

$$Q_{t,wall} = 93.24 \frac{W}{\text{m}^{\text{°C}}}$$

$$U_{max,door} = 1.6 \frac{W}{\text{m}^2\text{°C}}, U_{door} < U_{max}$$

$Q_{t,door} = 3.26 \frac{W}{\text{m}^2\text{°C}}$ , meets the standards, there is no need for additional thermal insulation

**Energy required to compensate for ventilation and transmission losses**

$$Q = (Q_T + Q_V) \cdot 24 \cdot HDD \cdot 10^{-3} [kWh]$$

$$Q_V = \Delta U_{tv} \cdot \sum A_i = 0.1 \cdot (104.95 + 2 \cdot 158 + 1.44 + 7.68 + 16.56 + 2.40 + 10.20)$$

$$Q_V = 47.11 \frac{W}{\text{°C}}$$

$$Q_{T,wall} = 93.24 \frac{W}{\text{°C}}; Q_{T,slope} = 28.91 \frac{W}{\text{°C}}; Q_{T,ceilling} = 30.33 \frac{W}{\text{°C}}$$

$$Q_T = 152.48 \frac{W}{\text{°C}}$$

**Energy consumption at the annual level**

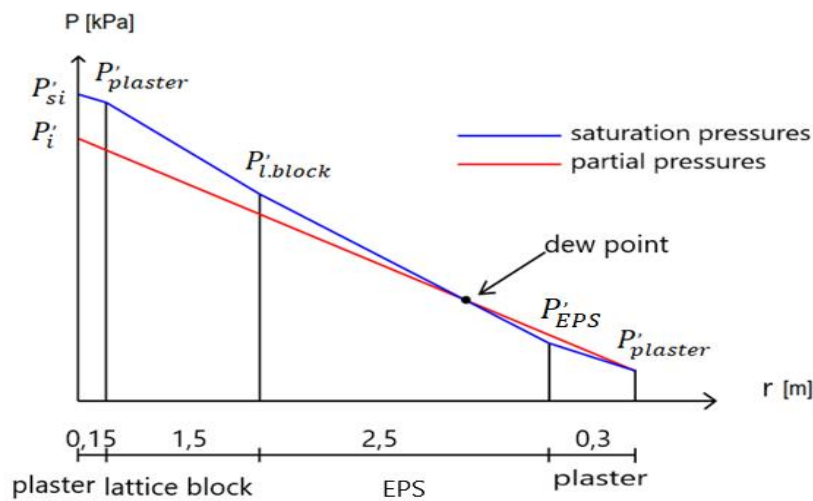
$$Q = (Q_T + Q_V) \cdot 24 \cdot HDD \cdot 10^{-3} = (152.48 + 47.11) \cdot 24 \cdot 3371 \cdot 10^{-3} = 16147kWh$$

The calculation of the required amount of energy for heating of the building

Table 6. The required amount of energy/energy products on an annual

Type of energy product	Energy value kWh/m <sup>3</sup>	Energy value kWh/kg	Overall requirement	
Electrical energy	---	---	16147.67 (kWh)	
Wood (beech)	2100	4.00	7.68 (m <sup>3</sup> )	4036.90 (kg)
Wood (oak)	2100	4.20	7.68 (m <sup>3</sup> )	3844.67 (kg)
Wood (conifer)	1700	4.40	9.49 (m <sup>3</sup> )	3669.91 (kg)

Water vapor diffusion, partial and saturation pressures, as well as equivalent thicknesses of the wall layers were calculated for the given location of the building.



Graph 1. Partial and saturation pressure (before additional thermal insulation)

There is an intersection of the saturation diagram and the partial diagram, which means that condensation of water vapor occurs. Condensation occurs in the styrofoam, which is not a bad solution.

**Thermal reconstruction of the building using cork**

In the previous calculation, a wall with insulation made of expanded polystyrene - styrofoam, of 5 cm thickness, was checked. The insulation of that thickness did not meet the needs of this building, so we will perform the reconstruction by installing cork on the inside of the building's exterior walls, because all the physical and mechanical characteristics of cork allow it to be used on the inside.

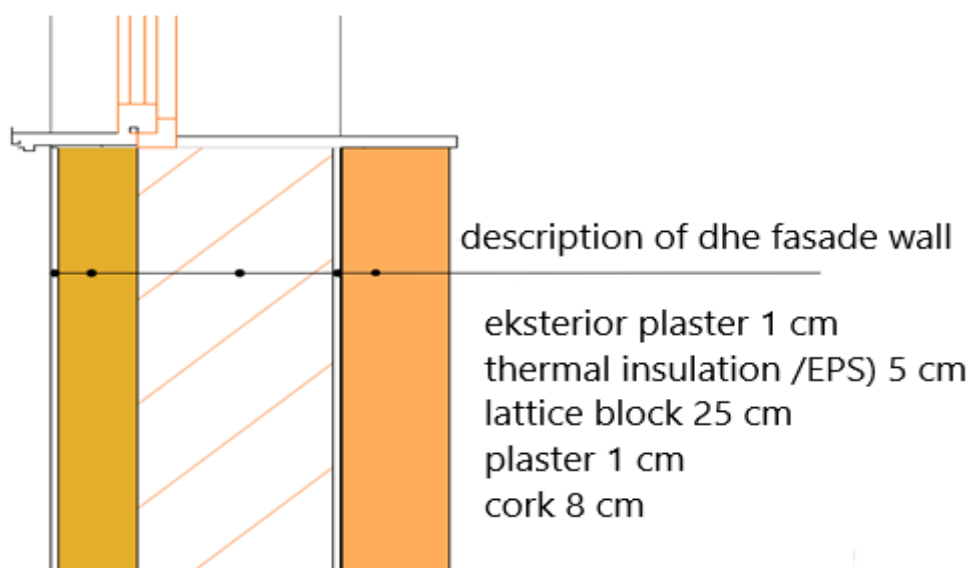


Figure 13. The cross section of the wall

$$U = 0.251 \frac{W}{m^2K}, U_{max} = 0.3 \frac{W}{m^2 \text{ } ^\circ C}$$

$U < U_{max}$  the wall meets the prescribed value, additional thermal insulation is not required.

Then, the calculation of heat transfer through the complete wall was carried out and a cross section was drawn.

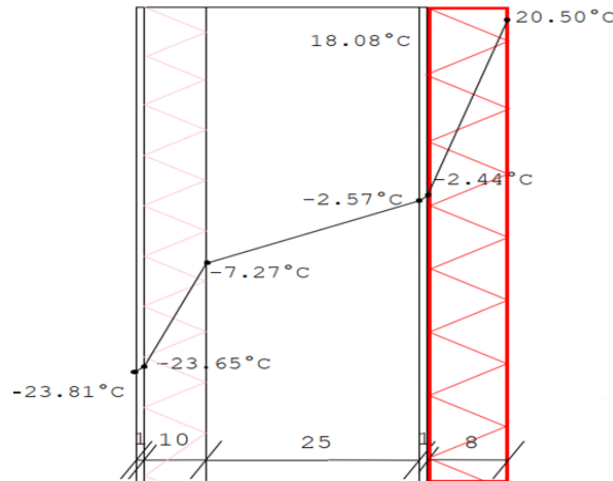


Figure 14. Display of heat loss through the wall layers (after additional thermal insulation, cork)

Table 7. Dew point temperature depending on air humidity and air temperature

$\theta_i$ [°C]	$\theta_s$											
	$\varphi_i$ [%]											
	30	35	40	45	50	55	60	65	70	75	80	85
23	4.5	6.7	8.7	10.4	12.0	13.5	14.8	16.1	17.2	18.3	19.4	20.3
22	3.6	5.9	7.8	9.5	11.1	12.5	13.9	15.1	16.3	17.4	18.4	19.4
21	2.8	5.0	6.9	8.6	10.2	11.6	12.9	14.2	15.3	16.4	17.4	18.4
20	1.9	4.1	6.0	7.7	9.3	10.7	12.0	13.2	14.4	15.4	16.4	17.4

Based on Table 7, we conclude that the dew point temperature at 65% relative humidity and 22°C internal air temperature is 15.1°C and is located in the thermal insulation layer.

Transmission heat losses through the wall are:

$$Q_{T,wall} = F_{xi} \cdot U_z \cdot A_{z,net}$$

$$Q_{T,wall} = 51.74 \frac{W}{^\circ C}$$

Transmission heat losses through the wall are:

$$Q_{T,wall} = F_{xi} \cdot U_z \cdot A_{z,net}$$

$$Q_{T,wall} = 26.34 \frac{W}{^{\circ}C}$$

The other elements of the building remained the same as before the reconstruction.

**Energy required to compensate for ventilation and transmission losses**

$$Q = (Q_T + Q_V) \cdot 24 \cdot HDD \cdot 10^{-3} [ kWh ]$$

$$Q_V = \Delta U_{tv} \cdot \sum A_i = 0.1 \cdot (104.95 + 2 \cdot 158 + 1.44 + 7.68 + 16.56 + 2.40 + 10.20)$$

$$Q_V = 47.11 \frac{W}{^{\circ}C}$$

$$Q_{T,zid} = 67.89 \frac{W}{^{\circ}C}; Q_{T,plo\check{c}a} = 28.91 \frac{W}{^{\circ}C}; Q_{T,tavan} = 30.33 \frac{W}{^{\circ}C};$$

$$Q_T = 67.89 + 28.91 + 30.33$$

$$Q_T = 127.13 \frac{W}{^{\circ}C}$$

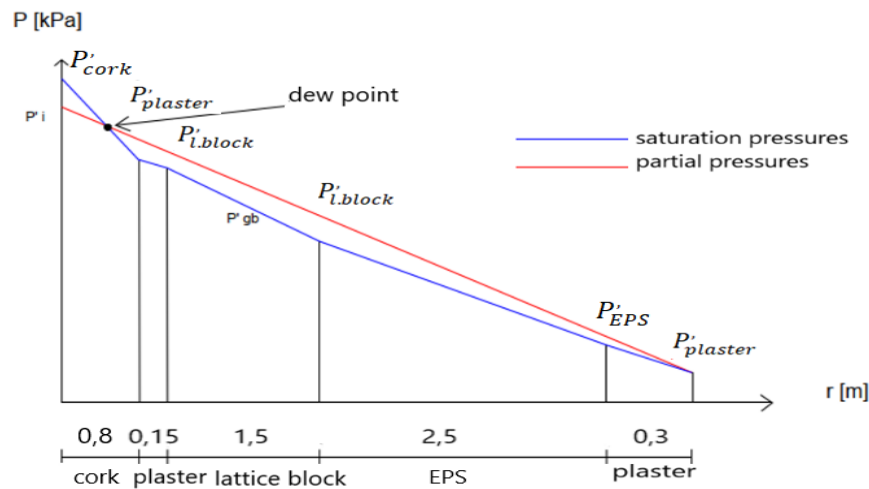
*Consumption on an annual basis:*

$$Q = (Q_T + Q_V) \cdot 24 \cdot HDD \cdot 10^{-3} = (127.13 + 47.11) \cdot 24 \cdot 3371 \cdot 10^{-3} = 12790 kWh$$

Table 8. Required amount of energy/energy products on an annual basis

Type of energy product	Energy value kWh/m <sup>3</sup>	Energy value kWh/kg	Overall requirement	
Electrical energy	---	---	12790 (kWh)	
Wood (beech)	2100	4.00	6.09 (m <sup>3</sup> )	3197.52 (kg)
Wood (oak)	2100	4.20	6.09 (m <sup>3</sup> )	3045.26 (kg)
Wood (conifer)	1700	4.40	7.52 (m <sup>3</sup> )	2906.84 (kg)

Water vapor diffusion, partial and saturation pressures, as well as equivalent thicknesses of the wall layers were calculated for the given location of the building.



Graph 2. Partial and saturation pressure (after additional thermal insulation, cork)

The dew point for an indoor air temperature of 22°C for the location Tutin, Serbia and an air humidity of 65% is 15.1°C. In that case, condensation in the facade wall occurs in the thermal insulation layer (cork). It is good that the dew point occurs in the thermal insulation, but it is bad that the dew point occurs near the inner surface of the wall. The dew point should be removed as far as possible from the interior, if possible, it should be completely removed from the layers of the wall. Dew point will not occur in the wall layers when the partial pressure line and the saturation pressure line do not intersect.

### Comparison of results

In order to determine which energy class our building belonged to before the reconstruction, we will divide the annual energy consumption by the building's heating surface:

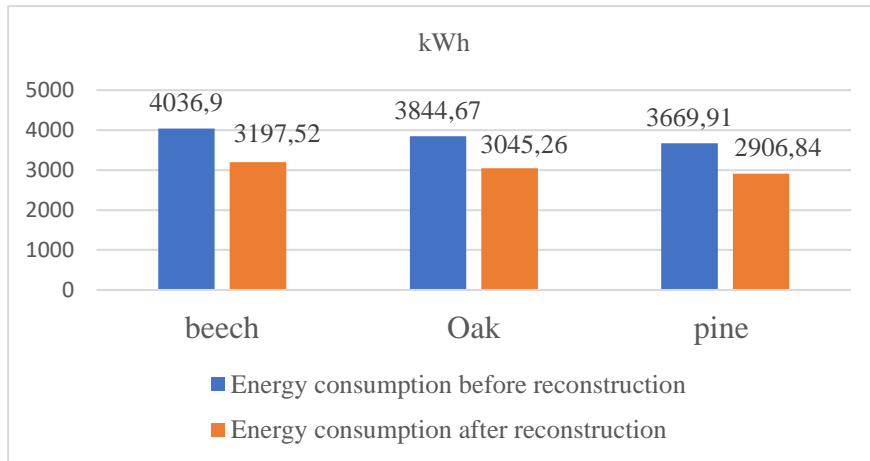
$$E = \frac{Q}{A_{heat}} = \frac{16147.63}{136} \approx 120 \frac{kWh}{m^2} \text{ annually} > 100 \frac{kWh}{m^2} \text{ annually}$$

where: E is the required heating energy ( $\frac{kWh}{m^2}$ )

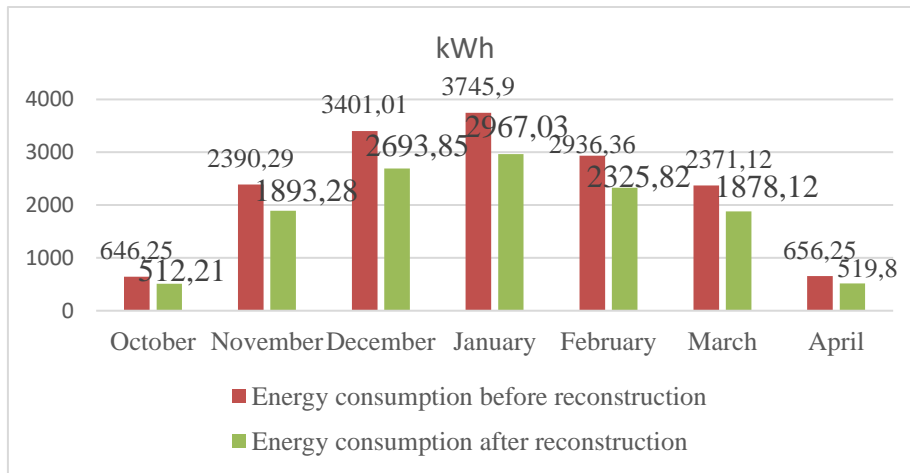
Which means that our facility before the reconstruction does not meet the requirements of the Rulebook on Energy Efficiency, i.e., the energy class is "D". After the reconstruction, using cork, we will calculate in the same way which energy class our building belongs to.

$$E = \frac{Q}{A_{heat}} = \frac{12790}{136} \approx 94 \frac{kWh}{m^2 \text{ annually}} < 100 \frac{kWh}{m^2} \text{ annually}$$

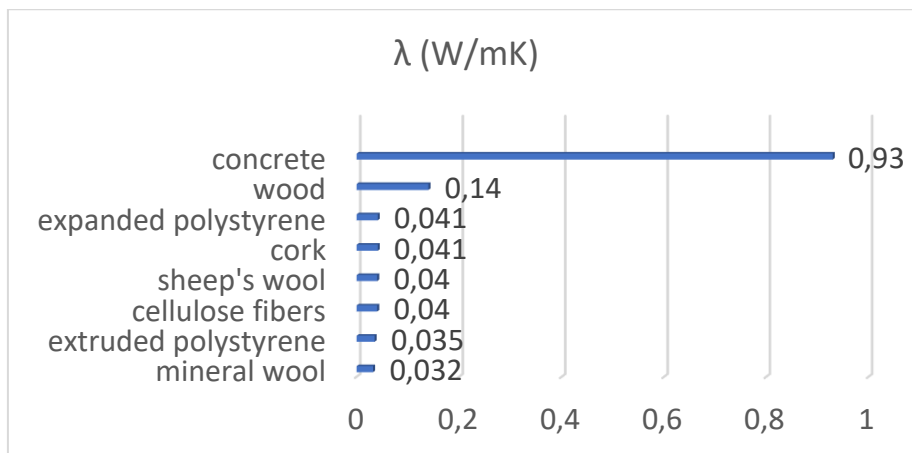
The significant reduction in annual energy consumption is noticeable, as well as the fact that the building belongs to energy class "C", that is, it has *average energy efficiency, i.e., meets the requirements of the Rulebook.*



Graph 3. Annually required energy [m<sup>3</sup>]



Graph 4. Monthly electricity consumption [kWh] during the heating season



Graph 5. Thermal conductivity of different materials

## Conclusion

Energy efficient materials in the modern age such as cork represent a significant contribution in reducing energy consumption and preserving the environment. It can be concluded that cork is an extremely efficient and environmentally friendly insulating material. Its use contributes to the reduction of energy consumption for heating and cooling, which positively affects ecology and climate change.

The use of corks as an insulating material enables the improvement of the building's thermal insulation, which results in heat losses reduction and the need for heating or cooling the space. In addition, cork is a renewable material, environmentally friendly and durable, which makes it the optimal choice for achieving energy sustainability. The integration of cork into construction projects plays a key role in creating energy efficient and environmentally responsible buildings.

The production of cork consumes a small amount of energy, which is also a contribution to energy efficiency and environmental protection. Cork is a material that can be recycled and used more than once, which additionally contributes to environmental protection.

The application of cork, in line with other sustainable approaches, can be one of the steps towards a better and sustainable future.

Given the above facts, cork is a material that deserves greater attention in its application as an insulating material in modern construction due to its energy efficiency and environmental friendliness.

In addition to reducing greenhouse gas emissions, cork also has a positive effect on air quality, reducing the risk of allergies and respiratory problems. Energy-efficient buildings with cork as an insulating material not only reduce energy costs, but also contribute to the sustainability of the construction industry. Through continuous research and implementation of innovations in the use of cork, it is possible to achieve high standards of energy efficiency and meet the requirements of modern standards of sustainable construction.

It can be concluded from the paper that the maximum effort should be made to install the thermal insulation from the outside. "Strong" thermal insulation on the inside of the wall brings the dew point closer to the inner wall surface, which is not desirable.

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