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TECHNO-ECONOMIC EFFICIENCY OF LOW ENERGY BUILDINGS

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Abstract

The guidelines for correct design of efficient low –energy buildings will be discussed in the paper. The goal of the research will be the reduction of heat losses which can only be achieved by appropriate erection of buildings without thermal bridges, by an appropriate facade, energy-efficient windows and an appropriate heating system.

Key words: *Low energy buildings, Heat losses, Heating, Ventilating, Solar energy collector*

1. INTRODUCTION

Nowadays, in the time period of saving energy and environmental protection one is looking for ways to cut specific annual consumption of warmth for heating due to the fact that older buildings require up to 200 kWh/m^2 per year for heating.

With the buildings, erected after 1995 and due to the introduction of stricter regulations, heat consumption was cut by one third in that the search for ways to cut heat consumption is still going on which is confirmed by the already erected low-energy consumption bulidings (NEH), 3-litre buildings and passive buildings (PH).

Low heat losses call for an appropriate heating system the further development of which has been defined by the goal of reduced emissions of carbon dioxide. The European Union has adopted a number of directives, among them the directive on efficiency of buildings [1]. The said directive calls for providing integral energy properties of buildings in the form of final or primary energy instead of the form of required energy, as valid up to date. Germany, however, poses an exception for on 1 February 2002 the country passed new regulations EnEV [2] which fully meet the requirements of the said directive. As regards Slovenia the maximum required temperature for heating has been defined by the new regulations on thermal protection and efficient use of energy in buildings [3] in that as of late this limit is to be defined by the entire amount of energy required for a buliding to function or else by primary energy. The paper brings fundamental guidelines to design heating and ventilation of a passive building while considering standards of low-energy consumption all of which can greatly reduce the costs and increase dwelling comfort.

2. ENERGY-EFFICIENT BUILDINGS

As regards architectural design, building design and use of heating systems there are the types of energy-efficient buildings as follows:

- **Low-Energy-Consumption Building** the annual amount of required warmth for heating amounts to 40 ÷ 60 kWh/m^2, with the obligatory air-tightness being $n_{50} \leq 1.5$ h^{-1}; in order to achieve the said standard a good insulation and an air-tight packing of a building are required, along with glazing of

windows with heat-insulating glass; fresh air is supplied by forced circulation without thermal recuperation of waste air, all of which calls for a conventional heating system.

- **Three-Litre Building** the annual amount of required warmth for heating amounts to 30 kWh/(m^2a), with the obligatory air-tightness being $n_{50} \leq 1\ h^{-1}$. The construction has to be realized without thermal bridges which call for a conventional heating system. Fitted into a three-litre building is one of the devices as follows: a solar device for heating of sanitary water and/or a ventilation device featuring heat recuperation of exploited air.
- **Passive Building** is an energy-saving building where dwelling comfort is assured without common heating systems or air-conditioning devices. The annual amount of warmth for heating cannot amount to more than 15 kWh/(m^2a) in that for heating the air is applied which has been heated through heat recuperation of exploited air; the reqiured air-tightness is set to be $n_{50} \leq 0{,}6\ h^{-1}$. The contruction is to be realised without thermal bridges ($\Psi \leq 0{,}01$ W/mK). The total amount of energy consumption cannot amount to more than 120 kWh/m^2a. Additional components as well as limiting figures are given by Table 1, and the annual balance of heat is given by Figure 1.

Table 1: Significant Components and Parameters of Passive Building [4]

Insulation	U=0,15 W/m^2K recommended figures from 2006 on= 0,1 ÷ 0,13 W/m^2K
Windows	Heat Conductivity U=0,80 W/m^2K Permeability – g = 0,50
Air-Tightness	Pressure Test n_{50} =0,6 h^{-1}
General Aspects	- construction without thermal bridges - high-efficiency ventilation featuring heat recuperation at low level power consumption - lowest possible heat losses at heating and distributing sanitary water - high-efficiency use of power in household
Required Warmth for Heating	≤ 15 kWh/m^2a
Heating Power	≤ 10 W/m^2
Final Energy	≤ 40 kWh/m^2a
Primary Energy	≤ 5 kWh/m^2a

The advantages and disadvantages of passive building are listed in Table 2.

Table 2: Advantages and Disadvantages of Passive Building

Advantages	Disadvantages
Low-Level Consumption of total primary energy; less than 120 kWh/m^2.	Precise building and realisation of details.
Low-Level consumption of heating energy; less than 15 kWh/m^2a; consumption of electricity less than 18 kWh/m^2a.	Cca 8-10 % more expensive building than classical building.
Permanent fresh air, even with windows closed.	Ignorance and inactivity of building industry.
High level of dwelling comfort.	No thermal bridges.
Good sound insulation.	Not enough stimulation on the part of the state; not enough examples of good practice.
Lower levels of energy consumption and, accordingly, reduced emissions of CO_2.	Mandatory close cooperation among architects, builders and experts throughout procedure, from planning to realisation.

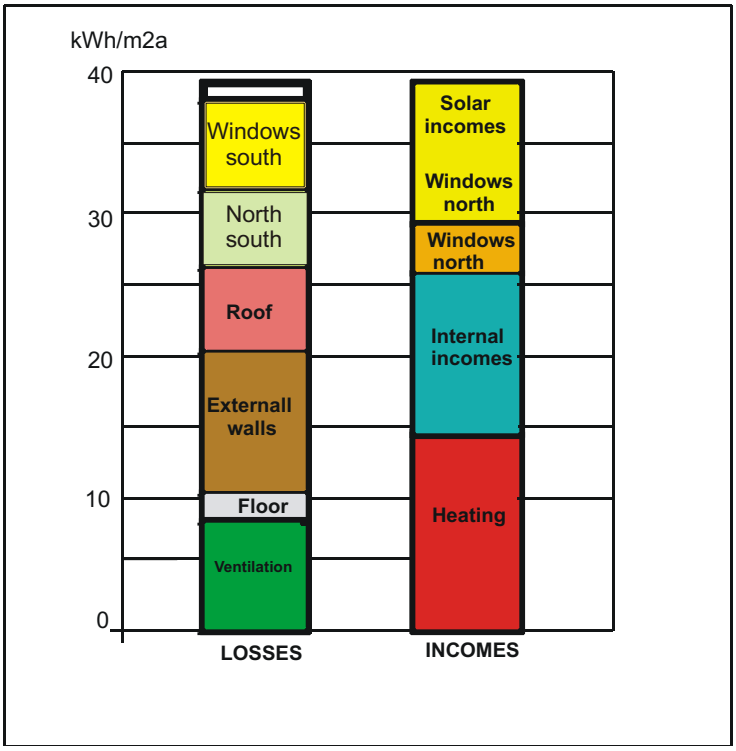


Fig. 1: Annual thermal balance of passive building [5]

- **Zero Heating Energy House** features a zero level of heating energy consumption; the required thermal and electrical energy is provided by solar energy thus it is not dependent on the public power grid. The summer electrical power surplus is transfered to public power grid. The said house features a layer of thermal insulation, the thickness of which is 40 ÷ 60 cm, and is realised without thermal bridges; it has no conventional heating system due to its active and passive use of solar energy. Even on cloudy days its large storage of heat meets its thermal requirements.
- **Energy Self-Sufficinet House** is an idependent house which acquires required energy for heating, electrical power for household and lighting from solar energy. As compared to zero heating energy house it requires larges areas of solar cells and batteries for energy storage in that the said house is not hooked on to public power grid. The summer surplus of electrical power is stored for the winter period. Hydrogen and oxygen are produced by electrolysis whereupon they are stored separately so that during the winter they are used as fuel in fuel cells.
- **Plus-Energy House** is a building with a built-in solar system, a photo-voltaic module, which is able to produce more energy than it uses and the energy surplus is transfered to public power grid.

Consumption of warmth for heating of various types of buildings is shown in Figure 2.

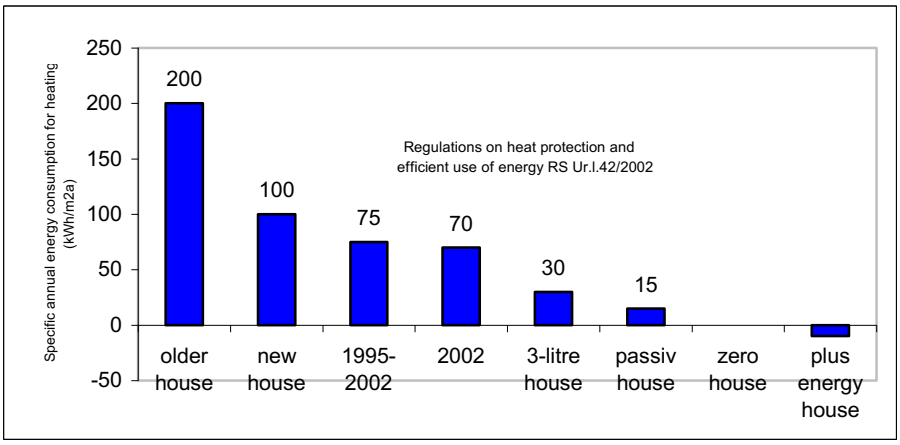


Fig. 2: Energy consumption for heating [6]

2.1. Energy Consumption

In practice energy consumption can be achieved by two types of measures, investment type and organisation type. Basic organisation measures are as follows:

- Appropriate Ventilation the valve of the radiator is closed and the window is opened wide for a few minutes. As necessary this is done several times a day instead of lengthy ventilation through a slightly open window.
- Removal of air from heating bodies; 15% of energy can be saved in this way
- Reduction of temperature in the room; a reduction of one degree presents a 6 per cent saving of energy.
- Removal of obstacles in front of heating bodies for the decrease radiation of heat.

- Appropriate use of hot water; taking a shower takes three times less water and energy than taking a bath in a bathtub.

Investment measures are as follows: routine investment maintenace of the building, sealing up of windows and doors, insulation of pipelines, unheated rooms and boiler room and correct regulation.

The principle of efficient function of a building is based on the three rudiments as follows:

- Excellent insulation of facade, windows included.
- Optimal passive-solar gains through large windowson the southern face of the building.
- Optimal and well-controlled ventilation featuring heat recuperation.

A significant reduction of loss through windows as well as dweloling comfort can be achieved through application of thermally protected windows (triple window panes, low-emission layer, gas-filled windows (argon/crypton), thermally-conductive glass panes $\leq 0{,}7$ W/m^{2}K). Dependence of dwelling comfort on thermal conductivity as well as properties of air motion are shown in Figure 3.

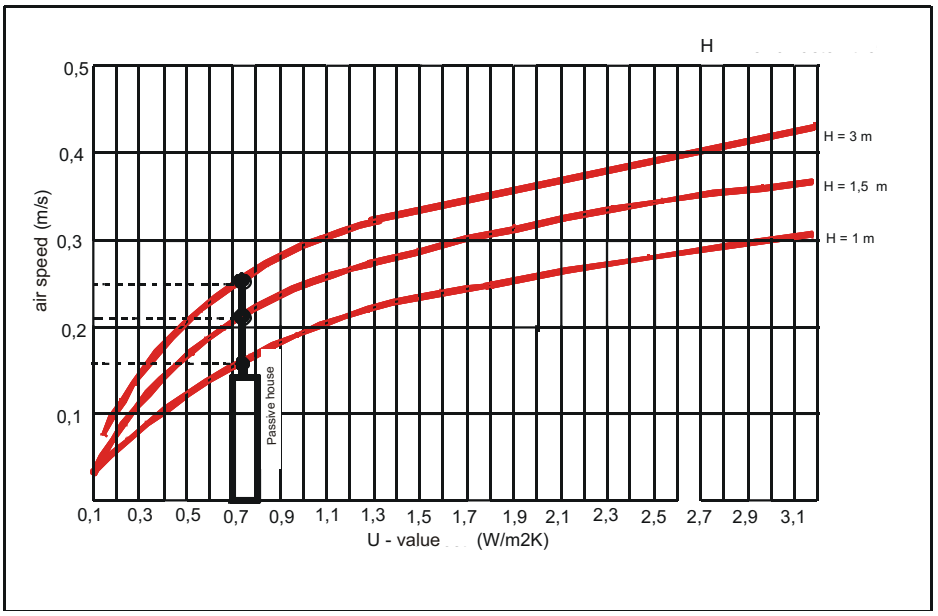


Fig. 3: Flow of cold air on insulating window glass [7]

Energy efficiency of a building is defined by the figure which one gets when one divides total energy consumption for heating and hot water with gross heated area of the building.

2.2. Ventilation

A good state of health and the ability to focus on one's work in a room, be it a dwelling room or a work room, depend on a lot of elements, such as temperature, lighting, air flow, noise level and air quality. The air has to comprise an appropriate share of oxygen, suitable moisture, an amount of scents which is not annoying and a low level of harmful substances thus rooms have to be aired accordingly, either naturally or forcefully.

With a normally air-tight building the amount of exchanges of air between 0,1 and 0,3 h^{-1} is quite sufficient.

With energy-efficient buildings a ventilation with restoration of exit air (heat recuperation) has been defined by regulations. Through a controlled operation of ventilating device high-quality air in a room can be achieved, along with a saving of a share of energy for heating – Table 3.

Table 3: Heat Losses due to ventilation [8]

Amount of exchanges	Ventilation through windows	Controlled ventilation with 90% of heat recuperation
0,7 h^{-1}	48,5 KWh/m^2a	6,6 KWh/m^2a
0,6 h^{-1}	41,6 KWh/m^2a	5,9 KWh/m^2a
0,5 h^{-1}	34,0 KWh/m^2a	5,2 KWh/m^2a
0,4 h^{-1}	27,7 KWh/m^2a	4,5 KWh/m^2a
0,3 h^{-1}	20,8 KWh/m^2a	3,8 KWh/m^2a

2.3. Heat Losses

Let us take, for instance, a building with a ground plan of 11 x 11 m, featuring general data as follows:

- gross area: 438 m^2,
- gross volume: 525 m^3,
- area of windows and doors: 38 m^2,
- shaping number f_o: 0,83 m^{-1},
- internal temperature: 20^0C,
- external temperature: - 16^0C.

Let us make a comparison of heat losses of non-insulated and insulated economical building, assuming that the non-insulated building has been erected with modular bricks (29 cm thick), in that the windows and the doors are fitted with double insulating windows panes and low-emission layer.

The insulated building features the specifications as follows:

- external walls, 12 cm thick insulation,
- floors towards the ground, 12 cm thick insulation,
- roof-ceiling, 25 cm thick insulation,
- energy-saving windows, λ = 1,4 W/m^2K.

Based upon the calculation of passage of heat U through individual elements of building constructions thermal load of the building can be defined, Table 4 and 5, in that the annual consumption of fuel can be seen in Figure 3.

Table 4: Non-Insulated Building

Construction	**U · A (W/K)**	**%**
external walls U= 1,5 W/m^{2}K	240	45
roof-ceiling U= 1,25 W/m^{2}K	163	31
floor on ground U = 1,2 W/m^{2}K	66	10
windows U = 2,6 W/m^{2}K	61	14
Total	**530**	**100**

Table 5: Insulated Building

Construction	**U · A (W/K)**	**%**
external walls U= 0,30 W/m^{2}K	48	32
roof-ceiling U= 0,15 W/m^{2}K	20	13
floor on ground U= 0,3 W/m^{2}K	22	15
windows U= 1,4 W/m^{2}K	61	40
Total	**151**	**100**

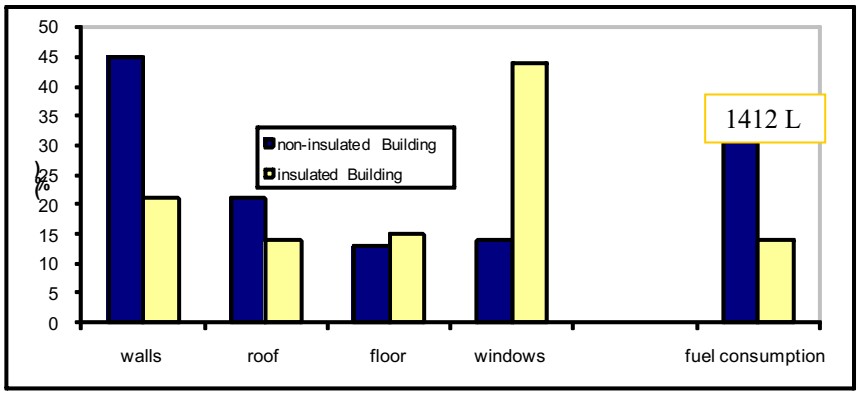


Fig. 3: Comparison of heat losses and consumption of fuel [9]

Findings: with a non-insulated building 76% of heat losses are due to external walls and roof and 24% of heat losses are due to windows and floors. With an insulated building 40% of heat losses are due to windows and 45% of heat losses are due to external walls and roof.

With a non-insulated building the consumption of fuel oil per season amounts to 3250 litres whereas with an insulated building the consumption amounts to 1412 litres of fuel oil.

3. SOLAR HEATING

3.1 Solar Collectors

The future of our planets lies in the reduction of consumption of fossil fuels and the exchange of the said fuel with exploitation of renewable sources which do not pollute the environment, such as the enegry of the sun. For a solar device to be fitted a large enough flat roof is required or else a roof with a certain slope, facing the south, south-west or south-east. Further on, a room for solar receptors is required, approximately one square metre per person (solar heating in multi-flat buildings) or else four to five square metres per household. The size of solar collectors depends on the hot water consumption as shown in Figure 4.

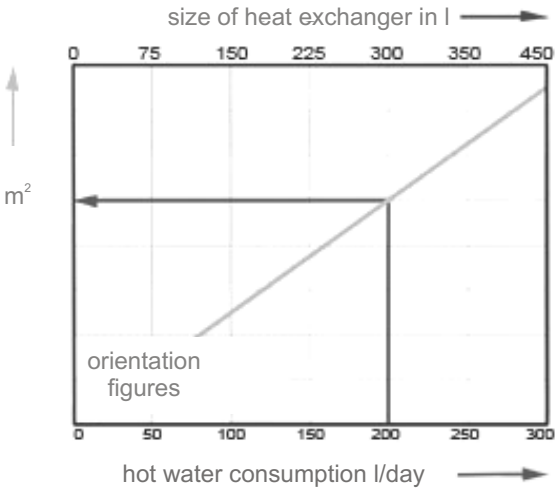


Fig. 4: Size of solar collectors and hot-water consumption [10]

Approximate figures of hot-water consumption per person per day are given in Table 6.

Table 6: Approximate amounts of hot-water consumption per person per day [8]

Type of buliding	Application,comfort, properties	Hot water in litres per person per day		
		low	medium	high
One family house; flat in multi-storeyed building	- simple standard	30	35	40
	- medium standard	35	40	45
	- high standard	40	45	60
Multi-family house	- social flat	25	30	35
	- self-built house	30	35	45
	- high level standard	35	40	50

Apart from purpose of use the location and the slope of collector are also crucial. Important criteria in determination of the area of solar collectors are as follows:

- the mode of operation of solar device,
- location where the device is installed (for example on the roof),
- installation of solar collectors with regard to the four points of the compass,
- type of solar collector.

Approximate number of solar collectors (area) for production of hot water, with regard to the number of people, is shown in Figure 5.

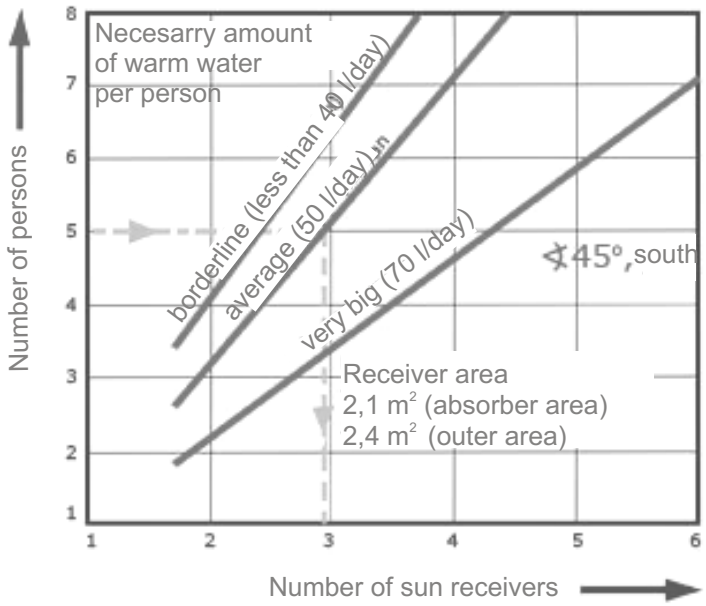


Fig. 5: Required area of solar collectors with regard to the number of people [11]

To precisely define solar systems computer tools and computer software programmes are applied. The influence of the angle of the slope upon the size of solar collector is defined by the correction factor f_N, Figure6.

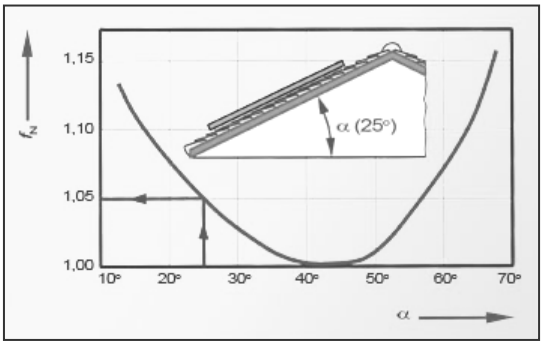


Figure 6: The influence of the angles of the slope on the size of solar collector [12]

The optimal angle of the slope depends on the duration of use, due to the fact that the position of the sun changes during the year, Table 7.

Table 7: The angles of the slope of solar collectors [13]

Duration of use (≈ 500 of northern latitude)	Recommended	Start
January through December (whole year)	40° - 50°	30° - 60°
April through September (summer only)	30° - 40°	20° - 50°
May through August (during season)	25° - 30°	15° - 45°
October through March (heating season)	55° - 65°	40° - 75°

30°C	With strong solar radiation during summer (optimal angle).
30°C	At the lowest point of the sun during winter (optimal angle).
30°C	Compromise during summertime.

When installing solar collectors it has to be considered that the optimal direction of solar collectors is toward the south, with a 10% deviation towards Z; during summer the slope of 55° is not to be exceeded while in winter the slope of 35° (f_{SA} = 1,1) is not to be exceeded.

The angle of the slope of solar collectors exerts a big influence on the efficient operation of the solar system, especially the deviation from the southern direction, Figure 7.

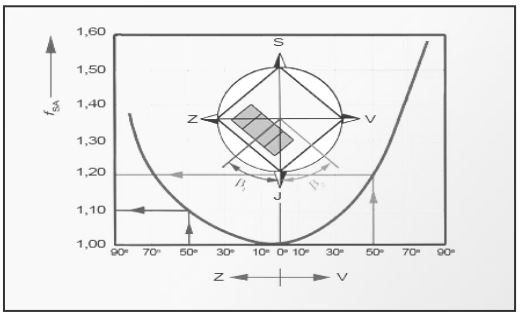
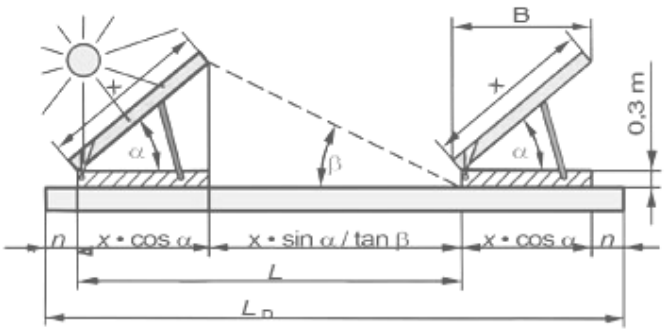


Fig. 7: The angles of the slope of solar collectors [14]

The distance among solar collectors depends on the slope and position of the sun towards the horizontal without screening from light (15° ÷ 17° degrees), the length of solar collectors (2070 mm in the given case) and the thickness of solar collector, Figure 8.



Minimal distance

$$X = L\left(\frac{\sin y}{\tan \varepsilon} + \cos y\right)$$

Fig. 8: Minimal distance between solar collectors [15]

The meaning of the signs in Figure 3.5 is given in a table

α	Distance L		**B**
	Vertical	Horizontal	
25°[1)]	4,74	2,63	1,84
30°	5,18	2,87[1)]	1,75
55°	5,58	3,09	1,68
40°	5,94	3,29	1,58
45°	6,26	3,46	1,48
50°	6,52	3,61	1,48
55°	6,74	3,73	1,48

L -minimum distance between two collectors
α -angle of slope towards horizontal
e -position of the sun towards horizontal,
without sun screening (15°÷17° degrees)
X -length of collector (here 2070 mm)
***L*D** -depth of collector (depth of roof)
n -distance from roof edge
B -dimensions of terraced collectors in m(space)

[1)]Adjustment: shorter telescopic support

With regard to the installation of solar system, Figure 9, expanding vessel is of vital importance and its dimension is defined in accordance with the number of solar collectors, Table 8.

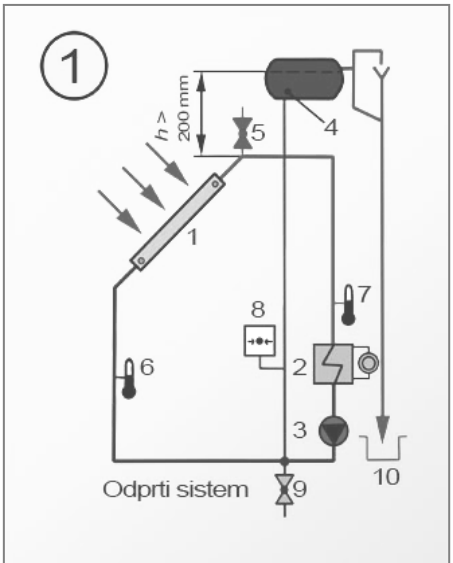




Fig. 9: Scheme of solar system [16];

The elements in the picture are as follows:

1 - solar collector
2- user of heat
2 - circulation pump
4- open expanding vessel
5 - ventilation device
6,7-thermometer
8 - manometer
9- outlet pipe
10- outflow
11- safety valve
12- diaphragm expanding vessel
13- return valve
14- supply pump
15-closing valve
16- heat storage

Table 8: Technical data of expanding vessel [16]

Number of collectors	2-4	4-6	6-8	Preset presssure of gas		Collector m^2	50	100	200	350
Volume of expanding vessel	18	25	32	Maximal working pressure 8 bar	Safety valve	DN	15	20	25	

For example:

- one-family house or two-family house,
- combined storage 750 l (1000 1 > 8 collectors),
- consumption 200 litres of water per day,

- direction of roof to the south,
- slope of roof 45°,
- temperature regime 40°C / 30°C,

the number of solar collectors is defined with regard to warmth requirements as well as the share in heating, based upon Figure 10.

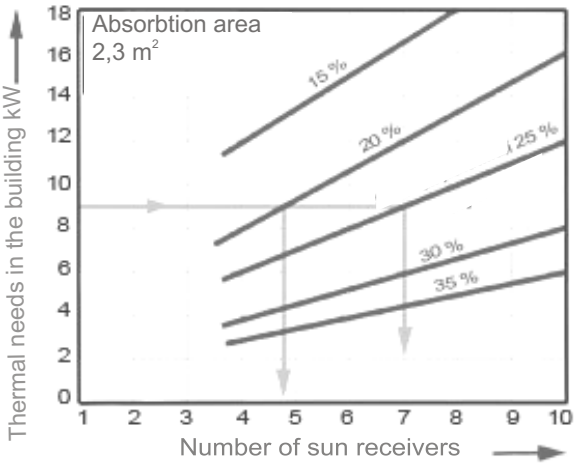


Fig. 10: Share of energy required for heating of water and building [17]

3.3 Heat requirements and solar surpluses

On average solar systems produce annually from 350 to 400 kWh per square meter of collector. With a low-energy level house the annual consumption required for heating amounts to 30 kWh/m^{2}a or less, thus solar systems can provide almost entire annual amount of energy for heating and hot sanitary water, in which case a well-insulated seasonal storage of heat can do, the capacity of which is 14 m^3. The impact of solar heating for various seasons of the year is shown in Figure 11.

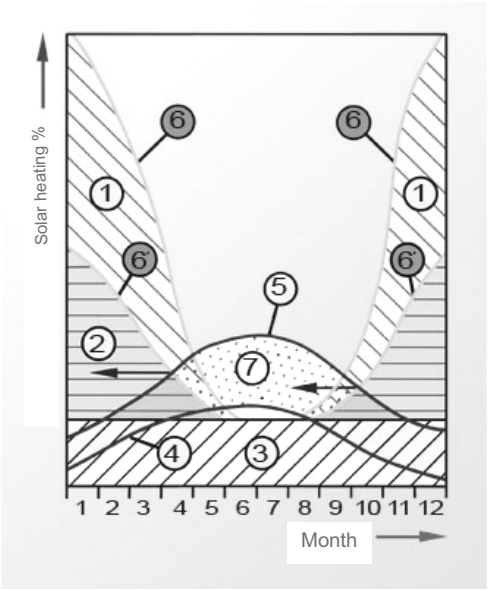


Fig. 11: Solar heating effect [18]

Legend:

1- Heat requirements in insufficiently heat-insulated building.

2- Heat requirements in well-insulated low-energy building.

3- Heat requirements for sanitary hot water.

4- Curve of annual sun potential (for heating sanitary hot water only; quite inefficient for heating).

The area between curve 5 and curve 6 presents additional heat requirements (heating with a boiler)

5- With the curve of sanitary hot water and the curve 6', the curve limits the field which enables additional heating with a solar system

6; 6'- Periodical heat requirement for insuffiently insulated building and well-insulated building

7- The curves 4 and 6 show the surplus of solar energy → nexploited solar energy between April and October

9. CONCLUSION

The problems, caused by the use of fossil fuels and other expensive sources of energy, complete with more and more frequent natural disasters, are, very likely, direct consequences of environmental pollution (increased concentration of carbon dioxyde, radioactive waste coming from nuclear power plants, emissions of various harmful substances, etc.), all of which has led to the destruction of natural balance in ecosystem and this, again, has, on the one hand, led to climate changes, changes in air temperatures, melting of glaciers, thunderstorms and floods and severe draughts on the other hand. Due to these warning changes of catastrophic magnitude it is of utmost importance that not only are the remaining energy sources used rationally but also that renewable sourced of energy get to be used more and more.

Correct design of low-energy buildings calls for several criteria to be considered. Each phase and each detail is an important factor which can contribute to efficiency, not only as regards energy but also as

regards economy. Ventilation has to be provided which can cut possible overheating during the summer months, along with the systems to re-use the heat of waste air during cold periods, and, last but not least, the architecture and the structure of building elements also play an important role. The operative word is the reduction of heat losses which can be achieved not only through a correct construction without thermal bridges, an appropriate facade and energy-efficient windows but also through an appropriate heating system.

The use of innovative heating systems and the use of renewable energy sources have to become a must in the near future, in order fornot only energy costs to be cut but also in order for our planet to be preserved at least the way it currently is.

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