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Co2olBricks

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Handbook of Energy Consumption in Historical Buildings

Training material for specialists: planners, engineers, architects

2013

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INTRODUCTION

Historical buildings were built at a time when energy conservation was not topical due to the relatively low energy prices and traditional construction methods. However, these buildings will be used for a substantial period of time, and if nothing is done to reduce the energy consumption, the European Union aims to reduce greenhouse gas emissions by 90-95% till 2050 in comparison to 1990 cannot be reached. Therefore, to reach such objective a drastic change is required.

Historic buildings average energy consumption from 2007 to 2011 in Latvia was 240 kWh/m^2, including space heating - 210 kWh/m^2, which is roughly similar in all three Baltic countries for energy consumption in residential sector, however it is significantly higher than the EU average. It is important to understand what works are needed to improve energy efficiency, so that for the next 15 years the EU's energy consumption won’t rise by 10% or more. At the same time it is related to the depletion of recourses. The available amount of primary energy resources (oil, gas, coal, peat) is limited. The stocks of these resources decreases, their obtaining costs increases. That causes a rapid increase of the price of these recourses. On the other hand, the increase of primary energy consumption will increase the pollution of the environment in such quantities that may cause irreversible changes in Earth's atmosphere, climate change and other processes threatening the existence of Earth.

Climate change and global warming is recognized as the largest and most serious problems humankind is facing in this century. Forecasts suggest that this process will lead to the sequence of major social, environmental and economic losses. Now with the increasing energy prices, the possibility of environmental disasters is increasing as well. Therefore in the World and Europe the issue of building energy efficiency is becoming increasingly topical. Not just building of eco-friendly houses, but also increasing the energy efficiency of existing buildings is becoming more and more actual. In the European Union the buildings sector has the largest share of energy consumption and greenhouse gas emissions. Until now, increasing of energy efficiency in existing buildings was associated with extensive and expensive building insulation, leaving in shade small but effective techniques of improving energy efficiency in buildings. Such energy-efficient measures not just save energy and reduce CO_2 emissions but also save money.

The bricks are used in building construction since ancient times, and their durability typically extends for several centuries. Ordinary clay brick has experienced many different periods of time. For many centuries it has been the main element of building walls and other constructions. The evidence of that are even castles, fortifications, churches and other structures preserved even to this day.

Two topical areas intertwined into one - energy efficiency and architectural heritage of brick buildings. It is important to address these two issues so that obtained result can meet today's requirements of energy efficiency and promote the preservation of historical buildings for future generations at the same time.

To do so the help of professional energy auditors, who are knowledgeable and able to analyze the actual measured heat consumption data, to measure, evaluate and compare the measured and calculated heat transfer results, to determine the moisture effects on historical brick buildings and to recommend energy efficiency measures, is required. This manual is designed for architects, builders, planners and engineers to deepen their knowledge and chart energy consumption and supply problems of historical buildings. It is designed as a complementary material to the existing national buildings energy efficiency legislation, including the methodology set by the EU Directive 2002/91/EC for the calculation of buildings energy efficiency.

1. ENERGY AUDIT

1.1. Main principles of energy audit

1.1.1. Energy audit levels

Building energy audit is considered a part of the building situation research that is carried out to determine the energy performance of the building and identify the opportunities to reduce energy consumption.

The definition of energy audit includes a wide range of engineering, economic and environmental aspects. It is a systematic procedure aimed to:

- obtain accurate information about energy consumption of the building and identify factors that influence the consumption;
- identify and compare the most economically advantageous energy efficiency measures;
- group energy efficiency measures by priority and suggest a sequence of measures to the customer
- determine CO_2 emission reduction potential and the associated measure cost-effectiveness, energy audit is one of the means to reduce CO_2 emissions.

Fig.1.1 Aims of the energy audit procedure

An energy audit is necessary to develop a renovation plan for the building.

Energy efficiency measures are not only energy-saving. They tend to have positive side effects. If the opportunities to carry out energy efficiency improvement measures are linked with other necessary improvements for the building, the recommended proposal profitability and economic efficiency increases.

For example, insulation of external walls will reduce not only the heating costs, but also cold and drafts problems - the building comfort level will increase. Insulating the walls, a new covering is applied, which in turn prolongs the life of the wall. Thus, execution of energy-saving measures can have a positive impact on other important things.

Energy audit can be done in more or less detail. Depending on the audited facility and tasks of the audit a variety of auditing techniques can be used and it may include a variety of components. The structure of the energy audit and resources available auditing, documentation and statistics on energy consumption audited building.

An energy audit conducted by a professional energy auditor differs with a higher quality, as well as the full analysis of the implementation potential of energy efficiency measures.

Usually calculations are made for the specific water and energy consumption of the building. If buildings overall quality is being assessed, recommendations on energy saving measures prepared and necessary investment calculations made, building project and other technical documentation will be necessary. A very good source of information, in order to assess the problems in the building, is survey of the residents of the house, house management and other personnel. Summarizing the information about indoor air quality, thermal comfort and lighting level obtained in survey and supplementing it with the results obtained in measurements, we can get a good picture of the audited buildings condition.

During energy audit the building is viewed as a system with subsystems. Heat balance describes the energy supplied and removed from the building or its subsystems, such as the heating system or air conditioning system. Accuracy of heat balance significantly affects the results. If it is possible to compile a sufficiently accurate building heat balance, well-justified energy and water efficiency measures can be developed and good investment advices made.

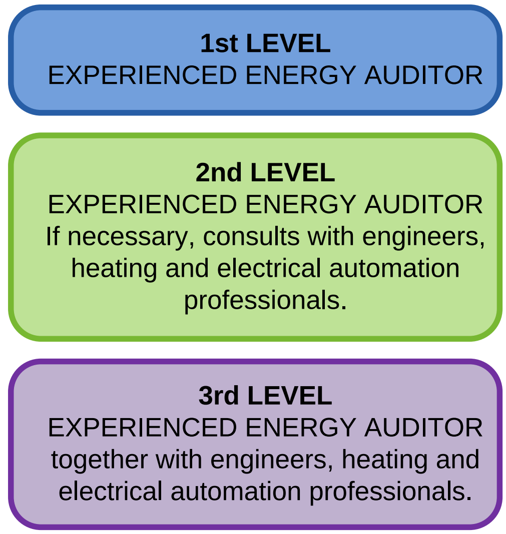


Fig.1.2 Different level energy audits

In practice there are three different level energy audits: 1st level is basic level, 3rd level is the most detailed.

1^{st} level is the Basic energy audit. It provides only basic information on energy and water saving opportunities. It can be called an audit "going through the building."

2^{nd} level. Proposals for energy and water saving measures are better justified than in 1. level, and the grounds also include analysis of specific measurements.

3^{rd} level. Energy and water consumption are analyzed in detail, and proposals for energy and water saving measures and the investments that are necessary for their implementation are sufficiently well prepared, so that they are ready for deployment.

Analysis carried out during buildings energy audit shows the economic energy efficiency potential scope: technical improvement possibilities are defined and economically evaluated. Taken measures are considered effective if the saved resources are enough to cover the investment in a given period of time.

To reduce energy consumption in a building, we must understand what heat losses should be compensated, why they occur, and what energy efficiency measures have to be taken. Since every house and energy system is unique, the energy efficiency measures will also vary. The organizations, that will be involved in the task differs as well. However, the implementation scheme of such measures is the same. The first step that must be taken to begin the planning of energy efficiency measures is energy audit.

1.2. Main stages of energy audit

1.2.1. Energy audit procedure

Energy audit is carried out step by step and every action dedicated to a specific place and order. Only a set of measures can lead to the main objective of energy audit: the energy audit report and building energy certificate. It displays both the current situation and the prioritized energy efficiency measures to be taken in the building. Capital investments of implementation and the economical benefits are evaluated. Energy audit procedure is schematically shown in Figure 1.3.

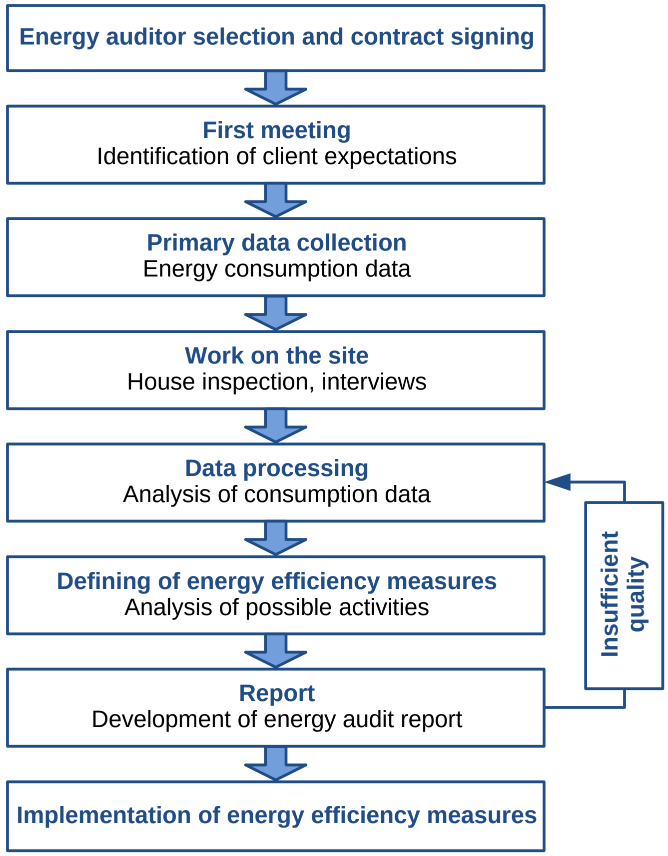


Fig.1.3 Energy audit procedure

The results of energy audit depends on the quality of original or raw data and data processing models, as well as computer software, which is used for compilation of results and optimization of energy efficiency improvement measures.

1.2.2. Data collection and processing

Energy efficiency evaluation and initial data collection depends on demands of power user and computer simulations used in the calculations. Methods to obtain the set of raw data may be different:

- processing of data from projects;
- statistical data and selective measurements gathered during the energy audit;
- continuous measurements during the monitoring.

During the first meeting energy auditor identifies all the customer's wishes for energy audit, as well as clarifies whether there are any special places, for which power users want special attention.

Energy audit uses energy consumption data from the archives of building manager. Necessary climatologic data on the past 5 years are: length of heating season, the average outdoor air temperature during the heating season.

The building is surveyed and data obtained on the building envelope, the thermo physical properties of its building structures, geometry, window share in demarcated building structures (position and type), building's orientation towards the cardinal directions, the number of curtain walls and the energy consumption.

Carrying out research of the energy user heat and electricity consumption modes different data collection methods - both direct measurements and data collection on the building are often used. These methods have advantages and disadvantages, so they often have to be combined. Frequently used methods nowadays are:

- direct measurements;
- observations and examinations;
- surveys;
- use of archives and records.

Quantity that has to be measured should be defined precisely, as should the formulation of conditions under what circumstances and how the measurement will be performed. All measurements are approximate, therefore giving the numerical value of the measurement, potential error should be noted.

During the pretreatment process the data are normalized using the climate correlation method. First, summarization of all the necessary data, obtained from the archives of the manager, residential home inventory files and information obtained during the survey. Then the calculations can be carried out.

After data processing data analysis carried out to find the graphical and analytical relationships between the dependent variable - buildings energy consumption - and independent variables, that affect the energy consumption, such as the number of degree days.

In order to achieve the goal mathematical statistical methods: correlation and regression analysis, a used. The acquired regression equation is used not only to determine the energy efficiency measures, but also for energy management monitoring.

1.2.3. Classification of energy audit recommendations

Energy efficiency projects based on the choice of proposals put forward (alternative solutions).

Generalizing the energy efficiency measures in buildings, they can be classified into six groups by unifying features (see Figure 1.4)

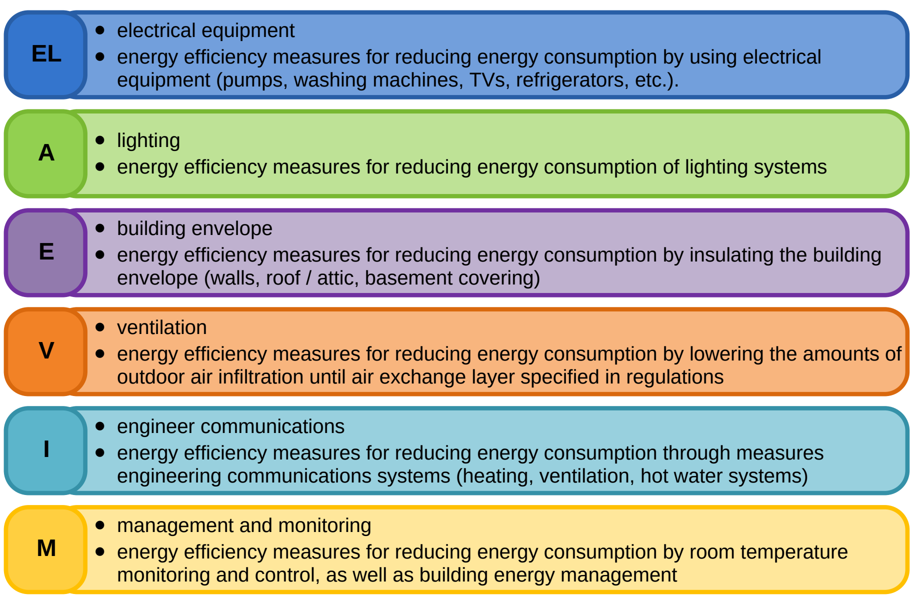


Fig.1.4 Groups of the energy efficiency measures in buildings

In order to achieve the planned reduction in energy consumption, the most common should be combined different groups of measures, such as measures of group I will be meaningless if not taken at the same time the group of M.

Some of the above-mentioned energy efficiency measures in can only be implemented by municipalities and citizens at the level of the building, but some - individually, e.g. in apartments and premises of municipal offices. The range of investments necessary for the implementation can be very wide: sometimes the costs are low, but in other cases it is necessary for large investments.

1.3. Specific issues related to energy audit in heritage buildings

1.3.1. Specific characteristics of the energy audit

Energy efficiency measures for historical buildings differ with the fact that it is not permissible to change the external appearance of the building. Therefore, the energy audit is more focused on the condition of buildings wall construction and requires an in-depth study of the state of external structures, their physical and chemical properties.

Main damage to historical brick walls are caused by: moisture, freezing - thaw cycles, acid precipitation.

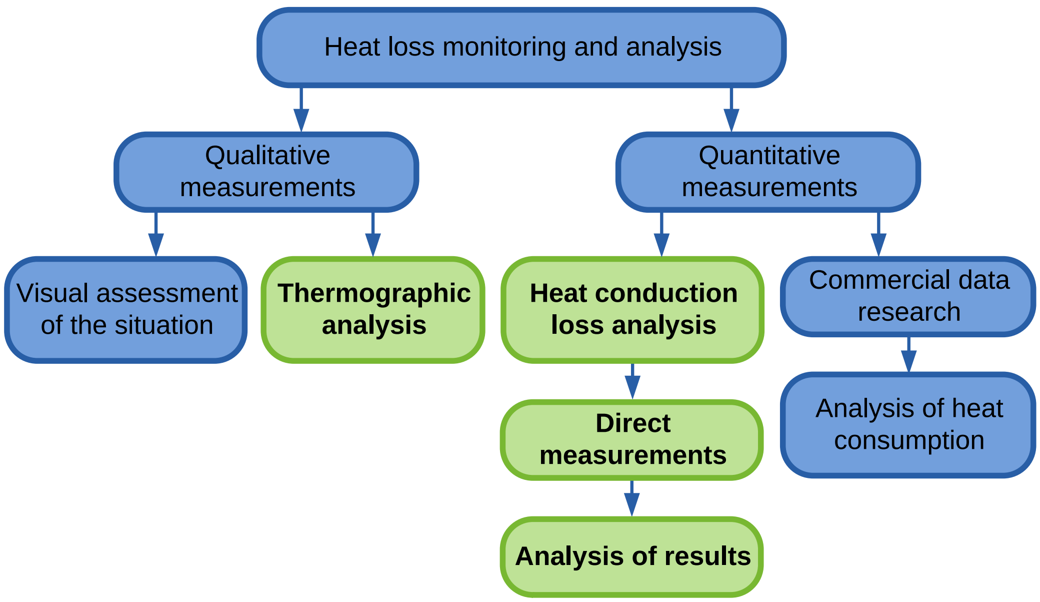


Fig. 1.5 Complex energy consumption monitoring and analysis algorithm

The most important moisture sources are groundwater and rainwater, which enter masonry in large quantities in cases of damaged roof gutters. Moisture and salt content in the masonry increases its thermal conductivity coefficient.

Water soluble salts can get into the bricks and mortar during brick firing process, with rain and groundwater, acid rain and chemical reactions between the brick and masonry components. Poorly burnt bricks have lower resistance to frost and salt crystallization effects.

Acid rain, frost and salt crystallization is the cause of brick masonry joint leaching phenomenon, brick and suture cracking, spalling and disintegration processes, wall collapse.

These buildings need a complex monitoring of their heat loss and analysis of energy consumption, which can best be done using the modules shown below, and the links between the specific objections for earlier built buildings (see Figure1.5). Colored modules have different measures for historical buildings.

1.3.2. Direct measurements

Determination of the heat flow

It is possible to qualitatively determine the nature of heat loss and find significant defects of the external containment, using thermo graphic express analysis, in result of which surface temperature is measured and visually presented. It gives an overall picture of the structure of different building elements, which in turn helps to choose the place where for the quantitative measurements of heat loss (heat flow measurements).

With the help of heat transfer measurements compliance with the construction norms and engineering calculations can be evaluated, as well as to determine the heat permeability of the building structures of unknown composition. Direct measurements are the most accurate method of determining the parameter values. Of course, this method does not exclude errors, but in general they are much smaller than in other methods. It is important to make sure that during the measurements building residents do not indirectly influence the results of measurements (no changes made to the measurement system - the change of temperature, air flow, etc.).

Direct measurements have to be carried out for duration of time, so that the results of measurement data are reliable.

Direct measurements for historical buildings include physicochemical measurements of the brick.

Methods for the research of physical and chemical characteristic historical bricks

Brick water absorption capacity is determined by soaking the samples in cold or boiling water.

Compressive strength of the historical brick can be determined using both the destructive and non-destructive method.

Moisture measurement for the brick wall can be done by infrared thermography, electrical properties, microwave, calcium carbide, and gravimetric measurement methods.

Visual status observations

During the study observations and inspections are used, which includes both qualitative and quantitative information about the building:

- building materials and their condition;
- window type and condition;
- orientation towards different directions.

1.4. Case study. Energy audit in heritage brick building Maskavas street 8, Riga

General information on the building

The building is located in *Spīķeri* complex, the industrial aesthetics of which is included into the UNESCO World Heritage List. The building has an area of 56,3 m^2. The building is currently empty and is not being used, but the earliest goal was to provide facilities comprising functions.

Fig. 1.6 Building Maskavas Street 8, Riga, location and facade

Building envelope

Exterior walls of the building are made of colored silicate bricks with thickness of 51 cm and it has an area of 129,13 m^2. Building has not been inhabited for several years and its constructions have been significantly affected by weather and human factors.

Fig.1.7 Building Maskavas street 8

In Figure 1.7 construction damage above the window can be observed, indicating a potential moisture penetration from the roof. Such damage reveals deeper not painted bricks which opposed to the bricks on the surface have not formed surface layer over time, so they are more rapidly exposed to moisture damage. The wrong design contributed to these defects, because there are no lintels. All the bricks are immured in parallel vertically and without complying with the required angle. Damage observed at the bottom left of Figure 1.8, where the gutter is not required angle, as a result of rain water enters into the walls. At the bottom right be observed the moss, leading to intensify brick deterioration.

Fig.1.8 Damage to wall, the lack of guttering and window

The Figure 1.8 shows that the final parts of building gutters can be stolen as a result the water is not drained 20 - 40 cm above the ground as recommended, but about 160 to 220 cm in height. One of the building windows have been replaced with plywood, which are not suitable fixed. At the bottom of figure 1.9. damage to the construction of the wall is visible, where the whole bricks are missing and the stitches crumbled away. Damages can be observed up to a height of 2 m on the annex joint.

Fig.1.9 The lack of gutters, humidity on the basics

Figure 1.9 shows that the top and final leg of gutter is missing, as result moisture drains into the wall. At the bottom of the picture is observed moisture damage to building foundations and on the right of the picture part of the joint is crumbled away.

Estimated building energy consumption

Table 1.1

BUILDING ENVELOPE

Envelope	The area, m²	Heat transfer coefficient, W/m²K	HT (UA), W/K	MWh/year
External walls	129,13	1,50	191,1	16,76
Roof	80,12	1,00	80,12	7,03
Windows	16,20	2,80	45,36	3,98
Floor to the bottom	80,12	0,80	64,09	5,62
Total			**408,7**	**35,8**

The building has not the mechanical ventilation system, so the building has natural ventilation system with air flow through the building envelope. The air exchange in building was set based on the type of building windows, and it was taken as a 0,5 h^{-1} during the heating period.

Heat flow measurements

During the measurements heat flows in brick walls are determined.

Before the installation of heat flows density measuring equipment measurement sites were surveyed with the help of termocamera, to make sure that the measurement point does not contain thermal damage, which could reduce the measurement accuracy. Figure 1.10 displays instantaneous heat transfer coefficients of the walls of Maskavas Street 8.

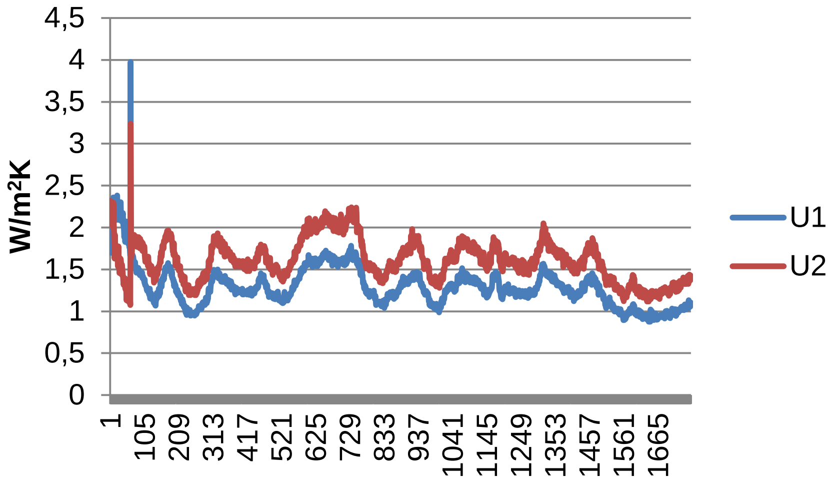


Fig. 1.10 Instantaneous heat transfer coefficients of the walls of Maskavas 8

The non-destructive measurement of moisture content

Moisture measurements were made by the dielectric moisture indicators *Trotec 600* and *650*. Using these devices moisture content in the wall can be determined quantitatively in a scale from 0 to 200 sections. If the measured temperature is less than 40 sections the building material is dry, if between 40-80 sections then - humid, and if more than 80 sections then - wet.

Measurements were made on Maskavas Street 8 building interior walls in six different locations. Measurement data are collected in Table 1.2.

Table 1.2

MEASUREMENTS IN MASKAVAS STREET

	5 cm depth	30 cm depth
1.	57,5	35
2.	61,6	45
3.	64,3	50,9
4.	107	30,3
5.	139,4	37,6
6.	141,3	40,5

Determination of water-soluble salts

To determine water-soluble salts qualitative test method based on the methods developed in „A laboratory manual for architectural conservators” by International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) was used. Quantitative analysis of sulfate was carried out using the „determination of barium in a form of barium sulfate" methods. It was determined that the sample contains 2,5 mg/l NO_3^- and minimal amount of SO_4^{2-} that can be caused by acid rains, sulfates may also form in brick burning process. It was determined that sampling site building interior walls are wet in 30 cm depth, which is due to the fact that the building is not being heated.

Conclusions

The estimated energy consumption for heating of the building is 35.8 MWh per year, or 633 kWh/ m^2 per year.

Measured thermal conductivity coefficient for bricks is different from the calculated values, which are based on the element structure and obtained using ISO 6946-1.

Calculated heat transfer coefficient is lower (1.32 W/m^2K) than measured (1.48 W/m^2K).

Moisture and freeze - thaw cycles have done grate damage to external wall structures of Maskavas Street building. The main cause of damage is poor technical condition of roof gutters.

While the main reasons for masonry cracking are three: the intense traffic and transport, poor foundations and groundwater fluctuations.

The sample, which was taken from the building in Maskavas Street 8 showed minimum concentrations of nitrate and sulfate content.

The building needs strengthening of wall constructions in places where cracks, loose joints and shifted bricks have developed. It is necessary to strengthen the window boxes, check the moisture barrier and prevent flaking of the joints.

Table 1.3 shows suggested insulating materials, which are suitable for exterior wall insulation from the inside.

Table 1.3

COMPARISON OF INSULATION MATERIALS

Insulation material	Thermal conductivity, λ W/(mK)	Insulation thickness, m	The new U-value $W/(m^2·K)$	Savings of U-value $W/(m^2·K)$	Reduction of heat consumption, MWh/year	Reduction of heat consumption, kWh/m^2 year
Eco wool	0,037	0,15	0,21	1,27	14,37	255,16
Flax	0,033	0,1	0,26	1,21	13,7	243,41
Hemp	0,055	0,1	0,39	1,08	12,22	217,03
Thermo wool	0,021	0,1	0,18	1,3	14,68	260,7
Aero gel	0,013	0,04	0,26	1,11	12,53	222,51
Vacuum insulation panels	0,004	0,06	0,06	1,42	16,07	284,86

2. BUILDING ENVELOPE

2.1. Strategy and physics of historical building thermal insulation

2.1.1. Insulation strategy

When reconstruction work related to the old, historical buildings is planned and proposed, it is important to understand the building beforehand. This means understanding the building reconstruction works and technical condition as well as the way to do these works. Building characteristics and cultural historical constraints must not be forgotten [1].

The basic function to reduce heat losses that occur due to air leaks in building and heat transfer characteristics of the materials is building insulation.

The main building insulation elements are (percentage of the loss from distribution elements are indicated in parentheses) roof (35%), walls (26%), floor (5%), windows and doors (8%), while the remaining heat loss are drawn up thermal bridges (7%) and ventilation (19%). The heating and hot water system renovation are also of great importance since they are two major systems which are able to get large energy savings. To get the best results and maximally increase buildings energy efficiency and its lifetime, a complex renovation of the building, including all the above elements and systems, must be carried out [1, 2].

2.1.2. Thermal Mass

From the thermal point of view historical buildings may be characterized differently than the modern buildings. They are referred to as thermally severe, or in other words, they have thermal mass. Thermal mass of the building can be used to store energy. During warm months, heat will be stored in the thermal mass. When temperature in room drops, solid walls (concrete, brick walls) heats the room [2, 3].

In order to avoid overheating in the summer, it is possible to introduce a night-cooling in conjunction with thermal mass. Night cooling can be used to lower the temperature of the buildings thermal mass when outdoor temperature is below normal indoor temperature [2].

Advantage of this system is that the massive wall structure allows delaying and increasing the difference of peak temperatures between outdoor and indoor temperatures. In turn the disadvantage is that greater amounts of energy are needed for the heating of the building [2].

In permanently inhabited buildings thermal mass saves energy, but in the opposite case, it may be a problem, especially in brick buildings with high thermal mass, and if the wall is moist. When the building is being heated, the surface begins to dry at high speed just when the heating system starts operating; humidity begins to evaporate at high speed therefore increasing relative air humidity. This may cause condensation on colder surfaces, which heats up more slowly [2].

2.1.3. Improvement of thermal properties

Making historical building envelope insulation from the inside one poses several problems. Often, there are different types of ancient paintings, sculptures and ancient architectural elements on the interior walls, elements they form gaps in insulation and thermal bridges because the insulation layer cannot be put uniformly over the entire wall. Dimensional changes caused by insulation layer may affect normal opening of windows and doors [1, 2].

Majority of historical buildings have rooms that cannot be heated, structural voids or cracks in walls and other places, where condensation risk may increase because other parts of building have been renovated and air flows are reduced too much.

A very important aspect that is currently not thought about during the housing renovation process is indoor microclimate. The air flow in the building cannot be overly restricted otherwise residents are not provided with fresh air exchange, which is necessary to prevent indoor pollution and humidity.

The most appropriate materials for historic buildings are natural fibre insulation, for example, wool and hemp insulation because it has hygroscopic properties, retains heat insulation capability if becomes wet and does not contain hazardous substances [4].

2.1.4. Internal insulation

In historical buildings the outer envelope surface insulation technology cannot be used because the authentic look has to be maintained. So, the only way to improve energy efficiency in buildings is an internal thermal insulation, when insulation material is placed on the inner surface of the envelope.

Selection of appropriate materials and systems depends on:

- Monument protection requirements;
- Location of the building (local climate);
- Type, material and thickness of the wall;
- Quality of protection against severe rain;
- The internal wall surface quality;
- Technical condition of covers and partitions [2].

Selection of internal insulation thickness depends on:

- Monument protection requirements;
- Material (hydrothermal durability);
- Living area loss;
- Comfort criteria and energy efficiency;
- Technical condition of covers and partitions [2].

Unambiguous regulations for the selection of optimal thermal insulation material does not exist, historical building must be individually studied, for example, using a two-dimensional building heat transfer simulation program Therm and/or combined heat and moisture transfer simulation program WUFI for the simulation period of several years [2].

Installation of thermal insulation from inside reduces the wall element temperature, which can increase the risk of condensation and freezing, as well as prolong wall drying time. Installation of thermal insulation can cause humidity and pressure changes. Lower cell temperature, longer drying, heightened relative humidity and altered pressure settings may adversely affect the quality and strength of wall structure. To reduce such risks, it is necessary to prevent rain water from entering wall structure and elements. To reduce indoor air, which is more humid, penetration in wall, the most common choice is to install a vapor barrier or a continuous air barrier. In order to minimize the risk of damage to the wall structure, it is necessary to evaluate the insulation thickness and find the balance between heat loss and temperature drop in the wall [5].

2.1.5. Internal insulation and moisture

Masonry walls can absorb large quantities of moisture, but when the thermal insulation is installed on the inside, the drying volumes that are focused on the inside of the wall decreases, extending the time period when wall is moist and increasing the negative effect of freeze-thaw cycles.

Experiments conducted in 4-year period within Northern Europe climate, shows that using a hydrophilic cotton wool thermal insulation without vapor barrier (steam-repellent coating of lime and cement, which is applied on the inner brick surface was used instead of the vapor barrier) the total thermal resistance of the brick wall increased approximately two times, and the maximum value of the relative humidity between the thermal insulation and repelling coating was 54%. Such a value does not create condensation risk. However the external wall surface is exposed to a high relative humidity, which contributes to the degradation of masonry. To prevent wall damage relative humidity level must range between 60 - 80% [6, 7].

A noteworthy observation is that the indoor relative humidity is low, around 30% in winter and 20% during summer, which is linked to central heating. From the can be concluded that in the building, in which an air barrier is not established, it is impossible to control humidity, and with it the air quality, because the installation of mechanical ventilation, increases pressure in the room, in this case promoting entering of more humid indoor air into the wall, which is not desirable [6].

2.1.6. Moisture transport

The most important moisture sources are groundwater as well as rain and snow waters which usually enters the brick wall in large quantities in cases of damaged roof gutters [8].

All bricks and mortars have a strongly explicit micro pore and small capillary structure, which provides a very good water absorption capacity. The smaller the pore radius, the higher water can climb in the wall and, therefore, soak up more water [8].

Water from the soil is absorbed in brick wall at a rate which decreases with increasing altitude, but evaporation from the surface occurs with almost constant speed. Close to the ground, where the climbing speed is greater than evaporation, there is very thin water pellicle on the surface of the wall [9, 10].

The flow of air masses between the external environment and the interior also serves as a source of moisture. The flow of air mass is caused by the difference in air pressure. During the winter, indoor air is warmer and therefore has lower pressure, and the outdoor air is cooler therefore the pressure is higher. Such distribution of pressure creates traction of cold air through the walls into rooms, which brings moisture [11].

2.2. Insulation technologies of historical building construction elements

2.2.1. Roof insulation

During the discussion about the roof insulation, the necessity of complete roof insulation should be taken into account. Otherwise, there is a high probability of the formation of thermal bridges and moisture condensation that will cause envelope and roof damage.

Roofs are divided into two groups - pitched and flat. Installation of thermal insulation material on the pitched roof can be done in two main ways, which are then divided into four methods:

1. Insulation at rafter level (warm roofs);
2. Attic ceiling insulation (cold roofs) [12,4].

The flat roofs, in turn, have three traditional insulation methods:

1. Warm roof coating;
2. Cold roof coating;
3. Inverted warm roof coating [13].

Pitched roofs

There are four pitched roof insulation methods (see Figure 2.1.).

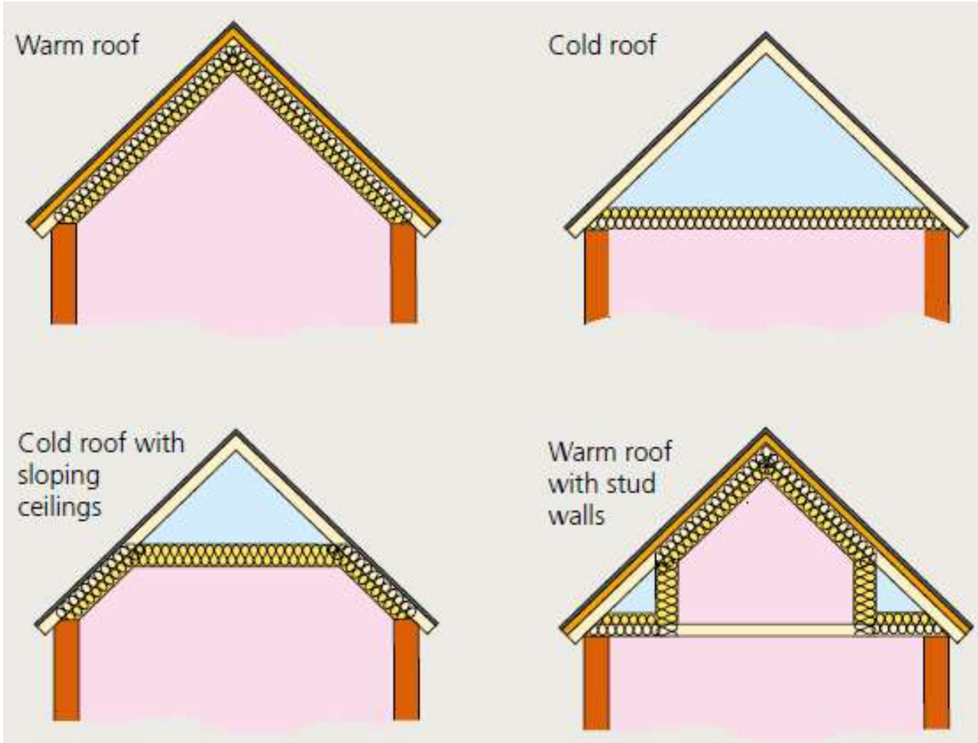


Fig.2.1. Insulation of pitched roofs [4]

The term "cold roof" means that the insulation material is laid horizontally on the building attic ceilings, leaving uninsulated roof space - attic. In contrast in the case of "warm roof" thermal insulation material is embedded between, under and / or over the roof rafters providing insulated attic space, which can be heated and used as a living space

Warm roofs

Advantages and disadvantages of the warm roof insulation methods are showed in Table 2.1.

Table 2.1.

REVIEW OF METHODS [12]

Insulation method	Advantages	Disadvantages
Thermal insulation above the rafters	• Continuous thermal insulation layer which provides 100% avoidance of thermal bridges. • Reduces the risk of condensation on a wooden frame. • Prevents attic from overheating caused by solar radiation. • Ceiling structure is not being damaged.	• Additional costs to provide scaffolding and temporary roofing. • Roof level rise, which leads to changes in the eaves and on the outskirts. • The roof is not always exactly in the same plane and without bumps, so the insulation installation requires a lot of attention to make a qualitative insulation plate connection. • Adding extra weight to the rafters, additional roof reinforcement is possible.
Thermal insulation between the rafters	• No visible roof level increase. • Lower cost. • Ceiling structure is damaged, if the insulation is installed from the top.	• Broad rafters are needed to impose a sufficiently thick insulating layer (the most common insulation layer is 75-150mm). • Cracks between the rafters and insulation may be formed, through which there will be an air infiltration, so in this case it is

		more appropriate to use soft insulating material instead of plates. • Water vapor impermeable insulation can cause moisture absorption in rafters and start wood rotting.
Thermal insulation under the rafters	• No visible roof level increase. • Continuous thermal insulation layer with well-sealed connections.	• Substantial improvements cannot be made without the reduction of interior space area. • It is hard to insulate joints around the openings and obtain a smooth layer of insulation. • It is not possible to insulate attic ceilings with elements recognized as cultural and historical heritage.
Insulation over and between rafters or between and under rafters	• The most effective type of insulation at rafter level. • Ensures combined advantages and excludes majority of the disadvantages from both.	• Increased costs.

Cold roofs

In case of the Insulation of attic covering the most efficient way is to put insulation in two layers. The first layer is laid between the ceiling joists but the second layer is laid over the beams - it helps to reduce thermal bridges from the ceiling joists [4].

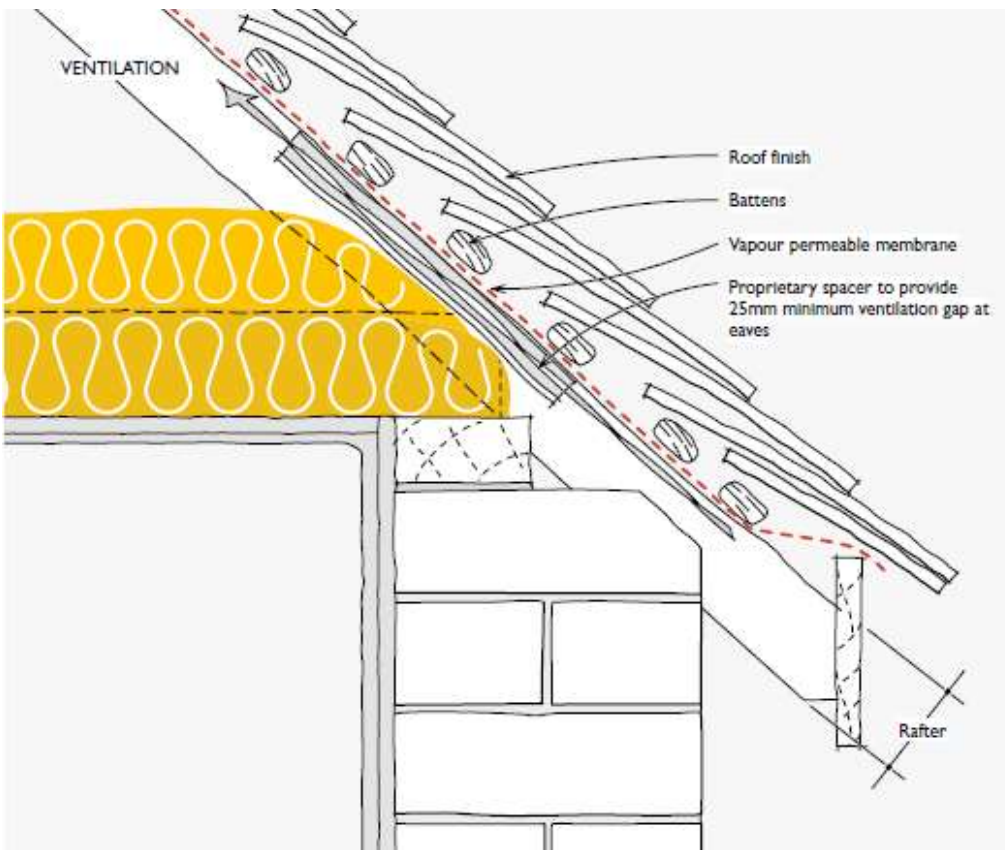


Fig.2.2. Eaves ventilation [4]

In many historical buildings joists can be uneven, with differing heights or not tick enough to ensure qualitative installation of the thermal insulation. In these conditions minor height differences and unevenness can be filled with cotton wool, but bigger ones - with bulk cellulose insulation.

Cold roof ventilation is provided with cavities in the roof, where there are open eaves (see Figure 2.2) or openings in gable walls, gable or through the roof coatings. Reduction of ventilation may cause moisture condensation problems, especially if the roof covering is water-proof. One possible solution is to install a fan at the roof eave, which would help to maintain the ventilation paths [4].

Flat roofs

The main risk for the insulation of the roofs like this is the increased risk of condensation in roof structures. This can lead to corrosion of some types of metal roofing and metal support structures or decay of wood constructions.

There are two main methods of dealing with the potential risk of condensation:

1. Installing a vapor barrier under the insulation;
2. Ensure effective roof ventilation in the cold area above the insulation

Which method is best depends on the individual circumstances of each roof and insulation type and thickness.

There are two ways in which thermal insulation can be incorporated into flat roof construction:

1. Below the roof and above the ceiling material (cold roof coating);
2. Above roof covering and below the waterproof layer (warm roof coating) [13].

Isolation with cold covering system is the most commonly used method for historical buildings, but not always the most appropriate. In order to obtain the highest possible efficiency, both systems are combined in compliance with thorough assessment of the condensation risk [13].

Cold roof covering

Figure 2.3 shows cold covering thermal insulation method.

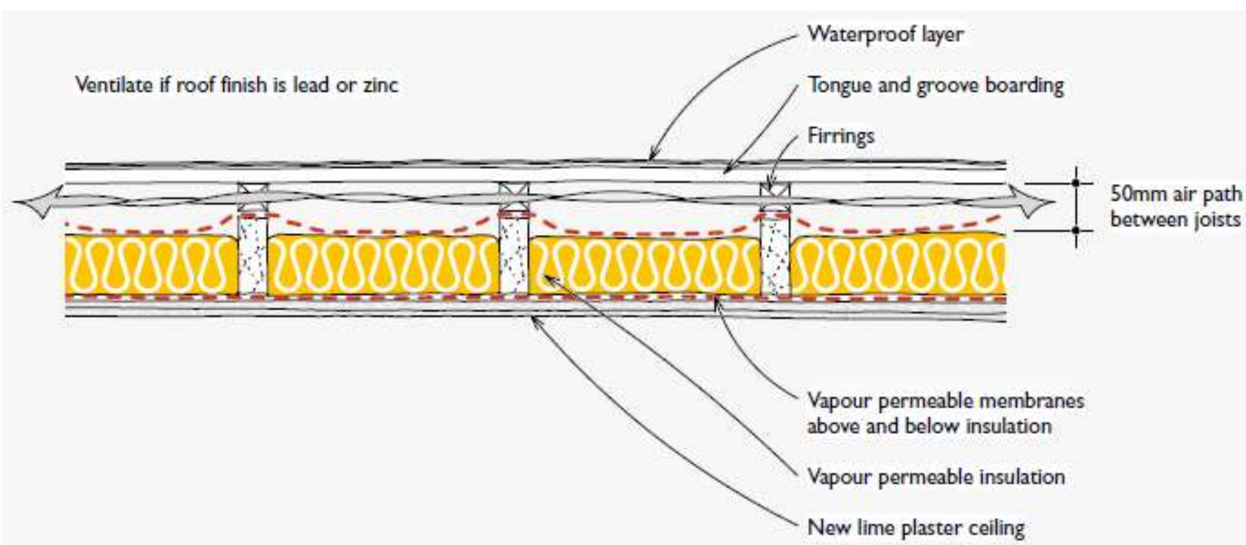


Fig.2.3 Cold roof covering [13]

Ceiling trim is removed to insert the insulation. Insulation material is embedded in it, in order to remain at least 50mm slot between the roofs for ventilation.

Warm roof covering

Where it is possible to lift the roof covering level without endangering buildings value, thermal insulation layer can be mounted above the surface (see Figure 2.4) Plates that can withstand compressive loads must be used for the insulation.

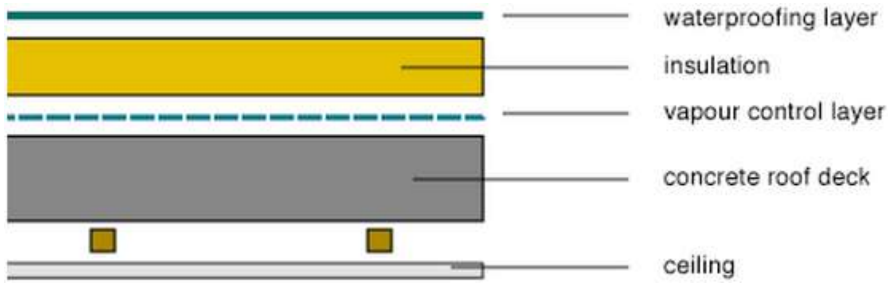


Fig.2.4. Warm roof covering [14]

If solid insulation boards are using, the new roof covering can be made of stainless steel or copper. The existing roof covering can serve as a vapor barrier, if its condition is satisfactory.

An alternative is to install wooden frame on the top of the existing coverage, but, if it is necessary to install thick thermal insulation layer old covering can be demounted and the insulation material embedded in the existing roof carcass in case where such method is used it is necessary to perform calculations checking the risk of condensation [13].

2.2.2. Floor insulation

The temperature difference between indoor and the first or basement floor is considerably lower than the temperature differences in external walls of buildings. Studies have shown that floor insulation provides a very small part of the total heat gains in comparison with roof and exterior wall insulation. Floors in historical buildings can also have a great cultural and historical value that makes it harder to install thermal insulation. However, if floor modification or reconstruction is planned the opportunity to improve the efficiency of it should be used [15].

Historical buildings usually have two types of flooring - solid or wood construction floor.

Wood floors

Insulation process of wood floors is easier in comparison with that of the solid floors. Hygroscopic insulating material is inserted between the joists (see Fig. 2.5.).

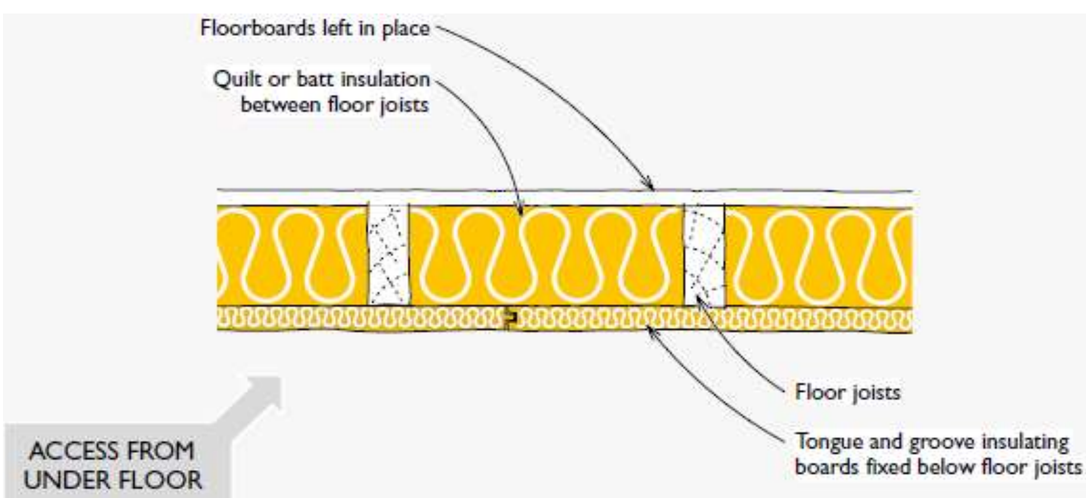


Fig.2.5. Insulation from below [17]

In Figure 2.5. insulation is applied from the bottom and the floor boards does not have to be removed. Soft heat insulation material, which is located between the joists are secured with hermetic wood fibre plates. Sheep wool or hemp insulation, which reduces the risk of condensation, would be more appropriate.

If the floor is not accessible from downstairs, insulation must be installed from the top. Insulating material may be affixed with permeable membrane or fastenings depending on the insulation material. Hygroscopic insulation materials are the most appropriate [17].

Solid floors

Traditionally, for the insulation of solid floors traditional thermal insulation materials are used, that is - foam glass, extruded polystyrene and others, below which waterproofing is incorporated to protect them from moisture.

Major risks that should taken into account after the installation of insulation is water vapor condensation and moisture absorption from the soil, because solid floors is in a direct contact with the ground. After the insulation the moisture that was absorbed by the original floor is drawn to fundaments, and then capillary forces move it up the masonry walls. To avoid such risks, a specific method is designed for the floor insulation of historical buildings (see Fig. 2.6.).

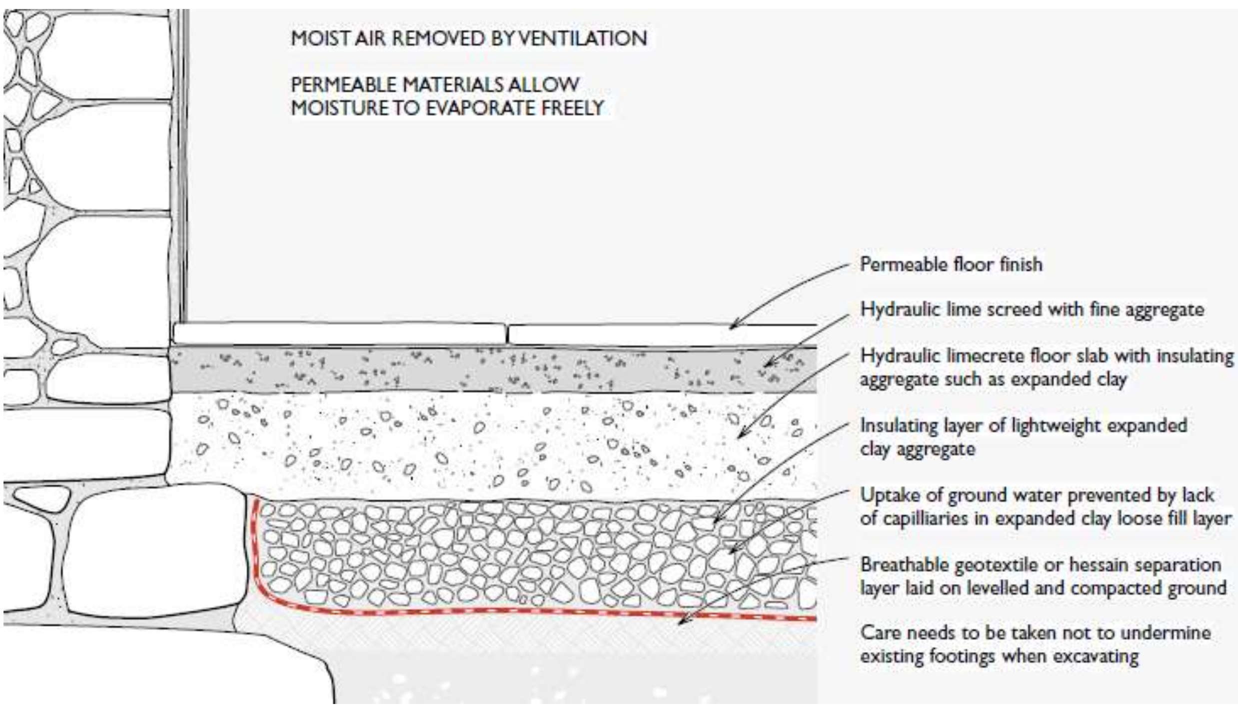


Fig.2.6. Lime concrete insulation [17]

Method is based on natural, hydraulic lime mixture and isolation mass. These materials have the ability to absorb moisture, and then give it to the environment, creating "breathing" floor system, which reduces the disadvantages of traditional methods.

2.2.3. Vapor barriers

The risk of condensation must be taken into account installing insulation materials. Condensation is not desirable in any part of construction, but it is very difficult to avoid because from kitchen and bathroom in the form of vapor and from human breath moisture enters the air. It is also important to remember that the lower the air or surface temperature, the lower air humidity is necessary for the condensation [11].

One of the ways to avoid wall damage caused by moisture is to use an insulation that allows water evaporation. If the insulation installed on the inside then wall temperature drops and dew point moves to masonry. To avoid such situations, installing thermal insulation on the inside, it must be protected by a vapor barrier. But note that such a wall is no longer breathing, which may degrade the indoor microclimate [11].

An intelligent membrane is air-tight, and depending on the design, some manage to lead moisture only in the direction of heat flow. Intelligent steam vapor membrane changes its resistance in relation to the relative atmospheric humidity. During the winter, they have a high resistance (s_d is about 10 m) and protects the wall construction from moisture. In summer, the resistance is low (s_d up to 0.25 m), allowing the moisture in the wall to evaporate into the rooms. The vapor flow rate can be up to 40 times higher. That means that the structure can evaporate up to 560 g of moisture per m^2 per week. Preventing the accumulation of moisture behind the barrier, which otherwise could lead to the condensation and promote the formation of mold. [18]

2.2.4. Breathing walls and connections

Traditionally, the masonry walls are called "breathing" constructions, because the moisture exchange between indoor and outdoor environment may take place through the enclosing structures. If any insulation works are being planned, it is very important that this feature of masonry is taken into consideration [19]**.**

Wall permeability or "breathing" may seem like a simple process, but in reality, water and water vapor transport in porous materials relating to the building envelope and the indoor environment is a complex and difficult process.

Ancient buildings are built in a way that there is a dynamic balance between water absorption and evaporation. To maintain this balance, when the insulation is carried out, it is necessary to install additional ventilation to remove excess moisture [2].

One must remember that the wall permeability is not related to the air flow because it occurs through windows, doors, cracks, ventilation.

Air flow will intensify when affected by wind, which may be greater if the building is closer to the sea, bordering with the territory without constructions (flat territories allows the wind to run), individual wall sizes and window/ door area. An increased pressure is formed on the side of the building from which the wind is blowing, but when the wind passes the corners turbulence is formed, which accelerates the wind flow and creates a strong negative effect of pressure on the corners and less powerful on the other walls [5, 20].

2.2.5. Hygroscopic insulation materials

Hygroscopic insulation materials are made from natural or synthetic fibres, and they are suitable for insulation of historical brick buildings. The best features of those materials are that the insulation fibres are able to absorb the moisture and then dispose of it through evaporation. The fibres allow the moisture to move from the indoor to the building envelope and vice versa. The most typical fibres and capillary active materials are cellulose, sheep wool, calcium silicate foam, wood fibre, flax, hemp.

Cellulose

Cellulose (polysaccharide, $(C_6H_{10}O_5)_n$) include insulation materials made of recycled paper or wood fibres mass. Manufacturing process produces wool-like material consistency. Boric acid (H_3BO_3) and borax ($Na_2B_4O_7*10H_2O$) are added to improve the fire resistance properties. Cellulose is widely used as an insulation material in bulk form to fill the air gap, but rolls and sheets are also produced. Sheets are produced by mixing paper with fibres and binders and pressing with steam [11].

Thermal conductivity is in the range from 0.04 to 0.05 W/(mK). The conductivity varies with temperature, moisture content and density. For example, the thermal conductivity can vary from 0.04 to 0.066 W/(mK) the moisture content increasing from 0% to 5% of volume [21, 23].

Sheep wool

Insulation material is made from pure sheep wool, which can be obtained from recycled wool. In the production process wool adds sodium salt and urea to protect the isolation from moths and beetles, when it's embedded in the wall. Thermal insulation plate consists of thicker plates, which are fixed to each other with polyester fibres and natural latex milk. Cotton wool is composed of 85% natural cotton and 15% polyester, which is added to maintain its shape.

Most of the natural insulation materials have good insulation properties, well as the sheep wool. It ranges from 0.04 – 0.045 W/(mK). The sheep wool insulation can absorb 30% moisture by weight, and then is able to return it quickly to the environment [2].

Wood fibres

As the raw material of the wood fibre insulation is used conifer, less hardwood (waste product). Wood is chipped and then treated by autoclaving before pulverization. The fibres subsequently mixed with a binder (latex or wax emulsion) and extruded into plates. Thermal insulation panels are treated with boric acid to raise the fire safety of the material, and less frequently with bitumen to obtain hydrophobic properties. If the material is treated with bitumen, then it cannot be used as an internal insulation.

Thermal conductivity of the wood fibres insulation is a wide range from 0.04 – 0.09 W/(mK), compared with the cellulose and sheep wool.

Flax

The flax thermal insulation is produced similar to all other natural insulation materials - flax fibres are pressed into plates with polyester binder and fire resistance properties are improved. Their thermal conductivity in the range of 0.035 to 0.045 W/(mK) [22, 23].

Hemp

The hemp insulation plates are made only from the hemp fibres or from a mixture consisting of hemp and recycled cotton or wood fibres with polyester as a binder. Thermal conductivity of the thermal insulation plates in the range of 0.04 – 0.049 W/(mK) [23].

2.2.6. Windows

Heat loss through windows can make up to 20% of the total building heat losses and therefore it is essential to improve their energy efficiency. Windows is often rated as the cultural and historical heritage, and a complete their replacement with modern, energy-efficient windows is not possible, but the use of individual methods or their combinations is possible in agreement with the competent authorities:

- Window sealing;
- Installation of secondary glazing;
- Replacement of old glass with the glass of low iron content and a low degree of blackness, leaving the old frames;
- Installation of light reflection system between the glazing;
- Shutters, curtain installation (night-time option);
- Complete replacement of the window with the highest possible energy efficiency class;
- Replacement of window boxes;
- Solar screening [2,15,24].

2.3. Heat and moisture transfer modeling

The most common simulation program for heat transfer modeling using two-dimensional building heat transfer is Therm. Combined heat and moisture transfer program WUFI is used to determine the changes in temperature and humidity layout after the installation of thermal insulation in various building structures.

Using a computer program Therm, which was developed by Lawrence Berkeley National Laboratory, it is possible to simulate the two-dimensional thermal transition effects for different building elements: windows, walls, foundations, roofs, doors and other elements for which the cold bridge effect are important. Therm allows assessing the effectiveness of products and elements and the temperature layouts that can cause condensation and moisture damage and a decrease of building element quality. Therm analysis uses the finite element method, which can model complex geometric shapes, resulting in a heat transmittance value of U, isotherms, color isotherms, heat flux vectors, the color lines for constant flow and temperatures [25, 26].

WUFI is a combined heat and humidity transition modeling program that has been developed by the Fraunhofer Building Technologies Research and Integration Centre.

With its assistance the calculation of several layer elements exposed to the natural climate impacts can be carried out. WUFI uses the latest discoveries of vapor diffusion and liquid transport in building elements.

Wall thickness and material, the data of which are taken from normal data libraries with the option to change them, are entered in WUFI. The opportunity is given to enter climate data or choose from the prepared.

Climate data includes the amount of rainfall and intensity of the sun, so it is important to specify the orientation of the wall and take the climate data from a site that is similar latitude.

Calculating heat flow WUFI computer program incorporates different assumptions:

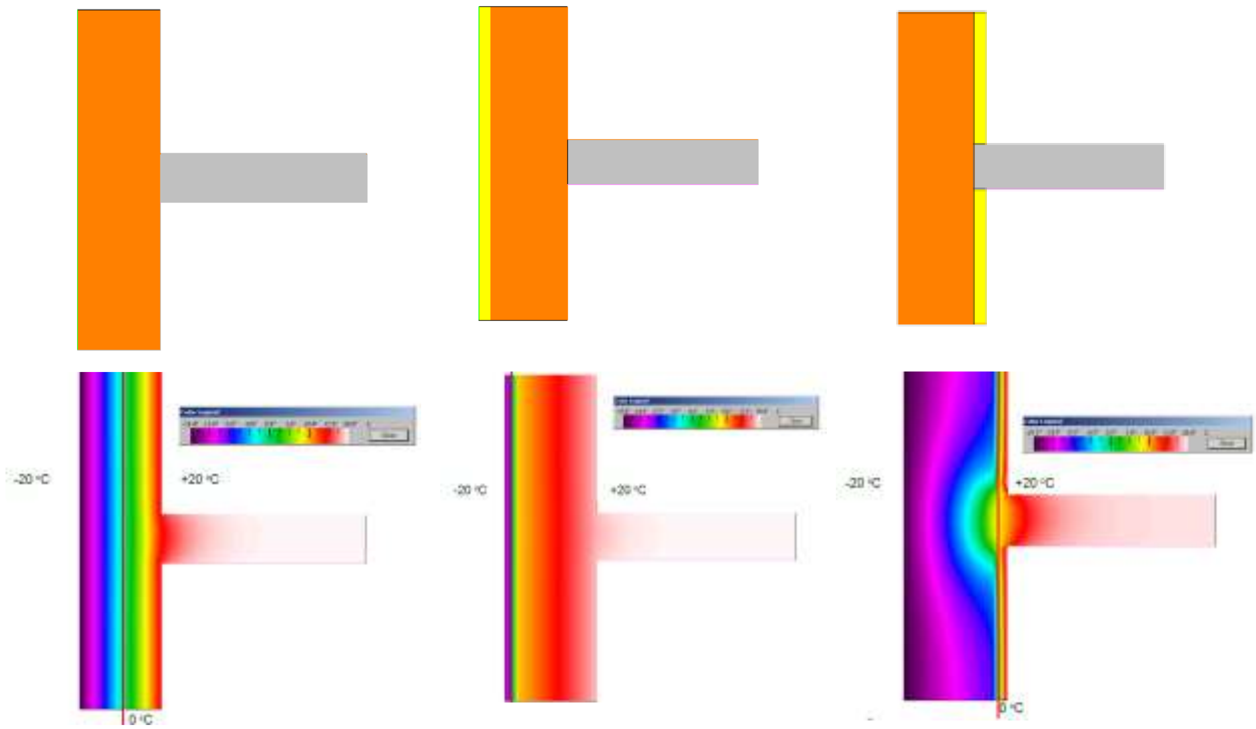
- Taking into account material thermal conductivity, phase change effects, short-wave solar radiation and, depending on climate data the night-time long-wave radiation cooling, but does not take into account the convective heat transport
- Taking into account the two vapor transport mechanisms: vapor diffusion and liquid diffusion, ignoring the vapor transport by convection air flow.
- Fluid transport mechanisms are capillary effects and surface diffusion. The flow due to the gravity, hydraulic flow due to pressure difference, electro kinetic and osmotic effects are not taken into account [27, 28].

2.4. Internal wall insulation and external wall insulation in historical buildings

When insulating walls from inside it is important to understand how this will affect the existing wall. There is an opinion that walls should not be insulated from inside because temperature level in the existing brick wall will be lowered and this will increase the speed of brick wall deteriation.

When insulating walls in historical buildings from outside it is very important not to alter the appearance of the building. In many cases insulating walls in historical builidngs from outside is not allowed by govermental institutions responsible for cultural heritage.

Insulation material changes temperature distribution in walls. In Figure 2.7. temperature distribution in brick walls is shown in case of internal and external wall insulation.



a b c

Fig. 2.7. Temperature distribution in brick wall for uninsulated wall (a), wall with external insulation (b) and wall with internal insulation (c)

As can be seen in the figure 2.7. biggest temperature drop happens in the insulation material because of its low heat conductivity. In case if indoor air temperature is +20 ^{o}C and outdoor air temperature is -20 ^{o}C the temperature on the surface between brick wall and insulation material for external insulation is +9 ^{o}C but for internal insulation it is -10 ^{o}C. This means that in case of external insulation brick wall in all weather conditions does not reach temperatures lower than 0 ^{o}C – there is no chance of water vapor or liquid water that is in the brick wall to freeze and damaging the existing brick wall. In case of internal insulation temperature in brick wall can easily drop under 0 ^{o}C, which means that wator vapor or liquid water that is in the brick wall can freeze and create damage to this wall. Therefore it is very important for walls that have internal insulation also to have vapor barrier that does not allow vapor transport in the wall. Also it is very important that wall that has to be insulated from inside is dry and does not contain too much water in any state. If the wall is wet it should be dried before insulating the wall from inside.

If wall is insulated from inside then the usual solution is a wooden carcass, which is filled with insulation material and afterwards covered with gypsum boards or other finishing materials.

If wall is insulated from outside then for historical brick buildings there is a solution where the insulation board imitates brick masonry.

External insulation Internal insulation

Fig.2.8. Insulation material for external insulation has to imitate bricks if it is [Energetic refurbishment of historic buildings in the Baltic Sea Region, Interim Brochure] while internal insulation has no such needs [http://www.sustainablebuildingsolutions.co.uk/training_courses/thermoshell-internal-wall-insulation-installer]

If the same material thickness is used in both internal or external wall insulation, the U-value (heat transfer coefficient) will be the same. Only if wall has internal insulation then larger thermal bridges will be observed in the places where ceiling meets wall.

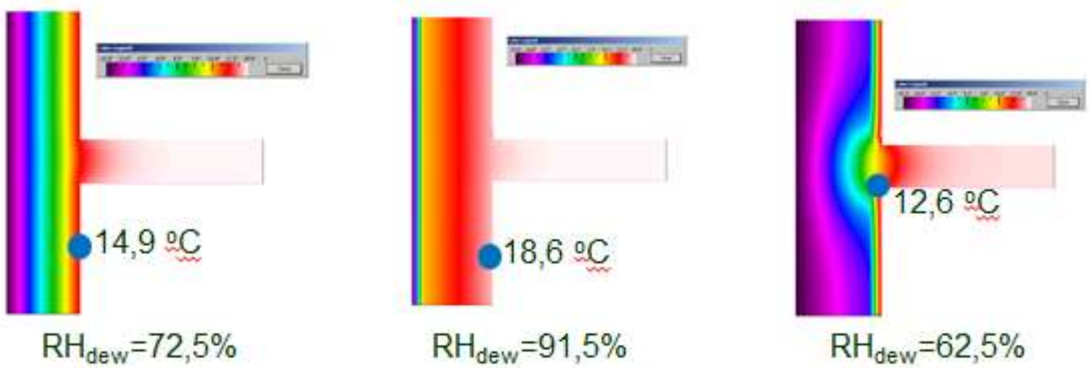


Fig.2.9. Minimal temperatures and relative indoor air humidity at which condensation will form

As can be seen from Figure 2.9. the lowest temperature on wall surface will be observed for the case when wall is insulated from inside. In this case surface temperature at the point where wall meets ceiling will be 12,6 ^{o}C, while minimal surface temperature on uninsulated wall will be 14,9 ^{o}C, but for insulated wall it is 18,6 ^{o}C. If indoor air relative humidity will be higher than 62,5% condensation will form on surface of wall that is insulated from inside. In the same time for wall that is insulated from outside relative air humidity has to be higher than 91,5% for condensation to form on inner wall surface.

3. VENTILATION AND AIR CONDITIONING

3.1. Ventilation systems

Definition. Ventilation (ventilatio – airing) – creation of the desired indoor air exchange. Its main task - to maintain the indoor air environment favourable for humans, to ensure the flow of oxygen necessary for breathing and to carry away the products of respiration (CO2 and water vapour).

Ventilation systems are divided into three main types:

- Natural ventilation
- Mechanical ventilation:
  - Local
  - Central
- Hybrid ventilation.

3.1.1. Natural ventilation systems

Natural ventilation system is:

- Easy to create in spaces with a small air exchange layer
- difficult to control
- dependent on the outside air conditions, building design, location, construction quality, etc.
- related to outdoor air pollution and noise level in populated areas
- it cannot be used in buildings requiring enhanced security
- used in energy efficient buildings.

Natural ventilation limiting factors are:

- The maximum depth of the space:
  - a depth of the space no more than 2.5 times the height of the room space with ventilation from one side
  - no more than 5 times the height of the room space with cross ventilation
- Wind velocity
- Emissions
- Indoor air parameters.

Natural ventilation systems operate on impact of wind and chimney effect, as well as impact of combined wind and chimney effect.

Wind effect

Wind effect on the building surfaces and natural ventilation depends on wind speed, angle of wind motion in relation to the surface, building density, building height, building geometry and shape, roof slope and the air density. The action of wind effect is shown on Figure 3.1.

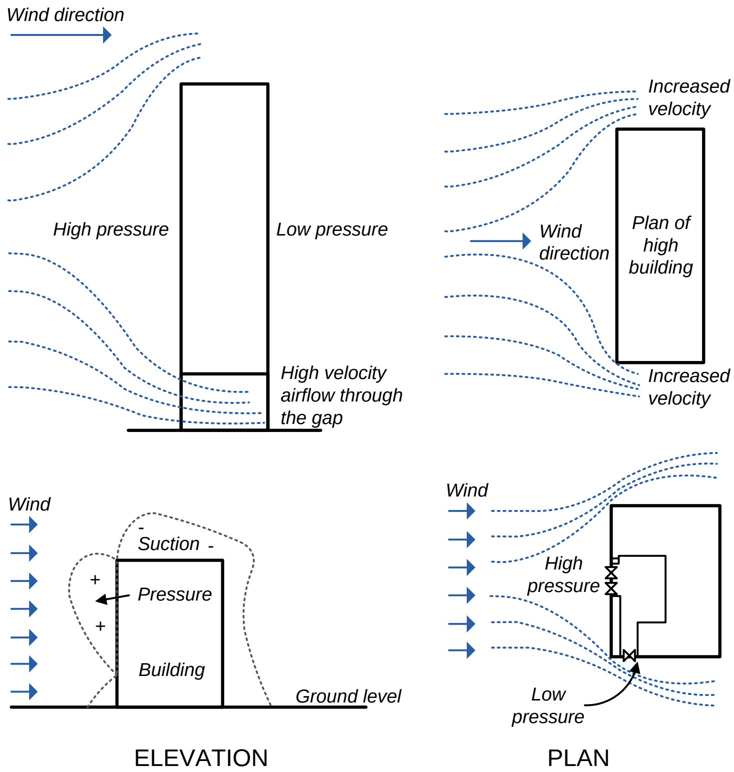


Fig. 3.1.Wind effect

Passive or stationary wind devices operating on impact of wind action are open windows, atriums and inner courtyards, wind promoters or wing walls, stack canopies, exhaust canopies, wind towers, double facades, wind catchers, wind floors.

Active or moving wind devices operating on impact of wind action are wind canopies / vanes, turbine ventilators, rotating stack canopy, vertical axis wind suction. Figure 3.2. shows an example of using the moving wind device in natural ventilation system.

Fig.3.2. Active natural ventilation system [32]

Stack effect

Air moves up through the air channels influenced by gravity due to the difference between outdoor and indoor air temperature (density).

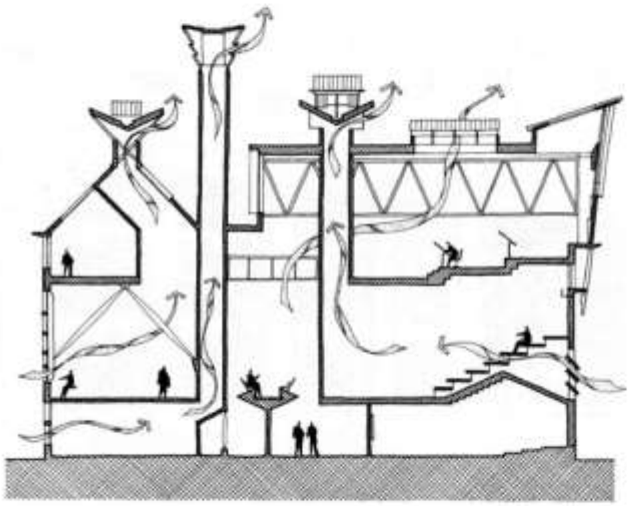


Fig.3.3. Stack effect in natural ventilation systems

Gravitational pressure that overcomes the aerodynamic resistance of system:

$$\Delta p = g \times h \times (\rho_A - \rho_T),$$

where

g – gravitational acceleration, m/s^2;

h – height of the air column, m (from exhaust louver to pit aperture in residential buildings);

ρ_A – outdoor air density, kg/m^3;

ρ_T - indoor air density, kg/m^3.

The estimated outdoor air temperature in residential and public buildings is 5 ° C (if it is higher, the natural pressure becomes undistinguished, and the space needs to ventilate). The natural pressure in the upper floors is less than the lower and the natural pressure is dependent on the season. Air cooling in ducts is undesirable because it reduces the natural pressure and can lead to condensate release.

Air infiltration

Supply air enters into spaces through the *leakages* around *windows, doors* and building constructions. An infiltration air stream into the room is heated with heating radiators.

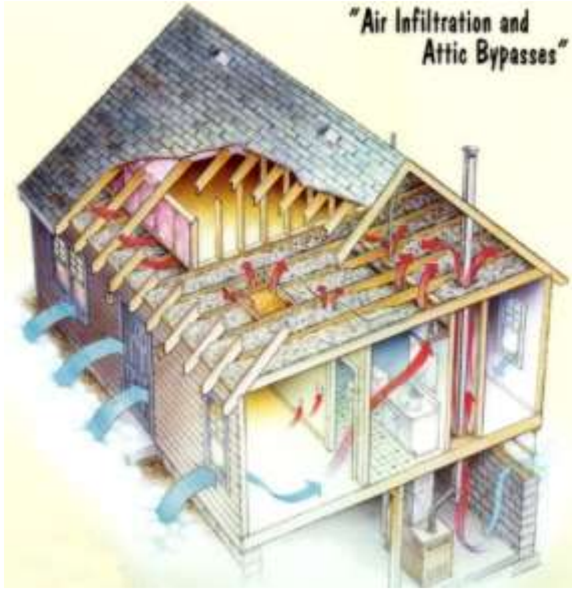


Fig.3.4. Air infiltration in the building

Use of natural ventilation for cooling

Air conditioning system is not always necessary for space cooling, as the same function can be performed a natural ventilation system. On the day indoor air is cooled:

- if the outdoor temperature is lower than the indoor temperature;
- the cooling of building construction is carried out;
- direct cooling of human bodies occurs

At night the building constructions are used as a cold battery, which is used for cooling during the night.

3.1.2. Mechanical ventilation systems

Mechanical ventilation systems may be distinguished by whether the air is being supplied or discharged, as well as the place of space in which it is organized. Mechanical ventilation systems:

- Supply systems;
- Exhaust systems;
- Supply - exhaust system;
- Local exhaust;
- Local supply;
- Air curtains;
- Special fans.

Exhaust ventilation

In buildings, where only exhaust air systems are installed, air exchange layer is small. Typically, such systems are used in residential buildings. The building with exhaust system operated by the central exhaust fan is shown on Figure 3.5. Supply air enters the building unchecked through the *leakages* of the building envelope. This type of system creates a negative air pressure in building and air overflows to the spaces with negative pressure. These are used to prevent condensation fall to the walls of the building, when indoors is a warm and humid air, while outside - it is cold. Energy consumption is much higher compared to systems that use heat recovery units.

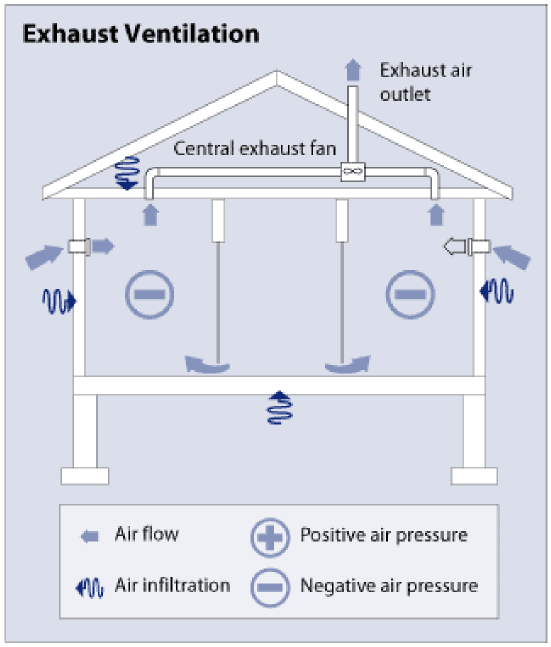


Fig.3.5. Building with exhaust system

Supply ventilation

In buildings, where only supply air systems are installed, air exchange layer is small. The building with supply system operated by the central supply fan is shown on Figure 3.6. Supply air enters the building through the air duct system from the supply fan, but passes the building unchecked through the *leakages* of the building envelope and the overflow valves in the walls. This type of system creates a positive air pressure in building and air overflows from the spaces with a positive air pressure to the spaces without a supply. Energy consumption is much higher compared to systems that use heat recovery units. Such a system is used, for example, in premises with elevated requirements for air quality.

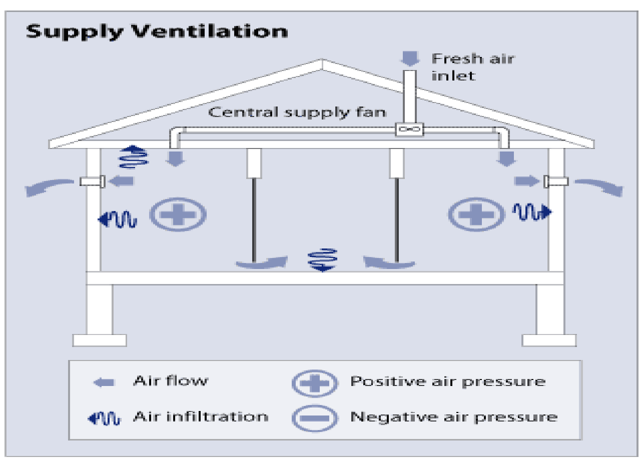


Fig.3.6. Building with supply system

Supply – exhaust ventilation

Supply-exhaust system or balanced ventilation system consists of supply and exhaust fans and air duct system and air handling equipment (heater, cooler, humidifier, filters, etc.). Their installation is more complex and more expensive as exhaust or supply systems. Energy consumption is much higher compared to systems that use heat recovery units. Supply -

exhaust system consists of a variety of air handling units and their type, capacity and other parameters depend on the requirements put forward to air in the space. In the part of supply valve, filters, air heaters, fan and silencer can be installed. In the part of exhaust valve, filters, fan and silencer can be installed. Supply- exhaust system is shown on Figure 3.7.

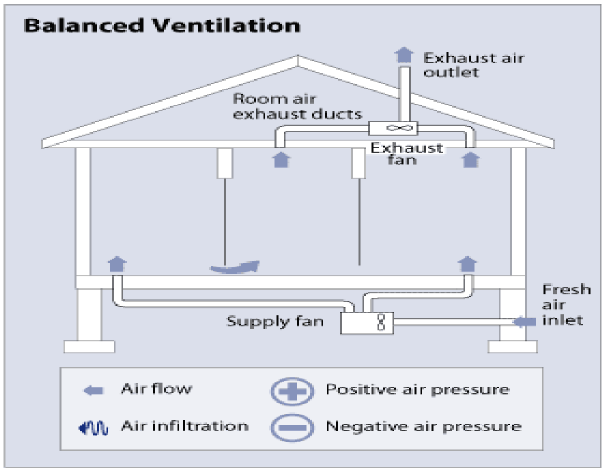


Fig.3.7. Building with supply- exhaust system

Energy efficient supply-exhaust system

Energy efficient supply-exhaust ventilation system ensures that the exhaust air heat / cold is used for heating or cooling of the supply air, thereby reducing energy consumption for air heating and cooling. Heat recovery units are used for heat / cold utilization. These equipments are more expensive, but they regain after few years, as they can save up to 80% on energy costs. Energy efficient supply-exhaust system is shown on Figure 3.8. More detailed description of the types of heat recovery units is given in chapter "Heat recovery units".

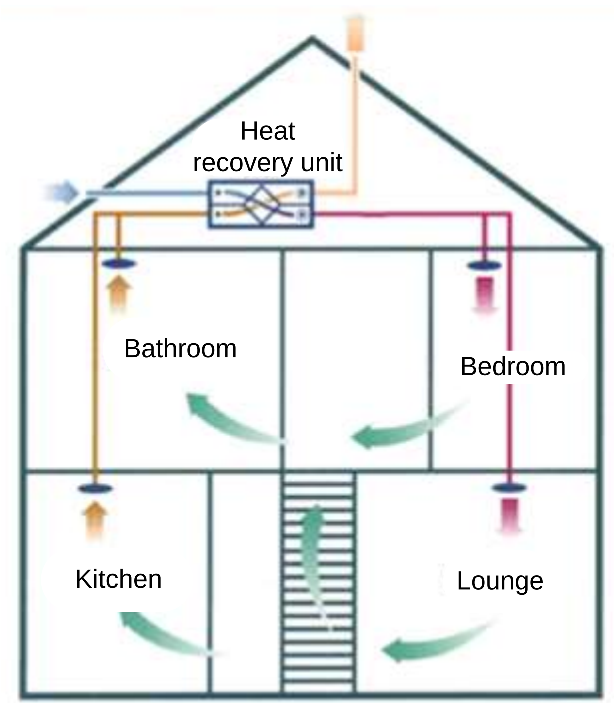


Fig.3.8. Energy efficient supply-exhaust system

Other mechanical ventilation system

Other types of systems are also used for ventilation needs:

- Local exhaust - air is exhausted from the work tables, cameras, etc. A single exhaust fan is used for it.
- Local supply - are used for sites where a separate supply air flow should provide, such as at the steel furnaces in foundries to reduce the risk of employees heat stroke.
- Air curtains - are used at the main entrances to buildings with intensive usage to block cold or hot air entering into the premises, as well as to ensure that the premises misses insects, dust and wind. Figure 3.9. shows the air curtain operating principle.

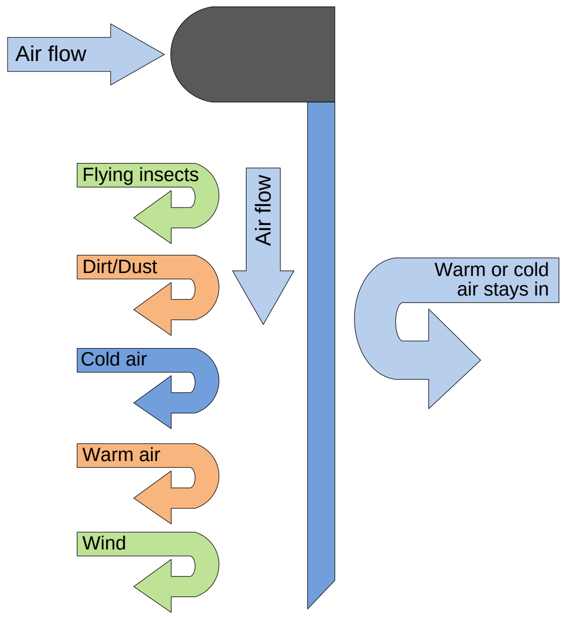


Fig.3.9. Air curtain operating principle

3.1.3. Hybrid ventilation systems

In the case of hybrid ventilation natural ventilation and mechanical systems work supplementing each other. Although energy consumption of natural ventilation is low, climate and heat discharge limits its use. Management of hybrid ventilation can be ensured by air conditioning, but it is penalized by the cost of energy.

Hybrid ventilation operating principles are different, so the most popular are three types of systems.

1. Natural and mechanical ventilation - this principle is based on two autonomous systems where the control unit switches from one system to another or one system performs a single function, and the other - another. For example, natural ventilation works during the transitional seasons, but mechanical – in winter and summer or mechanical ventilation works in the building during peak times, but natural – for night cooling.

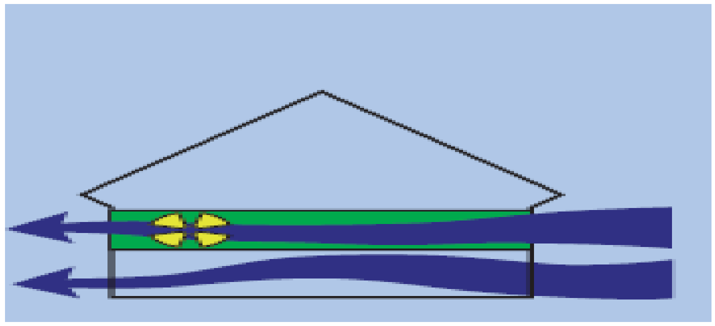


Fig.3.10. Natural and mechanical ventilation principle

2. Natural ventilation and exhaust fan - is based on a combination of natural ventilation with exhaust fan. Low pressure exhaust fan turns on during periods when natural ventilation is a small pull or during periods of high consumption.

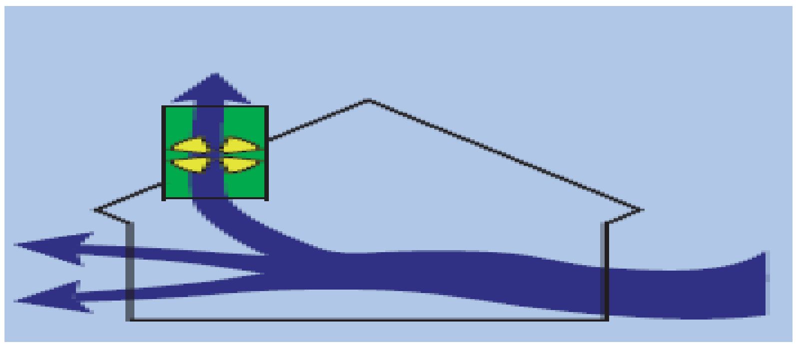


Fig.3.11. Natural ventilation and exhaust fan principle

3. Mechanical ventilation with wind and stack effect - this principle is based on mechanical ventilation system that makes optimal use of natural mechanisms. Mechanical system has low pressure loss, and natural mechanisms provide most of the required pressure.

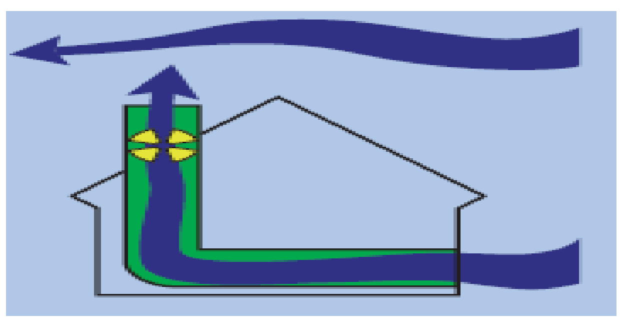


Fig.3.12. Mechanical ventilation with wind and stack effect principle

There are many similarities between the buildings with hybrid ventilation and the buildings with natural ventilation, and they have lot of low-energy building characteristics - good insulation, solid, good solar energy management, good daylight, energy efficient artificial lighting and solid construction.

If the hybrid ventilation is installed in building, building tenants have greater control over indoor climatic conditions - they can shade the windows, open/ close windows and blinds. Usually windows have automatic night ventilation system and the building is fitted with separate apertures to control the night ventilation.

The mechanical ventilation part of hybrid ventilation system is an energy-efficient - low energy consumption to operate fans, as there are large size air ducts with low air speeds and low pressure drop, frequency converters and space sensors, as well as heat recovery units are used.

Overnight ventilation is always used in hybrid ventilation systems - it can be both natural and mechanical. At night there is an automatic window or aperture opening and operation of the system is controlled by the temperature difference.

3.2. Air conditioning

Unlike the systems of ventilation, air conditioning system is able to maintain indoor year-round constant (predetermined) temperature and relative humidity. Air conditioning systems are of two types: local and central systems.

Definition. Air conditioning - air handling system is able to maintain the indoor year-round constant (predetermined) temperature and relative humidity. Air conditioning systems are local and central systems.

Central air conditioning systems

In central air conditioning systems air is drawn in the central air handling unit located in the ventilation chamber. It is a ventilation unit, which installed additional air cooling, humidification and dehumidification section (depending on the required air treatment processes). Air is cooled by refrigerant (chilled water, mixture of water and antifreeze or refrigerants which are used in the freezing process, such as freon). Refrigerant is cooled in the central cooling plant, which is most often mounted on the roof of the building.

3.2.1. Local air conditioning systems

In local air-conditioning system, air is cooled in each room separately using individual air conditioners, installed in the windows or on the floor, or using a so-called split type equipment, where the condenser is located outside the building, but the rest of the cooling cycle facilities - indoors. (see Figure 3.13.)

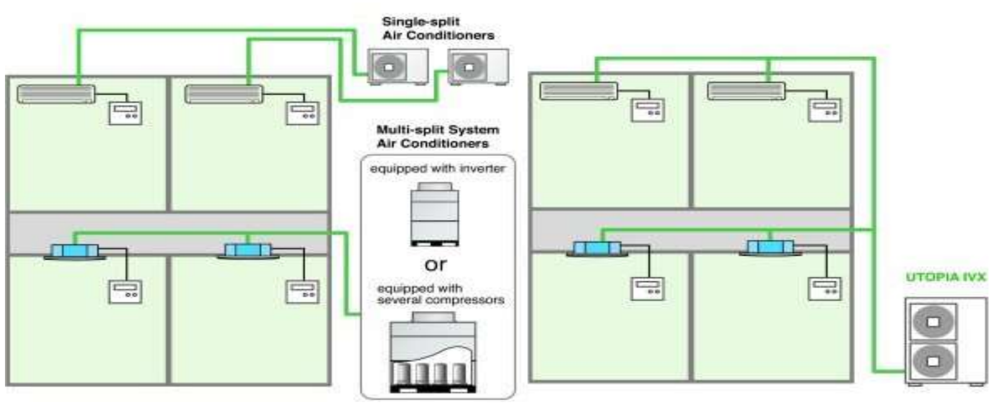


Fig.3.13. Split type equipment

In many buildings, especially in hotels and office buildings, is used the cooling system, where the refrigerant (usually water or antifreeze) is prepared in a central cooling plant (chiller) and transported through pipelines to the individual cooling devices, located in different areas. A variety of devices can be used for indoor, such as refrigerator, which is called a fan coil, where supply air is cooled. These devices are placed at the ceiling or on the wall instead of radiators and are powered by built-in fans. In plant, called a chilled ceiling, cooled refrigerant flows and electric power is not used in the operation because the cold air, being heavier than warm space air, goes down.

3.3. Air distribution in space

Air distribution in spaces can occur through one of three air distribution principles. They are shown in Figure 3.14.

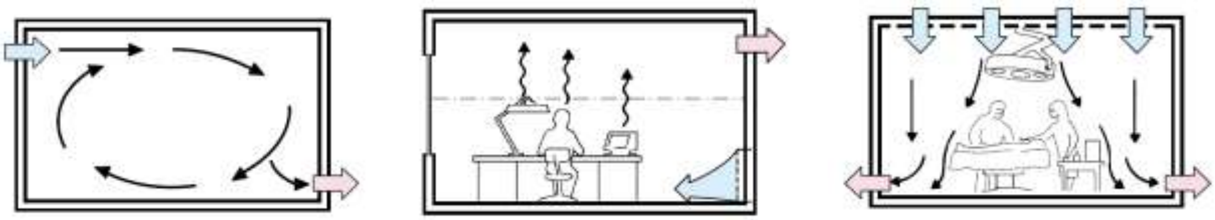


Fig.3.14. Indoor Air distribution in space: mixing (left), replacement (middle) and piston (right)

3.3.1. Mixing system

The main operating principle - supply air mixes with the space air. Mixing system for office premises and industrial premises is shown in Figure 3.15.

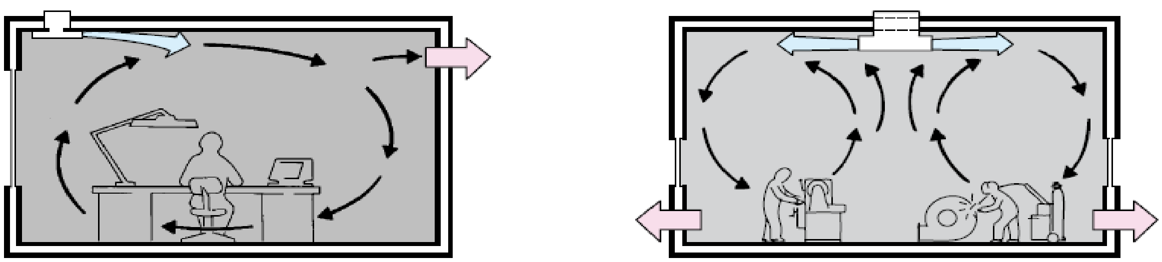


Fig.3.15. Mixing system for office premises (left) and industrial premises (right) [38]

Mixing system has the following advantages:

- Can be used in places where the supply air temperature is higher or lower than the room temperature;
- Stable airflow and quickly regain form after disturbances;
- Temperature is equal throughout the room;
- Flexible deployment of air splitters in space;
- Well suited for ventilation and heating in buildings with poor insulation.

Mixing system also has disadvantages, the main ones are:

- Air pollution is the same throughout the space;
- If the supply air temperature is higher than the room temperature and exhaust are in the wrong places, the air can circulate at close range;
- If there is a large cooling capacity and air flows through the barriers, drafts can be formed;
- It is difficult to change the air flow by maintaining ventilation effectiveness.

3.3.2. Replacement ventilation

Replacement ventilation operates based on laws of physics that warm air rises up - supply air with a lower temperature than room air flows into the space with a large volume and low velocity in the lower area of space, then space heats up and dirty and warm air rises up, where it is exhausted at the top of space. Replacement ventilation operating diagram for office and industrial premises is shown in Figure 3.16.

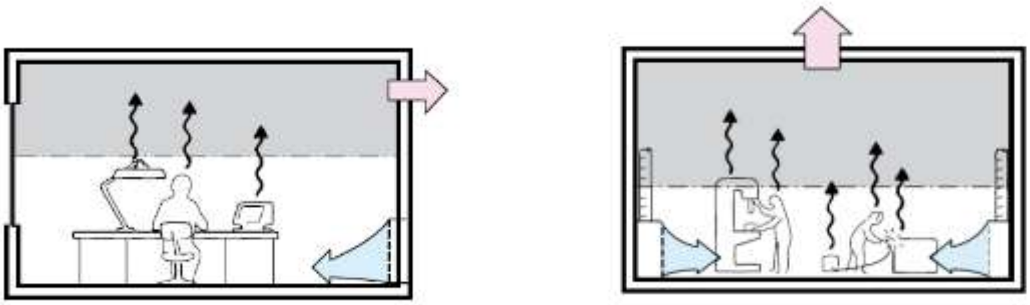


Fig.3.16. Replacement ventilation system for office premises (left) and industrial premises (right)

Advantages of replacement ventilation:

- Makes air stratification and the air in the work area is at a very low pollution concentration;
- Low air velocity;
- Low turbulence;
- Energy efficiency aspects:
  - Reduced cooling capacity;
  - An additional benefit through a combination of adiabatic cooling;
  - Lower supply air quantity;
  - Lower pressure drop.

Disadvantages of replacement ventilation:

- Not suitable for spaces where the supply temperature higher than the room temperature;
- At high air flows is possible that would be drafts in a comfort zone;
- Take up the floor area;
- Cooling capacity is limited;
- Not suitable for buildings with poor insulation.

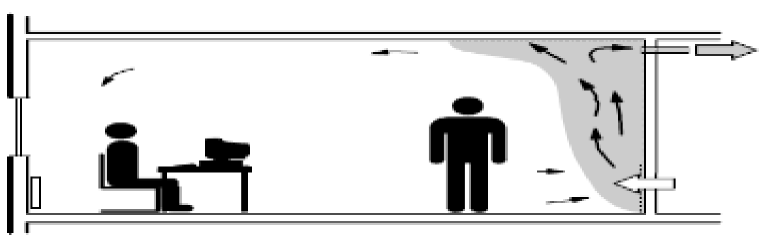


Fig.3.17. Replacement ventilation do not work when the supply air is warmer than the space air

3.3.3. Piston air distribution system

Using this system occurs effective removing of air pollutants with acceptable air velocity at a large amount of air (air exchange round 60 ... 600 1 / h) and at a low temperature gradient.

This system is not suitable for spaces where the supply air temperature is significantly above or below the space temperature. It is susceptible to disturbances at a small amount of air and it requires a large air splitters surface.

3.4. Indoor climate

People feel comfortable in an environment where just enough heat and moisture is drawn from as they body develops. Comfortable indoor conditions are such that people do not feel the cold, heat and air movement around them.

The human body comfort is affected by various spaces and its inhabitants' physical parameters and its behavior.

- Air temperature:
  - Affects the temperature difference between the body and the environment, that affects the body heat losses or gains from convection;
  - The most easily understandable indicator, but alone it does not provide full information on the thermal comfort;
  - Comfortable room temperature in winter is +20 ... 24 ° C, and in summer +27 ... 28 ° C.
- Air velocity
  - Air movement around people;
  - If the air is colder than the room air, it cools people;
  - Standing air in the room, that is heated, can create a sense that it is stale or it may smell;
  - Air movement in hot or humid space increases the convection heat losses without changing the room temperature;
  - Slight movement of air in cold or cool space creates a feeling that it is drafts. If the air temperature is lower than skin temperature, the convection heat loss increases.
- Surrounding bodies temperature:
  - The radiation from warm or cold object;
  - Greater emphasis on the human heat losses or gains than room temperature;
  - Examples: sun, smudge, electric fireplaces, stokers, stoves, kiln walls, ovens, dryers, hot surfaces, a large cold surface of the window and so on.
- Humidity:
  - If water is heated in the room, it evaporates into the air, and will increase the water content in the environment;
  - Relative humidity - the ratio between the actual amount of water vapor in the air and the maximum possible amount of water vapor in the air at a given temperature;
  - Affects the human body cooling because sweat evaporation is the main mechanism of the human body heat losses;
  - Relative humidity of 40 ... 70% do not significantly affect thermal comfort;
  - The environment with high relative humidity has a lot of water vapor in the air, which prevents the sweat evaporation from the skin, so increasing humidity, increases discomfort.
- Clothing:
  - Body convection, irradiation and evaporation heat losses are dependent on the type of clothing;
  - If clothing is too much, there is the possibility of heat stress, even if the ambient temperature is not high;
  - If clothing is not enough, there is a risk of hypothermia or frostbite.
- Age and gender:
  - Women metabolism is lower than for men, so women feel better at higher temperatures (approximately 1 ° C);

    - Children need space warmer than adults, such as infants spaces required by 2-3 ° C higher temperature.
- Human Activity:
    - An important parameter for thermal risk assessment;
    - The amount of heat which arises in the human body during physical activity:
        - Increase in physical activity, increases incurred heat;
        - Themore heat arises, the more the body is cooled, so that it does not overheat;
    - Each individual's body characteristics must be taken into account.
- Climate and seasonal changes;
- Duration of stay indoors

In the literature "sick building" syndrome is often mentioned. Sick building syndrome causes:

- Too large air velocity in space or turbulent air movement;
- The symptoms are caused by microbial allergens or toxins;
- Thermal regulation problems, because the room is too cold or hot;
- Problems caused by low frequency sound (below 100 Hz);
- Odors from the bad serviced humidifiers and filters.

If the space is not ensured the correct microclimate - the air temperature and the relative humidity is high, as well as not provided sufficient air exchange layer, the mould fungus may develop on the space enclosing structures and furnishings that are in direct contact with them, which substantially affects human health - develops allergies and other respiratory diseases. Figure 3.18. shows examples of moulds in buildings with package windows installed without ventilation louvers.

Fig.3.18. The growth of *mould* results as poor indoor climate

4. ENERGY SUPPLY

Energy sources are required for electricity and heat supply. The selection of Historical building power supplies are dependent on the specific design and constructional requirements that are set for the source from technological supply and their operating efficiency, environmental impact and economic evaluation. All these factors are summarized in Figure 4.1.

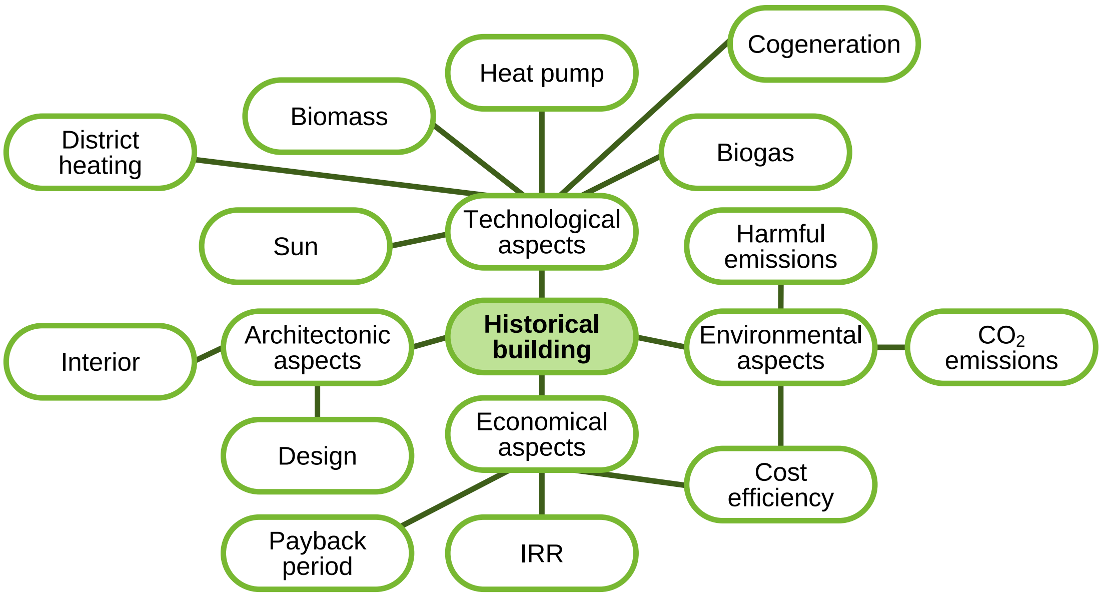


Fig.4.1. Factors for choosing heat supply of historical buildings

Engineering solutions for the heat supply of historical buildings include a wide range of technologies:

- Boilers;
- Cogeneration plants;
- Heat pumps;
- Solar collectors;
- Equipment using geothermal water;
- District heating elements.

Historical buildings power supply is carried out manly using heat from centralized distribution networks. Solar panels which help to produce electricity can be installed only in special cases, where permitted by the interior. Creation of photovoltaic construction innovations is developing rapidly and they can already be integrated into roofs, walls and windows.

4.1. Boilers

One of the most commonly used heat sources are boilers and boiler houses. Chemical energy form energy sources in boiler technological devices are turned in into the thermal energy. Boiler technologies are designed so that this transformation takes place with minimal power loss. Technological solutions of boilers covers whole set of boiler elements that are related to the combustion process and the organization of heat and mass exchange processes. Set of boiler elements can be divided into three groups.

1. Combustion technology and furnace equipment

Combustion process is organized in furnace. There the combustion products - flue gases, are formed. Combustion process is provided with the help of combustion technologies: burners, nozzles or grates that are placed in the furnace. Furnace walls can be covered with pipes, where circulates mixture of water and water vapor.

2. Boiler heating surfaces

Boiler heating surface is on one side surrounded by heat carrier (combustion products), but on the other side with work environment (liquid or liquid and vapor mixture). Heating surfaces play a key role in energy-efficient operation of the boiler, so they are placed in a specific order in the direction of exhaust gas flow (see Fig. 4.2.) Heating surface receives heat from hot flue gases, mainly due to the implementation of three heat transfer processes: radiation, convection and condensation. Heating surface is named depending on the dominating heat exchange type Radiation surfaces are placed in furnace, convection surfaces are installed in the convective part of the boiler, and condensation surfaces are placed behind the boiler unit in order to ensure steam condensation from steam-gas mixture.

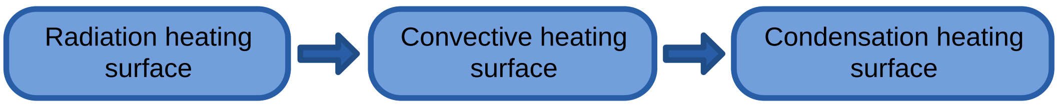


Fig.4.2. Organization of Flue gas flows through the heating surfaces

In hot water boilers the work environment is water, which heats up to a certain temperature by receiving heat from hot flue gases. Water heats up in coldest part of steam boiler heating surfaces, but phase transition processes and the formation of steam are organized in the hottest part.

3. Auxiliary equipment and mechanisms

The boiler is operated through balanced auxiliary activities. Auxiliary equipment can be grouped into three mutually independent, but related units:

- Fuel storage and supply facilities. Fuel facilities include biogas reactors and storage tanks, fuel oil tanks and feed pumps and biomass storage facilities with fuel supply mechanisms: moving floors, conveyor belts, screw mechanisms and bunkers.
- Air supply and flue gas removal unit. Air required for the combustion process is supplied through a duct system using a fan. Flue gas from the boiler is removed by a special gas duct and chimney (chimney stack). To overcome aerodynamic resistance of gas ducts it is often not enough with the drag caused by chimney, therefore a smoke exhauster that would feed flue gases into the chimney.
- The holding supply or feed water preparation.

Water-heating boiler feed water and steam boiler feed water is specially prepared in order to avoid forming of boiler scale and other sediments and to remove corrosion aggressive gases. Water supply unit includes pipes, pumps and heat exchangers for water heating before and after the water treatment plants.

Boiler design varies considerably and they are classified and grouped using a variety of features:

- Fuel type - fossil and renewable:
    - gas: natural gas, syngas and biogas;
    - solid: coal, wood, biomass, waste;
    - liquid: fuel, biofuels.
- Installed capacity: micro devices, small, medium and high capacity;
- Type of heat carrier (water, steam and hot air);
- Boiler design layout (horizontal and vertical);
- Furnace aerodynamics (primary, secondary and tertiary air supply).

These and other features affect the selection of boilers for historical buildings. It is important to define not only the usual conditions, but also the specific conditions for boiler selection:

- Choose boiler size so that it would be possible to put boiler in the room, given its restrictive size, location of the gas ducts.
- Select the capacity that provides necessary heat for heat supply system after the insulation of building, in order to operate boiler with the highest efficiency as long as possible during the year.
- Provide the necessary scattering of environmentally harmful emissions (nitrogen oxides, sulphur oxides, carbon monoxide, particulate matter) in the atmosphere, due to the position and height of chimney.
- Select boiler with the highest efficiency, changing load to ensure minimal energy resource consumption.
- Choose environmentally and climate-friendly fuel, that is CO_2 neutral and in combustion of which a minimal amount of environmentally harmful emissions are formed, and the equipment ensures low vibration and noise levels.
- Select economically viable fuel whose selection is based on the optimal investment, energy prices and boiler plant operation efficiency.

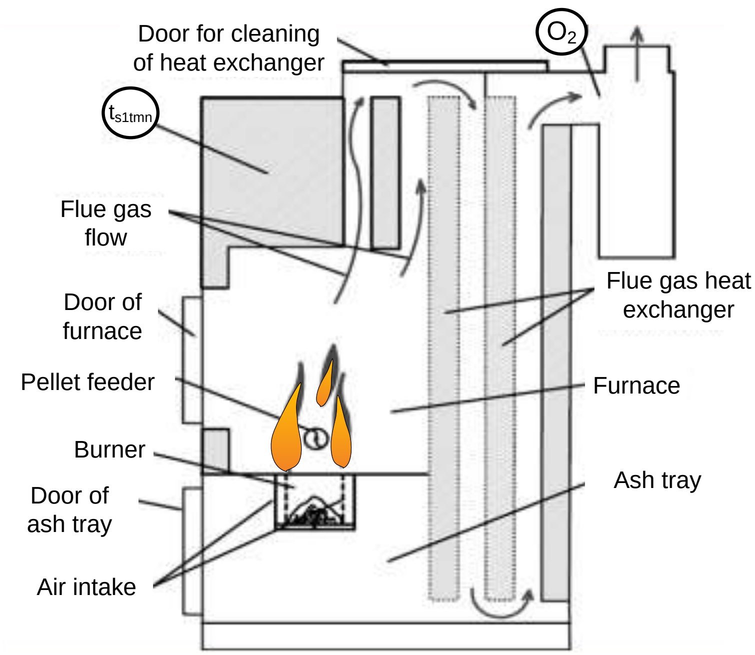


Fig.4.3. Principal scheme of pellet boiler

In historical buildings one of the most suitable and promising is pellet boiler, which is compact in design, environment and climate friendly and economically feasible. Principal scheme of pellet boiler is showed in Figure 4.3.

4.2. Cogeneration units

In the case of the combined system it is possible to simultaneously produce electricity and heat. The use of combined systems as energy sources of historical buildings is restricted by buildings design and interior decoration, the energy source is just auxiliary equipment, which is necessary to ensure power supply.

Definition. Cogeneration is the primary energy conversion process, where the generation of useful heat and electricity and mechanical energytakes place simultaneously with a plant-specific power relation to heat. Thermal and mechanical energy is produced, for example, using heat engines for drive (pump, compressor, etc.).

Useful thermal energy is the thermal energy produced from cogeneration process, supplied to the consumer to cover its economically justified heat or cold loads. Useful thermal energy is determined at output of cogeneration source, thus excluding the possibility to lower cogeneration efficiency assessments in the case of large networks heat losses. To support the cogeneration plants, additional conditions for energy tariffs are sometimes provided.

The term "economically justified load" means the load not exceeding what is really necessary and, according to market conditions, without the cogeneration it shall be covered with energy generated by another way.

The term "high efficiency cogeneration" means the equipment that meets the following conditions:

- Provides primary energy savings at least 10% compared to separate heat and electricity production;
- Provides primary energy savings in case of low power and micro cogeneration compared to separate heat and electricity production.

The use of cogeneration currently is an essential tool for energy efficiency improvement of energy development; it is rather a complex usage of technologies to meet customers' needs for heating, cooling, electrical or mechanical energy. The advantages of cogeneration as a type of energy production are evaluated in comparison with traditional separate energy development. Technically, it is possible to produce the energy by cogeneration with lower fuels consumption, and it also means higher energy efficiency. Forms of energy production are compared in Fig. 4.4.

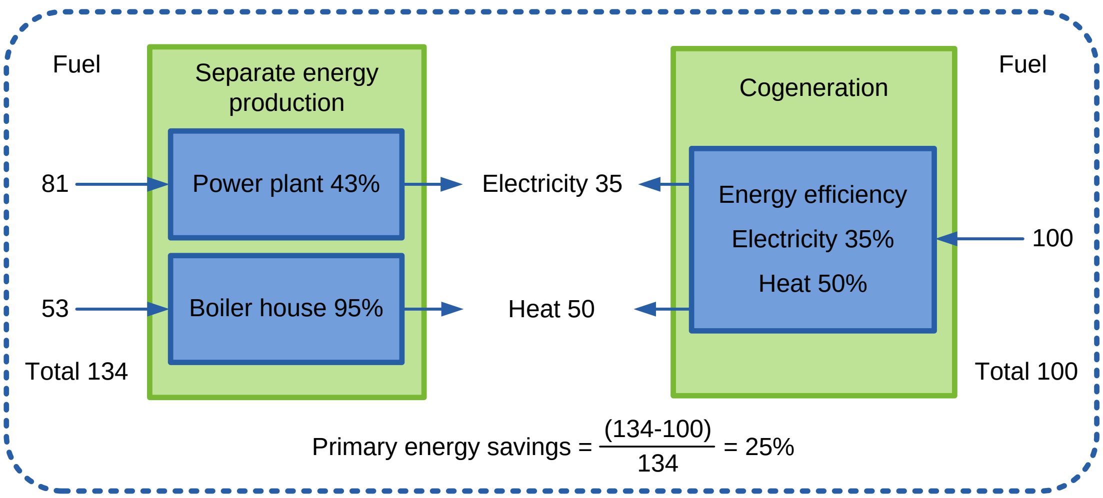


Fig.4.4. Comparison of cogeneration and separate energy production

It is seen that the same amount of separate heat and electricity production requires a greater amount of fuel. Energy efficiency indicators for cogeneration of electricity and heat production are under 35% and 50%. They correspond to real values using internal combustion engines. Energy efficiency of separate energy production affects the primary energy savings (because it higher, the smaller savings). Figure 4.4 discussed the option in which electricity is generated by the power plant with efficiency coefficient of 43% and heat - boiler house with efficiency of 95%. As shown in the Figure 4.4, in case of cogeneration primary energy savings are 25%. Primary energy (fuel energy) savings is an effective indicator for the comparison of energy development methods. Comparison refers to the two diametrically opposed borderline cases of electricity and heat production necessary for the historic building: two forms of energy are produced in cogeneration and two forms of energy are produced separately.

Principle of operation, range of applications, economic, and environmental parameters for cogeneration technologies varies. In historical buildings only small capacity stations or microcogeneration can be installed.

To select one certain technological solution for the establishment of energy source, it is always necessary to analyze alternative scenarios of equipment.

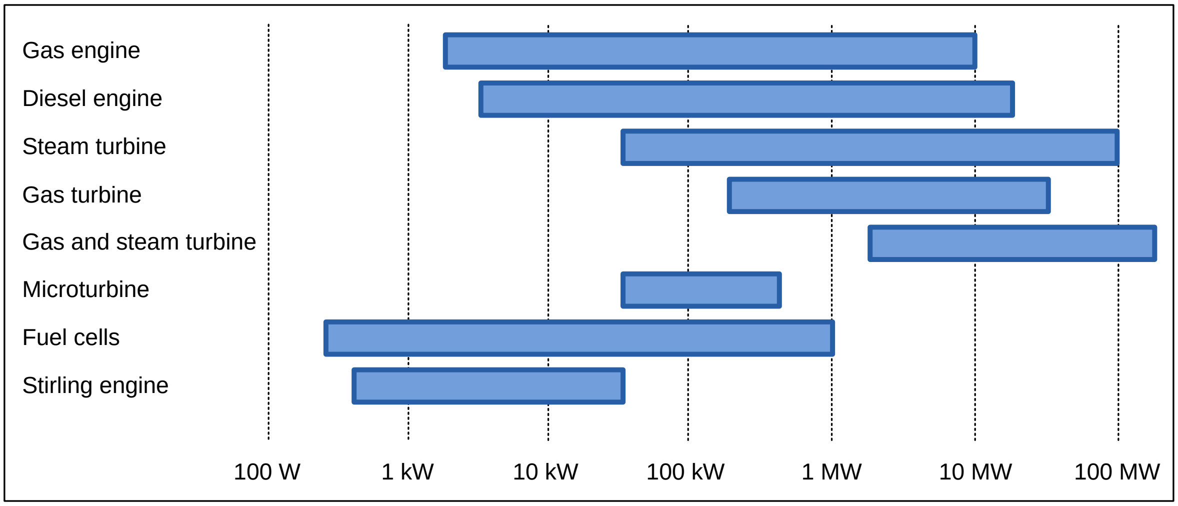


Fig.4.5. Capacity usage ranges of cogeneration technology

Cogeneration technology operating ranges are shown in Figure 4.5. Traditional technologies - internal combustion engines, gas and steam turbines - have offered a wide capacity range. For new technologies - micro-turbines and Stirling engines - it is narrower, but it can be expected that with the development of innovative technologies offered capacity range will increase. Fuel cells equipment has a significant advantage - high power generation efficiency.

Internal combustion engines

Internal combustion engines are the most effective, widely used in low-power non-directional power plants. They are quickly triggered, reach full capacity in a short period of time, and have relatively low capital cost. These devices are available in a wide power range and have relatively high power generation efficiency and high operation reliability. Thanks to the fast-start engine options, they are widely used as emergency or backup equipment in case of a power outage.

Cogeneration plant combustion engines must be equipped with optional heat recovery devices, so their capital investment is growing. The equipment has a high power generation on the developed thermal unit (ratio of electricity to heat can be in the range from 0.7 to 1.5)

The relatively high operating costs, noise and relatively high nitrogen oxide emissions can be mentioned as disadvantages of an internal combustion engine. This can be reduced by changing the combustion process, but then there will be a drop in engine efficiency indicators. To reduce emissions in flue gases uses tested treatment technology - catalytic converters.

Microturbines

Microturbines expands gas turbine technology offer in low capacity range. These are new technologies that offer capacity in 30-200 kWe range. These technologies are used as a low wattage cogeneration plant to cover electricity loads and the generation of heat in a form of steam or hot water.

One of the characteristics of microturbines is high number of turns. Low combustion temperature results in low nitrogen oxide emissions. The noise level of microturbines is lower than that of the internal combustion engines with a similar power.

Main disadvantages of microturbines are relatively low usage experience and high capital investment in comparison to internal combustion engines. Electricity price increase expands the usage market. A significant reduction in capital investment can be expected due to increasing demand and production. Principle scheme of microturbines is illustrated in Figure 4.6.

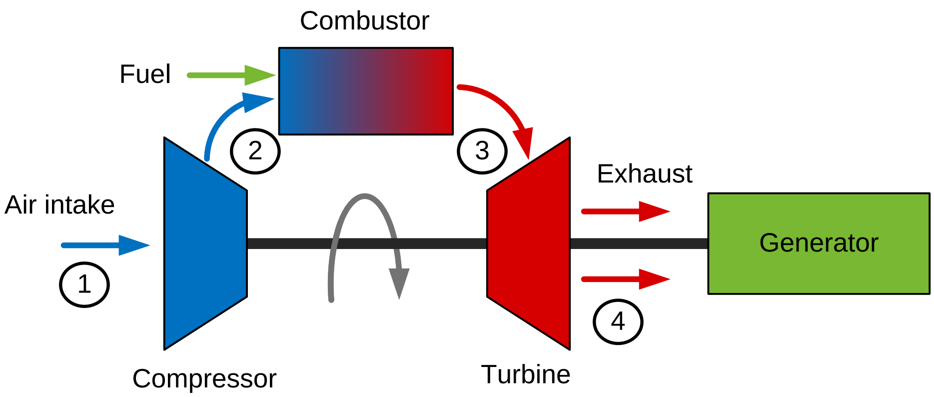


Fig.4.6. Biogas microturbine

Fuel cells

Despite the fact that the basic principles of fuel cell were discovered in 1839, the wider use was hampered by relatively high capital costs. Forecasts show that fuel cells can become one of the most common energy transformation facilities of cogeneration plants. Their main advantages are high efficiency, compactness, convenient maintenance and quiet operation. Since the machine does not have high-temperature combustion processes nitrogen oxide emissions are small. The main disadvantage is the high capital investment.

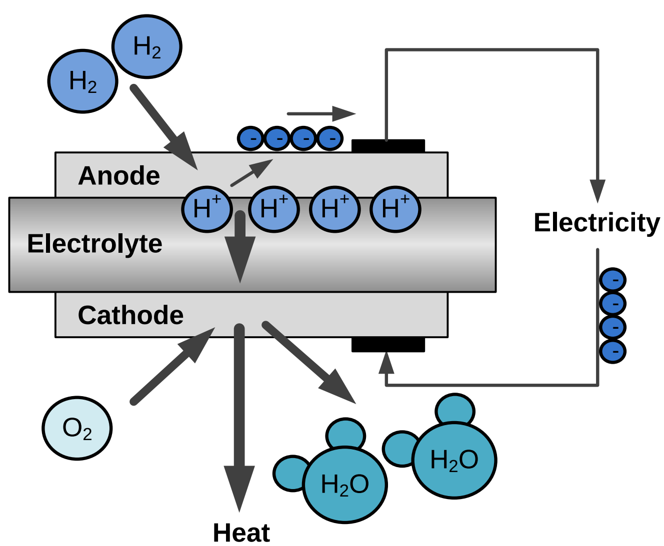


Fig.4.7. Principal scheme of the fuel cell

In fuel cells hydrogen and oxygen is used in an electrochemical process to produce electricity, heat, water and carbon dioxide. Therein chemical energy is directly converted into electricity through a reverse electrolysis process. Hydrogen is supplied to the negatively charged anode, at which the hydrogen atom is divided into positively charged protons and negatively charged electrons. Proton continues its way through the electrolyte and on the positively charged cathode connects with the oxygen atoms and electrons to form water molecules. Electricity is directly obtained from the separated electron flow, which cannot move through the electrolyte, but is moving in a roundabout way. Catalysts are used to speed up the electrochemical process. The principle of fuel cells circuit is shown in Figure 4.7.

Fuel cells that work with a high temperature can be used in cogeneration to produce electricity and heat. Such plants have high efficiency - up to 85%.

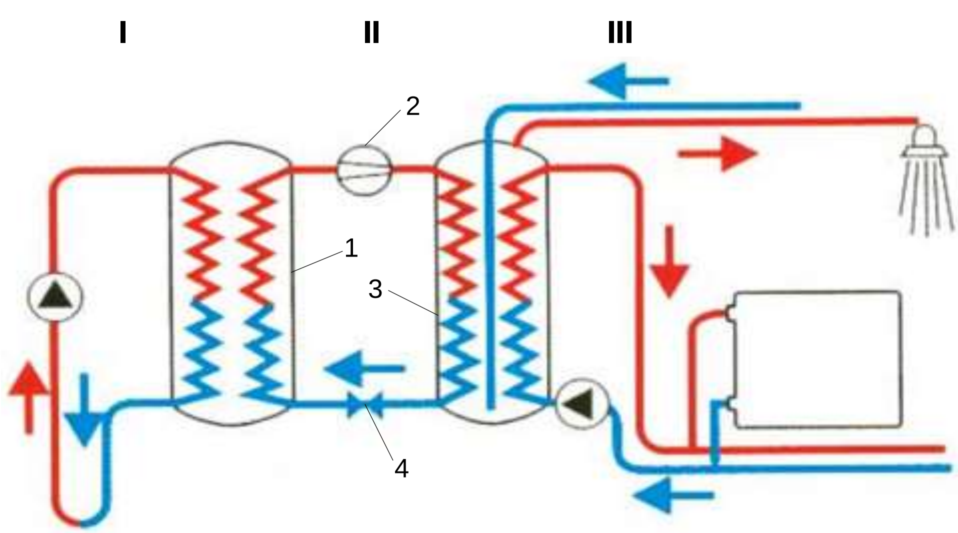
Operation of fuel cells requires hydrogen, whose source can be, for example, pure hydrogen produced in other technological process (or biohydrogen). The emissions related to fuel cells are formed during the fuel conversion process.

4.3. Heat pumps

In Historical buildings a widely used energy source is heat pump; it uses environment heat for heating and water heating, providing a stable, well-adjustable and automatically controllable heating system that works all year round. Heat Pump is a compact device without gas ducts and chimney. Heat pump operation requires solar energy and electricity, which is used for the operation of compressor and circulation pump.

Definition. Heat pump is an environmentally friendly engine that uses energy from the environment - solar energy accumulated by soil, land formations, water storage, borehole water and air.

Regardless of whether it comes to the outdoor air, ventilation air, surface or deep layers, ground water or sewage, everywhere there's heat energy, which is ready to be transported and converted into to energy of higher value. However, now only a small part of the excess energy released into the environment can be used.



1 - evaporator, 2 – compressor, 3 – condenser, 4 – throttle.

Fig.4.8. Heat pump principle scheme

Space heating with heat pump has a big advantage over the wood, peat or coal-fired boiler, due to the lack combustion process:

- Heating takes place automatically by the program entered in machine, it depends on the outdoor temperature changes.
- From the comfort point of view heat pump heating system is comparable to the centralized heating system.
- Heat Pump provides the ability to install environmentally clean space heating, during the operation of which no harmful emissions (CO, SO_2, NO_x, CO_2), harming the environment and human health and causing the greenhouse effect, which are locally produced, it also allows to save rapidly shrinking land resources and at the same time considerably reduce heating costs.

Principal scheme of heat pump is illustrated in Figure 4.8. It includes 3 independent and interconnected loops:

I – Loop, which extracts heat from the surrounding environment;

II – Heat pump installation loop;

III – Heating system loop.

Heat Pump not only looks like a refrigerator, but its operation is a reversal of the refrigerator operation, the house is heated from the inside, but cooled on the outside. According to the second law of thermodynamics, heat naturally flows from a higher temperature to lower. The heat pump consists of four key elements (See Fig. 4.8., II loop):

- Evaporator, which receives the heat from the collector and regulating the evaporator pressure with the expansion valve, it shall be ensured that in the desired temperature cooling agent starts to boil.
- Compressor, which increases the pressure in the system by raising the temperature of the liquid vapor.
- Condenser, where the cooling agent gives heat to the internal heating system, which is usually water circulation system of heat supply to the radiators or warm floor system, as well as the system providing hot water.
- Throttle, which lowers the pressure and removes cooling agent back to the evaporator, completely transforming it into a liquid state so that it can once again pick up the heat.

All these four parts are connected through a closed piping system. Most popular cooling agent liquid is on ethanol and propylene glycol base, which does not harm to the environment.

Despite of the similarities of heat pump elements, they differ have varying operation cycles, working environment and heat sources:

1. Heat pump operation cycles

Almost all currently offered heat pumps for buildings heat supply are based on either the vapor compression (compression heat pumps) or the absorption cycle (absorption heat pumps).

- Compression heat pumps. They operate on the vapor compression cycle principle. The main components of heat pumps are a compressor, an expansion tank, and two heat exchangers designed to vaporize and condense.
- Absorption heat pumps. Absorption heat pumps are powered thermally, which means that it is more advantageous to convey heat for the operation of cycle not mechanical energy. Absorption heat pumps for space conditioning are often powered by burning gas.

2. Heat pump working fluids

Heat pumps after the principle of work fluid interaction can be combined into two main groups:

- With open cycle, in which the liquid is removed from the external environment and returned to it.

- With closed cycle, in which the liquid circulates in closed circuit, interacting with a heat source and heat consumers with a help of heat transfer processes.

3. Heat sources of heat pumps

Heat pump types by the used kind of heat source are divided into three main groups. They use either air or ground heat:

- Outdoor air heat pumps;
- Exhaust air heat pumps;
- Geothermal pumps.

In this way, heat from outside is pumped into the house. Since a large amount of heat is accumulated in soil layer or outer air volume, then giving some of the heat ground or outside air the temperature does not change, but with this amount of heat the area can be heated to the required temperature. An example of heat pump installed in historical building is illustrated in Figure 4.9.

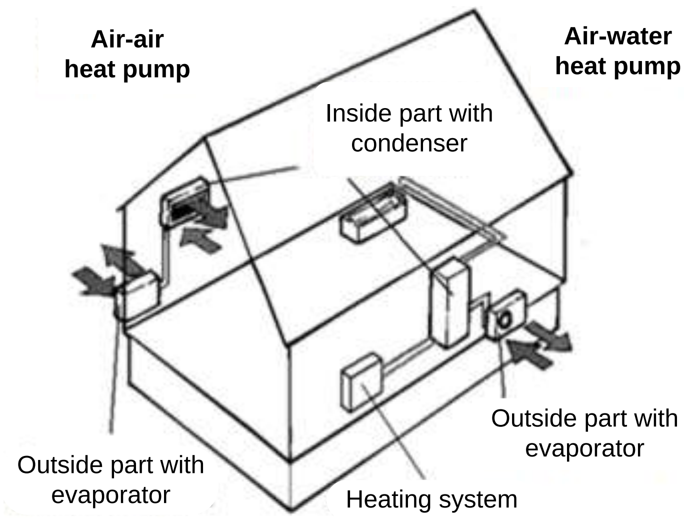


Fig.4.9. School in Latvia built in 1887 and its heat pump usage scheme

4.4. Solar thermal

Reduction of fossil fuels is not only the solution to problems of sustainable development, but the effects of climate change as well. Therefore, the use of fossil fuels and electricity to obtain a relatively low temperature required for heating or cooling should be regarded as unacceptable wastefulness of resources and energetically unfounded solution.

We can predict that the use of biomass and heat pumps for heating or cooling will increase. Biomass resources are limited, and their quantity in each country is restricted. Wide introduction of heat pumps as the main heating supply technology results in a rapid increase of electric energy consumption, which implies the need to increase the amount of renewable energy electricity.

Thus, solar thermal energy will, undeniably, be an important foundation stone for the future energy balance to provide heating or cooling processes. Solar energy can be used for heat and electricity production.

A limiting factor is the changes of historical buildings visual appearance caused by using solar collectors and photovoltaic cells.

Definition. Solar collectors are a key element in engineering system that converts solar radiation into thermal energy.

Solar thermal technologies have following advantages over other energy sources:

- They can be combined with almost all kinds of spare heating or cooling sources.
- They have the highest energy security potential, and they do not use resources that are needed for other processes and industries.
- They do not cause a significant increase in electricity demand, so there is no need to invest in new power generation capacity and increase of transmission cable capacity.
- It can be used almost anywhere.
- Installation and maintenance costs of these technologies can be determined very accurately, as most of them are related to investments in technology installation and therefore do not depend on fossil fuels, biomass or electricity price volatility in future.
- Technologies life-cycle environmental impact is low.

In order to assess the possibilities of solar energy usage, you need to consider not only technological solutions, but also solar radiation in countries where solar collectors are chosen for the heating of historical buildings.

1. Availability of solar energy

European Commission Joint Research Centre has developed a solar atlas in which practical solar energy potential on a horizontal surface in Europe year 2010 is summarized, see Figure 4.10.

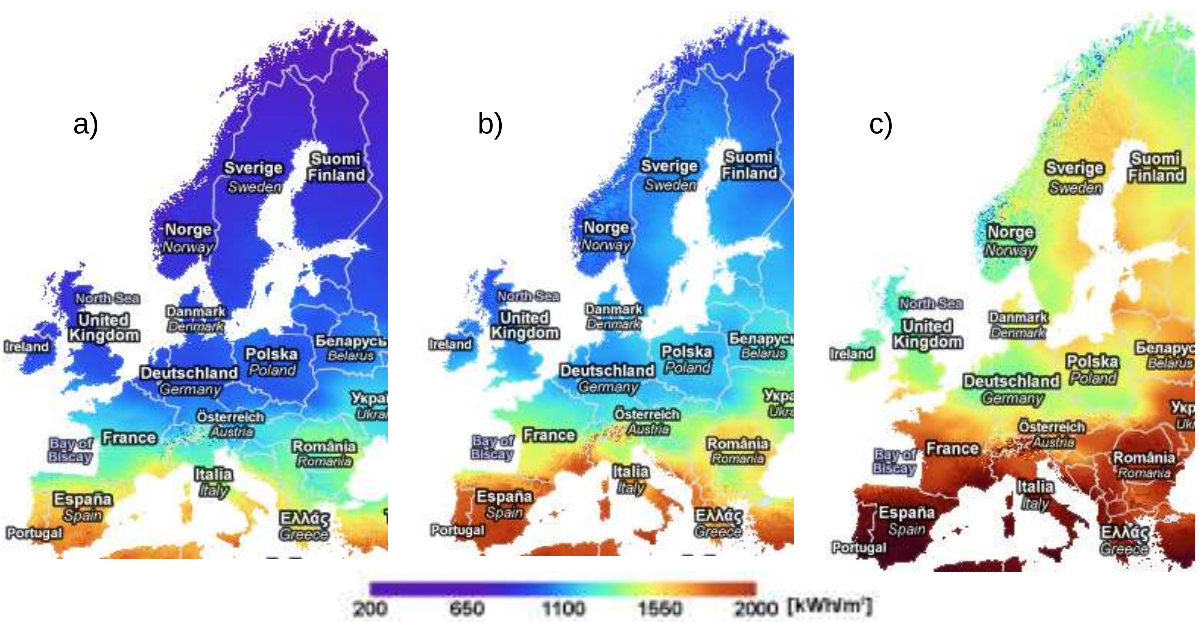


Fig.4.10. Solar thermal practical potential in Europe the 2010th. a) on a horizontal surface, b) on an inclined surface, c) collectors follow the sun's movement

The amount of solar radiation is (showed in Figures 4.10.a) is calculated per m^2 of solar collector area, which is oriented horizontally throughout the year In this case it could refer to the apartment building that has a flat roof and solar panels installed so that they are fully fit on the roof. The practical potential of solar energy in Belgium, the Netherlands, Denmark, the Czech Republic, the UK, Ireland, Poland, Lithuania, Estonia, Latvian and the largest part of the is similar. This tendency can be explained by the fact that solar collectors will also work if there are small amount of clouds and in bad weather. Solar collectors are totally unable to operate only in night and in cases of high cloudiness.

As mentioned above, 4.10.a image shows practical solar potential if the sun's rays fall on a flat horizontal surface throughout the year, but mostly it is possible to install solar panels at an angle with respect to, for example, the roof surface, which means that the available annual solar energy increases. In this case, it relates to the practical potential of solar heat on a slope. The solar atlas if the amount of solar energy that falls on solar collector positioned at an optimum angle are illustrated in figure 4.10.b.

We compare image 4.10.a with 4.10.b, it is evident that across the Europe the available practical solar potential increases if solar collectors are installed in the optimal angle for concrete geographic location instead of horizontally. It can be clearly seen that available amount of solar energy, for example, in Latvia is similar to the North regions of France and even a little bigger than in central Germany, however available amount of solar energy in Sweden is lower than in Latvia. Such sloped solar panels can be integrated into the building facade and installed on the roofs of buildings, as well, when there is a vacant space, it is possible to install the panels on the ground.

There is a third alternative for the installation of solar collectors - they can be mounted on a movable axle, which follows the sun throughout the day. It is logical to conclude that solar collector installed in such way will provide the highest practical solar power potential as it is shown in 4.10.c image, where you can see the maximum practical potential of solar energy in Europe. In this case, it is evident that available practical solar energy in Latvia, using solar collectors with a moving axis, is even higher than in the central region. This can be explained by the fact that not only the geographic location, but also the weather conditions (snow, humidity, air temperature, etc.), height above sea level and the surrounding shade are important factors.

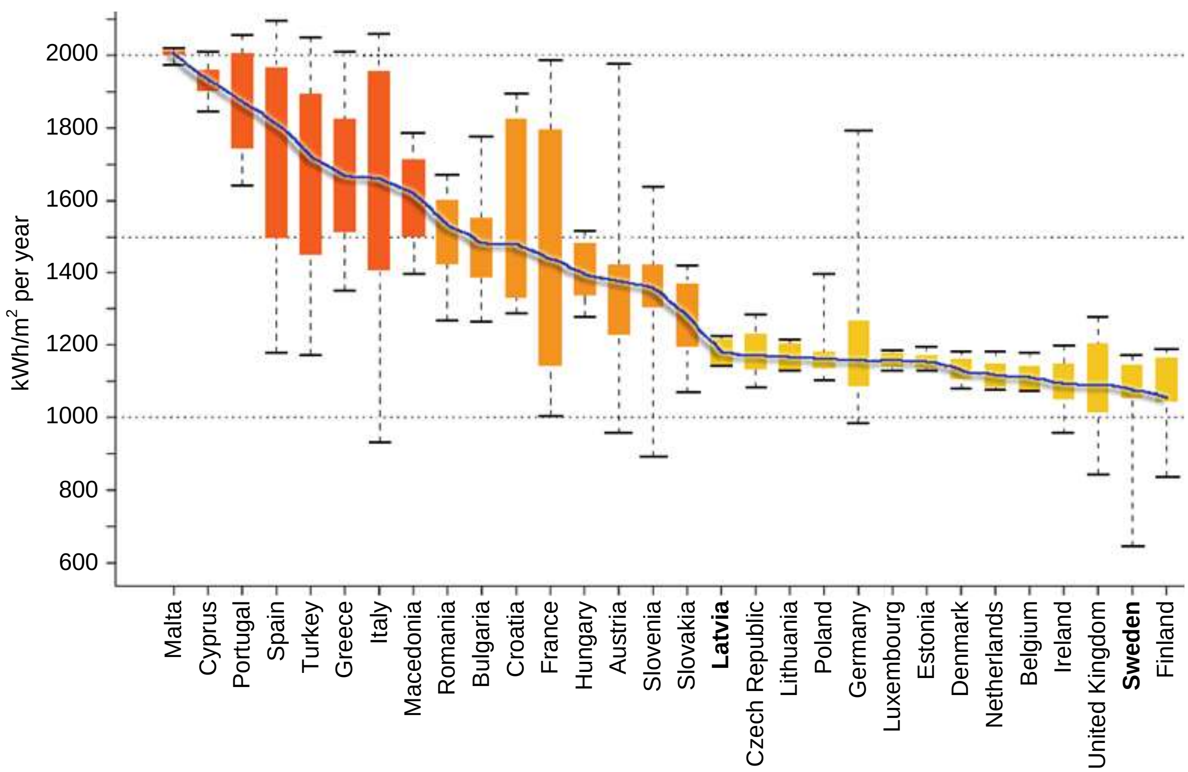


Fig.4.11. Comparison of annual global solar intensity in the optimal angle to the surface

The European Commission's Environment and sustainable renewable energy institute has estimated solar radiation intensity of European countries - findings of this study are presented in Figure 4.11.

The national average level is connected by a continuous line, national solar intensity minimum and maximum values are shown with dashed lines, shaded rectangles shows solar intensity values, placed where the 90% of the populated areas of the country are (see Fig.4.11). Taking into account the amount of practically available solar intensity (in 90% of the populated areas) it is obvious that in the Baltic countries, solar energy is comparable to countries such as the Czech Republic, Poland, Germany, Luxembourg, Denmark, the Netherlands, Belgium, Ireland, the United Kingdom, Sweden and Finland. This means that the potential of solar thermal technology market is similar in all of these countries.

2. Solar collectors

There are three types of solar collectors, based on the temperature range that these collectors can provide to the consumer - low, medium and high temperature collectors.

Low-temperature collectors (<80 °C) is currently the most widely used systems, they are normally used for domestic hot water and heating supply. Currently the market is dominated by glazed, flat and vacuum tube collector systems. Flat panel collectors dominate European market they occupy about 85% of the overall collector market. Because of the use of various techniques, including hot water and heating techniques, as well as different climate conditions, the market has a large number of different flat panel collector technologies. The selection of material for collectors' production is a crucial aspect of achieving higher efficiency. Improving the surface with anti-reflective coating, the collector efficiency increases by an average of 5%.

Heat carrier in low-temperature flat plate collector systems can be both: water and glycol solution and various antifreeze solutions to avoid water freezing in collectors when the outdoor temperature is below 0^0C. In other type of configuration collectors air is used as the coolant instead of aqueous solution. Flat collectors can be installed in modules (number of individual collectors that are connected in parallel or in series) on roofs or produced in bigger formats, to be integrated into the roofing and building facade.

Fig.4.13. Flat solar collectors on the roof of residential building in Latvia

Example of the flat solar collector installation on the roof of residential building in Latvia is shown in Figure 4.13.

Medium-temperature collectors operate in temperature range from 80 to 250 °C. There are extensive possibilities for the usage of technology in medium temperature range. Particularly significant this range is for buildings (cooling technology uses 120-180 °C), as well as water purification processes and water treatment processes. Currently the choice of collectors allowing using medium temperature is not very wide and it is relatively new solution in world market. Usually this type of system requires a large capacity (hence the large collector area), and has low cost, high durability and quality.

Vacuum tube collectors are more efficient than flat collectors, especially at higher temperatures. Vacuum tube collectors can be combined with solar ray concentrator (optical) collectors, creating configuration of a new type of collector system that can be very effective in the temperature range of 100 to 180 ºC.

High temperature collector technologies (>250 °C) are most commonly used for electricity generation. High temperature collectors are rapidly evolving and offered in dynamically growing market. The technical potential is determined taking into account efficiency coefficient of solar thermal energy technologies and its practical potential. Technical potential is a number that indicates how much heat or electricity will be produced using a given technology with a certain amount of available solar energy. This value indicates how much heat energy is available to the consumer. To get technical potential we need to know practical potential and efficiency coefficient of solar heat technology.

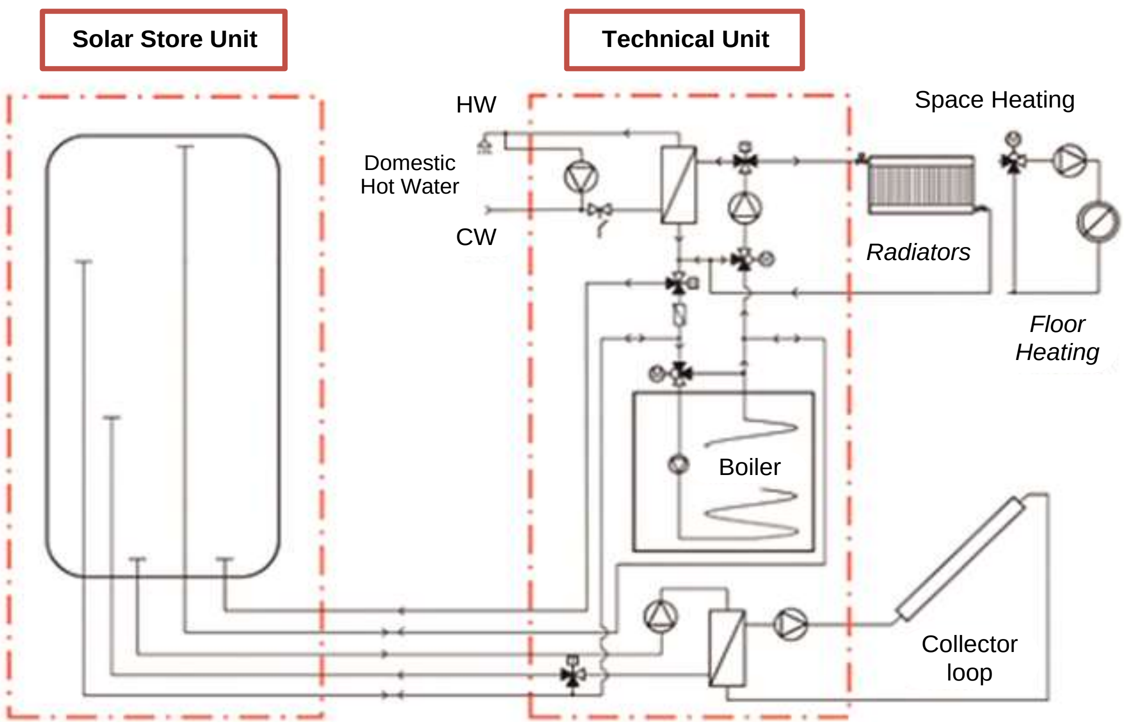


Fig.4.13. Principal scheme of solar combined system

Solar collector integration in energy source and heating system is shown in Figure 4.13. It is also necessary to install storage tank, heat exchanger and pumps in the energy source, as well as a boiler with heat exchanger to compensate the missing energy in heating system.

From a practical point of view, there are several obstacles to the use of solar collectors in historical buildings. First, not all of the roof covering can be usefully employed. Another problem is related to the roof shading. The third, accumulation of thermal energy and uneven daily, weekly, monthly, etc., heat consumption. Fourth, during the renovation, heating energy consumption will decrease, which means that it will require smaller solar collector area. All of this leads to the conclusion that required solar collector area is dependent on various factors, which should be evaluated prior to installation.

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