HEATING AND AIR CONDITIONING

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CONTENTS

INSTRUCTIONS TO STUDY

You have obtained training materials for the subject Heating and Air Conditioning intended for the 4th semester of the part-time master study programme Thermal Engineering and Ceramic Materials.

PREREQUISITES

This subject has no prerequisites.

AIMS OF THE SUBJECT AND OUTPUTS FROM LEARNING

The aim of this object is to familiarize students with the basic terms concerning heating and air conditioning systems. Students will learn the fundamental principles of heat loss calculation for buildings and the possibilities of reducing heating costs. They will learn more about the basic types of heat sources, district heating networks, heating systems, and the principle of air-conditioning equipment. After studying these modules each student should be able to apply his/her knowledge in practice as well as in related (interdisciplinary) fields.

AFTER STUDYING THE SUBJECT A STUDENT SHOULD BE ABLE TO HAVE:

Knowledge outputs:

- to define the main principles of heating buildings,

- to describe the basic types of heating and air conditioning systems, heating systems, and heating networks,

Skills outputs:

- a student will be able to use his/her expertise in deciding on how to reduce the costs of heating,

- a student will be able to apply his/her theoretical knowledge for buildings in terms of thermal technical characteristics.

DURING THE STUDY OF EACH CHAPTER, WE RECOMMEND THE FOLLOWING PROCEDURE:

Read one section and review the main concepts that you should learn about. If you still do not understand any of the concepts, you should return to it once again. Then go to the end of the chapter, where the main concepts are repeated again. If you still do not understand any of the concepts, you should return to it once again. To verify that you have mastered the chapter well and completely, there are some theoretical questions prepared. The answers to all the questions can be found in the text. For additional self-study each chapter is complemented with a list of recommended literature, which can be found at the end of each chapter.

METHOD OF COMMUNICATION WITH TEACHERS:

A part-time student will communicate with a teacher directly at the lectures of a given subject, or through consultation, both during the semester and during the examination period.

Semester works and projects necessary to obtain credits will be assigned directly at lectures or via electronic mail.

Assigned tasks will be checked at the workplace of a lecturer.

CONSULTATIONS WILL TAKE PLACE WITH THE GUARANTOR OF THE SUBJECT OR A LECTURER:

- at the group tutorials,

- at individual consultation sessions after prior arrangement by email or by phone.

The guarantor of object, Lecturer and Contacts: marek.velicka@vsb.cz , tel. 59 732 1538

<u>THE STRUCTURE OF CHAPTERS</u>

Time for study: xx hours

In the introduction of each chapter the time needed for studying the subject is given. This time is only informative and it can serve as a rough guide to study the entire subject or a chapter. For some of you the time may seem too long, for others the contrary. There are students who are new in this area and conversely some who have already gained a lot of experience in this field.

Objective

After studying this paragraph you will be able to

- define ......
- describe the ...
- solve ....

Immediately afterwards the goals are stated that you should achieve after studying this chapter - specific skills, knowledge.

Lecture

Then there follows the proper lecture of the subject studied, the introduction of new concepts, and their explanations.

A summary of the chapter (subchapter)

At the end of each chapter the main concepts that you have learned are repeated. If you still do not understand any of the concept, you should return to it once again.

Questions for the subject studied

To verify that you have mastered the chapter well and completely, there are some theoretical questions prepared. The answers to all the questions can be found in the text. The answers to these questions have not been worked up.

The literature that can draw you to further studies

At the end of each chapter a list of literature may be included, which was used for the preparation of the learning text. In the list of publications some literature for further individual study can be included.

1 Heat losses in buildings

Time for study 5 hours

Objective After studying this paragraph you will be able to

- define basic heat losses from room transmission
- locate the largest sources of heat losses in buildings
- describe the possibilities of eliminating heat losses
- define the concept of a heat bridge
- characterize the basic properties of insulating materials

Lecture

A heat loss in buildings is not only a simple sum of the heat losses in individual rooms but it is necessary here to assess the infiltration and time of operation for individual rooms, and take into account the local thermal gains.

1.1 Total heat loss of a room

Total heat loss of P_C (W) is equal to the sum of the heat loss from heat transmission through the structures and heat loss due to ventilation, reduced by the permanent thermal gains according to the relation:

$$P_c = P_p + P_v + P_{zr} \quad \text{(W)} \tag{1}$$

where

P_C is the total heat loss (W),
P_p - loss due to heat transmission (W),
P_v - loss of ventilation (W),
P_z - permanent heat gain (W).

1.2 Heat loss of transmission

Heat loss of transmission P_P (W) is given by the basic heat loss of transmission and by added values according to the equation below:

$$P_p = P_o\left(1 + p_1 + p_2 + p_3\right) \quad \text{(W)} \tag{2}$$

where

P_P is the heat loss of transmission (W),
P_o - basic loss of heat transmission (W),
p_1 - added value to compensate for the effects of cold structures (1),
p_2 - added value to speed up heating (1),
p_3 - added value for a cardinal point (1).

For a given room the basic heat loss of heat transmission P_o (W) is the sum of the thermal flows by heat transmission through the individual structures that surround the room. It is determined by the following calculation:

$$P_o = \sum_{j=1}^{n} k_j \cdot S_j \left(t_i - t_{ej}\right) \quad \text{(W)} \tag{3}$$

where

P	is	the basic heat loss by heat transmission (W),
k_j	-	the coefficient of heat transmission (W.m^{-2}.K^{-1}),
S_j	-	cooled internal room temperature (m^2),
t_i	-	the calculation of internal room temperature (°C),
t_{ej}	-	calculated ambient temperature on the outer side of a structure (°C).

1.3 Heat loss of ventilation

Further losses of a building may arise due to the forced ventilation of a room. There is a need for adequate ventilation to replace air, and the risk of fungi and moulds.

$$P_v = 1300 \cdot V_v \left(t_i - t_e\right) \quad \text{(W)} \tag{4}$$

where

P_v	is	the heat loss of room ventilation (W)
V_v	-	the volumetric flow of ventilation air (m^3.s^{-1}),
t_i	-	the calculation of internal room temperature (°C),
t_e	-	calculated external temperature (°C).

1.4 Location of heat leakage from an object

To find out the heat losses when heating a low energy building, we must make use of several proven methods. Most information gives us a thermovision measurement that uses the physical phenomenon in which the surface of any body emits the electromagnetic radiation into the surrounding area. This principle will be used to measure the intensity of radiation and then we can estimate the temperature of this body from it. A direct relation is valid here, the higher the level of radiation, the higher the temperature. The most intense radiation at room temperatures, which interests us most, is in the area of infrared radiation, which is measured using infrared thermometers. Thermal imaging cameras operate using the same principle. When measuring with a thermovision camera, an indisputable advantage is the ability to scan a temperature in many points at the same time, while with infrared thermometers just one point can be measured. With this thermovision measuring we can identify thermal leaks precisely. By assigning the temperatures to the chromatic spectrum obtained from our measurements, we get the image, determining the distribution of surface temperatures in the given body.

In accordance with a low energy standard, a building should have a high quality insulation shell closed all around. Sought trouble spots will be found in the places, which will be depicted by a thermovision camera as thermal bridges. The measurement itself is quite simple. It is a similar process as in digital camera photography. Unlike ordinary colour photos, the image is stored as the temperature map, so the temperature can be read later for any point within the image, and we can get an optimal picture of heat leaks. For the easier identification of measured spots, many types of thermal cameras have the possibility of taking the thermal shot as a standard image.

For credible results it is the best if the temperature difference between the indoor and outdoor is at least 10 °C. It is inappropriate to carry out measurements at the time when the sun beams fall on a building, since the temperature of the surface increases and disparities caused by heat losses are overlaid by the sun beams. We must take into account also thermal inertia, which can occur in the event of a large difference in temperature between the interior and exterior of this object.

1.5 The possibility of reducing heat losses

Energy savings represent an important possibility of reducing the cost of our home operation. Many times we are not even aware that what we really need is a service that the energy is supposed to provide, not the energy itself. In heating objects our utmost interests it the heat transfer through the walls, windows, and doors.

In recent years during the construction of buildings a completely different approach and requirements begin to apply. Thermal and energy efficiency, together with the efficiency of the building, has become a very important issue.

Optimal thermal insulation reduces heat losses through the perimeter structures and at the same time seals a building against the penetration of colder air from the outside into the interior rooms. A further benefit here is the elimination of the heat bridges which reduces the condensation of water vapour in the construction. In overall, the temperature inside the building increases. Among the benefits of insulation we can include a reduction of energy consumption, but cost savings substantially depend on the original state of the building. For buildings where the shell has a low thermal resistance reductions of up to 30 % can be achieved. Insulating will also reduce the formation of moulds that are largely appearing in the colder parts of corners. We will also improve the thermal stability of buildings despite the inconsistency of the external temperatures.

For a new building the most common form of thermal insulation is the form of thermal insulating plaster. For example polystyrene of 6 cm thickness has the same parameters as the thermal plastering of an 18 cm thickness. At the present time buildings are insulated using polystyrene material normally to a thickness of up to 15 cm.

The ways of additional insulating can be divided into two types, namely the dry and the wet process. Under the concept of a wet process we understand the use of thermal insulation plaster, which can be placed from the inside or outside of the cover. Its thickness depends on the original wall and on the need to achieve sufficient values of heat resistance. For a bigger thicknesses the lining system is applied to a pre-adherent mesh, which transmits the tensions arising between the junction of thermal insulating material and the original wall. A dry process includes claddings with the complete exclusion of the wet process. It is a method using different cladding panels, mostly with the creation of ventilated cavities.

Σ A summary of the Chapter 2 concepts

When heating we must be concerned about the amount of heat that escapes from the heated object. To limit these losses, we must achieve the best seal between the junctions of a structure, have good quality windows, doors and materials that have a low coefficient of heat transmission. If this is not the case, there is the need to locate the heat bridges in the building, and subsequently take additional measures, most frequently concerning insulation and the replacement of windows. There are usually the largest heat losses. If the building is well insulated, heating costs are decreasing substantially, and the return on investment is achieved within the next few years.

Questions to Chapter 2

1. Define the various types of losses in buildings.
2. How can you find the heat losses in buildings?
3. Where are heat bridges occurring most frequently?
4. How would you divide heat bridges according to their origin?
5. What possibilities are there to reduce heat losses?
6. What characteristics should the appropriate insulating materials have?

The literature that can draw you to further studies

[1] BYSTŘICKÝ, V., POKORNÝ, A. *Technická zařízení budov*. Praha: ČVÚT, 2006. 203 s. ISBN 80-01-03450-X.

[2] CHROMÍK, R., KLEIN, Š. *Stavební tabulky: Vytápění budov*. 6. vyd. Brno: ART-PROJECT, 2004. 506 s. ISBN 80-239-3447-3.

[3] *Vše o úsporách energií: Edice renovujeme, stavíme, zařizujeme.* JAGA GROUP, s. r. o. 2007- , roč. 8. Bratislava: Available from the web: <www.jaga.sk>. ISSN 1335-9177.

[4] BAŠTA, J. aj. *Topenářská příručka: 120 let topenářství v Čechách a na Moravě*. 1. vyd. Praha: GAS s.r.o, 2001. 1122 s. ISBN 80-861-176-81-9.

[5] ŠÁLA, J. *Zateplování budov*. 1. vyd. Praha 7: Grada Publishing, spol. s. r. o., 2000. 176 s. ISBN 80-7169-833-4.

[6] ČSN 06 0210. *Výpočet tepelných ztrát budov při ústředním vytápění.* Praha: Český normalizační institut, 1994.

[7] CIHELKA, J. *Vytápění, větrání a klimatizace*. 3. Vydání Praha: SNTL Brno, 1985. ISBN: 80-214-1142-2.

[8] Termobraz.cz. [online]. [cit. 2013-07-16]. Available from: http://www.termoobraz.cz/tepelnymost.html

2 Heating buildings

Time for study 5 hours

Objective After studying this paragraph you will be able to

- define the sources of heat for heating houses
- describe solid fuel furnaces
- characterize the basic types of heating systems
- describe the types of fossil fuels
- define the thermal gains and losses of buildings

Lecture

An integrated approach to tackling energy systems in buildings and building elements is the best way how to reduce the energy consumption of a structure and the operating costs. In addition to the technical equipment for the heating and ventilation of buildings, it is mainly due to the rapid development in the field of designing buildings in terms of thermal-technical characteristics and the development of systems for the intelligent management of buildings, which help to ensure the link between the subsystems and can harmonize the operation of the whole building.

2.1 Heat sources

In our climate heating makes around 55% of all energy consumption of households. During the heating period this ratio reaches even about 65 %. The heating system in the "normal" house is usually the same as the district heating in a low-energy building. However, there are important differences. These include energy and heat sources selections, depending not only on the economy of their operation but also on the protection of the environment that goes beyond the requirements, laid down in the relevant legislation or binding technical standards. Potential clients are more and more aware of the impact issues of construction on the landscape and they attempt to minimize the pollution caused not only by the very construction of a building, but also by its subsequent operation.

There is a good choice of many types of boilers on the market, being the main source of heat for local heating. Most of the boilers are produced mainly for the performance required for standard houses, as a rule the performances are higher than required to cover the heat losses of low-energy houses. Family houses or buildings similar in size to this standard space need, in the vast majority of cases, a heat source with a capacity of up to 10 kW, while the heating system using a higher source of performance is completely uneconomical. This problem can be solved using a storage tank. Various energy sources (typical boiler, solar system electrical heating rods) heat the water in the tank using the full (rated) capacity, where the effectiveness of the resource is the highest and its composition of emissions prevails. After warming the tank up the boiler switches off or goes into a run-down mode. The heating system can then take the heat from the tank as required. The size of the tank shall be chosen according to the heat consumption in the house and the size of a boiler. Its disadvantage is the selection of an appropriate place for this tank. For the efficient use of heat a not negligible tank should be installed in the "hot" zone of a residential area within the house.

Solid fuel boilers

When selecting the optimal boiler type it is important that the source of heat supply in terms of performance copies the immediate need for heat. The most common solid fuel boilers, in whatever version, work mostly with performance around 20 - 25 kW, and therefore they are used in connection with an accumulation of heat.

Simply said, solid fuel boilers can be divided into:

- the traditional atmosphere boilers for the combustion of coke, coal, wood. Their performance is dependent on the calorific value of the fuel used. These types require user's operation. Their efficiency is ranging between 72 % and 80 %,
- the boilers with an automatic filling of fuel and with an air fan. Depending on the type of the boiler the fuel can be coal or wood pellets. Performance of these types is controllable, regulation uses a microprocessor to control inter alia the fuel feeder mode and the fan. The efficiency of combustion for pellets is around 85%. These boilers may be equipped with an unattended electric ignition,
- semi-gasification boilers for timber and briquettes,
- gasification boilers for wood, or a combination of wood and coal. With gasification of fuel these boilers will reach a high level of efficiency and low emission values. They are based on the principle of a two-stage combustion. The effectiveness of these controllable gasification boilers may be up to 90 %,
- there are combined boilers for gasification wood + pellets, wood + gas, wood + light fuel oil with the possibility of switching the burners.

Fireplaces, woodburning and tiled stoves

Fireplaces or woodburning stoves are beginning to be applied again, especially as a secondary heat source. They become the secondary or additional source of heat, given that their operation needs the attention of a user and so they serve as a supplement to the basic heating system. Concerning their design closed combustion chambers are used mostly today, using cast-iron fireplace inserts, whose performance is about 70%. Previously used open inner hearths showed very low efficiency, reaching from 5% to 20% with various fuels

Basic fireplaces and stoves can be divided into:

- the hot-air stoves and fireplaces. Air flows around the preheated fireplace insert, it heats up and together with the heat emission from heat resistant glass it heats the ambient space,
- combined radiant heating and storage heater. They work on a similar principle as the hot-air heat stoves, but they are sheathed with accumulation material, so they transmit heat after the fire goes out for a longer period,
- tiled stove. The surplus energy charges an accumulation wall placed beside the fireplace, which after the fire goes out emits the accumulated heat for another e.g. 36 hours,
- double-walled fireplace inserts,
- fireplace inserts and stoves with a hot-water exchanger,
- pellet stoves.

The gas boilers

For new buildings where the area has a gas pipe installation low emission condensing gas boilers are the most often used. Their advantage is the use of condensation heat from the water vapour produced during the combustion of hydrogen in natural gas (or propane), when cooling the combustion gases under the dew-point. In this way its efficiency may increase up to by 15 %. Another advantage of this system, and also for other types of gas boilers, is the possibility of applying a high quality temperature control. It is the control which monitors the external temperature and the temperature of heating water before the boiler. The advantages of this control, which increases efficiency in comparison with the internal temperature by some 10 to 20 %, is that there are small traffic delays and quick responses to the changing external temperature. The savings lie in the fact that the required heat input can include the calculation from the thermal gains of internal devices and from the solar radiation. When using boilers of an output exceeding the thermal needs of a building it is desirable to put it into operation with a storage tank.

There are two types of gas boilers. The first type removes air for combustion from a room, in which it is placed, and combustion gases are conducted using chimney or a flue pipe outside this building. Devices of the second types are closed, the combustion air is drawn in from the outer area and the combustion gases are again conducted outside the heated building.

2.2 The heating system

The heating system in the building is another essential element on the way of energy passing from the source to the place of consumption, and it can significantly affect the overall efficiency of the heat supply. The heating system must take into account both the characteristics of resources and the requirements for heating rooms, given by its heat-technical and operational characteristics. According to the heating fluid heating systems can be divided into the hot-water systems and the hot-air systems.

The hot-water heating

The difference in the application of traditional hot-water heating in low-energy houses from conventional systems lies in a substantially lower installed performance of heating surfaces. The requirement for such a system is the better flexibility of its power changes for arbitrary internal gains and the possibility of self-regulation used in each room.

Water is currently the most frequently used heating substance, having a number of advantages:

- easily adjustable,
- high specific heat capacity ($c_p \approx 4.2$ kJ.kg^{-1}.K^{-1}),
- easily accessible,
- harmless,
- in central heating it allows reaching low surface temperatures for heating surfaces.

For low-energy houses the hot-water low- temperature system is used. The hot-water and warm-water systems are inappropriate for their high operating temperature. For the hot-water heating we can use:

- convectors - a typical system of heat transfers, predominantly using convection and only partly radiation,
- floor heating - low temperature heating, appropriate in connection with heat pumps,
- wall heating - applicable in particular to a construction with a higher accumulation, for light wooden buildings it can be used only for installation into separate and much greater masonry partitions.

The hot-air heating

The basis of this system is a hot-air unit linked to the distribution unit of heated air. The main drawback is:

- its small specific heat capacity ($c_p = 1$ kJ.kg^{-1}.K^{-1}),

- its large specific volume,
- its unsuitability for transporting heat to greater distances.

Fireplaces equipped with a fireplace insert may be structurally adapted to use the air heating distribution for several rooms at once, or eventually for the entire house. Concerning the thermal comfort the absence of radiant components is solved by placing the fireplace into the main room of an apartment or a house. The hot-air ducts use either:

- gravity circulation, i.e. without the use of a fan - system it is used in case the outlets of warm air can be placed into other rooms without the need of any fan. For investors these ducts are financially more accessible and often more effective,
- forced circulation, i.e. using a fan - this system has the advantage of possible control using a thermostat built into the fan, and the possibility of heating more distant rooms. However, one condition here is to select a proper fan, according to its performance.

Radiators

To heat individual rooms radiators are often used. They are either parts of the whole central heating, or placed locally. The heating element transfers its heat to the heated area via radiation, conduction, and convection. Heat is shared by all the above mentioned ways, in the various proportions of the individual components. These ratios depends on the design of a heater. Radiators are divided as follows:

- convection
  - cell,
  - plate,
  - tubular,
  - convectors,
- radiant heating surfaces - according to their placement - floor, wall, ceiling,
- hot-air units,
- local heaters - heaters for solid, liquid or gaseous fuels,
- convector heaters, accumulation hybrid electric heaters.

Individual central heating is a system based on one heater which produces heat and distributes it via tubular ducts into the heating elements located at the same level as the heater itself (without any transfer of heat into other floors). Typically, one circuit of individual central heating is used for one housing unit, one floor of a house, offices, etc. (Fig. 1).

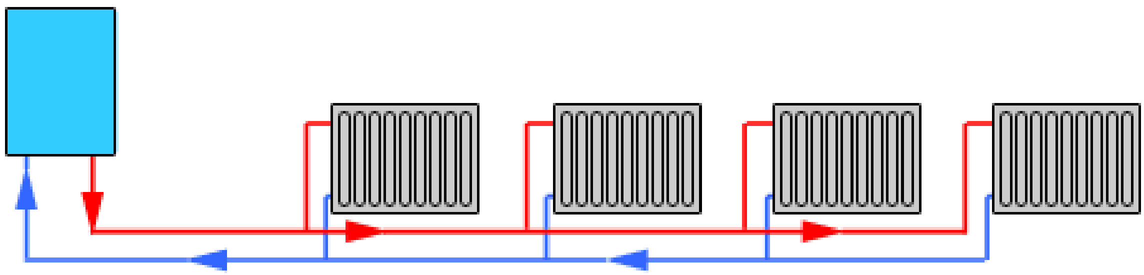

Fig. 1 Schematic illustration of an individual central heating [7]

With an appropriate design, a well-designed project and properly dimensioned radiators for individual central heating it is a very effective heating system and can bring significant savings during heating season. There are no unnecessary losses of heat due to conducting tubes outside the heated rooms, the costs are not shared by more payers, and so its operator is motivated to find and implement cost-saving measures to eliminate unnecessary waste, which is often a painful area of the heating systems shared by more taxpaying users.

Compared to a local heating system its advantage is a single heating unit, usually placed outside the room, which makes it possible to maintain the premises for house cleaning more easily.

Cell radiators

These heaters are made up of individual parts, regardless of their shape. They are produced from a variety of materials, using different technological processes. The most commonly used materials are steel, cast irons and aluminium alloys.

The two essential parts of the unit are its upper and lower chambers and cartridges with threads on the same axis. The chambers are interconnected by differently shaped heat transfer areas. Cells have an external heat transfer surface distributed mainly into its depth, which leads to an increase in the heat module. A further increase occurs in ribs which extend to the external transit area. The shape and size of the ribs depends on the technology used during their production.

Plate radiators

They belong to the most commonly used. Under plate radiators we understand coherent smooth plates or sheets with a surface enlarged by waves. They have small water content, which allows their rapid response to regulatory intervention, and they are also lighter.

Essential parts are the top distribution and lower collecting chamber placed in the direction of the length of this body, with the same cross-section. Both chambers are connected by the offsets forming the ducts. The whole body consists of two offset plates made of a steel sheet that are welded on their perimeters.

Tubular radiators

The essence of designing tube heaters lies in the distribution and collection chambers, connected by a number of tubes with smaller cross-sections. These tubes have circular, square, rectangular, or combined cross-sections. The most frequent forms are: meander, a register with horizontal tubes, and a register with vertical tubes. The tubes, most frequently made of steel or copper, may be smooth, profiled into various shapes, or eventually may have on the outer side an enlarged transfer area.

Convectors

A convector is a heater that shares the heat into a heated area, predominantly by convection. It usually consists of a heat exchanger and a housing, which has some grate at the top to allow for proper air flow. The role of an exchanger is to transfer the heat supplied by the heated substance into the heated area, using the air flowing around. The movement of air is secured by either a natural lift, or by a fan. It is divided into:

- case shaped - these are available as a whole, or a part of the enclosure that can be formed by a wall construction or by some interior equipment,
- socle - they are situated within the heated area into a low cabinets near the floor. It is often called a sub-parapet, since they are placed under a low parapet, along its entire length,
- embedded - cabinets are parts of the building, mostly built into the floors. A rib is placed in a floor channel under the window, and it is covered by a stepping cover mat.
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2.3 The energy balance of buildings

From an energy point of view, each object is characterised by its energy demands (its need for energy) and also by its energy intensity (energy consumption). The energy demands represent the amount of energy that an object requires objectively in order to function. Typically, the greatest need for energy is represented by a heat for heating, which is given by the difference between the heat losses of transmission and ventilation, and the thermal gains from all solar and internal sources. Energy intensity is de facto a quantity of energy which the systems require to cover the above mentioned energy demands. Concerning the energy intensity of buildings we do not asses only the need for energy to heat the building, but also other energy consumption such as ventilation, cooling, air conditioning, lighting, etc.

More precisely energy intensity can be determined using an energy balance evaluation. Assessment methodology includes both the heat loss (of heat transmission and the loss caused by the air exchange) and thermal gains (from solar radiation through the glazed areas, by the metabolic heat of persons, domestic appliances, office equipment, and the components of artificial lighting). The calculations shall be carried out using periodic intervals, most frequently after a month. This balance must evaluate all the factors which influence the consumption of energy in a building in the course of the year. The result is the calculation of the heat amount that must be delivered by a heating system to reach the pre-set internal temperature.

Thermal gains

Thermal gains can be divided into profits of metabolic heat from persons, profits obtained by heat released into the heated area by domestic appliance operation and artificial lighting. In some cases the profits resulting from the present production devices can be attributed, as well as the gains from so-called passive solar gains (solar energy penetrating into this interior through the glazed areas). As a part of the internal heat gains can be considered also the heat losses from the heating system, and from the hot water preparation that is re-used in the building. Some exceptions are necessary for e.g. washing machines or dishwashers, in which a part of the heat, as well as in the use of warm water, is wasted and flows with water into sewers. This exemption applies in the majority of cases for the use of stoves and ovens, as their operation requires more ventilation for hygienic reasons (water vapour, odour, or possibly natural gas fumes). The important issue is to determine if the thermal balance is the variability of all these resources.

Metabolic heat and power from electrical appliances and artificial lighting acting for the benefit of building interior are grouped for balance sheet calculations and expressed in the form of heat amount related to the floor area unit.

The calculations can be performed in compliance with the technical standards ČSN EN 13790, The Energy intensity of Buildings - Calculation of the energy consumption for heating and cooling, which replaced the standard ČSN EN 832, The Thermal Performance of Buildings in October 2009.

Heat losses

Heat losses represent the sum of heat transmission and losses due to the need to replace air, i.e. the loss of ventilation. Heat transmission can take place directly through structures that are in contact with the outside air, or indirectly, if there is an area between the heated space and the outer exterior - unheated or heated only partially. Another more complex case is heat transmission through the soil adjacent to the building. There are situations where under the heated building there is just a base plate on the soil, that is an open access hole, an unheated underground floor, or some underground floor heated only partly or totally. When calculating we must take into account also the thermal relation (heat bridges) to the outside environment. The loss of ventilation was previously determined using predominantly the calculation of joint air permeability. Today, with the use of tight covers on buildings it shall be determined in accordance with hygienic requirements. Normally, it is 0.3 to 0.6 of the internal room volume per hour, or the amount of fresh air per a person per hour is determined (e.g. in classrooms it is 20 m3/h per pupil). The amount of heat is then determined by multiplying the quantities of air, its density, and its specific thermal capacity.

Heat losses can be calculated using the harmonized standards ČSN EN 12831 Heating Systems in Buildings - Calculation of the heat output, which replaced the long-time used popular standard ČSN 06 0210 Calculation of Heat Losses of Buildings in Central Heating. The calculation according to the valid standards using the different methods of calculation is more accurate for low-energy and in particular for passive houses. This is thanks to the inclusion of the losses of thermal links between the structures (heat bridges), which are not inconsiderable any more for the high heat resistance of structures.

A summary of the Chapter 3 concepts

In view of the constantly increasing worldwide and in particular European pressure to reduce energy consumption in relation to the need of greenhouse gas emissions reduction, but also for the economic reasons and security, the areas of the operational savings of buildings are getting more to the forefront, and represent around 40 % of total energy consumption in developed countries. The interest to reduce the energy intensity of newly built but also reconstructed buildings is also influenced by an increasing interest on the side of investors and owners. The reason for this is the existence of various incentives in the area of subsidies for efficient buildings, but also because of the needs to reduce the negative impact of high energy prices, largely affecting the overall costs of housing. The specific feature of buildings is not only their large share of total energy consumption, but also a relatively long life and thus greater warranty on the return of invested capital. This section describes the basic sources used to heat buildings and their distribution. There is also a summary of the basic types of heating systems and types of fossil fuels, which may be used for heating. The last part describes the heat gains and losses of these buildings.

Questions to Chapter 3

1. Describe the basic types of solid fuel boilers.
2. What are the criteria according to which we can divide the boiler rooms?
3. How can the heating systems be divided according to heating fluid?
4. What radiators do you know?
5. Describe the basic types of fossil fuels.
6. Characterize the energy intensity of a building.
7. What are the thermal gains of buildings?
8. What are the heat losses of buildings?

The literature that can draw you to further studies

[1] CHROMÍK, R., KLEIN, Š. *Stavební tabulky: Vytápění budov*. 6. vyd. Brno: ART-PROJECT, 2004. 506 s. ISBN 80-239-3447-3.

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3 Heat Pumps

Time for study 4 hours

Objective After studying this paragraph you will be able to

- define the concept of a heat pump
- define the concept of the heating factor
- divide a heat pump according to its heat transfer medium
- describe the basic types of heat pump operations

Lecture

Heat pumps are becoming a well-liked source of heat. Interest in it is the result of energy cost growth, deriving from the political and economic situation in our state and on an international scale. The trend of increased interest in heating using heat pumps will continue, as a heat pump user may not buy a part of energy from the overall quantity, but it comes from the area around the heated object for almost a negligible price.

From an economic point of view a heat pump is a very convenient source of heat. In comparison with other systems and fuels it has almost always lower heating costs, so that the heat pump is sometimes presented as an investment that will be paid back in a few years. Therefore, there are many myths connected with heat pumps, and sometimes they attribute some unachievable technical parameters to them. They are relatively expensive devices, so one must count with a high cost of purchase. Whether the return on investment will be achieved in only a few years will be determined by the development of fuel prices in the future.

Environmentally, a heat pump in comparison with the solid fuels boilers does not pollute the environment with emissions escaping into the air, and thus has no negative impact on the environment. The use of heat pumps has its own specificities, and therefore it is always good to consider all the pros and cons.

3.1 The principle of heat pumps

Heat pumps use "low-potential energy" from the surrounding environment, which is around us in huge quantities and can be converted into some usable form. For its operation it needs to deliver energy, most often electricity to drive a compressor ensuring the circulation of a coolant. A heat pump internal drive with a combustion engine or an engine gas, compared to an electric drive, is less effective, and so it is less often used today.

The electric motor in comparison with a combustion or a gas engine has higher durability and reliability, it is simpler in design, there are no movable parts outside its case, and it is absolutely safe for operation. There are also heat pumps where the circulation of a coolant is not ensured by a compressor. Instead, there are different types of sorption pumps. Their operation is absolutely quiet, but they are not used for heating.

The heat pump utilizes the properties of substances, whose boiling and condensation temperatures depend on pressure. On the inlet side of such a heat pump there is a heat exchanger, called the evaporator. Using a heat transfer medium (according to the type of heat pump) it supplies a low-potential temperature from the surrounding area and into its second half the liquid of a cooling medium is injected under high pressure using the thermostatic jet of an expansive valve. The pressure in the evaporator is smaller, so the liquid refrigerant evaporates quickly, and this causes cooling to a lower temperature than the ambient temperature, from which the heat is taken. Thus, the heat from the ambient surrounding heats the supercooled gas, sucked in by a compressor. The gas sucked in carries all the gained energy. After this compressor depresses the gas, it strongly heats up, and the compressor adds the energy required to compress the gas to the energy derived from the surroundings. On displacement from the compressor a higher temperature is achieved than in the water within the fuel system. The gas is conveyed from the outlet side to the heat exchanger called a condenser, where the gas is liquefied and the heat is transmitted to cooler heating water.

Energy taken from the surroundings is usually 1.5 to 4 times higher than the energy for the heat pump drive. One of the most important parameters of heat pumps suitability is the value of the heating factor, comparing the consumption of electricity and its overall performance.

$$e_t = \frac{P}{P_e} = \frac{P_0 + P_e}{P_e} = \frac{T_c}{T_c - T_z} \quad (1) \qquad (5)$$

where

e_t is the theoretical heating factor (1),
P - total power (W),
P_e - electric power input to drive the heat pump (W),
P_0 - power obtained from the surrounding environment at temperature T_z (W),
T_c - temperature at outlet (K),
T_z - temperature of a heat source (K).

The heating factor is a non-dimensional number ranging from 2.5 to 5. It varies according to the ambient conditions, as the heat pump uses more energy with a larger temperature difference between the outlet of heat pump T_C and heat source T_z.

The heating factor is always greater than 1 and its value increases with decreasing temperature the difference *between* T_c and T_z. For practical use it is therefore unfavourable to have a heat source with the highest temperature and supply the heat into the system working with lower temperatures. In practice the theoretical heating factor is not important, but the real heating factor e_{sk} is. This shall be determined on the basis of long-term measurements and the rated input includes all the energy for heat pump operation.

3.2 Types of heat pumps

The choice of a primary source of heat has a crucial impact on the structure and the characteristics of the heat pump. In the name of heat pumps first position is occupied by the source of the heat, followed by the medium into which the heat is transmitted. The primary source of heat to be used from the surrounding environment can be divided into several group: the terrestrial heat of rocks, collected from the surface layer of the Earth or from its depth, the heat from the surface water or groundwater, and the heat from the surrounding or wasted air.

The earth-water heat pump

It collects heat from the Earth's surface. The heat from the subsoil is pumped via vertical ground collectors or via horizontal ground (area) collectors. In both cases closed heat exchangers at the primary side of heat pumps are used, filled with anti-freezing solution.

A vertical ground collector is a plastic heater exchanger embedded into a deep well with a depth of 50 to 150 m. If there is a need for greater performance, more holes are made. The distance between the individual wells is at least 5 to 10 m, so that they do not influence one another. For 1 kW performance of a heat pump some 10 to 18 m deep boreholes are needed, in accordance with the geological conditions. A heat pump with the 10 kW output needs for its operation a borehole with a depth of 130 m, or two wells deep 65 m. It is better to choose one deeper well than two shorter, because the temperature at 10m depth is almost stable over the whole year, reaching 10 to 12 °C. With the increasing depth the temperature also increases, having the temperature gradient of 1 to 2 °C at 100 m. Thus, the heat pumped has a stable and relatively high temperature, making the heat pumps with deep-hole drilling reaching a heating factor, which does not change almost all year round.

Another possible way of taking heat out from the Earth's surface is to use a horizontal ground or area collector. Heat is drawn from the soil using an exchanger, designed with polyethylene pipes placed into an excavation. This method of heat offtake, compared to the underground boreholes, has a lower cost of purchase, and a worse average annual heating factor due to temperature fluctuations in soil depending on the outside temperature. The heating factor has the smallest value at the end of a heating season, when the soil is chilled. Achievable performance of the ground collector is given within the limits of 20 to 25 $W.m^{-2}$ on the Earth's surface. Heat must be accumulated over the summer in the ground, therefore its amount is limited and the area from which it is to be collected should be three to four times greater than the size of heated surfaces. The length of individual sections for the ground collector with 1 kW output of a heat pump ranges from 40 to 160 m, according to the moisture content in the soil.

Water-water heat pump

In the case of heat pumps using the energy of water the low-potential heat source is mostly ground water, available from a local source well, which is discharged into a soakage well. The temperature of ground water is stable in the course of the year, and in depth ranging from 8 to 10 m it reaches a temperature of approximately 10°C. A good source of groundwater may be the best source of heat for the heat pumps. The flow of primary water must be adequately monitored in order not to interrupt or prevent its reduction below the required quantity. This would cause the water freezing in the evaporator and damage this heat pump. The required flow rate shall be determined on the basis of the required performance for the heat pump from:

$$P_0 = \Delta T \cdot Q_v \cdot \rho \cdot c_p \quad \text{(W)} \qquad (6)$$

where

- P_0 is the desired performance of a heat source (W),
- ΔT - cooling of the primary water (K),
- Q_v - flow of primary water ($m^3.s^{-1}$),
- ρ - density of a liquid (water) ($m^3.kg^{-1}$),
- c_p - the specific heat capacity of water ($J.kg^{-1}.K^{-1}$).

Wells as sources of heat are required not only to supply the required quantity of water, but also it must reach a proper purity and chemical composition. Dirty or heavily mineralised water can cause malfunction in the primary water circulation by clogging the water evaporator. Pumped water is returned to the Earth using the soakage well, which should be distant from the source wells by some 8 to 10 m.

Another option to recover the water energy as a source of heat for a heat pump is the surface water running or stagnant water. In practice, the surface waters are used very rarely. The temperature of the surface water is relatively low, it freezes and it is usually contaminated.

Direct and indirect heat offtake from the water running out of streams, rivers and ponds must be authorised by its owner or by the administrator of the given river basin district. The temperature of water varies in the course of the year, reaching the freezing point in winter, which can cause water freezing in vaporizers with the slower flow. Indirect heat offtake from the running water source using collectors may be preferable, since the closed primary circuit with added antifreeze mixture is not dependent on the purity of water and it eliminates the potential problems with freezing vaporizers. Collectors are represented by one type of area collectors, deposited at the bottom of a water flow, and the antifreeze solution must be environmentally friendly. Permission to deposit the collectors is also subject to the consent of an owner or a manager of the river basin district.

Air-to-water heat pump

A low-potential heat source can be the ambient air or internal (waste) air. Air-water heat pumps need not drilling or ground collectors, and therefore the purchase costs are lower and installation easier. Simple installation and the availability of air as the source of heat is paid with the reduction in performance and a heating factor in colder months, when the outdoor temperature drops and so does the performance of the heat pump. The energy content in the air depends strongly on moisture and if the air is cool, it also includes a little amount of water, and thus there is a drop in the amount of energy in the air. For this reason, at the time when the external temperature is the lowest and the need for heat in the premises the highest, the heat pump works with the lowest heating factor and performance. Good results therefore are achieved by heat pumps using the ambient air as a source of energy, in a temperate climate zone with fewer freezing days (Fig. 2).

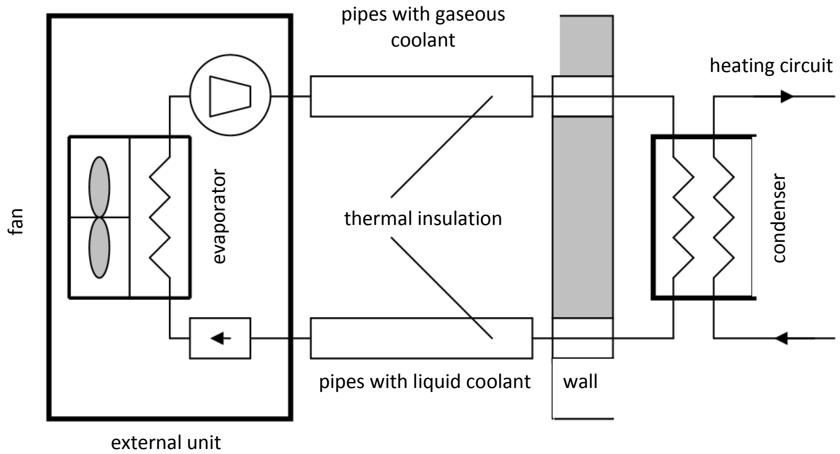

Fig. 2 Heat pump air – water

Heat pumps using air energy usually have a two-piece design, with an external and internal part, and we call it a split heat pump. Outdoor air in the outdoor area of a heat pump is sucked in by a slow running fan and then cooled. The air flow is of thousands of $m^3.h^{-1}$ .In certain designs, there is an evaporator in the outdoor part, an expansion valve, and a fan; all the remaining parts including the compressor are placed in the internal part. The exterior and interior parts are linked by heat-insulated copper pipes, in which the coolant flows. Another implementation of heat pumps, which do not have an external or internal part, is called the compact. There the entire heat pump is placed outside an object and heating water flows through the pipes from the heat pump into this object. It is important to ensure the protection of pipes with heating water against freezing in case of malfunction, or the heat pump is located directly in the object and air is sucked and discharged through the holes in the walls. Here it is necessary to prevent the suction of cooled air.

3.3 Operation of heat pumps

The performance of a district heating system and a source of heat are dimensioned, so that the internal temperature in an object reaches the required values according to the purpose of the object also in a day, when the exterior temperature is equal to the calculated value, which is -15°C, in milder climate temperate areas -12°C, and in regions climatically harsher -18°C. Days when the temperature drops below -15°C, are relatively few, and days when the average daily temperature drops below this level are even fewer. If the daily temperature rises above 20°C, the heating system is already switched off.

Heat pump is dimensioned for the performance according to the kind of operation, which may be a monovalent or bivalent. Furthermore, the connection to the heating system with a thermal gradient 90/70°C, or in a heating system with a smaller thermal gradient, e.g. for floor heating is taken into account.

Its performance is not too excessive and cannot be simply regulated. Usually the heat pump performance does not correspond to the need for the heat offtake in the heating system. In the secondary circuit the heat pump needs the continuous flow of water. If the thermostatic valves are used in the system, regulating the temperature of heating elements by limiting the flow from the resources, or some other regulation reduces the flow of heating water, this water in the secondary circuit heat pump can overheat faster and then frequent switching on and off in the heat pump occurs. For this reason a storage tank is placed between the heat pump and the heating system; then the heat pump heats up this tank and the flow of heating water in the secondary circuit is stable, independent of changes in the thermostatic valves. The frequency of switching on and off is reduced, the tank accumulates thermal energy, and for the time the heat pump is switched off during the high tariff period of electrical energy consumption it is supplied to the heating system.

Σ A summary of the Chapter 5 concepts

Heat pumps belong to the alternative sources of energy, because they can offtake the heat from the surrounding environment (water, air or land), convert it to a higher temperature level and then use it efficiently for heating or for hot water preparation. Virtually, that substance (soil, water, or air) is cooled by a few degrees, thus we take the heat off, and use this energy to heat other substances, e.g. water in the pool, hot water, or water in the fuel system, which is also warmed by a few °C, reaching a level acceptable for us.

For pumping the heat to a higher temperature level, also for the operation of a heat pump, it is necessary to deliver a certain amount of energy. This means that the heat pump uses some electrical energy to drive the compressor. Because its quantity is not negligible, the heat pump can be considered an alternative source of heat only partially. Put simply, we can say that the heat pump consumes approximately one third of its output in the form of electrical energy. The remaining two thirds are represented by heat, which is withdrawn from the cooled substances.

The heat pump contains four basic parts in a cooling circuit: an evaporator, compressor, condenser, and expansion valve. The heat accumulated from the outdoor environment is transferred in the evaporator to a working substance (liquid coolant) at a relatively low temperature. By heating the coolant it changes into a gaseous state and vapours are then compressed in the compressor to high pressures. The pressurized refrigerant enters the condenser, where it transfers the heat during condensation to the heating water at a temperature higher than that the heat that was taken off in the evaporator. In the expansion valve the cycle is closed and there is a decrease of refrigerant pressure to its original value in the evaporator.

? Questions to Chapter 5

1. Describe the principle of a heat pump.
2. What is the heating factor?
3. Describe the principle of a ground - water heat pump.
4. Describe the principle of a heat pump water - water.

5. Describe the principle of a heat pump air - water.
6. What conditions are heat pumps dimensioned for?
7. Describe the bivalent system of heat pumps operation.
8. Describe the system of monovalent heat pump operation.

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4 Solar heating

Time to study 5 hours

Objective After studying this paragraph you will be able to

- describe solar radiation as a source of energy,
- describe the principle of generating electric energy from the sun
- characterize heat generation from solar energy
- describe the basic types of solar panels

Lecture

Solar radiation, being almost inexhaustible source of energy, can be harnessed in many ways. The forms of the solar energy utilization in practice can be divided into these two basic groups.

The passive use of solar energy is based on the utilization of the so-called solar architecture, and it is given primarily by the architectonic and structural design of buildings. Its principles are known from the ancient times and allow the maximum use of solar energy in winter seasons, and vice versa in the periods of high solar radiation they prevent the overheating of objects.

The active use of solar energy lies in the conversion of solar radiation to heat or electricity, and it is realized by additional technical equipment. Heat production is carried out using solar panels, and the heat is used for preparing hot water, heating swimming pools, and to heat the buildings using hot-water or hot-air heating. To produce electrical energy it is possible to use both photovoltaic cells and thermocouples, as well as fuel cells.

4.1 The use of solar systems for the generation of electricity

One way to use solar radiation, falling on the Earth's surface, is the conversion of this radiation into electrical energy. Electricity from the sun can be produced in two ways, either directly or indirectly. It can be obtained directly using photovoltaic panels, or indirectly using thermocouples.

The basic building block of photovoltaic systems is a photovoltaic cell. Photovoltaic solar cells are one of the results of semiconductor research, and recently they are a part of rapidly growing industries. The production of electrical energy in them is based on the photoelectric effect, discovered in 1938. This phenomenon is characterised by electrons emitted from a given substance (most frequently metal, also e.g. zinc, silicon, and others) thanks to light activity. The emitted electrons are called photoelectrons. Cells are made of silicon carbide (monocrystalline and polycrystalline). The base here is a thin silicon plate, (a semiconductor of the P type) on which a layer of N type semiconductor is applied during its manufacture. Those two layers are separated by the P-N transition. At the impact of photons onto this silicon plate electrons are emitted and thus a voltage (0.5 to 3V) occurs, and its size is proportional to the number of coats and solar radiation.

The entire photovoltaic panel consists of a series of photovoltaic cells involved in series or in parallel structures, depending on the total voltage required.

The first generation of photovoltaic cells is represented by the currently widespread technologies of crystalline silicon cells. The disadvantage of crystalline cells in comparison with the newer technologies are higher demands for the semiconductor material consumption. In the case of silicon, which is one of the most frequent elements in the Earth's crust, this is a problem only in terms of energy consumption used for its production. Other elements (gallium, germanium) might however become scarce in the massive expansion of photovoltaics.

The second generation of photovoltaic cells is a response to the disadvantage of the first generation. This category may include most types of thin cells, such as commercially available types - cadmium-tellurium, copper-indium-selenium, copper-indium-gallium-selenium, amorphous silicon ones.

The latest knowledge in this area has resulted in the preparation of the third generation of photovoltaic cells. The higher efficiency can be achieved by using multiple layers, each of which uses only a part of the solar spectrum - photons whose energy is greater than the width of the prohibited belt in a given layer emits remaining radiation into the lower layers. A double-layer cells may theoretically reach an efficiency of 42%, triple-layer of 49 %, and six-layer around 65%.

Solar systems used to produce electricity may be either in conjunction with central distribution networks, or work separately.

4.2 The use of solar systems for heat production

The energy of the Sun can be used not only for the production of electricity, but also for the production of heat. Applications of solar systems for the production of heat is currently the most widely used method to utilize solar radiation. The majority of such installed systems is intended for hot water, a minor part for heating, or eventually to heat water in swimming pools.

The essential parts of the solar system is the absorber (absorption board). The body of the absorber is usually made of aluminium, copper, or steel, its surface is coated with an absorbing layer that is designed to absorb as much of the incident solar radiation as possible. Simpler and cheaper systems are using dark, matting surfaces; collectors of a higher quality have a special layer of galvanically coated or vacuum-steamed metals (black chrome, black nickel). These layers have a very high absorption (up 96%), and poor ability in light reflection (only 4 to 15 %). The cover of an absorber is made of solar tempered glass, with a thickness of up to 5 mm. Its strength characteristics make them resistant to snow load, hail, etc. This solar glass is characteristic for its high permeability for visible radiation and near IR radiation. On the contrary it is the least permeable for long-wave heat radiation. Obtained thermal energy is taken from this collector using a heat transmitting medium (antifreeze liquid, water or air), which is running through the tubular system of a different orientation and shape, fixed to the collector (Fig. 3).

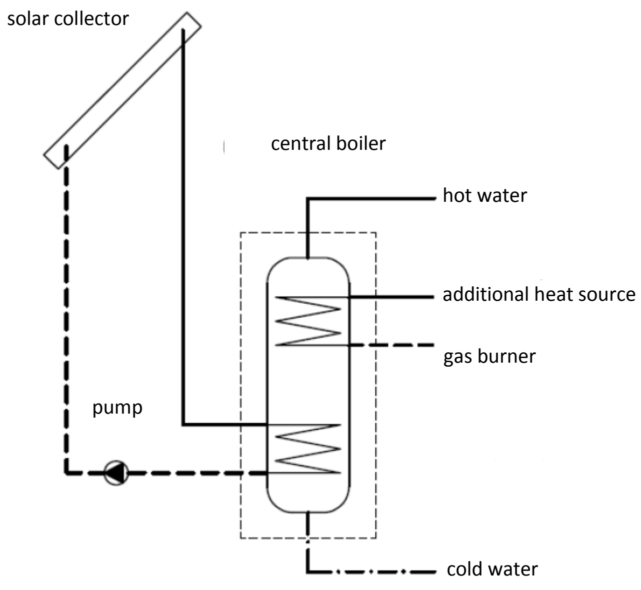

Fig. 3 Wiring diagram of the solar system [7]

Another necessary part of the solar system is the solar boiler - a vessel which serves for the heating and storage of hot water (TUV). In addition the TUV they may be heated by heat energy from the central heating or by applying electricity. The size of a boiler for the solar system shall comply with the surface of solar panels. Another part of solar assembly is the solar heat exchanger, ensuring the transfer of heat from the heat transfer medium into the heated water and it is a part of the boiler. The supply pipe is designed for appropriate pressure, flow, and the temperature of the heating transfer fluid in the piping. In the event the pressure increases due to temperature fluctuations, it is required to compensate it. This is happening in the expansion vessel, which must be built for the expected maximum value that the heat transfer fluid can develop (summer heating - water, all year round operation - antifreeze). In most systems the transport of heat transfer fluid is provided by a circulating pump. The entire system must of course be linked via pipes to a vent valve.

4.3 The design and types of solar panels

Currently it is possible in practice to distinguish between several designs of solar panels, from the simplest types intended only for seasonal operation, up to highly efficient devices that can be operated all year round. Collectors shall be divided into two basic types, flat liquid types and tube vacuum collectors.

Flat liquid collectors

Flat liquid solar collectors are nowadays the most widespread solar collectors. They have a highly selective layer of absorber, achieve excellent performance characteristics at annual operation, and show a favourable ratio of reached output in relation to the single investment costs. The topmost layer is a special protective glass. This has to protect the collector from weather influences. These collectors are adapted for the all year operation. All technology components which do not need to be fixed on the roof are placed in boiler rooms. Collectors can be placed not only on the roof or in the open terrain but also e.g. on the facade of a house.

Tube vacuum collectors

The tube vacuum collectors show greater efficiency in the spring and autumn time, in comparison with the traditional collectors. They can be also used for the production of domestic hot water, or to heat water in a pool. At present their price is starting to reduce and due to their greater efficiency they are desired goods on the market. These types of collectors are suitable to be installed on house facades, but they are more susceptible in winter (to snow and ice). The advantage is that when one tube is damaged, there is no need to put aside the entire collector, but the tube can be purchased separately and simply replaced. The life of tubes indicated by a manufacturer is up to 20 years, since the tubes are all-glass and sealed.

Concentration collectors

Another special type of collector is the concentration collector. Concentration collectors are facilities in which elements of active and passive solar systems are imperfectly combined. With these systems, the basic construction element is the solar radiation concentrator, the linear Fresnel lens, which is made of glass by the method of continuous casting. Double glazing with this Fresnel lens are placed into the glazing frames made of aluminium or wood. These frames are then fixed as a roof skin and they replace roofing material. These collectors have two functions - they serve as a brightening element and at the same time they capture the thermal energy for the production of domestic hot water.

The Fresnel lens focuses the solar radiation into a linear focus, where the absorber with a copper pipe is placed. There the solar radiation changes into heat energy. From the changing position of the Sun the focus position of these Fresnel lenses is amended - this is why the aluminium frame with the absorbers is adjustable and its position is controlled by electronics. The effectiveness of the collector is approximately 1/3 in comparison to the flat collectors - and therefore they are rather placed where there is no other possibility, e.g. on historical buildings from the aesthetic point of view.

4.4 Types of solar systems

Division according to the system used

Active systems are frequently called solar systems with forced circulation. Thermal transfer liquid is circulated in the system using a circulation pump. The flow of heat transfer fluid in the system is possible to regulate and to have under control. This ensures a greater efficiency of heat transfer, which together with better efficiency is one of the most important advantages of systems with forced circulation. The disadvantages of the active system are higher purchase costs, the complexity of the whole system, and less reliability regarding the potential failure of a pump.

Passive systems are not dependent on the pumps, nor on an external source of power, as the circulation of a thermal transfer medium in this system uses gravity force between a collector and a boiler. The liquid flows thanks to different densities between the heated and cooled heat transfer fluid. For this reason it is necessary to place the solar tank above the collectors. One of the disadvantages of a passive system is its worse regulation of flow and less efficiency. On the contrary the advantages of such a solar system with the self-circulation are its lower purchase costs, its simplicity, and as it has already been mentioned at the beginning, its independence to any external source of energy.

Division according to the number of lines

According to the number of lines we divide solar systems into open and closed systems. Open solar systems draw hot service water directly from solar collectors, i.e. they are using one circuit. Closed solar systems draw hot service water from a heat exchanger and this draws it from solar collectors, i.e. they are using two circuits.

Single circuit systems preheat the hot service water directly from the collectors and thus they work without a heat exchanger. The advantages of these systems are their very high efficiency of heat transfer, lower purchase costs, and simple installation. On the other hand, you can use the system only for seasonal operation, as there is the danger of different bacteria and algae developing. In addition, there is the danger of water freezing at low ambient temperatures. Thanks to the use of untreated tap water there is the danger of plugging and corrosion in the entire system. Therefore, it is used exclusively in the easiest plants for seasonal water heating.

Dual circuit systems are working with a heat exchanger and two independent circuits. The first of the two circuits distributes the heat transfer fluid to the collectors and to the heat exchanger, the second then takes the heat from the heat exchanger and distributes it to the point of consumption. The primary circuit has an antifreeze treatment to cope with low temperatures. One of the great strengths of these two circuit systems is the possibility to use them all year round. The disadvantage for these systems are losses of heat in the heat exchanger, and higher purchase costs.

Division according to their operating time

According to the time of operation solar systems can be divided into systems with an all year application and into systems for seasonal use only. They differ from each other as to the used materials and fluid contained, which will be indicated in the following text.

Solar collectors for the all year operation deliver power throughout the whole year, even in the cooler period of the year. The hydraulic section of the primary solar circuit is filled with an antifreeze liquid, the entire system is firmly embedded and operates in most cases on the principle of forced circulation. Its advantages are high effectiveness, long service life, and its resistance to high temperatures in summer. Automatic operation of the whole system is in the charge of a differential temperature control, thanks to which permanent operating maintenance is not required.

Solar systems for seasonal operation are not usually fitted with any thermal insulation and glazing, and therefore they can fulfil its function only in the summer time. Its absorbers are made of plastic and have lower absorption efficiency and cannot resist too high temperatures. This system directly heats up water that is consumed, e.g. hot service water, or water in a pool. In winter the whole system is drained out and it is recommended to remove it completely from the point of use. It works on the principle of self-gravity, if it is permitted by height ratios, or there must be installed some differential temperature control.

Division according to the flow rate of medium

High-Flow system (HF) is fitted with a common boiler, which heats up slowly, so it takes longer to reach desired temperatures. This is due to the fact that the heat transfer liquid in collectors heats during one flow just by some 8 to 12 °C at full sunlight. The flow rate is dependent on the regulation setting and the same pressure of pump. The fact that there are small increases in temperature of the fluid in the collectors, makes it possible to say that their efficiency is utilised at its maximum. Smaller solar systems are nowadays controlled, in an overwhelming majority, by this technology.

Low-Flow systems (LF) work with a greatly reduced flow in the solar system. This leads to the fact that the heat transfer liquid can be heated in a very short term by some 50 ºC. Rapid heating of the liquid is an advantage that, to fully utilized the LF system, must be equipped with a tank with charging in layers. For this system the pipes are made with smaller diameters, which leads to less heat losses, and therefore to price savings. Thanks to the slow circulation of the heat transfer fluid the system does not need a pump with a great output performance. The temperature of fluid at the inlet of collectors is useful to be kept at lowest temperatures, to avoid worse efficiency due to the fact that the collector operates at high temperatures. Large systems are now without exception designed for operation in the LF system.

Matched-Flow system (MF) seeks to combine the advantages of both these solar systems. LF technology can provide enough heat, and the HF can bring optimal yield. The flow of the heat transfer liquid in the so far implemented systems is between 10 – 40 $l.m^{-2}$ $hours^{-1}$.

Drain-Back system (DB) is designed with an atypical construction. During the time with an insufficient solar radiation, when the heat transfer fluid is not heated at a sufficient temperature, the entire liquid from this system is pumped into a reservoir, before the pumps are switched on and start to distribute the liquid back to the system. The heat transfer liquid in this case can be represented by regular water. The fluid cannot reach its boiling point, as the pumps scan its temperature and can switch off automatically when endangered. For this reason they are considered to be one of the safest types of these solar systems.

Σ A summary of the Chapter 6 concepts

Solar engineering is one of the industries that has shown recently a rapid growth in production. It is not a new industry, as it could appear, but it has been developing for more than a half of the century.

After the low utilization of solar energy in 1980s the solar treatment of hot water preparation began to gain its significance. During the summer and winter months hot water is required for the whole household, and during the summer time there is a lot of solar energy available. Thus it is very convenient to use this heat from the Sun to prepare hot water. In recent years we have experienced a rapid growth of solar technologies, supported by poorly considered legislative measures in the Czech Republic. Solar heating at lows level was employed in households and also in our industry. A great share of solar systems is installed in houses for one or two families, where about 80% of energy is used for the heating and preparation of hot service water.

In our climate it is possible to recommend the solar system mainly for the above mentioned heating of service water or for swimming pools, but the energy gained from the Sun has also another application. It can be also used to heat buildings during the winter time, even though this method cannot be fully applied in the climatic zone in which the Czech Republic is located, as we do not have a sufficient amount of solar radiation during winter. One exception here are costly systems with a long time accumulation of heat gained during the summer months. A broad sphere of activity has solar energy in so-called passive solar heating, in which the building itself catches the solar radiation, or for hybrid systems with an energetic facade.

Questions to Chapter 6

1. Define solar radiation as a source of energy.
2. What principle does a photovoltaic cell works on?
3. What function has the absorber in a solar collector?
4. Describe a flat liquid collector.
5. Describe a tube vacuum collector.
6. According to which criteria we can divide the solar collectors?

The literature that can draw you to further studies

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5 Air conditioning and ventilation

Time for study 5 hours

Objective After studying this paragraph you will be able to

- define the term ventilation of buildings
- describe the climatic factors
- characterize the types of air conditioning systems

Lecture

With ventilation and air conditioning we can improve air pollution and the thermal condition in dwellings, public and industrial buildings, the means of transport, technological areas and farm houses. These areas are burdened with pollutants (gasses, vapours, solid and liquid particles) and thermal energy from various sources (persons, technological devices, housed animals, biological processes in agriculture, the sources of pollution in the exterior surroundings, the outer climate etc.)

5.1 Ventilation

The ventilation of houses with a low-energy demand is necessary as to the breathing of a human, but also to take the moisture, caused by humans (breathing, sweating) and by their activities (cooking, washing, drying, bathing) out of the building, and at the same time to get rid of other harmful substances. Producers of these harmful substances can be not only humans themselves, but also to a large extent also furniture, flooring, cleaning solutions, paints, etc.

Among the most significant harmful substances belong carbon dioxide, water vapours, odours, poisonous gasses and vapours (nitrogen, hydrocarbon, and aldehyde). Furthermore, there are micro-organisms - bacteria, viruses, spore of fungi, mites. Another significant part is represented by radioactive substances (from the subsoil) and carcinogenic fibrous material (e.g. asbestos).

A general principle that good quality inner air is ensured lies in the following three areas:

- the reduction or elimination of pollutants within the interior of buildings, or eventually preventing them to be further released into this interior,
- the transfer of localized emissions using controlled drawing-off system,
- the sufficient dilution of pollutants in the air replacing the air (ventilation), sometimes in combination with some filtration of the air inlet.

Natural ventilation

In traditional buildings the exchange of air was always ensured in a natural way via infiltration and exfiltration. Infiltration is a spontaneous ingress of fresh air inside buildings and exfiltration is a spontaneous penetration of used air directly outside of this building. For the proper functioning of natural ventilation, due to the leakage of windows, doors, etc., there must be a pressure difference between the internal and external environment.

Airtightness of the perimeter constructions and the low joint air permeability of airtight windows have the effect of imperfecting "spontaneous breathing" in new and renovated buildings.

This will not ensure its necessity to exchange the air. The result of insufficient moisture removal is its condensation and formation of mould on critical points, and thus the quality of air is not sufficient in the other indicators as well.

To comply with the hygienic conditions users of premises keep opening their windows, which causes uncontrolled ventilation with a great need for heat. Incoming fresh air is heated by a heater. Frequent ventilation thus causes an increase in the consumption of heat energy. The use of the fourth position of a handle, so-called micro-ventilation for a window wing, is also not an appropriate one, as it increases the noise from the external environment and also a systematic excessive cooling in the period with the outside temperatures below the freezing point.

The compromise between the energy savings and the requirements for the exchange of air is in use of ventilation elements, accompanied by the window frames or elements located in the boxes of external blinds. These elements must be easily closable and they must be also equipped with efficient silencers, but at the same time the condition of pressure difference existence between the internal and external air must be observed.

Forced ventilation

The priority of forced ventilation is to ensure a high quality internal environment in low-energy houses. These systems can ensure the exchange of air for one or several rooms, or for the entire construction.

To save energy air in a forced ventilation system the following reasons occur:

- the quantity of air is relatively well dosed, a user has no reason to ventilate using a permanently ajar window, etc.
- for systems with a controlled air supply it is likely to use the heat from the exhaust air, for energy-efficient heat recovery,
- the system can be combined with other elements, e.g. natural heat exchangers.

a) Ventilation with the forced air conduction

Air supply from the outer area is solved using the elements in a perimeter skin (the frame structure of windows, roller shutters boxes, or they are integrated in the peripheral walls), which shall be added to the heating and air conditioning devices. This serves to conduct exhaust waste air from the interior. The whole system has two disadvantages:

- the air entering the interior has the temperature of the outside air and only in a very accurate design it is possible to achieve a situation where the temperature distribution of air in a room is correct,
- the quantity of air is adjustable, but it is not possible to use the heat recovered from the exhaust air.

b) Ventilation with the central air inlet and outlet

The central systems with a forced air inlet and outlet allows many benefits, whose utilization leads to energy savings, and will positively affect a desirable microclimate construction. Induction units of the heated fresh air shall be placed into each room, finding appropriate places according to their size and purpose. Among this system advantages belong:

- the regulation of the air amount concerning the immediate needs of users (based on the monitoring of moisture sensors, odours, CO_2 , or motion sensors), the exchange of air during his/her absence, under unfavourable pressure (during inversion) the conduction of the most polluted air,
- filtration - the absence of dust and protection of fresh air against pollen, in which the fabric or electrostatic filters trap the dust particles of 1 - 3 microns with an efficiency of 95 - 99 %,

- heat recovery from the used air with an efficiency of 60 – 80 %, the use of heat gains (from the solar radiation, persons, lighting, equipment, etc.),
- the management of maximum moisture in an interior, minimizing the temperature variation in this interior.

Fresh air is mostly drawn in through a rainwater shutter, or at the non-sunlit facade of a house; in a dense urban area above the roofs of the building, or from another suitable place.

Decentralised units with the air inlet and outlet

This is a system where every room in the building is equipped with its own small ventilation unit. There is the possibility of individually controlling the quantity of replaced air based on the user's requirements, or in automatic operation by monitoring the humidity, or eventually the temperature. The construction must be equipped with a suitable system for heating, which in the winter period covers the heat loss of transmission and a part of heat loss caused by ventilation. Using recuperation to warm the outdoor inlet air for ventilation brings energy savings. The disadvantage of this system is the increased level of noise in residential rooms.

Ventilation with a heat recovery unit

The energy consumption to heat the ventilation air in regular houses is about 30 % of the total consumption. The better the house is insulated, the higher this ratio. The main reason for the power ventilation is the possibility of using heat conducted from the exhaust air. In a recuperation exchanger the heat from the polluted air, which is conducted outside a building, passes its heat to the fresh air that is fed in from the external environment. In the winter the fresh air is heated, in the summer it is cooled. The air inside the building may be also filtered, or eventually humidified, which will reduce dust and increase comfort in such a home.

A more efficient distribution of heat between rooms is dealt with by the circulation system. In the period of low outside temperatures this fresh air and part of the heated air from the interior is brought into the ventilation unit, from which it is transported into individual rooms. Air from the places with pollutant emissions (WC, bathroom) after passing through the heat exchanger leave the building immediately (here the circulation is prohibited), the exact volume of fresh air and recirculating air from other rooms is cleaned regularly when passing through the exchange filters of the heating and air conditioning unit. A system of this kind is shown in the figure.

5.2 Air conditioning and the cooling of buildings

Air conditioning system is a device in which the air is adjusted - filtered, cooled/heated, dehumidified, or humidified. An air conditioning unit works on the same principle as the refrigeration equipment, i.e. on the basis of the exchanges and transfers of energy. This is a system that ensures cooling of internal environment in the period of increased thermal load.

The principle is the same as the system of a refrigerator. For its operation it needs a source of cold - cool transfer substance (air, water, or coolant itself). It is a compressor cooling system based on changes in the state of a refrigerant. Into the evaporator the circulating air flows from the room, and there the refrigerant evaporates. This is a change in the state of a coolant from a liquid to a gaseous state, which cools the ribbing of the evaporator. The evaporation takes away the heat from the air-conditioned room - circulating air is cooled, but also filtered. The compressor will draw in the gaseous refrigerant, which is compressed and its temperature and pressure increases. In the outdoor unit (in the condenser) a change in the refrigerant state occurs again (refrigerant fluid liquidizes), at which the heat from the air-conditioned room is conducted via the condenser to the surrounding, outer area (Fig. 4).

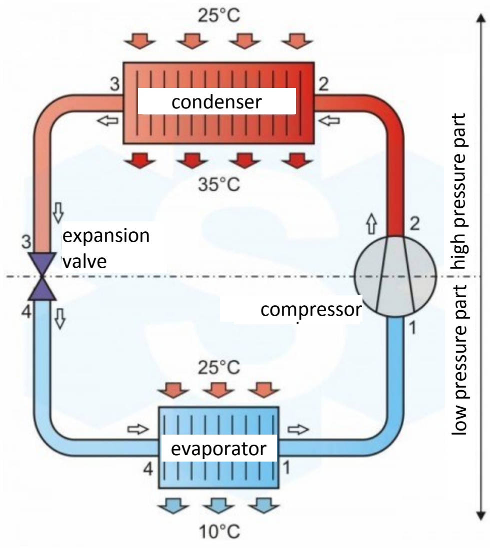

Fig. 4 Scheme of air conditioning units [5]

Mobile air conditioning equipment

Mobile air conditioning system, as well as the traditional fixed air conditioning system, essentially no longer cools the air, but only receives the heat from the area where it is undesirable and conducts it outside the air-conditioned room.

The refrigerant in the air conditioning system shall take the heat from the intake air, which in turn returns in the condenser, and the heat is blown off outside the air-conditioned room. Around the condenser and compressor that compresses there is even more heat and the refrigerant blows air, using a powerful fan. For its activity, however, this system inevitably needs the heat outlet into the exterior environment. To do this, a telescopic plastic hose is used, for which it is necessary to prepare the output through the wall or a window. The condensate is collected into a condensate container, which can be removed and emptied. The cooling power is around 5 kW.

Window air conditioning device

A window air conditioning unit is a device that is placed in the frame structure (into a wall or a window), so that one side is facing the outside environment, and the other the interior. Indoor and outdoor fans are driven by one motor. They cool the air inside and preheat the one from outside. The advantage of window air-conditioning is its undemanding installation.

Split systems

A split air conditioning system is a divided system, which has a condensate unit placed outdoor and an evaporator unit in the air-conditioned area. As a rule it only works with the circulation of air inside and does not provide any ventilation. The interior units are split and placed in a wall, parapet, under the ceiling, in a coffered, channel or column design. The exterior part with the compressor, condenser, expansion valve, and fan is due to the elimination of noise placed on the roof, terrace, etc.

MultiSplit is a system where one outdoor unit is connected to multiple internal units.

Cooling ceilings (sides, floors)

This is a system of pipe networks or capillary mats, through which the cooling water flows in a laminar way. These mats are placed directly in the construction of a building (under plaster, below the metal structure).

Cooling ceilings can be divided into open or closed. Open ones are characterised by their holes or airways that allow air to flow and have a higher proportion of convection. A cooling system for closed ceilings uses the principle of inbuilt piping network in floors or walls. They have a higher proportion of radiant transfer for cold and a lower performance, which restricts the air flow. In both systems this temperature of cooling medium must be set so as to avoid moistening with dew.

A summary of the Chapter 8 concepts

Air conditioning (commonly referred to as AC) is a device to treat the air in the whole buildings or in individual rooms and in means of transport.

It draws air from outside (at minimum 15 % of fresh air must be conducted) that it filters, adjusts the temperature and humidity to the desired values and by using fans it transports it to the appropriate places, or eventually large air conditioning equipment uses the circulating water for the removal of heat. The air conditioning system automatically keeps permanent conditions (temperature in particular) regardless of the external environment.

Air conditioning equipment for the creation of the thermal comfort in a room uses several principles of physics, namely - compression (compressed gases), the condensation (the liquefaction of gases) and evaporation.

In the first stage the vapours of cooling substances are reintroduced to the compressor , where they are compressed (and as the result of the compression they are heated). Hot air is blown by a fan outside. Then the cooling medium with a high temperature and pressure is conducted to the exchanger - condenser, where it is cooled (refrigerant condenses). Released waste heat is conducted by a fan outside. The liquid under pressure is then transported through the tube or via the expansion valve to the exchanger - the evaporator (places with lower pressure and higher temperature), where it expands and thus it cools down sharply. The liquid will start to evaporate, warm up, and thus it removes the heat from the evaporator. The evaporator is cooled. A fan that is located around the evaporator serves for the distribution of cold air into the room. Then the gaseous refrigerant enters the compressor and the cycle is repeated.

Questions to Chapter 8

1. Why is the regular ventilation of the building important?
2. What types of ventilation do you know?
3. What is the principle of ventilation with a heat recovery system?
4. Describe the principle of air conditioning.
5. What types of air-conditioning equipment do you know?

The literature that can draw you to further studies

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