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Management of energy efficiency in buildings

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1. Introduction

Environmental concern and increasing amount of pollutants from human activities are serious topics nowadays. Air pollutants, among other pollutants, contribute to climate change, natural disasters, global and local ecosystems and well-being of humans, as well as economy and social issues. It is proven that production and use of energy is one of the major contributors to these problems. At the same time, the consumption and prices of electricity, fuels and heating are increasing all over the world, putting even more pressure on these problems worldwide. In this battle, energy efficiency in buildings can be seen as one of the fastest and most effective tools towards sustainable tomorrow.

Energy efficient buildings consume less heating, cooling and electrical energy, besides fuel consumption. At the same time, greenhouse gas emissions and other emissions from energy production and use can be reduced effectively. Energy efficient buildings often improve indoor air quality, adding the well-being of occupants. While saving energy, economic advantages take also place. Furthermore, energy efficient buildings tend to have better value on markets.

There is a huge work to be done in the whole building sector in order to reduce energy consumption and improve the efficiency and indoor air quality in buildings. Legislation will push us towards more and more energy saving buildings, and tighten regulations will take place in future. Thus, energy efficiency in buildings is very topical issue today.

Today, buildings consume more than 40 % of energy in EU. Thus, building sector is one of the largest contributors to climate change as well as other environmental problems. Not only the operation of the building when being occupied but also the construction of buildings requires energy. Hence, improvement in energy efficiency in buildings is one of the main targets fighting against global change. (Martinkauppi, 2010)

In colder climates, heating can form almost the half of the total energy consumption of buildings. Heating is mainly required to keep up healthy and comfortable indoor conditions as well as producing warm water for showers, dishwashers and so on. Heating is produced by separate heating systems (e.g. furnace and electric radiator), solar radiation, occupants and heat losses from appliances. During warmer periods, cooling energy is needed to cool down the building interior in order to maintain adequate building climate. Especially in southern countries, cooling energy can form the biggest portion of the energy consumption in buildings. (Bauer;Mösle;& Schwarz, 2010)

Manufacturing of construction materials and both construction and operation of buildings require fuels. For instance, heating systems may require wood, oil or gas. It must be also considered that district heating and electricity is often generated by using different fuels that include, in the worst case, fossil fuels, such as coal, oil and natural gas. One should keep this in mind when considering efficient and sustainable buildings, especially because fuels are releasing substantial amount of air pollutants and other compound during its whole life cycle. (Martinkauppi, 2010)

One essential part of the energy consumption of buildings is electricity. Electricity is needed in some heating systems in order to produce heat, run control systems, but also in domestic appliances, lighting and so on. Lighting is also consuming substantial amount of electricity, especially during darker periods and in municipal buildings, such as offices. Most of our daily routines, like cooking, watching TV and charging batteries require electricity. Nowadays, electricity consumption in the building sector can form almost 50 % of the total electricity consumption. It must be also taken into account that production of electricity for energy efficient and green buildings should be done by using renewable resources. (Bauer;Mösle;& Schwarz, 2010)

Ventilation and air conditioning requires also energy in order to operate and provide adequate indoor air quality (IAQ) to building interiors. Air conditioning provides usually cooling or heating energy and distributes it with an appropriate fresh air flow. In addition, humidity and contaminant levels can be controlled by ventilation systems. (Kreider, 2001)

In colder climates, lot of energy is needed during winter. Thus, energy consumption reaches its peak in winter time when substantial amounts of heat and electricity is needed because of darkness and coldness. Daily peaks in households occur during mornings and evenings, when people are active (and generally at home). In offices, peak hours usually occur during day time, when people are working and both lighting and ventilation is needed. (Energypriorities, 2012)

The purpose of this work is to give general guidelines and introduce technical tools in order to achieve the goal of an energy efficient building. The concept of indoor air quality is also introduced. We will also take a brief look into renewable energy sources in buildings. Emphasis is on buildings in Northern areas, where the climate is cold and relatively dry.

2. Components of energy efficient buildings

Energy efficient building is a sum of many actions. As a result, an energy efficient building, besides saving energy, should provide adequate indoor air quality, taking occupancy requirements into consideration. In many cases, to maximize advantages, an optimum between energy efficient technologies and solutions must be found. One solution, for example a big south oriented window can maximize the amount of daylight and bring heat to interiors, but can also increase heat loss during winter time. Figure 1 below illustrates the issues to be considered in an energy efficient building. In later chapters, we will discuss more about these issues. One must also remember that renewable energy sources are usually a part on an energy efficient building.

Figure 1. *General issues to consider in energy efficient buildings*

3. Building design and building envelope

3.1 Location

As we know, climate conditions vary substantially in different regions on the Earth, and hence the location plays an important role when designing energy efficient buildings and is always involved in to the design process of new houses. In building design, it is important to take into account regional and local climatic conditions as well as micro climate. In addition, e.g. topography, landscape, surrounding buildings and vegetation are important factors defining the site for the building. (CIBSE, 2004)

The main climatic conditions to be considered at the building site are outside temperature and humidity levels, local wind conditions, the amount of solar radiation and both seasonal and daily fluctuations in weather. For instance, the decision of insulation levels is mainly defined by outside temperature. The climatic conditions are also affecting to the decision of HVAC systems. Moreover, the topography, vegetation and the existence of surrounding buildings can contribute to the local wind conditions, solar radiation, shading and air pollution. The utilization of local resources can bring many advantages such as passive use of solar energy or generating electricity from the wind. (Bauer;Mösle;& Schwarz, 2010)

3.2 Architecture

Architectural design is an essential tool towards energy efficient buildings. First of all, the shape of the building is affecting to energy efficiency in many ways. Compact shape in buildings leads to decreased heat losses through building envelope and decreased exposure for weather conditions due to the decreased ratio of building surface area and floor area, as presented in figure 2. Especially in colder climates, compact shape saves heat energy significantly during winter and can offer better solutions also for organizing HVAC systems (less ducts etc.). (CIBSE, 2004) (Bauer;Mösle;& Schwarz, 2010)

Figure 2*. More compact shape (a) is usually more energy efficient choice than more complex shape (b)*

Orientation of building is also a part of the building design. The design should allow the incoming solar radiation from south (free energy), bringing both heat and light, resulting decreased amount of artificial lighting energy and heating energy during colder periods. Thus, south oriented windows, having bigger glaze area, can be very beneficial. North facing windows contribute often to heat losses and are exposed to cold winds, so adequate insulation and size of these windows play very important role. On the other hand, incoming solar radiation can heat up the building considerably, especially during summer. Thus, the design should take into account passive methods in order to prevent excess heating of the building and thus minimize the use of cooling energy. Such passive methods include e.g. eaves, sun blinds and vegetation. Deciduous vegetation can be utilized to maximize solar gains during winter, while minimizing it during summer. (Bauer;Mösle;& Schwarz, 2010) (Motiva, Hyvä talo. Rakennetaan energiatehokas pientalo., 2008)

Besides the orientation of the windows, the amount and size of the windows have to be optimized during the design because windows conduct substantial amount of heat, but also allow solar radiation to enter the building, heating the building during colder periods and increasing the amount of daylight. In many countries, regulations can limit the size and amount of glazed areas. Nevertheless, the size of windows must be optimized. It is also more energy efficient to have one bigger window than many small ones in the same wall. (Motiva, Hyvä talo. Rakennetaan energiatehokas pientalo., 2008) (CIBSE, 2004)

Generally, the northern facade of the building is exposed mostly to cold winds and rain, for instance. Due to this, the building should be covered and sheltered by using e.g. vegetation and other buildings, or by placing the building in south facing hill, if possible. In addition, placements of rooms can also be an issue in energy efficient buildings. As a rule, spaces requiring less heating (bedrooms, storages etc.) should be oriented to north, while areas requiring more heating (living rooms, offices) should be oriented to south. (Bauer;Mösle;& Schwarz, 2010)

Electricity consumption in buildings can be reduced by designing carefully the placement and amount of artificial lights, while maximizing the amount of daylight. Artificial lighting should be used only when there is no enough daylight available. In addition, the design should consider the possibility to utilize reflected daylight from light surfaces. (Bauer;Mösle;& Schwarz, 2010)

3.3 Building envelope

Building envelope forms the boundaries between building interiors and exteriors. Usually, the building envelope consists of walls, floor, roof, windows and doors. Building structure can also consist of e.g. atrias. For energy efficiency in buildings, the envelope plays an important role e.g. for heat losses and moisture transfer. Building envelope inside the building is in touch with inside conditions (temperature, moisture, pressure etc.) and outside the envelope is exposed to outside conditions (solar radiation, wind, rain, low temperature etc.), so identifying these factors is essential to take in to account when designing energy an efficient building envelope. When it comes to heat losses, one has to remember that heat can be lost through convection and radiation, not only conduction. (Hagentoft, 2001)

At first, heat losses through building envelope can be prevented by using adequate insulation, where the most important factors are U-value of building structure, the total area of building envelope and temperature differences between building interiors and exteriors. Secondly, air leakages through building envelope can contribute significantly to heat losses and indoor air quality of the building.

Insulation

The insulation of building envelope and structures is necessary in order to avoid heat loss and excessive consumption of heating energy during colder periods, besides transfer of heat in to the building during cooling period. Thus, the thermal resistance of building envelope should be maximized. Adequate insulation of building structures can also decrease draught, add thermal comfort and improve IAQ in buildings. Especially in colder climates, heat tends to transfer from building interiors to building exteriors due to temperature differences, so insulation is mandatory. (Seppänen, Rakennusten lämmitys, 2001)

Walls, roof and floor

Walls, roof and floor form the largest area of building envelope. When designing the insulation for building walls and roof, indoor and outdoor temperatures must be considered. In the case of floor, the heat conductivity of soil must be taken into account (heat conductivity varies between different soil types). Heat conductivity through the floor structure is usually biggest in corner areas because distance between floor and outside air is smallest. (Turner & Doty, 2007)

Heat transfer through building envelope is greatly affected by the thickness and physical properties of insulation materials. Usually, the increasing porosity in materials increases the amount of air in the material (heat conductivity of air is 0,026 W/mK), which leads to decreased heat conductivity. (Seppänen, Rakennusten lämmitys, 2001)

Water content in materials increases the heat transfer substantially. First of all, water conducts heat very efficiently and secondly, water conveys heat in the material. This is especially true with porous materials. In colder climate, humidity levels in building interiors are often higher than outside. Thus, vapor barrier is essential to install. Generally, vapor barrier is installed as near as warm building surface as possible. (Binggeli, 2003)

Other important factors affecting the heat transfer in insulators are temperature and material density. Moreover, some gas with high heat resistance can be added in porous materials in order to increase the heat resistance. (Seppänen, Rakennusten lämmitys, 2001)

So, different insulation materials have different values of heat conductivity. Common insulation materials in buildings include mineral wood, polystyrene, polyurethane, light concrete and wood fiber slabs. Factors affecting the decision between insulate materials is done by considering e.g. heat conductivity, price, weight, chemical and mechanical permanence, safety, air tightness, humidity resistance and fire resistance. Some general values of heat conductivity of insulators are presented in table 1. (Seppänen & Seppänen, Rakennusten sisäilmasto ja LVI-tekniikka., 2004)

Table 1. *Heat conductivity of some insulation materials*

Material	λ (W/mK)
Mineral wool	0,041 - 0,045
Polystyrene	0,041 - 0,055
Polyurethane	0,030
Concrete	1,7
Brick	0,6 - 0,7
Wood (pine, spruce)	0,12

Insulation should be evenly distributed in building envelope. In many cases, changes in the building structure or change in building composition can lead to increased local heat conductivity. These kinds of areas are called thermal bridges. Such places include e.g. corners, metal studs and structure beams. Thermal bridges should be avoided because of increased heat conductivity but also because of decreased local surface temperature. Decreased surface temperature of the structure due to better heat conductivity can contribute to the condensation of moisture, leading to several problems (e.g. formation of mold and increased draught). Thus, special attention in insulating these areas must be paid. (Turner & Doty, 2007) (Seppänen & Seppänen, Rakennusten sisäilmasto ja LVI-tekniikka., 2004)

Windows

The amount, size and properties of windows are affecting greatly to heat losses in buildings. Thus, careful design of windows must be done. First of all, heat losses in windows can be decreased by increasing the thickness of the window, installing more than one glazed layers and letting air gaps between the layers (or some insulation gas). Moreover, the use of shutters and blind shades affect to the heat conductivity of windows. It is also considerable that window frames and other structures can conduct substantial amount of heat, especially in older buildings. (Seppänen & Seppänen, Rakennusten sisäilmasto ja LVI-tekniikka., 2004)

Energy efficient windows should also have a coating, which allows the entering of short-wave solar radiation in to the building. In proportion, glazed area should be designed so that it absorbs and reflects long wave radiation from building interiors, decreasing the overall heat loss through windows. Heat loss through window frames must be also taken into account. (Turner & Doty, 2007)

Doors

Doors are also included to building envelope, and thus one have to take heat losses through door slab, door window and door frames into account when defining the total heat loss through building envelope. (Seppänen, Rakennusten lämmitys, 2001)

In Finland, the insulation in buildings is well regulated. There are regulations for upper limits in different parts of buildings. In warm spaces (T ≥ 17 °C), U-value in windows is not allowed to exceed the value of 1,8 W/m^2K and 0,6 W/m^2K in other structures. For colder space (T ≤17 °C) the upper value for U-value in windows is 2,8 W/m^2K. Usually, insulation in Finnish buildings is much more energy efficient, especially in new buildings. (Ympäristöministeriö, Rakennusten lämmöneristys, 2010)

Air tightness

Air tightness (infiltration) in building describes the movement of air in the building structures. Air can flow from the building interiors to outside and the other way around, depending on the existing pressure and temperature between inside and outside air. Other factors affecting to air tightness (and air leakage coefficient q, describing air tightness) are e.g. the properties of building envelope materials and wind conditions. Cracks in building materials contribute the movement of air through building structure. (Bauer;Mösle;& Schwarz, 2010)

Air leakages from building interiors contribute to heat losses through building envelope. In cooling season, warm air can flow from building exteriors to interiors, leading to increasing requirement of cooling energy. Moreover, the air moving through building envelope can also lead problems with moisture and may transfer contaminants to building interiors, so it is important to seal building structures properly. (Turner & Doty, 2007)

As said before, air tight building decreases heat losses and usually contributes to better IAQ. However, when the building is very air tight and insulated well, some problems with moisture can occur in the critical areas of the building (e.g. on thermal bridges). Due to this, and adequate ventilation system (usually heat recovery system) is recommended in order to remove excess moisture and avoid problems with e.g. mold. Ventilation system also maintains slightly smaller pressure in building interiors than outside, avoiding the driving of moisture in to structures, but still preventing the excess movement of air from outside to inside. It is also necessary to install an air barrier to block out excess movement of unwanted air. In Finland, the air leakage coefficient can have the value of 4 m^3/m^2h at maximum. (Ympäristöministeriö, Rakennusten energiatehokkuus, 2012)

Thermal weight and special insulation materials

Building envelope can store heat from outside (free energy) and inside. By controlling e.g. the mass and heat capacity of the building structure, we can affect to thermal weight of the building. For example thermally "heavy" building structure can store free energy (e.g. solar energy) during warm summer day and release it in building interiors during colder night. Thus, savings in heat energy consumption e.g. during nights can be obtained, besides cooling energy during summer. Appropriate materials for thermally heavy building envelope include e.g. concrete, brick, stone and tile. (Turner & Doty, 2007)

Some light transmitting insulation materials can be used in order to increase the amount of absorbed heat. In colder climates, these kinds of materials are more likely used in outer walls, where solar radiation transmit the material, absorbing then to thermally heavy material. In addition, there are also insulation materials that can allow a certain amount of air leakage. In this case, the structure exchanges heat between conducting heat and heat carried by the leakage air. By doing this, the heat flux through inner or outer envelope structures can be controlled. Some phase change materials are also available. (Seppänen, Rakennusten lämmitys, 2001)

5. Heating, ventilation and air conditioning

The main purpose of heating, ventilation and air conditioning system (HVAC-system) is to provide adequate indoor conditions for occupants. Such conditions include e.g. maintaining appropriate temperature (cooling and heating) and humidity levels, removal of harmful compounds and distribution of fresh air. In order to maintain these basic needs in the building, energy must be used. One must keep in mind that energy efficient HVAC system can consume less energy, while providing better indoor air quality, improving the quality of life. More information about indoor air quality can be found from chapter “Occupant requirements and indoor air”. In addition, water heating is discussed in chapter seven.

In many cases, HVAC systems can be distinguished to active or passive systems. Active systems include all the “technical” or mechanical solutions and passive systems include non-mechanical solutions. Furthermore, HVAC systems can be distinguished to centralized and decentralized units.

4.1 Heating

Heating is necessity for buildings in order to maintain appropriate temperature in building interiors. Heating can form a major section of energy consumption in building sector and it is also contributing substantially to emissions from buildings. Nowadays a large proportion of heat is produced by using fossil fuels (such as natural gas, charcoal and oil) in the building (or as a district heat, which should be replaced by renewable energy sources). This chapter will take brief look into the heat production and distribution systems and energy efficient solutions, while chapter 7 discusses more about renewable energy sources in building applications.

The total heat demand of the building is determined by heat losses through building envelope, heat conduction to the soil, heating demand of ventilation system, heating demand of air leakages and heating demand of water. When evaluating the whole heat production of the building, heat loads from occupants, electric devices and lighting must be taken into account. Especially in densely occupied buildings, heating load from humans can be relatively big. This free heat should be utilized as efficiently as possible. (Seppänen, Rakennusten lämmitys, 2001)

Nowadays the most of heat for buildings is produced by district heating facilities. Compared to boilers in buildings, these kind of bigger heat production facilities have some advantages such as better efficiency and controllability of the equipment and cheaper raw-material costs. Moreover, air pollution is not necessarily generated in the building area. Unfortunately, district heating facilities use quite much different fossil fuels, such as coal, natural gas, oil and peat. (Seppänen & Seppänen, Rakennusten sisäilmasto ja LVI-tekniikka., 2004)

Different kinds of boilers, furnaces and fireplaces are commonly used in buildings in order to produce heat. Due to high heating values and low volume requirement of oil, coal and natural gas, these fuels are often used. Still, besides the environmental impact, the prices of fossil fuels are increasing, which are restricting the use of these fuels. (Turner & Doty, 2007)

Nowadays more preferable fuels from environmental point of view are wood, biogas, pellets and other biofuels. Disadvantages of these fuels are usually related to higher prices, lower heating values and bigger volume requirements. However, these combustion based fuels can release enough heat for building in many cases. To make the heating system more energy efficient, there are systems available that can recover heat from flue gases and transfer the heat for example to water. In addition, the use of pellets can offer viable choice for replacing wood or fossil fuels due to their high energy density and low price, storage volume and low emissions. (Hirsilinna, 2012)

Furnaces and fireplaces can act as thermally heavy heat storage, heating surrounding air through convection and radiation. On the other hand, heat from the heat source can be used in order to heat up water, which can be further distributed to heat releasing systems, such as radiators. It is possible to use air or water as a distribution media, but water is still the most common media used due to its great heat transfer properties. (Seppänen & Seppänen, Rakennusten sisäilmasto ja LVI-tekniikka., 2004)

Warm water is commonly released by different kind of radiators and convectors. A common radiator type is a panel radiator, which are usually placed under a window to avoid draught. However, in many cases more energy efficient solution can be realized by using floor distribution system, which has bigger heat transfer area and removes the problem of cold floor surfaces. Distribution system can be also installed in ceiling. Still, furniture and carpets can block heat effectively from floor radiant system, decreasing the efficiency of the floor heating system. (Seppänen, Rakennusten lämmitys, 2001)

Space heating can be produced also by using electricity. Heat can be generated in a central system by using electricity, and produced heat can be further transferred to e.g. water. It is also possible to have electric resistance heating in e.g. radiators. This kind of system responds quickly to temperature changes in rooms. In addition, lower price electricity during night time can be used in electricity heating applications by storing the produced heat into heat storage. Nevertheless, electric heating is not the most efficient and cheapest way of heat production. (Turner & Doty, 2007)

Nowadays there are more sustainable and efficient systems for heat production in buildings. Heat pumps can produce heat with low electricity use reliably over the year. Other systems include such as active solar thermal collectors and bio mass based heat resources. These active systems are discussed more in chapter 7. (Awbi, 2008)

Utilization of solar irradiation passively is common in buildings in order to add the amount of free heating energy. Solar radiation can be utilized passively in many ways. At first, direct gain heating is one option, where windows are used to allow the incoming short wave irradiation to enter the room, while reflecting back most of the long wave radiation (heat). Thus, heat can be produced directly through windows when it is sunny weather. Usually windows are oriented to south in order to maximize heat gains. There are many factors affecting to the amount of gained heat, such as window area, heat losses through window and absorptance of the room surfaces. Excess heat gains can be prevented by installing solar shading system. Still, because of heat losses during winter, window size should be optimized in order to maximize direct solar gains and minimize heat conduction through window. (Duffie & Beckman, 2006)

Solar radiation can be used passively by absorbing incoming radiation to building structures. Collector-storage walls or solar walls can absorb solar radiation and transfer the absorbed heat in to rooms by radiation and convection and radiation. In many cases, these kinds of structures have a special insulation material, which allows the incoming radiation to enter the absorbing structure. Between these structures there can be a glaze and the gap between glazing and the absorbing structure can be vented or unvented. Moreover, if vented, ventilation can be forced or natural. Heated air can be distributed to rooms which are colder (shadow side rooms). However, thermally heavy building structure can store heat and release it during e.g. nights when it is colder. Steep and dark colored roof structure can absorb bigger amounts of solar energy than light colored gentle roof slope. (Duffie & Beckman, 2006)

There are also window structures that operate like collector-storage systems. In these applications, e.g. blind shade between glazes absorbs heat, which can be further leaded to rooms. Moreover, sunspaces, which are separate glazed areas in buildings, can utilize solar radiation passively. Heat can be stored in structures (e.g. floor and walls) and direct gains can be generated. In addition, hybrid systems, which use solar radiation actively and passively, can be used. (Duffie & Beckman, 2006)

4.2 Cooling

In colder climates, inside air temperatures can raise substantially during summer, affecting to comfort of occupants. Thus, cooling energy must be provided. The cooling system applied depends on the amount of removable heat load. During sunny summer days, it is important to minimize the heat production in buildings. This can be done by using solar shading system in front of windows, which block solar radiation effectively. The size of west and east oriented windows can be minimized to avoid excessive heat gains. In high buildings, warm air can be ventilated outside through an air gap at the ceiling. (Bauer;Mösle;& Schwarz, 2010)

Good insulation and appropriate air-tightness of building envelope prevents heat transfer from outside to building interiors. Moreover, heavier thermal mass can absorb heat and release it later during cooler periods, e.g. during nights. It is also important to place devices producing unwanted excess heat in separate rooms. (Seppänen & Seppänen, Rakennusten sisäilmasto ja LVI-tekniikka., 2004)

If these passive methods described above cannot be used to provide enough cooling energy, active cooling takes place. In many cases, cooled air is distributed by an air conditioning system, where a separate cooling coil produces cold air. On the other hand, heat recovery system can recover cooling energy and lead it back to the building. However, auxiliary cooling systems with cooling coils use electricity, which increases the overall energy consumption of the building, and should thus be avoided as much as possible. (Kreider, 2001)

If outside air is warm and dry, an evaporative cooling system can be used. Evaporative cools down the incoming warm and dry supply air by transferring heat in to water droplets. In addition, mist air feels cooler. Moreover, absorption refrigeration and desiccant cooling system can provide low temperatures to building interiors. (Binggeli, 2003)

Heat pumps and other refrigeration cycle devices can provide efficient cooling energy for buildings. These devices can use building interiors as a heat source and release heat to a heat sink (i.e. air, ground or water). In addition, ground can be used as a pre-cooler for cooling systems. For instance, during summer, the temperature of the ground in certain depth can be much cooler than the temperature of air and topsoil. With rather small electric input for heat pump compressor and fans, lot of cooling energy can be provided. (Awbi, 2008)

4.3 Air conditioning and ventilation

Ventilation is necessary in every building in order to maintain appropriate indoor air quality and occupant comfort. Ventilation removes such as odor, pollen, hazardous contaminants and moisture from the building. With air conditioning system, also adequate temperature and fresh air can be brought to the building. There are several different ventilation systems available, but this text concentrates only on the most energy efficient ones, which are used in colder climates.

Heat recovery

Nowadays heat (or energy) recovery system is default in almost every new building in Finland. Heat recovery removes warm and contaminated air from the building interior, transferring heat to the fresh and colder air from outside. The filtered fresh air is introduced to building interior. Thus, heat it not released outside – it is recovered, leading to better energy efficiency of the building. Heat recovery system can also work opposite, bringing cooling energy to building (recovery of cooling energy). Heat recovery units can also transfer moisture, leading to controlled healthy moisture levels in building. The control of moisture levels is important especially in highly energy efficient buildings, where moisture can condense on thermal bridges. (Awbi, 2008)

When using heat recovery system, one must ensure that the building envelope is airtight enough and there are no air leakages in ducts, so that heat is not lost through the structures and the heat recovery system can work as efficiently as possible. Additional heating and cooling coils can be also added in order to heat or cool down the supply air, but this kind of procedure consumes extra energy. Energy efficiency can be increased by constructing preheating unit, which transfers heat to from e.g. ground to supply air. (Kreider, 2001)

Natural ventilation and hybrid solutions

Natural ventilation can be used in some cases in order to ventilate rooms. Natural ventilation can be organized e.g. through windows or ceiling openings. However, window based natural ventilation is not enough in colder climates, where heating is needed most of the time. In addition, simultaneous use of window and mechanical ventilation system is usually inefficient. Hence, window ventilation can be used when a mechanical ventilation system is turned off. However, window ventilation can bring impurities, cold air and moisture into the building, leading unhealthier and unaccepted indoor air. (Awbi, 2008)

Natural ventilation includes also convective ventilation, in which warm stale air raises towards ceilings where it is removed and fresh outdoor air infiltrates from lower building levels. Besides natural forces, fans can be also used. Convective ventilation can be used especially in high buildings. In the end, heat can be recycled back to the building. However, this kind of system must be designed very carefully, especially in colder climates, because of heat losses through infiltration areas and too cold air intake. (Binggeli, 2003)

Some hybrid solutions, such as integrated heat pump with heat recovery system, can lead to better energy efficiency of the system. Switching between natural and mechanical ventilation can also lead to energy savings, especially in bigger buildings, where heat loads e.g. from people are really high. (Awbi, 2008)

When designing energy efficient HVAC system for buildings, the air distribution system must be considered as a part of energy calculation. At first, ducts can have a certain amount of heat loss when distributing the air. Secondly, air is distributed by fans, which are consuming electricity. The electricity demand for fans depends on the fan efficiency, the properties of the duct (friction, length, area, shape, the amount of other equipment etc.), operation time and required flow rate (i.e. pressure difference). Turning off the ventilation when is not needed saves a lot of electricity, especially in office buildings. On the other hand, fans produce some heat while operating, which have to be taken into account. (Seppänen & Seppänen, Rakennusten sisäilmasto ja LVI-tekniikka., 2004)

HVAC systems require also a measurement and control system, which consumes electricity. In addition, some air conditioning systems have heating and/or cooling coil or preheaters, which can run by using electricity. These kinds of actions consume more energy, obviously. Energy losses through the ventilation unit must be also evaluated. In addition, heating demand of ventilation air must be included in to energy demand calculations. Correct sizing of HVAC system have also crucial role in the energy efficient design. (Ympäristöministeriö, Rakennuksen energiankulutuksen ja lämmitytehontarpeen laskenta, 2007)

The optimal use of HVAC system increase also energy efficiency. HVAC system should provide sufficient conditions for occupants. Minimum or “just enough” – principle works in many cases. Following issues are essential to remember when designing HVAC system:

- Do not ventilate with full power when a room is not occupied
- Avoid excess heating and cooling
- Provide just enough ventilation air
- Do not use simultaneous heating and cooling, if possible

4.4. Water heating and distribution

Buildings consume significant amounts of water every day. In colder climates, approximately 40 – 50 % of water is consumed as warm water. Thus, substantial amount of energy is needed in order to produce warm water for building and occupant purposes. This is especially true with residential buildings, swimming halls and sport centers, where warm water is for e.g. in showers, washing machines and cleaning. Usually taking care of personal hygiene shares the biggest part of warm water consumption. In office buildings, water heating can share smaller part of total energy consumption. (Seppänen, Rakennusten lämmitys, 2001)

Heat is often transferred from district heating system to warm domestic water. As presented before, water can be also heated by using boilers or electricity. Today, water heating should be more efficient and renewable energy sources should be used in water heating. Thus, water heating can be assisted by using solar thermal collectors, heat pumps (air-to-water, ground-to-water or water-to water) or combination of solar thermal collectors and heat pump. It is also possible to utilize heat from wastewater streams. Recovering heat from wastewater is more economical in bigger municipal buildings, such as swimming pools. (Awbi, 2008)

Water heating and distribution should be as efficient as possible. Factors affecting to the efficiency of water heating include heat losses through heat production system, pipes, valves and other equipment. In addition, pressure losses in pipes should not be too big. Otherwise excess electricity is needed in pumps etc. One has to always remember that water consumption should be also minimized by changing habits and having efficient water nozzles and domestic appliances, besides lowering the temperature of the hot water. Energy demand of water systems can be also decreased by utilizing grey water in toilets and gathering rain water and leading those to e.g. vegetable garden, if possible. (Bauer;Mösle;& Schwarz, 2010)

The temperature of the domestic hot water should be high enough (between 55 - 65 °C) in order to avoid harmful growth of bacteria (especially *Legionella pneumophila*). On the other hand, lower water temperature e.g. in pipes and storages prevent from excessive heat losses through surfaces. Thus, lowest possible temperature should be used. Placing the water storage tank in warm room prevents also from heat losses. (Seppänen, Rakennusten lämmitys, 2001)

6. Electricity and control systems in buildings

5.1 Electricity and lighting

Buildings consume substantial amount of electricity annually. Electricity is needed in lighting, HVAC systems, electric appliances and other equipment, such as lifts and escalators. Increasing electricity price and pollution from electricity production is pushing towards savings in electricity consumption. Thus, careful electrical and lighting design must be undertaken when designing energy efficient buildings.

Lighting can share a big part of electricity consumption of buildings. More energy efficient lighting does not only save electricity, but it can also contribute to the quality of light and productivity of workers in buildings. Usually, daylight should be utilized as much as possible. South facing windows and obstruction free courtyard decrease the need of artificial lighting. Utilizing daylight can be seen one of the most effective and cheapest method to reduce electricity consumption of lighting. The quality of daylight is also comfortable. However, the optimization between windows gaining daylight and preventing from heat losses must be done. (Bauer;Mösle;& Schwarz, 2010)

By using light colors inside the building, the reflectance of daylight can be improved. At the same time, daylight can be distributed better to interiors. In addition, the amount of daylight can be utilized by using toplights and skylights. These solutions provide excellent amounts of daylight, especially if south oriented. At the same time, the effect of glare can be reduced. (Binggeli, 2003)

When artificial lighting is needed, the electricity consumption can be decreased by increasing the lamp efficiency. Decreasing the amount of luminaries can cut down the electricity consumption. Artificial lighting should be used only when needed and where needed. This is especially true in hospitals and offices, besides rooms where special tasks have to be done. Allocating light where it is mostly needed can save energy. In addition, there are several lighting control systems available, such as time clocks, photocells and occupancy sensors. These control systems can turn of lights when not needed, leading to substantial electricity savings. (Turner & Doty, 2007)

HVAC system can form 40 to 50 % of total electricity consumption in buildings. However, efficient HVAC system brings other advantages. Electricity in HVAC systems can be decreased by shutting down ventilation when is not needed and using passive cooling or heating methods. (Kreider, 2001)

Domestic appliances consume some energy, and attention should be paid on energy efficiency of these devices. In addition, other devices, such as lifts and escalators require electricity. Electricity can be saved also by decreasing the amount of these devices and using them only when needed. (CIBSE, 2004)

5.2 Energy management and control systems

Control and automatic systems are advantageous when making an energy sparing building. These systems, besides optimal energy use, enable also safe, economical and appropriate operation of target device or system and lead to optimized indoor air conditions. As a result, building can be more energy efficient by being implemented with “smarter” technology.

Smart electric power management system (EPMS) ensures safe and reliable power quality, when bringing economic advantages and reduced energy consumption. Based on measured and monitored power consumption, power quality (i.e. outages, surges and sags, for instance) and event alarms, the power management system can suggest or initiate schemes for reducing power consumption. The system can also respond to power demand during peak consumption hours by defining power saving schemes, such as reducing power consumption of HVAC system and lighting or using electricity production systems on site. During peak consumption hours, the price of electricity can be more expensive. Thus, the system can bring substantial economic benefits. (Sinopoli, 2010)

Smart meters measuring power consumption in detail are essential part of EPMS. By providing real-time data about the amount of consumed power and information about consumption time and seasons, smart meters enable customers to monitor and control power consumption and evaluate schemes to improve energy efficiency, while minimizing power costs. EPMS can also have submetering devices monitoring power distribution in different areas in buildings. By submetering, customers can follow real-time power consumption in specific areas, and control then e.g. power consumption. In addition, smart power strips can decrease the electricity consumption of devices being shut down or having standby mode. (Sinopoli, 2010)

The ultimate goal of EPMS would be storing electricity and running devices during night, when electricity is usually cheaper. Electricity could be stored e.g. in batteries communicating with other domestic appliances and even with an electric car. Furthermore, EPMS can have different power usage settings for energy savings, such as holiday scheduling, yearly scheduling, night time settings, hot water reset and so on. The advantage of EPMS is that it can use wireless digital control. (Turner & Doty, 2007)

Lighting control system can include several control methods available decreasing the electricity consumption of lighting. At first, scheduling (or time clocking) can be used, in which the device holds light on, turning them off after a certain period of time. Other option is occupancy sensors, which recognize if the room is occupied or not, and controls then the lighting. Usually the occupancy sensors sense e.g. body heat, movement, sound or combination of these, putting then lights on. (Sinopoli, 2010)

Photoelectric devices can control the amount of artificial lighting, when daylight is available. Thus, the device turns lights off when daylight is at large. Automatic blinds, for instance, can be also possible to prevent excessive passive solar heating. Furthermore, dimmers can be used in order to cut energy use of lamps. Dimmers can be especially useful when there is some supplementary lighting required besides daylight or during the day time, when electricity demand is at peak. (Sinopoli, 2010)

HVAC control systems can also use this kind of sensors controlling the operation of the system. For example, if occupancy sensor is not sensing any people in the building, ventilation is put off. On the other hand, occupancy sensors can measure the amount of occupants in the building, controlling thus the operation rate HVAC system. Real time monitoring enables an appropriate control of temperature, humidity, pressure and airflow levels. To avoid overlapping in heating and cooling, a dead band thermostat can be used. This device shut HVAC off, having a clear difference between cooling and heating. (Turner & Doty, 2007)

7. Renewable energy in buildings

Most of buildings nowadays use fossil fuels in order to produce heat. Furthermore, electricity is brought from the outside source of the building in many cases. Raising environmental concern, increasing energy prices and tighten regulations are pushing us towards renewable energy in buildings. The use of renewable energy sources, when realizing the application or combination of applications appropriately, can bring substantial economic and environmental advantage. This chapter presents the most common renewable energy sources in building applications.

As mentioned in earlier chapters, building sector consumes a substantial part of total energy. Especially, the main part of heat is consumed in buildings. In addition, buildings can use even 50 % of total electricity supplied. At the moment, prices of electricity are raising, pushing us towards energy savings in buildings. Furthermore, production of electricity is one of the main contributors to environmental hazards, such as climate change. Thus, the use of renewable energy sources should be used more, also in buildings. Figure 3 presents electricity production by source in Finland and figure 4 describes some common renewable energy sources, which can be integrated in buildings. (Tilastokeskus, 2008)

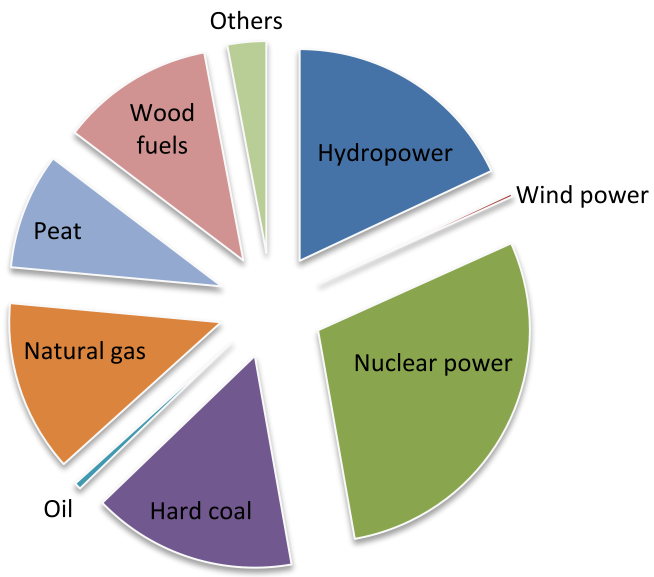


Figure 3. *Supply of electricity by energy source in Finland 2007* (Tilastokeskus, 2008)

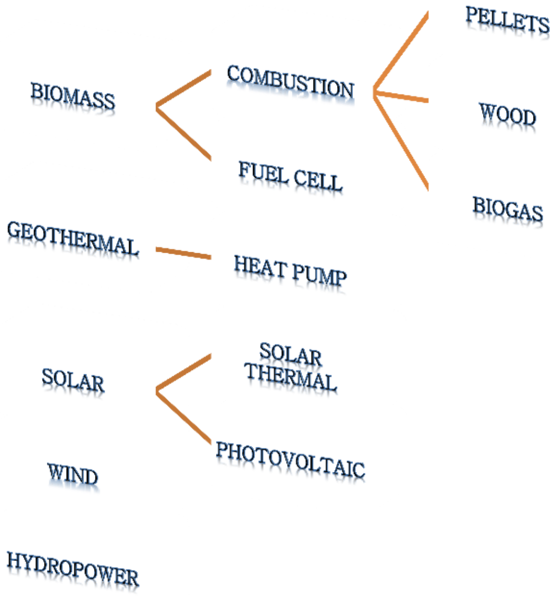


Figure 4. *Common renewable energy sources in buildings*

7.1 Biomass

Biomass can be used in order to produce heat or electricity. The most conventional biomass based fuel that is used in buildings is wood. Through combustion processes in furnace, wood can produce sufficient amount of heat for space heating, water heating and e.g. cooking. Wood based combustion is still recommended in small and medium scale buildings and especially in seasonally occupied buildings as a heat source. Recently, more energy dense, tubular shaped pellets can be used instead of wood in furnaces. The advantages of modern pellet systems, besides higher energy density, are easier storability, automatic fuel supply and controlled combustion conditions. (Twidell & Weir, 2006)

Some buildings produce heat by using natural gas and other fossil fuels. It is possible to replace these gaseous fuels by biogas produced from anaerobic digestion or syngas produced from gasification process. Liquid fuels can include ethanol, biodiesel and bio-oil. These fuels can be combusted and used to heat up boiler, for instance. (Twidell & Weir, 2006)

Especially in future, fuel cells can have a great potential in buildings because these devices have multi-scale options and rather good efficiency. Fuel cells can utilize e.g. hydrogen, methane and carbohydrates as an energy source. It is possible to produce both electricity and heat through fuel cells. (Bauer;Mösle;& Schwarz, 2010)

In residential areas, bigger CHP plants can produce electricity and heat for surrounding buildings. These kinds of plants can include combustion, gasification, pyrolysis and anaerobic digestion plants. (Twidell & Weir, 2006)

7.2 Geothermal

Geothermal sources include air, water and ground. In building applications, geothermal applications can generally provide heating and cooling. Nowadays, heating and cooling is provided extensively in different climates with devices called heat pumps. In heat pumps, a refrigerant flows in pipes (usually closed loop) and extracts energy from a low energy system (air, ground or water) and brings heat for a high energy system (building) by work done by a compressor. (Kreider, 2001)

Conventional heat pump uses air as a heat source. More advanced water-source heat pumps can extract heat from lakes, rivers and sea. It is also possible to pump ground water from the ground to a heat exchanger unit, where heat is transferred and ground water is led back to the source. (Awbi, 2008)

Ground-source heat pumps use soil or bedrock as a heat sink and source. Heat collection or rejection system in the case of ground-source heat pump can be vertical or horizontal. Horizontal piping requires more space, which can be problem in urban areas. On the other hand, vertical installation (U-pipes) can be rather expensive. It is also possible to install energy piles in construction auger piles when in new buildings to avoid excessive costs. (Awbi, 2008)

Heat pump applications can provide space heating during winter and cooling energy during summer. Water heating is also possible by using these applications. In some cases, solar thermal collectors can be integrated to heat pumps in order to enhance water heating. Heat from wastewater can be also utilized by using heat pumps. (Seppänen, Rakennusten lämmitys, 2001)

7.3 Solar

Utilization of solar energy passively is very common in buildings. Active use of solar radiation can be distinguished to solar thermal collectors and solar photovoltaic cells (PV). In colder climates, the biggest restrictive factors for the use of solar energy is dark winter time, when solar radiation is at minimum and electricity and heat demand are at maximum. Other restrictive factors affecting the energy production of active solar energy are e.g. daily variations in the amounts of irradiation (day – night), weather conditions, rather low efficiency and presence of pollution. However, solar energy can bring sufficient amount of energy during summer. (Duffie & Beckman, 2006)

Solar cells can convert incoming photons from the Sun into electricity. The efficiency of a certain cell usually varies generally between 10 – 20 % and cells can be placed on the roofs, walls and other building structures. Solar cells have become popular in buildings in southern countries, but increasing attention is gained also in northern areas. Still, the main restrictive factors for the use of solar cells are low efficiency, high price and lack of solar radiation during winter. Direct current from solar cells can be utilized for example in water pumps, but usually DC is converted to AC, which is suitable for domestic appliances. (Luque & Hegedus, 2003)

Solar thermal collectors absorb solar irradiation with dark colored absorption surface and transfer the absorbed heat to fluid, which is flowing through the collector. Heat transferred to the fluid can be used in order to heat up the usage water or circulated in water circulating space heating system, such as floor radiator. In colder climates, solar thermal collectors can provide auxiliary heating for building space and water. (Duffie & Beckman, 2006)

Solar thermal collectors can be distinguished to direct or indirect systems. In direct system, water flows through the collector and water is heated up. In indirect system, a fluid (usually freezing resistant fluid) flows through the collector and releases absorbed heat in to water in a separate heat exchanger. Furthermore, solar thermal collectors can be divided to pump assisted active systems and passive systems based on gravity and density forces. (Duffie & Beckman, 2006)

In active solar energy applications, it is important to consider the roof area of building. The bigger the area is, larger amount of solar radiation can be utilized. (Bauer;Mösle;& Schwarz, 2010)

7.4 Wind

Wind energy can be used when there are sufficient wind conditions. Usually, the economic operation of wind mills requires wind velocities up to 4 m/s, which cannot be met in every building area. Especially, in urban areas, other buildings can block wind efficiently. One of the main disadvantages of wind turbine application is that it is not always windy, leading to unreliable production of electricity. (Manwell;McGowan;& Rogers, 2009)

With sufficient wind conditions, wind power can provide auxiliary electricity for building applications. There are several different wind mill sizes available on the market. Some special applications where wind mills can be used, besides conventional electricity production, are e.g. water pumps and ice making (cooling storage). (Manwell;McGowan;& Rogers, 2009)

7.5 Energy storage

In order to save energy and enable the use of renewable energy in buildings, energy storage is often involved. By using energy storages, free energy can be also stored. In addition, it is possible to use energy from energy storages during peak consumption hours, when the price of electricity can be higher. Generally, energy storages can be distinguished to thermal, chemical, electrical and mechanical storage. Biological storage is an option, but it is not discussed in this context.

Thermal storage

Thermal storage is often integrated to building structure. As discussed in earlier chapters, building’s thermal mass can store heat passively from solar radiation. With high mass and great heat capacity, the structure can store heat during a day and release it during cooler night periods. This kind of procedure saves cooling energy during day and heating energy during night time. (Duffie & Beckman, 2006)

Hot water (or other liquid) storage with sufficient insulation can used as thermal storage over weeks or even few months. Tanks can be placed above or under the ground. For instance, heat generated by solar thermal collector can be further stored in this kind of system. Water storages can be also used as cold water storage. In addition, phase changing materials having e.g. higher melting points than water can be also possible heat/cold storages, such as Gauber's salt ($Na_2SO_4 \cdot H_2O$). Energy can be also stored in ice storage utilizing the latent heat of phase change in order to get cooling energy in warmer periods. (Twidell & Weir, 2006)

Chemical storage

Chemical storage provides an option where electricity or heat can be stored in chemical bonds of compounds. These compounds can be further broken down in exothermic reactions, such as combustion, in order to produce heat. One option for chemical energy storage is hydrogen (H_2). Hydrogen can be produced from water by using electrolysis. Thus, direct current from renewable energy resources in buildings could be stored in hydrogen molecules that can be stored and burned or used in fuel cells. (Twidell & Weir, 2006)

Electrical storage

Electricity is conventionally stored in batteries. In buildings, batteries can be charged with e.g. renewable electricity from solar cell or wind mill, or cheaper electricity from the grid can be stored during nighttime. Electricity can be used during peak consumption hours. Electric cars can also work as electric battery storage. (Twidell & Weir, 2006)

Mechanical storage

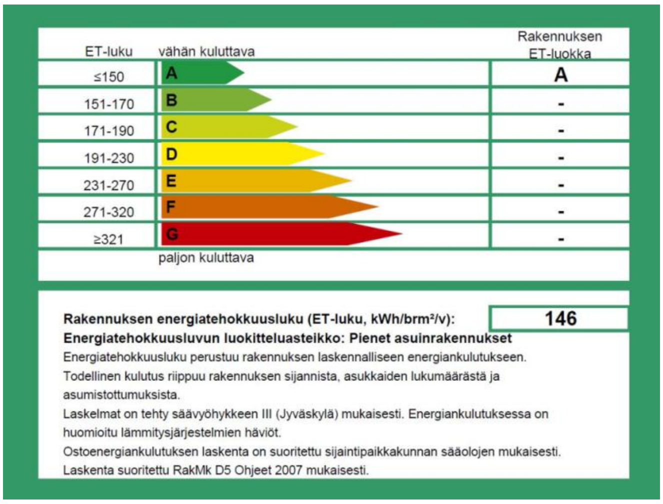
Mechanical storage systems have usually bigger scale and are more expensive solutions. However, bigger commercial buildings can use mechanical storages in some cases. First of all, water can be pumped in to higher water reservoirs by using electrical pumps. During immediate demand or peak consumption hours, or when electricity is not produced from renewable sources, water can be led out from reservoirs in order to run a turbine and produce electricity. Mechanical storage systems can include also flywheels and compressed air storages. (Twidell & Weir, 2006)

8. Energy auditing and economic considerations

In many European countries, EU energy efficiency directive is pushing us towards more and more energy efficient buildings. According to the directive, energy efficiency must be improved not only in new buildings, but also in existing buildings. The directive also obligates that public buildings must be almost zero energy buildings by the year 2019. Every new building must be almost zero energy buildings by the end of 2020. (ympäristö.fi, 2012)

In this challenging problem of energy efficient buildings in future, energy auditing plays important role. By doing energy auditing, customers can get information about the energy consumption of building. Energy audit will provide useful information about where and how much energy is used. It will also give suggestions for more energy efficient solutions and actions. Energy audit can also reveal faults e.g. in building insulation and air-tightness. Energy auditing is done by using several different kinds of measurement tools, such as infrared cameras, light meters, thermometers, voltmeters and air flow measurement devices, besides calculation models. In the end, buildings can be distinguished to e.g. different energy classes according to their energy consumption. (Turner & Doty, 2007)

In Finland, the energy audit tells about the energy efficiency and total energy consumption in the building, including all consumed heating, cooling and electrical energy (total amount of bought energy (kWh/m^2/yr)). In the end, the energy efficiency of the building is described with E – number (E – luku or energiatehokkuusluku in Finnish). The value of the E – number determines the energy class of the building, which can be from A to G, where A is the most energy efficient result and G the most energy consuming one, respectively. Conventional buildings generally have energy class of D in Finland. Different forms of energy have different coefficient and are thus related to determination of E- number. Generally, every new building in Finland requires the energy audit. The picture above illustrates the



Finnish energy audit. (Ympäristöministeriö, Rakennusten energiatehokkuus. Määräykset ja ohjeet 2012, 2012)

Many customers and companies are interested in energy efficient buildings, because of economic advantages. Indeed, energy efficient buildings usually have higher initial costs, paying costs back in most of the cases. At the same time, image and value of the building, besides occupancy health can be improved. In the case that building generates excess electricity, it is possible to sell it to the common grid. Especially, this kind of procedure will be common in future. Thus, with minimal consumption of energy, it can be also possible to integrate economic evaluations to energy audit. (CIBSE, 2004)

As mentioned before, initial costs for energy efficient equipment can be higher compared to conventional solutions. On the other hand, the situation can be opposite. For example, installing energy recovery system can be cheaper compared to conventional systems. To evaluate the overall economy of the system, payback time is commonly used tool. In addition, life cycle analysis is effective tool evaluating the whole economic performance of the system. Life cycle analysis for e.g. heating system includes purchase, maintenance, repairing, and operation and energy costs, providing thus an approach for long term implications. (CIBSE, 2004)

9. Occupant requirements and indoor air

An energy efficient building should walk hand in hand with appropriate indoor climate, where occupancy comfort is as high as possible. Indeed, many solutions improving energy efficiency in buildings contribute also to better indoor air quality as well as quality of life. Technical structures and devices, such as ventilation system, are designed to meet indoor air and occupancy requirements, and usually these requirements put limiting values for the design of systems.

Adequate indoor air and satisfied consumer requirements are important because most of the time of human life is spend in buildings. Thus, it can be said that many health problems origin from building materials and inside air conditions. In addition, work productivity and “mood” is closely connected to indoor air conditions. Hence, occupancy requirements and indoor air are necessary factors to consider in the context of energy efficiency. In most cases, adequate levels for indoor air conditions in different building applications can be found from standards.

Thermal comfort and air flow

Adequate temperature in a room is essential. To be more precise, the correct term for inside temperature we are sensing on our body is operative temperature, where convection and radiation are affecting. Other factors affecting to thermal comfort are metabolic rate, clothing and humidity. These factors should be taken into account when designing and maintaining adequate indoor thermal comfort conditions. As a result, the main part of occupancy (approximately 90 - 95 %) should be comfortable with the final temperature. (ASHRAE, 2004)

To keep occupants satisfied, temperature should not fluctuate too much during short period. It is also necessary to avoid draught, which adds dissatisfaction in rooms. Typical sources of draught are badly sealed structures (e.g. doors), large glazed areas, air leakages through building envelope, thermal bridges and inadequately operating ventilation system. Displacement of ventilation air supply can also cause draught. Building envelope should be air-tight from outside in order to prevent the movement of air from outside to inside, especially when it is windy. Building envelope with bad air-tightness can lead to excess use of electricity of ventilation system and heat losses. (Terveys-lehti, 2009)

Air flow and temperature should be evenly distributed in a space. Thus, local warm or cool surfaces or e.g. fans can cause thermal discomfort. The most uncomfortable air flow orientation is flow allocated straight to face or neck. Moreover, vertical differences can also cause thermal discomfort. Thus, floor heating can bring heat to feet area. (ASHRAE, 2004)

Temperature can be controlled individually in some cases. These kinds of cases can include e.g. office rooms, where thermal comfort can be added manually setting higher or lower temperature from thermostat. It is considerable that for example an open door can lead excess use of ventilation energy, if there is temperature difference between the office room and corridor. It is also considerable that too high room temperature can lead to worse indoor air since warm air can lead to increased chemical activity and promote the growth of microbes. (ASHRAE, 2004)

Light and noise

Energy efficient lighting should bring adequate amount of light depended on the application. The amount of life affects to the "mood" and also the productivity of work. In office buildings, approximately 500 lux illuminance level should be achieved. However, some special tasks e.g. in hospitals may require even illuminance level of 1000 lux. It is also proven that adequate amount of daylight can increase working mood and well-being of occupants. (Bauer;Mösle;& Schwarz, 2010)

Noise levels should be set between 30 and 55 dB in buildings, depending on the building type (lower values recommended). Especially, noise effects from heating, ventilation and air conditioning system and water pipe systems should be minimized by adequate noise insulation. (Terveys-lehti, 2009)

Humidity

Too high or low humidity levels can bring several problems for building structure and occupants. Thus, relative humidity of building interior should be 20 – 60 %, depending on the building type. Since the moisture content of buildings is closely related to ventilation and other energy related issues, it is important to discuss about it. (Terveys-lehti, 2009)

Too high moisture levels in a room can promote the growth of mold and other microorganisms in building structures, leading to health and odor problems. This is especially true if there are cold surfaces (e.g. thermal bridges) where moisture can condense. High humidity levels can also be harmful for wood structures. Ventilation system operating appropriately removes moisture effectively. In addition, thermal bridges should be avoided by insulating these areas with extra care. Building envelope must have also vapor and air barriers. It is also important to replace ventilation exhaust air intakes near the moisture source, e.g. in bathrooms and kitchens. Increasing thermal discomfort can be also due to higher humidity levels in room air. (Terveys-lehti, 2009)

Too low moisture content in a room can lead to problems with the mucous membrane of the respiratory system and can contribute to irritating eyes. Dry air can lead to cracking of wood materials and shrinking of furniture, besides contributing to electrostatic shocks. Energy recovery systems, which can control moisture levels in residential buildings, can be used. In addition, it is possible to install an air humidifier as a separate unit or in touch with the ventilation system. However, humidifier adds the energy consumption of the building after all. (Awbi, 2008)

Chemical compounds and particles

Building air can contain several harmful compounds that origin from building structures and outside such as ammonia, asbestos, formaldehyde, CO_2, CO, styrene, ozone and different VOC compounds. Concentrations of carbon dioxide can be really high in densely occupied rooms, such as classrooms. These compounds can be avoided by having building structures emitting none of these compounds, having air filters and maintaining adequate ventilation rates in rooms. (Binggeli, 2003)

Room air contains some amount of particles, which origin from outside sources (pollen, particles from transportation etc.) or inside sources, such as building structures. Room air particles can include room dust, inorganic fibers, asbestos and microbes. The size of air particles in rooms varies approximately between 2,5 and 10 µm. Energy efficient building should minimize the amount of unfiltered air taken from outside. Appropriate building materials and efficient ventilation play also important role when removing particles form building air. (Sisäilmayhdistys, 2012)

Microbes

Microbes are everywhere in building structures and air. Still, excessive amount of moisture besides adequate temperature can promote the growth of microorganisms in building structures. Microorganisms, such as yeasts, can cause harmful odor, toxic compounds, particles and damage building structures. Keeping windows closed prevents from microorganisms to enter building air. Still, removing excess moisture from building by ventilation is more important. Moisture should not also condense on thermal bridges and lower temperature can slow down the growth of microbes. (Terveys-lehti, 2009)

10. Types of energy efficient buildings

So, what can be the result of all these presented tools, actions and technologies? At the moment, energy efficient buildings are generally distinguished to four classes:

- Low energy building
- Passive house
- Zero energy building
- Plus energy building

All these building types consume much less energy than conventional ones, having also better indoor air quality. In Finland, construction of low energy buildings and passive houses is not unusual anymore. Table 2 below presents reference values for energy consumption in low energy and passive house buildings in Finland.

Table 2. *Reference values for energy consumption in buildings in Finland*

Energy consumption	Conventional building in 2010	Low energy building	Passive house
Heating of rooms (kWh/m^2/yr)	100 - 110	26 - 50	15 - 25
Warm domestic water (kWh/m^2/yr)	30	20 - 25	20 - 25
Electricity consumption of devices (kWh/m^2/yr)	25 - 35	30 - 35	25 - 35

As we can see from table 2, low energy building consumes much less energy than conventional building in Finland. The total heating energy required in the low energy building is around 60 - 90 $kWh/m^2/a$, while conventional buildings consume usually more than 120 $kWh/m^2/a$.

The consumption of primary energy in passive houses in Finland is separated to three classes according to the location of building:

- Southern Finland ≤ 130 $kWh/m^2/a$
- Central Finland ≤ 135 $kWh/m^2/a$
- Northern Finland ≤ 140 $kWh/m^2/a$

Passive houses must have also maximum air leakage number of n_{50} ≤ 0,6 1/h in Finland. The design of passive houses starts from definition of location and orientation. Typical passive house has thermally heavy structure and compact shape. It uses solar energy passively and contains also passive cooling methods, e.g. shading. Special attention is paid on heating and ventilation system, besides heat losses. According to Finnish VTT, construction costs of the passive house (excluding the price of the site) can be only approximately 5 – 10 % higher than in normal buildings. Table 3 below presents general reference values for building envelope in Finland. (Motiva, Energiatehokas koti, 2012)

Table 3. *General reference values for building envelope and heat recovery in Finland*

Reference value of building envelope	Conventional building in 2010	Low energy building	Passive house
Wall λ (W/m^2K)	0,17 – 0,40	0,15 – 0,17	0,10 – 0,13
Ceiling λ (W/m^2K)	0,09	0,10 – 0,15	0,06 – 0,08
Floor λ (W/m^2K)	0,09 – 0,16	0,12 – 0,15	0,08 – 0,12
Doors and windows λ (W/m^2K)	1,0	0,8 - 1,0	0,4 – 0,7
Air-tightness, n_{50} number (1/h)	2,0	<1,0	<0,6
Yearly efficiency of heat recovery	45 %	>70 %	>80 %
Ventilation power ($kW/m^3/s$)	<2,5	<2,0	<1,5

The determination of a zero energy buildings is that it consumes the same amount of yearly energy that is produced by the building. The ultimate goal of energy efficient building is a plus energy building, which produces more energy yearly than consumes. These buildings produce energy by using e.g. solar cells, solar thermal collectors, heat pumps and bio energy (e.g. wood). In many cases, plus energy buildings produce excess amount of energy during summer, but may require e.g. electricity from the public grid during winter. For plus energy buildings, the communication with the national grid is often essential. (Motiva, Energiatehokas koti, 2012)

11. Conclusions

Energy efficient buildings save fuels, besides heating, cooling and electric energy, while providing appropriate indoor air quality. By saving energy in a building, an effort for better environment can be done. At the same time, economic benefits can be reached. Taking into account occupancy requirements and indoor air quality, building interiors can be healthier, leading to better comfort of occupants.

The design of an energy efficient building should start from the beginning, when considering e.g. the location, orientation and size of the building. Local renewable energy resources and climatic conditions must be also identified, as well as possibilities of using free energy. In the end, with the mixture and careful design of technological and architectural solutions, besides consumer habits, an extremely energy saving building can be reached. In colder climates, special attention must be put on insulation and air-tightness of building envelope and windows. The final energy consumption of the building can be checked by energy auditing.

Energy efficiency of existing buildings can be improved with small investments, such as re-designing lighting, improving window insulation and installing a heat recovery system or heat pump. In new buildings, energy efficiency is “must-to-do” in all cases. The goal of an energy efficient building is normally a low energy building, passive house, zero energy building or, ultimately, a plus energy building.

So, cooperation between engineers, architects and building occupants is essential. Some kind of optimum between energy efficient solutions must be found because one solution can have its own advantages and disadvantages. In the end, the building should be able to ensure comfortable atmosphere, while not closing too many options for clients to design the building interior when occupied.

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