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OULUN YLIOPISTO

GREENSETTLE PUBLICATIONS

Management of Energy Efficiency in Buildings

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Abbreviations
EeB – Energy efficient building
IAQ – Indoor air quality

1 Introduction

Increasing amounts of pollutants from human activities are of a serious concern. Air pollutants, in particular, contribute to climate change, natural disasters, disruption of global and local ecosystems, which may negative impact the well-being of humans. The 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 a sustainable tomorrow.

Energy efficient buildings (EeB) consume less heating, cooling and electrical energy and fuels. This will also result in economic savings. At the same time, greenhouse gas emissions and other emissions from energy production and use can be reduced effectively. EeB also aim to improve indoor air quality, adding to the well-being of occupants. Due to these considerations, EeBs tend to have a better market value.

There is a substantial amount of work to be done in the building sector in order to reduce energy consumption and improve the efficiency and the indoor air quality of buildings. Legislation is also pushing towards energy saving buildings, which makes this subject a very topical issue.

In the European Union, buildings contribute to more than 40 % of primary energy consumption. This makes the building sector one of the largest contributors to climate change as well as other environmental problems. Buildings require energy during their occupation as well as the construction phase. Hence, improving the energy efficiency of buildings is a key element in a strategy to combat global change. (Martinkauppi 2010)

In cold climates, heating contributes to nearly half of the total energy consumption of buildings. Heating is required to maintain healthy and comfortable indoor conditions as well as producing warm water for showers, washing. Heat is produced by heating systems (e.g. furnace and electric radiator), solar radiation, occupants and heat losses from appliances. Heating systems may require wood, oil or gas or district heating. One should keep this in mind when considering efficient and sustainable buildings, especially because fuels are releasing substantial amounts of air pollutants and other compound during their whole life cycle. (Martinkauppi 2010) During warmer periods, cooling energy is needed to cool down the building interior in order to maintain an adequate building climate. Especially in southern countries, cooling energy comprises the largest portion of energy consumption in buildings. (Bauer et al. 2010)

An essential part of building energy consumption is electricity. Electricity is needed in some heating systems in order to produce heat, run control systems, but also in domestic appliances and lighting. Lighting is consuming a substantial amount of electricity, especially during darker periods and in municipal buildings, such as offices. Many of our daily routines, such as cooking, watching TV and charging batteries require electricity. Electricity consumption in the building sector can form almost 50 % of total electricity consumption. Electricity and district heating is often generated using fossil fuels, such as coal, oil and natural gas. It must be taken into account that production of electricity for energy efficient and green buildings should be done by using renewable resources. (Bauer et al. 2010)

Ventilation and air conditioning requires also energy in order to operate and provide adequate indoor air quality (IAQ) to building interiors. Air conditioning usually provides 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, energy consumption reaches its peak in winter time when substantial amounts of heat and electricity are 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. (Energy Priorities 2012)

The purpose of this work is to give a general guideline and an introduction to technical tools in order to build an EeB. 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

An EeB is a sum of many actions. As a result, apart from saving energy, an EeB should provide an adequate indoor air quality, taking also into consideration occupancy requirements. In many cases, to maximize advantages, an optimum between energy efficient technologies and solutions must be found. As an example, a large south-facing window can maximize the amount of daylight and bring heat to interiors, but can also increase heat loss during winter time. Figure 1 illustrates the issues to be considered in an EeB. It is to be mentioned that using renewable energy sources are an essential part on an EeB. ■

3 Building design and building envelope

3.1 Location

Climate conditions vary substantially in different regions, hence the location plays an important role when designing EeBs and is always involved in the design process of new houses. In building design, it is important to take into account regional and local climatic conditions as well as microclimate. In addition, 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 seasonal and daily fluctuations in weather. The climatic conditions and outside temperature are decisive in insulation levels are also affecting HVAC systems. Moreover, the topography, vegetation and the existence of surrounding buildings can contribute to 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 et al. 2010)

3.2 Architecture

Architectural design is an essential tool towards EeBs. The shape of the building affects energy efficiency in many ways. Compact shape in buildings leads to decreased heat losses through the building envelope and decreased exposure to weather 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 (fewer ducts etc.). (CIBSE 2004, Bauer et al. 2010)

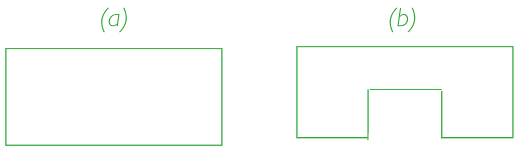


Figure 2. More compact shape (a) is usually more energy efficient choice than more complex shape (b)

The orientation of a 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 in a decreased need for artificial lighting and heating during colder periods. Thus, south oriented windows, having a larger glaze area, can be very beneficial. North facing windows often contribute to heat losses and are exposed to cold winds, so adequate insulation and size of these windows play a very important role. On the other hand, during summer, solar radiation can heat up the building considerably. 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 et al. 2010, Motiva 2008)

Apart from the orientation of the windows, the amount and size of the windows have to be optimized by 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, regulation can limit the size and amount of glazed areas. It is also more energy efficient to have one larger window than many small ones in the same wall. (Motiva 2008, CIBSE 2004)

Generally, the northern facade of the building is exposed mostly to cold winds and rain. 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 EeBs. As a rule, spaces requiring less heating (bedrooms, storages etc.) should be oriented north, while areas requiring more heating (living rooms, offices) should be oriented south. (Bauer et al. 2010)

Electricity consumption in buildings can be reduced by carefully designing the placement and amount of artificial lights, while maximizing the amount of daylight. Artificial lighting should be used only when there is not enough daylight available. In addition, the design should consider the possibility to utilize reflected daylight from light surfaces. (Bauer et al. 2010)

3.3 Building envelope

The building envelope forms the boundary between building interiors and exteriors. Usually, the building envelope consists of walls, floor, roof, windows and doors. The building structure can also consist of atria. For energy efficiency in buildings, the envelope plays an important role in terms of for heat losses and moisture transfer. The building envelope inside the building is in touch with indoor conditions (temperature, moisture, pressure etc.) and outside the envelope is exposed to outdoor conditions (solar radiation, wind, rain, low temperature etc.), so identifying these factors is essential to take in to account when designing an EeB 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)
Heat losses through the building envelope can be prevented by using adequate insulation, where the most important factors are the U-value of building structure, the total area of building envelope and temperature differences between building interiors and exteriors. Also air leakages through the building envelope can significantly contribute to heat losses and the indoor air quality of the building.

Insulation

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

Walls, roof and floor

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

Heat transfer through the building envelope is greatly affected by the thickness and physical properties of insulation materials. Usually, 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 2001)

The water content in materials increases 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 cold climate, humidity levels in buildings are often higher inside than outside. Therefore, it is essential to install a vapor barrier. Generally, the vapor barrier is installed as near the warm building surface as possible. (Binggeli 2003)

Further important factors affecting heat transfer in insulators are temperature and material density. Gas with high heat resistance can be added to porous materials in order to increase the heat resistance. (Seppänen 2001)

Common insulation materials in buildings include mineral wood, polystyrene, polyurethane, light concrete and wood fiber slabs. Factors affecting the decision regarding insulating materials are 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 2004)

Table 1. Heat conductivity of some insulation materials (Seppänen & Seppänen 2004)

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 the 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 must be paid to insulating these areas. (Turner & Doty 2007, Seppänen & Seppänen 2004)

Windows

The amount, size and properties of windows affect greatly the heat loss in buildings. Therefore, careful design of windows must be done. Heat losses through 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). The use of shutters and blind shades also affect 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 2004)

Energy efficient windows should also have a coating, which allows the entering of short-wave solar radiation 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 in the building envelope, and thus heat losses through door slab, door window and door frames will also have to be taken into account when defining the total heat loss through building envelope. (Seppänen 2001)

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

Air tightness

Air tightness (infiltration) in buildings 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 the properties of building envelope materials and wind conditions. Cracks in building materials contribute to the movement of air through the building structure. (Bauer et al. 2010)

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

Heat losses are lower in air tight buildings and usually contribute to a better IAQ. However, when the building is very air tight and insulated well, some problems with moisture can occur in critical areas of the building such as the thermal bridges. For this reason, an adequate ventilation system (usually a heat recovery system) is recommended in order to remove excess moisture and avoid problems with mold. The ventilation system also maintains a slightly smaller pressure in building interiors than outside, avoiding the driving of moisture into the structures, and 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 most. (Ympäristöministeriö 2012)

Thermal weight and special insulation materials

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

Some light transmitting insulation materials can also be used in order to increase the amount of absorbed heat. In colder climates, these kinds of materials are more likely to be used in outer walls, where solar radiation transmit the material, absorbing then in 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 2001) ■

4 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 an energy efficient HVAC system can consume less energy, while providing better indoor air quality (IAQ) and improving the quality of life. In many cases, HVAC systems can be characterized as 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 a necessity for buildings in order to maintain an appropriate temperature in the building interior. Heating can form a major portion of energy consumption in the building sector and it is also contributing substantially to emissions associated with buildings. 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 a brief look into the heat production and distribution systems and energy efficient solutions, while chapter 6 discusses more about renewable energy sources in building applications.

The total heat demand of buildings 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 entire heat production of the building, heat loads from occupants, electric devices and lighting must also be taken into account. Especially in densely occupied buildings, heating load from humans can also be relatively high. This free heat should be utilized as efficiently as possible. (Seppänen 2001)

In Finland, most of the heat for buildings is produced by district heating facilities. Compared to boilers in buildings, these kinds of larger 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 built areas. District heating facilities also use large amounts of fossil fuels, such as coal, natural gas, oil and peat. (Seppänen & Seppänen 2004)

Boilers, furnaces and fireplaces are also commonly used in buildings in order to produce heat. Due to the high heating values and low volume requirement of oil, coal and natural gas, these fuels are often most used. Still, apart from the environmental impact, the prices of fossil fuels are increasing, which are restricting the use of these fuels. (Turner & Doty 2007) More preferable fuels are wood, biogas, pellets and other biofuels. Disadvantages of these fuels are the usually higher price, lower heating values and larger volume requirements. However, in many cases, these combustion based fuels can release enough heat for building. 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 a 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 the 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 2004)

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

Space heating can also be produced by using electricity, and the produced heat can be further transferred to water. It is also possible to have electric resistance heating in the radiators. Such systems responds quickly to temperature changes in rooms. In addition, lower-priced electricity during the night can be used in electric heating applications by storing the produced heat. Nevertheless, electric heating is not the most efficient and cheapest way of heat production. (Turner & Doty 2007)

There are also other sustainable and efficient systems for heating in buildings. Heat pumps can produce heat with low electricity use reliably over the year. Other systems include active solar thermal collectors and biomass-based heat resources. (Awbi 2008)

Passive use of solar irradiation is common in buildings. 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). Windows are usually 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. Despite the potential 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

Even in colder climates, indoor air temperatures can raise substantially during summer, affecting to the 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 systems and overhangs in front of windows, which block solar radiation effectively, especially when using an exterior shading system. The size of west and east oriented windows can be minimized, to avoid excessive heat gains during mornings and evenings. In high buildings, warm air can be ventilated outside through an air gap at the ceiling. (Bauer et al, 2010)

Good insulation and appropriate air-tightness of the 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, 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)

During the summer period, when the outside temperature is lower than inside temperature, it is possible to bypass the heat exchanger in order to supply free cooling energy to the building. This kind of procedure can work similarly during night time (also called as night ventilation) by leading cooler air to the building interior and saving electrical energy of heat exchanger. (Kreider, 2001)

If outside air is warm and dry, an evaporative cooling system can be used. Evaporation system cools down the incoming warm and dry supply air by transferring heat into water droplets. In addition, moist air feels cooler. Moreover, absorption refrigeration and desiccant cooling systems 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, the 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, the necessary 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 odor, pollen, hazardous contaminants and moisture from the building. With an 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

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 the building interior. Therefore, heat is not released outside – it is recovered, leading to better energy efficiency of the building. The heat recovery system can also work in reverse, bringing cooling energy to building (recovery of cooling energy). Heat recovery units can also transfer moisture, leading to controlled, healthy moisture levels in the building. The control of moisture levels is important especially in highly EeBs, where moisture can condense on thermal bridges. (Awbi, 2008)

When using heat recovery systems, it must be ensured that the building envelope is airtight 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 also be 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 a preheating unit, which transfers heat e.g. from the ground to the air. (Kreider, 2001)

Natural ventilation and hybrid solutions

Natural ventilation can also 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 to an unhealthier and unacceptable 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. Apart from natural forces, fans can also be used. Convective ventilation can be used especially in high buildings. At the end, the 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 larger 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. Firstly, 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, 2004)

Nowadays a lot of attention is paid on pressure losses over different duct components. Reducing pressure loss of ducts (Pa/m) is one of the main targets as well as pressure loss over filters, heat exchangers and fans. It is possible to decrease the pressure loss of dampers, supply air intake and ehaust air outlet by oversizing these units. The HVAC engineer must also consider the need of cooling and heating coil because these devices form an additional pressure loss over the system, increasing the consumption of energy. For instance, in moderate climates, heating coil is not necessary in some cases. In addition, some low energy diffusers are beign developed, such as diffuse ceiling method. (Kreider, 2001)

HVAC systems require also a measurement and control system, which consumes electricity as well. 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. Energy losses through the ventilation unit must also be evaluated. In addition, heating demand of ventilation air must be included into energy demand calculations. Correct sizing of the HVAC system also has a crucial role in the energy efficient design. (Ympäristöministeriö, 2004)

The optimal use of the HVAC system increases also energy efficiency. The HVAC system should provide sufficient conditions for occupants. Minimum or "just enough" –principle works in many cases. The following issues are essential to remember when designing HVAC systems:

- 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 used in showers, washing machines and for cleaning. Usually taking care of personal hygiene uses the largest part of warm water consumption. In office buildings, water heating has a smaller part in total energy consumption. (Seppänen, 2001)

Heat is often transferred from the district heating system to warm domestic water. Water can also be 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 larger 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 large. Otherwise, excess electricity is needed in pumps, etc. It needs to be remembered that water consumption should also be minimized by changing habits and having efficient water nozzles and domestic appliances, and 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 et al., 2001)

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 also prevents from heat losses. (Seppänen, 2001) ■

5 Electricity and control systems in buildings

5.1 Electricity and lighting

Buildings consume substantial amounts 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 EeBs.

Lighting can contribute to a substantial share 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 for artificial lighting. Utilizing daylight can be seen as one of the most effective and cheapest methods to reduce electricity consumption of lighting. The quality of daylight also contributes to comfort. However, the optimization between windows gaining daylight and preventing from heat losses must be done. (Bauer et al., 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 lamp efficiency. Decreasing the amount of luminaries can cut down the electricity consumption. Artificial lighting should be used only when and where needed. This is especially true in hospitals and offices, and 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)

The 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 to 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 automation systems are advantageous when making an energy sparing building.

These systems, besides optimal energy use, also enable safe, economical and appropriate operation of target device or system and lead to optimized indoor air conditions. As a result, the building can be more energy efficient by being implemented with "smarter" technology.

Smart electric power management systems (EPMS) ensure safe and reliable power quality, and bring 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 an 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 in a 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 in 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 the lighting accordingly. Usually, the occupancy sensors sense e.g. body heat, movement, sound or combination of these, and switch the 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 also be installed, 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 time, when electricity demand is at peak. (Sinopoli, 2010)

HVAC control systems can also use these kinds 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 the operation rate of the 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 shuts HVAC off, having a clear difference between cooling and heating. (Turner & Doty, 2007) ■

6 Renewable energy in buildings

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

As mentioned in earlier chapters, the building sector consumes a substantial part of total energy use. Especially heating energy is mainly 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, electricity generation is one of the main contributors to 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)

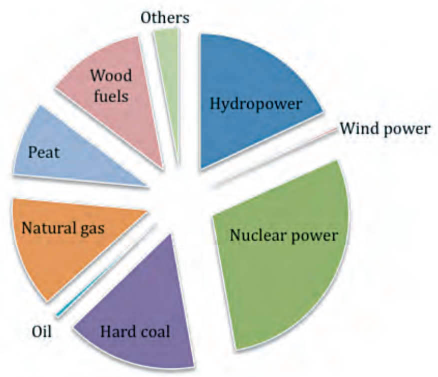


Figure 3. Supply of electricity by energy source in Finland 2007 (Tilastokeskus, 2008)

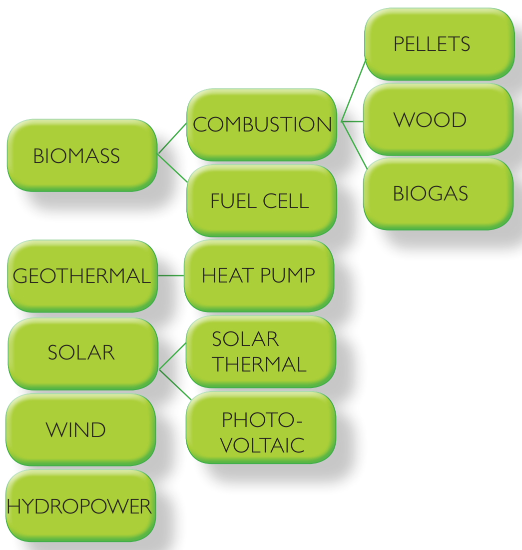


Figure 4. Common renewable energy sources in buildings

6.1 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 by anaerobic digestion or syngas produced by gasification process. Liquid fuels can include ethanol, biodiesel and bio-oil. These fuels can be combusted and used to heat a boiler, for instance. (Twidell & Weir, 2006)

Especially in the 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 et al, 2010)

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

6.2 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 a compressor. (Kreider, 2001)

The 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 a 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 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, 2001)

6.3 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 (PV) cells. In colder climates, the largest 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 the 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 PV cells usually varies between 10 – 20 %. Cells can be placed on roofs, walls and other building structures. PV cells have become popular in southern countries, but increasing attention is gained also in northern areas. 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 hot water or circulated in water circulating space heating system, such as floor heating and 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 as direct or indirect systems. In direct system, water flows through the collector and water is heated up. In indirect systems, a fluid (usually freezing resistant fluid) flows through the collector and releases absorbed heat 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 larger the area, the larger amount of solar radiation can be utilized. (Bauer et al., 2010)

6.4 Wind

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

With sufficient wind conditions, wind power can provide auxiliary electricity for building applications. There are several different wind turbine sizes available on the market. Some special applications where wind mills can be used beside conventional electricity production are water pumps and ice making (cooling storage). (Manwell et al., 2009)

6.5 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 also be stored. In addition, it is possible to use energy from storage during peak consumption hours, when the price of electricity is higher. Generally, energy storages can be distinguished to thermal, chemical, electrical and mechanical storages. Biological storage is an option, but it is not discussed in this context.

Thermal storage

Thermal storage is often integrated to the building structure. As discussed in earlier chapters, the 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 be 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 change materials having e.g. higher melting points than water can also be 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 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 turbine, or cheaper electricity from the grid can be stored during nighttime. Stored eectricity can then be used during peak consumption hours. Electric car battery can also work as electric storage. (Twidell & Weir, 2006)

Mechanical storage

Mechanical storage systems are usually of a larger scale and are more expensive. However, larger commercial buildings can use mechanical storages in some cases.

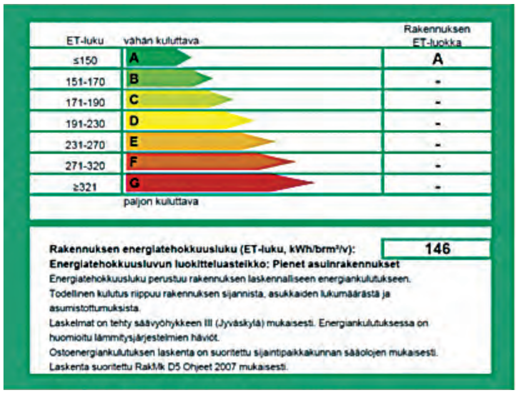
Firstly, water can be pumped to elevated water reservoirs by using electrical pumps. During immediate demand or peak consumption hours, or when electricity is not produced from renewable sources, water can be led out from reservoirs in order to run a turbine and produce electricity. Mechanical storage systems can include also flywheels and compressed air storages. (Twidell & Weir, 2006) ■

7 Energy audits and economic considerations

In European countries, the EU Energy Efficiency Directive is pushing us towards more and more EeBs. According to the Directive, energy efficiency must be improved not only in new buildings, but also in existing buildings. The Directive also requires that public buildings must be almost zero energy buildings by the year 2019. Every new building must be an almost zero energy buildings by the end of 2020. (Ympäristöministeriö, 2012a)

In this a challenging problem of EeBs in future, and energy audits play an important role. By performing energy audits, customers can get information about the energy consumption of the building. The 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. At the end, buildings can be distinguished to different energy classes according to their energy consumption. (Tuner & 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)). The energy efficiency of the building is described with the 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 and G the most energy consuming one. Conventional buildings generally have energy class of D in Finland. Different forms of energy have different coefficient and are thus related to determination of the E number. Generally, every new building in Finland requires an energy audit. The picture above illustrates a Finnish energy audit. (Ympäristöministeriö, 2012b)

Many customers and companies are interested in EeBs, because of economic advantages. Indeed, EeBs usually have higher initial costs and pay-back in most of the cases. At the same time, the image and value of the building, and the occupants' health is improved. In the case that the building generates excess electricity, it is possible to sell it to the common grid. It is foreseen that this kind of procedure will be common in the future. Therefore, with minimal consumption of energy, it can be also possible to integrate economic evaluations to the 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 a commonly used tool. In addition, Life Cycle Assessment is an effective tool evaluating the economic performance of the system. Life Cycle Assessment e.g. for heating system includes purchase, maintenance, repairing, and operation and energy costs, providing thus an approach for long term implications. (CIBSE, 2004) ■

8 Occupant requirements and indoor air

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

An adequate indoor air and a satisfied consumer are important, because humans spend most of their life in buildings. It can be said that many health problems origin from building materials and indoor 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

An adequate temperature in a room is essential. To be more precise, the correct term for inside temperature we are sensing by 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 a 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. (Ympäristö ja Terveys, 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. (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 to 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 deteriorated 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 depending on the application. The amount of light affects to the "mood" and also the productivity of work. Especially daylight is very appropriate for this purpose. In office buildings, approximately 500 lux illuminance level should be achieved. However, some special tasks e.g. in hospitals may require illuminance levels of 1000 lux. It is also proven that adequate amount of daylight can increase working mood and well-being of occupants. (Bauer et al., 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. (Ympäristö ja Terveys, 2009)

Humidity

Too high or too low humidity levels can bring several problems for building structure and occupants. The 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 requires attention. (Ympäristö ja Terveys, 2009)

Too high moisture level in a room can promote the growth of mold and other microorganisms, 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. The building envelope must also have vapor and air barriers. It is also important to place 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 a room's air. (Ympäristö ja Terveys, 2009)

Too low moisture content in a room can lead to problems with the mucous membrane of the respiratory system and can contribute to eye irritation. Dry air can lead to cracking of wood materials and shrinking of furniture and contribute 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, a humidifier adds to the energy consumption of the building. (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. EeB should minimize the amount of unfiltered air taken from outside. Appropriate building materials and efficient ventilation also play an important role in removing particles form building air. (Sisäilmayhdistys, 2012)

Microbes

Microbes are everywhere in building structures and air. Excessive amount of moisture and adequate temperature can promote the further growth of microorganisms in building structures. Microorganisms, such as yeasts, can cause harmful odor, toxic compounds, particles and damage to building structures. Keeping windows closed prevents microorganisms from to entering the building. Therefore, removing excess moisture from buildings by ventilation is very important. Moisture also should not condense on thermal bridges, and lower temperature can slow down the growth of microbes. (Ympäristö ja Terveys, 2009) ■

9 Types of energy efficient buildings

The tools, actions and technologies presented in this report are instrumental to building EeBs. At the moment, four classes of EeBs can be distinguished:

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

All these building types consume much less energy than conventional ones, and have also better indoor air quality. In Finland, construction of low energy buildings and passive houses is no longer rare. Table 2 below presents reference values for energy consumption in low energy buildings and passive houses 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/m²/yr)	100 - 110	26 - 50	15 - 25
Warm domestic water (kWh/m²/yr)	30	20 - 25	20 - 25
Electricity consumption of devices (kWh/m²/yr)	25 - 35	30 - 35	25 - 35

As we can see from Table 2, in Finland, low energy building consumes much less energy than a conventional building. The total heating energy required in the low energy building is around 60 - 90 kWh/m²/a, while conventional buildings consume usually more than 120 kWh/m²/a.

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

- Southern Finland $\leq$ 130 kWh/m²/a
- Central Finland $\leq$ 135 kWh/m²/a
- Northern Finland $\leq$ 140 kWh/m²/a

Passive houses in Finland must also have a maximum air leakage number of $n_{50} \leq 0{,}6$ 1/h. The design of passive houses starts from the definition of location and orientation. A typical passive house has a thermally heavy structure and compact shape. It also uses solar energy passively and contains passive cooling methods such as shading. Special attention is paid to heating and ventilation systems and heat losses. According to the Technical Research Centre of Finland (VTT), construction costs of passive house (excluding the price of the site) can be approximately 5 – 10 % higher than those of conventional buildings. Table 3 presents general reference values for the building envelope in Finland. (Motiva, 2012)

The definition of a zero energy building is that, on a yearly basis, it consumes the same amount of energy that it produces. The ultimate goal of building energy efficiency is a plus energy build-

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

ing, which produces yearly more energy than it 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. Therefore, even for plus energy buildings, the communication with the national grid is essential. (Motiva, 2012) ■

10 Conclusions

Energy efficiency buildings (EeBs) save fuels, heating, cooling and electric energy, while provide an appropriate indoor air quality. By saving energy in a building, an effort for a better environment is 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 EeB should start from considering the location, orientation and size of the building. Local renewable energy resources and climatic conditions must also be identified, as well as possibilities of using free energy. At the end, with the mixture and careful design of technological and architectural solutions, considering consumer habits, an energy saving building can be built. 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 an energy audit.

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 a "must do" in all cases. The goal of an EeB is a low energy building, passive house, zero energy building or, ultimately, a plus energy building.

Cooperation between engineers, architects and building occupants is essential. An optimum between energy efficient solutions must be found because any solution can have its own advantages and disadvantages. Ultimately, the building should be able to ensure a comfortable atmosphere, while not closing too many options for clients to design the building interior when occupied. ■

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