Energy-Saving Methods and Principles of Energy-Efficient Concept Design in the Northern Hemisphere

Yulia A. Kononova and Zhang X. Ning

***Abstract*—As it is known, people are spending an enormous amount of energy every day of their lives. Because of the uncontrolled energy usage, people have to increase energy production, that causes such problems as climate changes, environment pollution, animals' extinction, and lack of energy sources. Nevertheless, nowadays, architectural development is getting faster, and there are kinds of buildings, which can save or even produce energy, combining several energy-saving principles. The main aim of this research is to provide information that helps to apply energy-saving methods while designing an environment-friendly building. The research methodology requires gathering relevant information from literature, building guidelines documents and previous research works in order to analyze it and sum up into a material that can be applied to energy-efficient building design. To mark results it should be noted that the usage of all the energy-saving methods applied to a design project of building results in ultra-low energy buildings that require little energy for space heating or cooling. As a conclusion it can be stated that developing methods of passive house design can decrease the need of energy production, which is an important problem that has to be solved in order to save planet sources and decrease environment pollution.**

***Index Terms*—Accumulation, energy-efficient building, storage, superinsulation, passive house.**

I. Introduction

Passive house is a building with extremely minimized heat loss, optimally oriented to the cardinal points, blending in with the surrounding landscape. Ideally, passive house is supposed to be an independent energy system, providing comfortable temperature inside of which does not require any expenses. All the energy for human activity is to be produced inside the house. An indicator of the object efficiency is heat loss per square meter (kWh/m^2) per year or per heating period. Usual losses amount is around 100-120 kWh/m^2. In European countries a rate of about 10 kWh/m^2 is set [1]. The most effective are those projects that are designed with combination of several passive systems. Energy saving has been researched in a considerable number of works, for example, "Engineering methods for energy efficiency and environment quality increasing problems solving" by G.Berner, where he gives guidelines for engineers, researchers, investors dealing with energy and environmental protection. Methodology: landscape usage; passive cooling and ventilation: cross ventilation, stack effect, wind towers, evaporative cooling, earth coupling; structure insulation; passive heating. When designing a passive house it is required to follow certain rules and principles. Following methods and principles are given according to climate characteristics of Northern Hemisphere.

Manuscript received April 20, 2017; revised August 25, 2017. This work was supported in part by College of International Education of Harbin Institute of Technology.

The authors are with the Architectural Creation and Research Institute of Harbin Institute of Technology, Heilongjiang province, Harbin, China (e-mail: julia_kononovalist.ru, 22199103@163.com).

II. Climatic Features Are to Be Considered

The first problem to be solved while designing an energy efficient building is its location on the site relative to the cardinal directions. Typically, the most "blank" wall faces north, while the biggest amount of windows overlook south. No less important are the climate, topography and flora of the area in which the house is located.

The climate can be conventionally divided into four types: dry-hot, humid-hot, temperate and cold. Taking some steps of improvement in each of them can create its own microclimate, which would be perfect for living and saving sources.

Therefore, in regions with temperate climate, special attention is recommended to be given to protection the building from winter winds and accumulation of sun warming properties during cold period of year. However, the solar heat that is to be collected in winter through windows and the roof in the summer can significantly increase costs for air conditioning. To resist the absorption of heat during the hot time of year shading is able to help. With the same weather conditions, air temperature above ground shaded by a tree, and air temperature above an open space of paved road can have 14 ℃ difference [2].

Inhabitants of humid and hot regions should take care of dense shade to cool roofs, walls and Windows, and eliminate plants that require frequent watering from the landscape.

In humid-hot regions, it is necessary to allow the wind to cool houses in a natural way — the area should be designed so that in summer the wind would be blowing towards the house.

In addition, ponds or other water reservoir helps with cooling and humidifying the air nearby the building.

Deciduous trees are usually planted to block the sun's heat around the house. For shading porches, patios and other sites it is recommended the use dense shrubs and fences with climbing plants, e.g., grapes. However, you should avoid planting plants with dense foliage directly next to the house — this increases the humidity inside of it.

In cold regions, a problem of wind protection arises. The best method to keep the nearest area away from strong winds using landscape is to plant windbreaks on the North and West sides and to let the southern area of the site open. Dense evergreen trees and shrubs are most often for this purpose, they should be planted on the North and North-West at the distance of 2 to 5 times their size at full growth.

Additional lanes of low shrub on the most windward side will help to reduce the amount of snow blown by wind.

The height of the windfall has a direct impact on its efficiency: the higher it is, the more it reduces wind speed. The best windbreaks block wind close to the ground, using trees and shrubs with low crowns [3].

Trees and shrubs are often planted together to block wind from the ground to the tops of the trees. Evergreen trees planted next to wall, fence or earth embankment can deflect or lift the wind over the house.

In addition to large windbreaks, planting shrubs and climbing plants near house creates an air space providing thermal insulation of the house in both winter and summer. The distance between the wall of the house and an adult plant should not be less than 30 cm.

III. Shape of the Building

It is generally recommended to design a compact, close to square shape of the building plan with a minimum perimeter of exterior walls. The longer side should be oriented from West to East. An indicator of compactness is the coefficient equal to the ratio of the area of external walls to the internal volume of the building. Cylindrical, hemispherical and other non-traditional forms can be used to reduce the surface of the outer walls. Increasing the insulating properties of the building enclosing elements is possible by the use of better insulating materials, the elimination of infiltration and ventilation through doors and windows openings, the use of triple glazing in cold regions. The differentiation of spaces according to energy needs and the mode of maintaining also give big effect. Less heated spaces (closets, pantries, bathrooms, garages, etc.) are recommended to be placed along the Northern wall as buffer elements.

IV. Landscape Usage

1) North side of house is to be closed (green spaces, stone fence) in order to protect building’s yard, roof and wall’s surfaces from cold winter wind. A hill also can be used for this purpose, if to place a house on its south.

2) Southern part of the house is to be open in order to receive as much sunlight in winter as possible.

V. Space Planning

1) Small footprint of the building is helpful to prevent over loss of heat. The more surfaces a house has the bigger are its heat losses in winter.

2) Absence of protruding volumes (terraces, balconies, eaves) is also useful for buildings in cold regions. Nevertheless, usage of this kind of structures while designing a building in warm regions helps to prevent overheating.

3) Functional zoning. An important requirement in the design of a passive house is a competent zoning. It must enforce the terms of insolation for sanitary comfort.

VI. Passive Cooling and Ventilation

1) Ventilation system with heat recuperation. An air heat exchanger is a device that provides recovery of effluent gases’ heat. Effluent air changes temperature of supplied air before going out from building, depending on its temperature: if temperature of the effluent air is higher than temperature of the supplied air, then the effluent air heats the supplied air up; if temperature of the effluent air is higher than temperature of the supplied air, it works opposite way and the effluent air cools the supplied air down. Heat exchangers are designed in a way that provides air streams separation to prevent their mixing. The heat exchange between the fluids proceeds through a separating wall, the direction of air flows is not changed. Through the use of air heat exchanger the executive air passes up to 70 % of its heat to the supplied air [4].

2) The use of ground heat exchangers - heat pumps. Heat pumps allow collecting free energy from land around the building, stored in soil, groundwater and air. A pipe, which takes a role of the first circuit, is placed in a well or buried directly into ground. Non-freezing heat-transfer fluid moves inside of the pipe, temperature of the heat-transfer fluid is raised to the similar characteristics of land (about 8 degrees) and enters the second circuit. The second circuit takes heat from the liquid. While circulating the Freon starts to boil and to be converted into gas, which is being sent to a compressor after. After its being compressed up to 24-28 atmospheres, thereby increasing the temperature to 70-80 degrees. At this work stage, energy concentrates in one small clot. This increases the temperature. The heated gas is supplied to the third circuit, which is represented by water boiler or even a heating system of the building. While heat transfer possible losses are around 10-15 degrees, but they are not significant. After, when Freon cools down, pressure becomes decreased, and it turns into a liquid state again. When its temperature gets to 2-3 degrees it goes back to the second circuit. The cycle is being repeated again and again. No harmful emissions while this process: Since heat pump requires only the electricity needed for operation of the compressor, only 25% of the energy required for heating and preparation of hot water is provided by electric current, and the remaining 75% is extracted from the environment [5].

This system works both ways in template regions. In winter it heats the building, and in summer it works opposite way cooling it down.

3) Cross ventilation. If to place inlets and outlets to optimize the path air follows through the building when placing ventilation, it will be more effective than ventilation that does not pass through the whole space [6]. If windows and mechanical ventilation devises are situated in opposite parts of a building it will make a natural flow through room’s structure [7].

4) Stack effect. The principle of stuck effect is widely used around the world at factories and different heating systems based on solid fuel. To achieve the stuck effect two opening should be done; one of them is to be placed high in the building, and another one low in the building. This way is based on the fact that warmer air naturally goes up, while cooler air goes down, hence when outside is hotter than inside the inside cooler air will go out from the opening that is placed low in the building; and when it is cooler outside, then the inside warmer air will rise up and go out from the opening high in the building. These air movements course natural

ventilation [8];

5) Wind towers. Ideally, the opening at the top and the bottom should be the same as the cross-sectional flow area of the vertical shaft [9];

6) Evaporative air-cooling is possible through the evaporation of water, when water molecules receive heat and take it away from the building while evaporating;

7) Nocturnal cooling. As at night external temperature becomes lower, than building surface temperature, the building starts to lose its heat, which moves towards to a cooler place [10];

8) Using solar panels. Usage of solar collectors can reduce cost of hot water heating by two thirds, the cost of heating by 30% per year. However, it should be noticed that in harsh climate, the solar system is rather auxiliary and should be reserved or supported by other sources of heat: electric heating, solid fuel boiler, etc. [11].

9) Use of wind energy. The main part of wind energy cost is determined by the initial cost of wind turbines construction Wind generators do not consume fossil fuels in the process of operation. A wind turbine of 1 MW working for 20 years allows saving about 29 thousand tons of coal or 92 thousand barrels of oil [12].

10) Heat accumulators. When using a storage tank, the efficiency of boilers operating on solid fuel, reaches up to 84%, and allows saving 20-30% of energy by smoothing the burning peaks. The accumulator also keeps the "surplus" of energy in times of hot water demand recession (at night, in the middle of day) and therefore releases it during the period of active demand (morning, evening), allowing to avoid waiting for the water to become hot. The storage tank is a container, insulated on all sides with polyurethane with a thickness of 80-100 mm, where several heat water exchangers are integrated. The accumulator provides the ability to install one or several electro tubular electric heaters ranging from 3 kW to 24 kW. A storage tank with volume from 250 to 2000 l is to be connected to the boiler and accumulate thermal energy from 14 to 116 kW, as follows [13]. The heat accumulator can be used instead of water boiler (actually prices are similar), this is especially true for solid-fuel boilers, in addition to the water heating function, it provides heat accumulation for heating system.

VII. Façade Design

1) Sun protection (canopies, cornices, etc.) in summer allows keeping comfortable microclimate inside a building without using auxiliary engineering devices for it, such as air conditioner.

2) Minimal glazing on the North side (10%)

3) Maximum glazing on the South side (70 %) helps to receive as much solar radiation as possible, what is useful in winter.

4) 20% of glazing on the East side.

5)10% of glazing on the West side.

VIII. Energy-efficient Heating and Heat Accumulation

1) Presence of massive structures, such as thick walls, inside a house helps to accumulate solar heat during daytime; at night, when air temperature becomes lower than the wall surface temperature, the wall starts to give the accumulated heat to the surrounding air, keeping comfort microclimate in a building.

2) Planning of shallow areas

3) Storage of "internal heat sources" energy

Radiant floor heating is a comfortable and efficient heating system, its 25-30% more efficient than usage of radiators. Uniform heat distribution allows the use of lower temperatures. The flow temperature in radiant floors is 30-50 ℃, depending on floor covering and heat loss of the room depending on time of year. Modern design solutions allow applying water radiant floor heating in all types of buildings. Depending on ceilings' type, floor requirements and structural features of the premises, different types of radiant floor heating are to be used: concrete system or nonconcrete system for weak beams. Application of room automation saves up to 15% of heat energy. The use of weather-automation gives another 15% of savings [14].

4) Condensing boilers. The name "condensing" is used because of their ability to select so-called "hidden" heat of condensation of water vapor contained in the combustion products from products of combustion. Condensing technology allows to reduce gas consumption up to 35% [15]. In low-temperature systems, for example in the system "water warm floor", these boilers are particularly efficient because there are perfect conditions for condensation created, since the temperature of the return water is always below the dew point (i.e., below 40-50 ℃). When included in a low-temperature system (for example "water warm floor") condensing boilers can reduce gas consumption up to 35% per year, respectively, reduce up to 35% of gas cost.

IX. Structure Insulation

1) High-quality exterior insulation. All masonry joints must be sealed in order to prevent additional heat loss.

2) Tightness of the external building envelope (airtightness).

3) Building foundation should be a solid one - piece plate, which is stacked on the insulation layer. A heat transfer coefficient of foundation should not exceed 0.15 W/m2K, walls and roofs are desired not to exceed 0.1 W/m2K.

4) Roof structure also needs to be made sealed and thoroughly insulated. Roof is one of the most important parts of a building to be insulated. Warm air naturally moves up inside a building, it means that air temperature close to ceiling is higher than temperature close to floor. If not to provide proper insulation there comes risk that this heat is going to be lost through buildings' roof.

5) Windows should be three-glazed with insulating inert gas between the glass-layers and low-emission coating on their surface. All these measures allow achieving 0.8 W/m^2K heat transfer coefficient of windows [16].

Following this changes a residential house becomes converted into so-called "thermos" (with the rejection of traditional ventilation, through which there is significant heat loss).

X. House Orientation

When designing energy efficient house it is important to consider its orientation as it affects the microclimate in the premises. There are following fundamental requirements for orientating houses to the cardinals.

1) In houses, which are situated to the North of 50 degrees North latitude, bedrooms are recommended to be oriented to the South and South-East, and dining rooms, living rooms and hallways to be oriented to the South, Southeast and East. This way allows collecting more solar heat in bedrooms, a little bit less in dining rooms, hallways and living rooms. It is necessary to provide comfortable temperatures in those rooms of a building, where people spent the biggest time of a day. In houses that are to the South of 50 degrees North latitude, bedrooms are good to be oriented to their South, and dining rooms, living rooms and hallways to the South and Southeast following the same purpose. Orientation of non-residential premises is possible at any part of the horizon as habitants do not spend long time in this kind of rooms.

2) House entrance should be on the leeward side, hence wind will not take warm air while habitants entering or leaving.

3) Windows oriented to the North should be small (two times smaller than the rest windows of a building) as they cannot receive much solar heat during daytime, they can course auxiliary heat loss. However, it can be possible to do without them also;

X. Efficient Use of Heating Devices

Following are the main of the simplest techniques of efficient use of heating devices:

1) Covering the heater with decorative plates, curtains reduces the amount of heating income by 10-12 per cent;

2) Paint with oil paint – reduction of heat income 6.5 per cent (for cast iron radiators even more, up to 13 per cent).

3) Installation of the reflector for a heating appliance (e.g. a reflective insulation, like laid or aluminum foil) increases the efficiency of heating of device by 20-30 per cent;

4) Flushing of the heating system before heating season can improve its performance by 15-40 per cent;

5) Furniture in rooms needs to be placed so that there is no obstruction of the circulation of warm air from the battery.

XI. Conclusion

Assembling mentioned technologies and methods into one architectural creature prevents extra energy loss and provides auxiliary sources for heat supply and accumulation. Realizing the concept is environment friendly and provides with following benefits. It must be noted that an energy efficient house is 15-20%more expensive than a traditional one. However, the savings in operation allow recouping these costs in 7-10 years. Additional costs for insulation can be compensated by building's compactness. Additionally, it is possible to save energy while exploitation of the building using appropriate engineering equipment (heat pumps, solar collectors, solar panels, wind turbines, etc.), working with alternative sources of energy (heat of the earth and sun, wind, etc.). These systems in an energy efficient house are not required and can increase the value of the building by 10-30%, but they are desirable.

References

[1] G. Badyin, *Building and Reconstruction of Small Energy-efficient Building*, Saint Petersburg: BHV-Petersburg, 2013, ch. 6.

[2] F. Wolfgang and A Yelokhov, "The main aspects of passive house design," Building Universities Association, p. 144, 2008.

[3] Edipresse Ukraine, "Landscape for energy efficient house," *Ukraine* 2013.

[4] Y. A. Tabunschicov, M. M. Brodach, and N. V. Shilkin, *Energy Efficient Buildings*, Moscow, 2003, pp. 160-175.

[5] D. Ray and D. McMichel, *Heat pumps, Re-edition*, Moscow, Energoizdat, 1982, ch. 2.

[6] H. Skistad, "Displacement ventilation in non-industrial buildings," *AVOK*, pp. 55-58, 2006.

[7] Autodesk education community. Natural ventilation. *Sustainability Workshop*. [Online]. Available: http://sustainabilityworkshop.autodesk.com

[8] C. Wright, "Convective flow due to stack effect," *Consulting, LLC*, p. 1.

[9] A. A. W. A. Rizk, M. A. M. A. Ghaffar, and M. Hefnawy, "The effect of wind-catchers (el-Malaqef) on the internal natural ventilation in hot climates with special reference to Egypt: A study on small physical model," *Asyut*, pp. 1-3, 2016.

[10] D. Darling, "Encyclopedia of alternative energy," 2005.

[11] N. V. Kharchenko, *Individual Solar Facilities*, Moscow, Energoatomizdat, 1991, ch. 1.

[12] E. Osokin, "Current characteristics of hydro and wind energy. Their influence on environment," *Saint Petersburg*, SZTU, p. 3, 2011.

[13] Online magazine ESKO, "Heat accumulators," no. 7, July 2008.

[14] E. G. Malyavina, *Heat Losses in Buildings: Reference Guide*, Moscow, 2011, ch. 7.

[15] V. N. Karpov, *Hot-water Heating Systems of High-rise Buildings. Technical Design Guidelines*, Moscow, October 2010, ch. 5.

[16] E. P. Matvee and V. V. Meshechek, "Technical solutions for structures thermal protection and strengthening in residential and public buildings," Moscow, 1998.

Yulia A. Kononova was in Russia, Krasnoyarskiy Krai, Krasnoyarsk city, on Sept. 23, 1992. She got the bachelor's degree in architecture, Siberian Federal University, Krasnoyarskiy Krai, Krasnoyarsk city, Russia in 2014, the master's degree in architecture, Harbin Institute of Technology, Harbin, Heilongjiang Province, China – in process.

She has ever worked in Architect (Universalproject), Krasnoyarsk, Russia in from 2012b to 2014; Intern in ADRI of Harbin Institute of technology, Heilongjiang province, China since 2015. Her current research lies in winter Olympic architecture.