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# Energy-Efficient Building Design in the Context of Building Life Cycle

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Additional information is available at the end of the chapter

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## Abstract

Energy is one of the most important catalysts in wealth generation, economic growth, and social development in all countries. Buildings have a significant share in total energy consumed globally; therefore, they have a profound impact upon the environment. Energy is used in every stage of building life cycle (these stages are choice of locality, architectural design, structural systems and material selection, building construction, usage and maintenance, demolition, reuse-regain-recycle, and waste disposal). According to World Watch Institute data, buildings are responsible for the annual consumption of 40% of the world's energy. Energy consumption of buildings can be reduced significantly in every stage of a building life cycle. This study investigated the energy-efficient methods in building life cycle. In this context, we give information about the life cycle of building and explain energy-efficient guiding principles in life cycle stages.

**Keywords:** building—life cycle, building—energy consumption, energy efficiency in buildings, energy and environment

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## 1. Introduction

Buildings consume energy at different levels in every stage of life cycle. Approximately half of all nonrenewable resources (water, energy, and raw materials) mankind consumes are used in construction. Contemporary human civilization depends on buildings and what they contain for its continued existence, and yet our planet cannot support the current level of resource consumption associated with them [1].

Construction also has a major impact on the environment in its consumption of energy. For example, building materials occupy a great share of this consumption. The large bulk of materials used consume a great deal of energy for transport [2].

There is a growing concern about energy consumption in buildings and its possible adverse impacts on the environment. These are issues that the building professions in the whole world have to address [3].

Energy consumption is rapidly increasing due to the increase in population and urbanization. Residential energy requirements vary from region to region, depending on climate, dwelling type, and level of development [4]. The construction activities consume 38% of the globally used energy every year [5]. There is a growing concern about energy consumption in buildings and its possible adverse impacts on the environment. These are issues that the building professions in the whole world have to address [6].

Buildings consume energy at different levels and different aims in every stage of the life cycle. In an operating phase, a building with at least a 50-year lifespan, energy used for production of materials, transportation, and construction, "at least five times" as is required in the amount of energy use and operating phases. A large part of the energy (35–60%) is used for heating, air-conditioning, ventilation, and artificial lighting at this stage. Energy-efficient approaches that have the potential to significant energy economy, most of the buildings if you live a long time considered more than 50 years. Even if only to focus on the use and operation phase is very important [7].

## 2. Methods for ensuring energy efficiency in buildings

It is not possible to bring recommendations of solution that can procure energy efficiency for all buildings. As the function, system, position, and importance of a building changes from building to building, the ways of solution providing energy efficiency will also change. Therefore, a conscious approach needs to be developed in order to reach the right solution at the stage of architectural design through enabling necessary data. In the end, the product to be obtained must be aimed to have the quality of being more efficient, in other words, spending less resource within a longer period of time to perform the same action.

There are very different applications targeting the decrease of energy consumption of buildings. Considering energy consumption in each phase of structuring is achieved with the analysis of building life cycle.

In this respect, we need to know the life cycle of building. Building life cycle is divided into three main phases such as the prebuilding phase, building phase, and postbuilding phase. These phases have some processes. Prebuilding phase includes the appropriate site selection, site planning, building form, building plan, and appropriate space organization, building envelope design choosing energy-efficient building materials, energy-efficient landscape design, obtaining raw materials for building material, manufacturing, and transporting them. The building phase includes the construction and usage processes of the building. The postbuilding phase is the phase following the completion of building usage. In this phase, we have the demolition, recycling, and wipe-out of the building.

The methods applied so as to fulfill the energy efficiency of buildings depending upon life cycle phases.

## 2.1. Energy-efficient designing methods in the prebuilding phase

The prebuilding phase includes the choice of the space where construction is to be built, the design of the building, the choice of building materials, obtaining raw materials for building material, manufacturing, and transporting them. In these processes, the strategies have been explained with significant energy saving in building life cycle such as the appropriate site selection, site planning, building form, building plan and appropriate space organization, the design of building envelope, the choice of building material, landscape design, and benefiting from renewable energy resources in sequence. These strategies are explained below.

### 2.1.1. *Appropriate site selection*

The locations of the hemisphere, slope, and aspect are important design parameters. Location of the building determines the microclimate conditions which has very important role in building energy efficiency, as it is important for learning, climatic values such as sun radiation, air temperature, air circulation, and humidity, which effect energy costs [8].

The site of building and distance between other buildings are one of the most important design parameters, which affect sun radiation amount and air circulation velocity around the buildings. For this reason, the site of the building in the area should be determined to benefit and defend from the renewable energy resources like sun and wind [8].

In order to provide adequate protection from the prevailing wind and sun, the orientation of buildings on the land needs to be appropriate to the climatic conditions of the region. In cold regions, lower overnight temperatures cause colder, denser air to accumulate in hollows and valleys. Therefore, in cold regions it is advisable to position buildings on hillsides rather than in valleys. Such sloping areas are not affected by cold wind as much as valleys and benefit from more direct as shown in **Figure 1** [9].

The topography of the location of the building is important because of the effect the angle of incidence of solar radiation, slope, and orientation of the land in terms of the use of daylight and natural ventilation, solar radiation. If the settlement will be sloping, gained solar radiation energy is reduced in summer, and gained solar radiation energy increases in winter. Therefore, the slope of the land, the amount of incoming solar radiation, and the latitude are very important parameters [11].

It is well known that a south slope is warmer and has the longest growing season in the northern hemisphere. When a choice of site is available, a south slope is still the best for most building types. In the winter, the south slope is the warmest land due to two reasons: the south slope receives the most solar energy on each square foot of land because it most directly faces the winter sun. The south slope will also experience the least shading because objects cast their shortest shadows on south slopes [12].

**Figure 2a** illustrates the variation in microclimate with different slope orientations. The south slope gets the most sun and is the warmest in the winter while the west slope is the hottest in the summer. The north slope is the shadiest and coldest, while the hilltop is the windiest location. Low areas tend to be cooler than slopes because cold air drains into them and collects there [12].

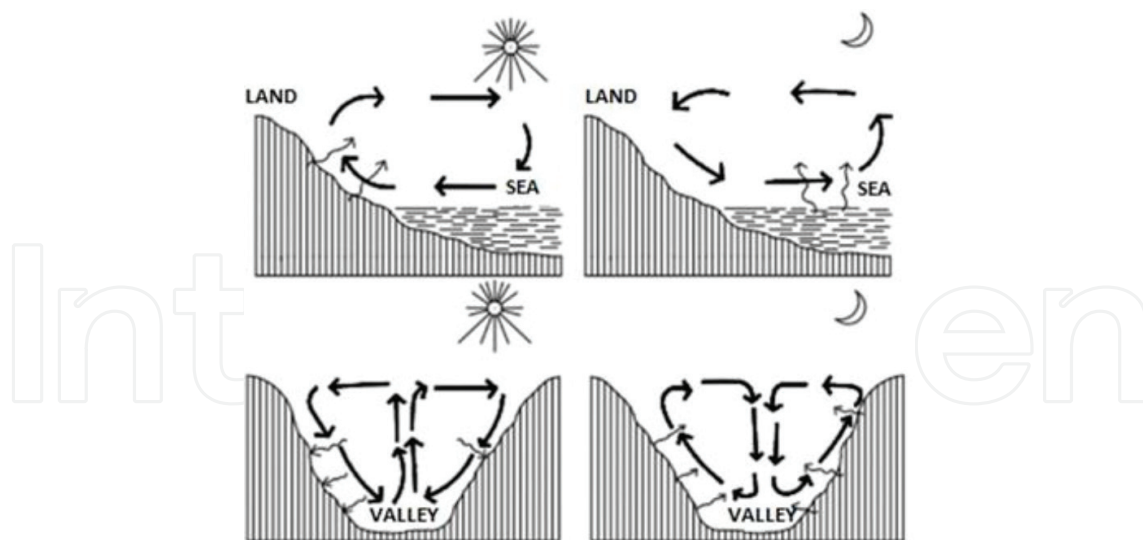


Figure 1. The change of climate conditions surrounding the building depending on the location of the building [10].

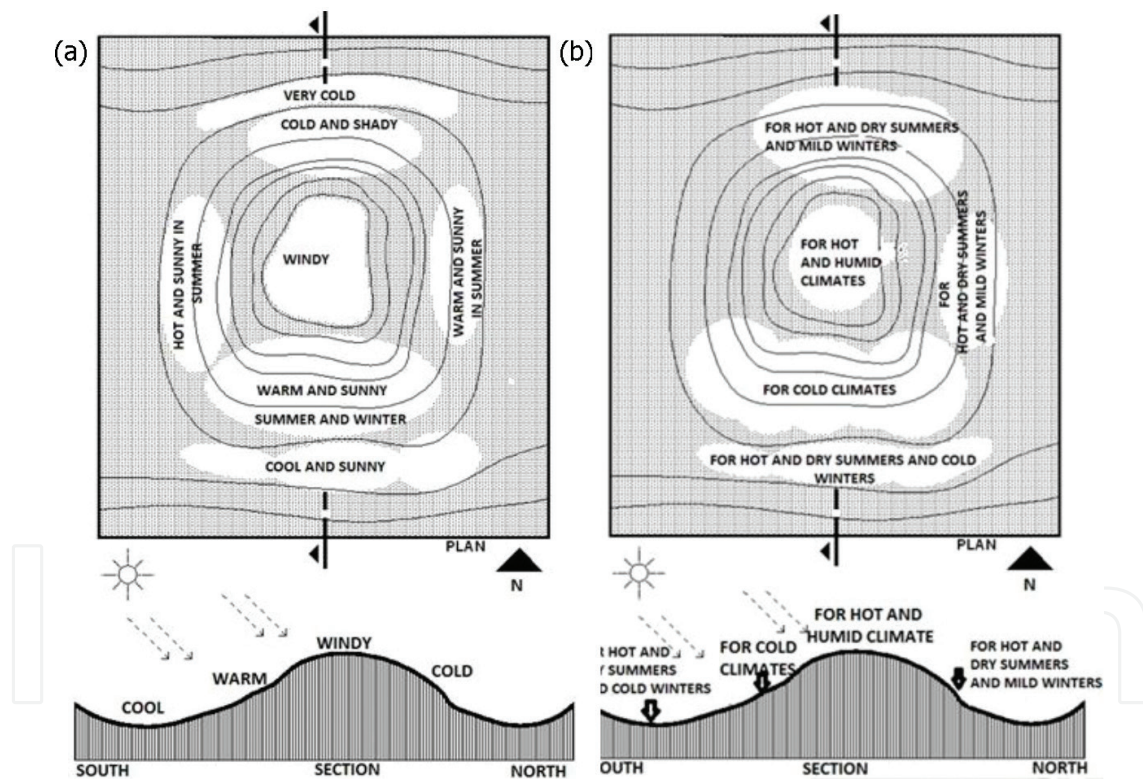


Figure 2. Suitable land for settlement according to the different climate zones [12]. (a) Microclimate around a hill; and (b) preferred building sites around a hill in response to climate for envelope-dominated buildings.

The best side site for a building on hilly land depends on both climate and building type. For envelope-dominated buildings, such as residences and small office buildings, the climate would suggest the sites as shown in **Figure 2b**.

For example, in cold climates, south slopes maximize solar collection and are shielded from cold northern winds. Avoid the windy hilltops and low-lying areas that collect pools of cold



air. In hot and dry climates, build in low-lying areas that collect cool air. If winters are very cold, build on bottom of south slope. If winters are mild, build on the north or east slope, but in all cases avoid the west slopes. In hot and humid climates, maximize natural ventilation by building on hilltops but avoid the west side of hilltops because of the hot afternoon sun. Also the cool low-lying areas are appropriate especially to the north of hills. For internally dominated buildings, such as large office buildings that require little if any solar heating, the north and northeast slopes are best [12].

In **Figure 2**, according to the information described above, according to the different climate zones, appropriate residential areas are shown on a theoretical terrain. In terms of climatic effects, the part of the slope that has the mildest qualities for each slope is defined as “thermal belt” [13].

Building altitude leads to differentiation of solar radiation values. As we go above the sea level, we get an increase in solar radiation values. The reason for this increase is dealt with atmospheric conditions, clarity of the atmosphere and shortening of the distance taken. In return, for the increase in solar radiation values, as we go above the sea level, we get a decline in the air temperature. With the increase of altitude, gale force also increases, which leads to the increase of heat loss in the building [14].

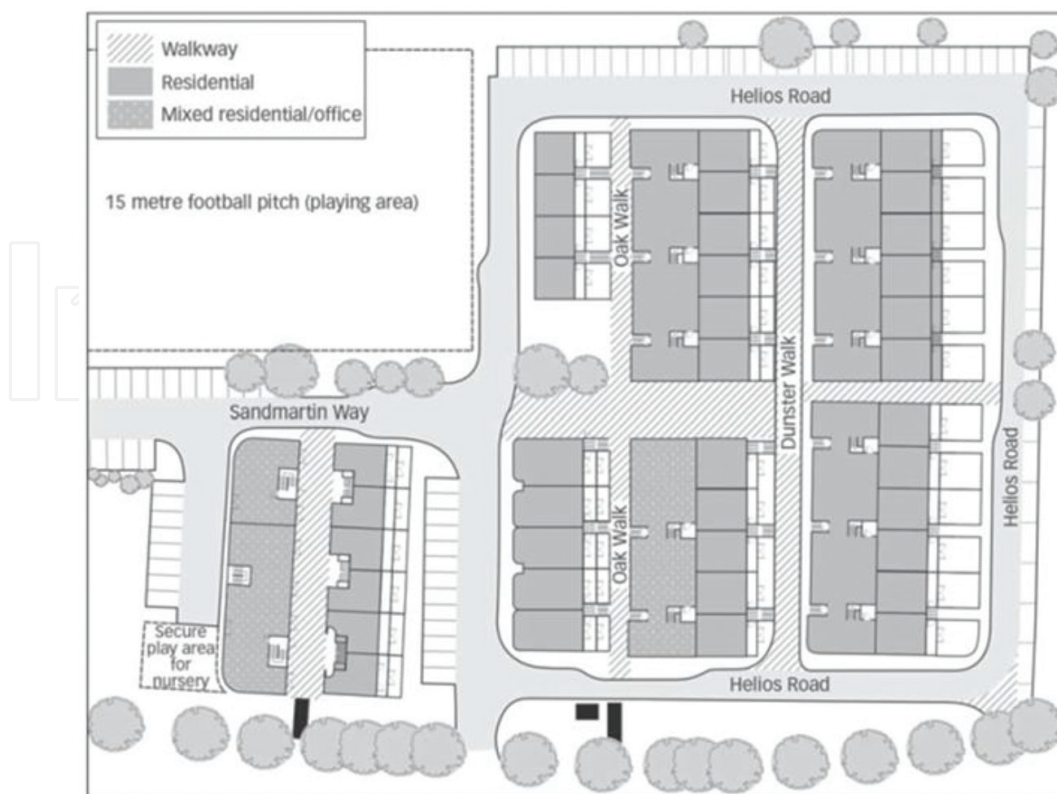
### 2.1.2. Site planning

In the design of buildings, distance between buildings is an important designing parameter that affects utilization of solar energy, wind direction, and speed concerning artificial environment. In the design process, building should be handled as a whole with its environment. The distances between buildings highly affect the energy performance in the usage phase of building. The fact that a building remains within the shading space of other buildings influences the utilization of solar rays and will raise the consumption of energy. In order to utilize solar radiation, building spaces must not be less than the tallest shade height of other buildings. Besides, the position and distance of other buildings affect the speed and direction of wind on building, and this impacts the energy performance of building [15].

Orientation of building affects the ratio of the solar radiation gain of building sides, consequently the total solar radiation gain of building. In addition, the side of buildings affects wind amount, consequently, affecting natural ventilation possibility and heat loss amount by convection and air lack. For this reason, according to the necessities of that region, buildings must be oriented for avoid of or benefit from the sun and wind according to the conditions [8].

As the positioning of buildings as attached to each other would decrease the building envelope/volume rate, declines heat loss and gains through building envelope. In addition, positioning them in the direction of south, southeast, and southwest as an external curve crescent make them utilize solar ray more [16].

In London-BedZED settlement, separate houses having their own gardens were designed. So as to lessen the heat loss of buildings, both compact forms were used and construction groups were gathered together and it tried to decrease the outer surface space/volume rate as shown in **Figure 3** [17].



**Figure 3.** Site plan of London-BedZED ecological settlement [17].

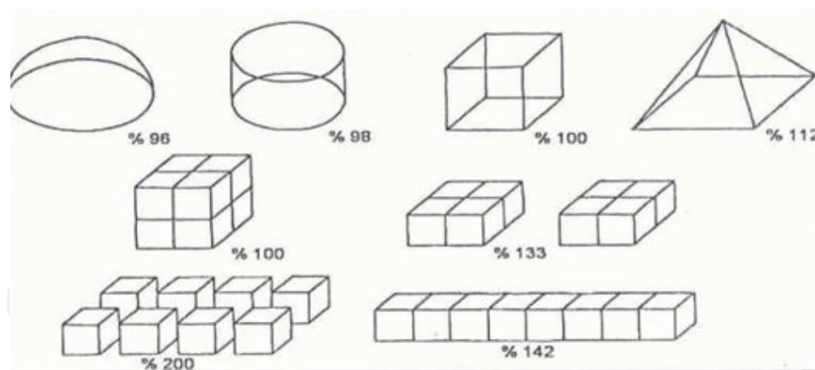
### 2.1.3. Building form

The shape of building which is a considerable factor affecting heat loss and gain can be defined through geometrical variables making up building such as the proportion of building length to building depth of the building in the plan, building height, type of roof, its gradient, front gradient, and bossages. Heat loss-gain of building may rise and decline depending upon the proportion of the surfaces constituting environment to volume [18].

Energy performance of building is affected by such factors as its form, volume surface rate and frontal motions. There is a direct relationship between the geometrical shape and energy performance of building.

In the conducted studies, it was observed that different results were obtained in the energy performance of the masses which had the same volume but made in different forms [14]. It was calculated that the surface area of the masses has the same volume but different forms. The surface of the cube that was taken as 100 was accepted as a reference (**Figure 4**).

The shape of building is important in areas that have different climate conditions. In cold climate regions, compact forms should be used which minimize the heat loss part. In hot-dry climate regions, compact forms and courtyards should be used which minimize heat gain and helps to provide shaded and cool living spaces. In hot-humid climate region, long and thin forms whose long side oriented to the direction of prevailing wind makes possible maximum cross-ventilation. In mild climates, compact forms, which are flexible more than the forms used in cold climate regions, should be used [8].



**Figure 4.** Building form-surface relationship [19].

#### 2.1.4. Building plan and appropriate space organization

Building plan and shapes should be effective in energy conservation. Therefore, buildings should be formed to ensure minimum heat gain in warm seasons and maximum in cold. Due to simple plan types such as square or rectangle having a reduced surface area, their heat-loss and -gain are also reduced. Smaller buildings, where internal space has been used efficiently, use less energy as they can be heated, cooled, and illuminated more efficiently than larger buildings [20].

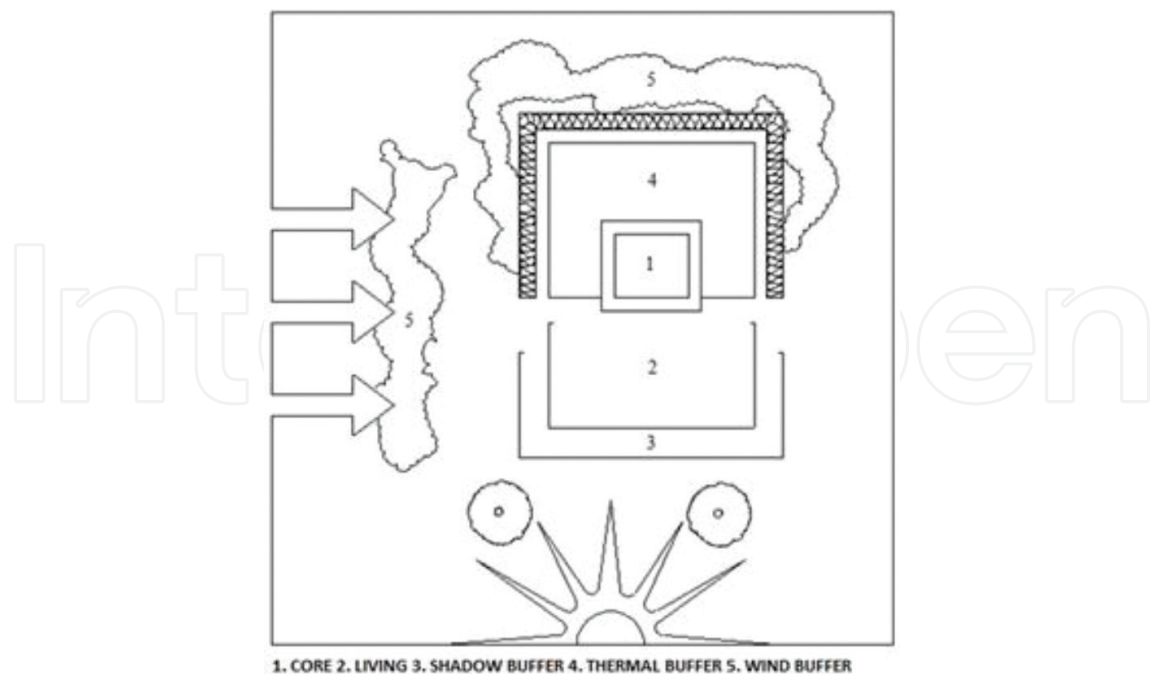
According to the results of the research called “Construction and Energy” performed by German Ministry of Research and Technology, the place of space in the organization of plan is more efficient than the orientation of space with respect to energy consumption [21]. The energy requirement of buildings can be reduced by the internal layout of the design. By making the best use of the sun’s radiation, the need for heating energy can be reduced. These communal areas require more heating, whereas spaces with a lower heating requirement such as the pantry, bathroom, and toilet can be used as buffer areas, reducing heat transfer to the exterior by placing these in areas of heat-loss. Spaces such as sun rooms, if located on south façades of buildings, also contribute to heating of the building and energy conservation, by storing solar radiation [20].

In the building design, stratification can perform zoning depending on buffer zone, sanitary spaces, noise level, lighting level, and heating need. Therefore, areas with many users and which are used throughout the day should face southerly direction. Thermal zoning and the settlement of indoors can be designed in a way to raise mutual air motion (**Figure 5**). Deep plans and the use of too many dividing elements may restrict air motion in environments [22].

#### 2.1.5. Building envelope

Building envelope is the components such as wall, ceiling, ground, window, and door which separate building (conditioned space) from outdoor and let heat energy transfer into inside or outside. As an indoor and outdoor reagent, it has a vital impact on energy consumption [10]. While the cost of constructing a building envelope makes up 15–40 of the total constructional cost, its contribution to life cycle costs especially to energy cost is around 60% [12]. The skin of building performs the role of a filter between indoor and outdoor conditions, to control the intake of air, heat, cold, and light [24]. Building envelope should minimize the heat loss in the winter and the heat gain in the summer.





**Figure 5.** Spatial zoning [23].

The physical and structural specifications of building components, such as walls, windows, flooring, and doors, which make up the outer shell of the building, have a significant impact on the energy consumption of the building. The thermal performance, thickness, and color of the materials used in these components play a significant role in regulating the heat loss and gain of the building [20]. The energy-saving features of the building components analyzed are described below.

**Outer walls:** Thermal and massive characteristics of outer walls are related to building material constituting them and the characteristics of building element layers and how they are sorted. The walls that will minimize heat loss and gain are well-isolated massive walls with high heat-storing capacity.

The formation of outer surfaces that can get most solar radiation or be protected from radiation in terms of heat gain should be handled depending upon the characteristic of climatic zones. To keep sunlight as much as possible in winter, wall-to-window ratio is desired not to exceed 15% with the use of dark and high-density materials in the parts exposed to the sun [25].

**Roofs:** In commercial and institutional buildings, roofs are generally flat, and the insulation can be resting on the suspending ceiling. In gabled roof construction where the attic is not used, the insulation is generally in the ceiling [12]. The shape, material, gradient, orientation, outer surface color, and insulating qualities of the roof determine the thermal performance of the buildings. Therefore, roofs need to be designed in such a way to suit the climatic conditions [20].

Thermal insulation qualities of roofs, their gradient and facade should be chosen properly to climatic character, their outer surface color and stratification order should, however, be chosen taking heat gain and loss into account. In temperate dry and temperate humid climatic zone and cold climatic zones, the well-isolated gradient roofs should be preferred. In hot and dry climate zones, flat roofs should be preferred to reduce the impact of solar radiation; in hot and humid climates that allow air flow, raised or sloping roof should be arranged [9].

Windows: Windows affect energy efficiency in buildings via heat loss or gain, natural ventilation, and illumination. The most appropriate direction is south in terms of heat gain, after the east and west side. Large windows reduce the need for artificial lighting while improving daylight [26].

Windows should be designed in the magnitude that is sufficient to provide natural lighting. For example, window magnitude should be at least 15% of the room's floor area [27].

While taking a decision on the transparency rates in building envelope, in which climatic zone the building is placed should be ascertained in advance. Since protection from solar radiation and wind is the basic purpose in hot and arid climatic zones, small and few windows should be used. In hot and humid climatic zones, by taking necessary precautions, large openings should be used in order to raise indoor air circulations. In cold climatic zones, to minimize the heat losses stemming from windows, again small and few windows should be used. Yet, so as to utilize the beneficial effect of solar radiations, the window openings in the southern front should be kept more than the ones in other fronts. In temperate climatic zones, however, it should be given to openings that would enable sufficient air circulation [28].

The use of windows also serves a number of essential purposes such as ventilation, natural lighting, and opening to scenery; it does not bring much load on constructional cost. In the climatic zones having cold winters, positioning window openings in the north should not be preferred due to the fact that heat gain from the sun is too little to be considered and air penetrations increase because winter winds usually blow from the north and thus heat losses grow. It is possible to obtain a certain amount of sun gain from the openings placed in the east and west, even if it is less in winter than the southern front. However, since the summer sun comes horizontally in the morning and afternoon hours, it is very difficult to protect these openings and we may face the problem of overheating. The windows looking toward south, however, may utilize solar rays coming horizontally in winter almost the whole day; in summer, they may be easily protected from the rays coming more vertically [29].

Because of all of these components, southern windows are the systems which can be very commonly used in utilizing sun passively. Yet, compared with wall, due to their weak isolation qualities they are much more open to heat-loss and gain; therefore, it is needed to take precautions for winter and summer. In this case, the application of double-glazing gains a high importance. Night isolation applications, however, are necessary to dismiss the heat losses that may occur after sunset. These isolation elements may be shutter, roller blind, or jalousie fixed either from inside or outside. Or, losses should be reduced through at least bringing curtains strictly down. In summer days, windows may be easily protected by the help of eaves, sunshade, or curtain [29].

In the front, high performance glass that has the most suitable thermal and light transmittance coefficient for the desired qualities depending on climate, sun direction, and the usage purpose of building should be used. Energy can be efficiently used thanks to isolated joineries, low-E covered glasses, argon or krypton-filled double-glazing and air proof detailing and montage.

**Doors:** The position of outer doors should be chosen considering wind effects, heat gain, and losses. In cold climatic zones, windbreak is suggested in order to be protected from the wind effect increasing heat losses. In hot-arid and temperate climatic zones, as wind does not have a restorative impact on comfort, surfaces closed to wind should be preferred [9].

**Floors:** Floorings grounded on soil should be arranged in a way to enable the desired performance in terms of heat and moisture. In cold and temperate climatic zones, well-isolated floorings should be preferred. In warm-humid climatic zones, however, heightened floorings can be preferred since air streams become important [9]. In the volumes getting sunlight, floor laying can be used as a thermal heat store. In floor laying, dark color materials having a high heat-storing capacity should be preferred. Not laying carpets on floor and leaving it open increase its capacity of heat absorption.

#### *2.1.6. Choosing energy-efficient building materials*

Building materials both in the production phase should have energy-efficient features in the use phase. Energy-efficient building material properties are described below.

**Local material:** In the total energy consumption of constructions, the amount of energy spent for transportation of the construction materials to construction sites is considerable and also affects the constructions' energy efficiency and economical cost. For this reason, if the construction materials are local material and are manufactured in nearby places to the construction site as much as possible, energy consumption in transportation will decrease and that saving in transportation will give the construction an important ecological quality [30].

**Recycled resources:** A large amount of energy is used in manufacturing many building materials. In the manufacture of building material, using recycled sources instead of the sources which are not newly processed material provides a considerable preservation of raw material and also a considerable amount of energy saving. Recycling building materials are essential to reduce the embodied energy in the building; for instance, the use of recycled metal makes considerable energy savings between the rates of 40 and 90% comparing the material produced from natural resources [31].

**Materials manufactured through low density industrial processes:** Building materials play a significant role in the energy efficiency of buildings. A large proportion of the total energy used during the building life cycle is consumed during the production of building materials (especially embodied energy). The proportion of the energy amount consumed in the manufacture of construction materials to the total energy amount of a construction with a 50-year process of use consumes in its life cycle processes varies between 6 and 20% depending on the construction methods, climate, and similar conditions [31]. The intensity of energy consumption in the first of these phases for the production of buildings and their components has

increased with industrialization [32]. Nonexistence of heavy procedures in the manufacturing process will cause less energy consumption, which provides energy efficiency to materials. Using the developed technologies in industrial processes such as a heat recovery method reduces energy consumption. For instance, in cement manufacturing technology, using the shaft furnaces instead of the conventional rotary furnaces makes energy saving between 10 and 40%. Similarly, the use of an arc furnace instead of a rotary furnace in the steel industry makes about 50% energy saving [31].

Natural materials are quickly obtained from renewable resources: Generally, the energy content of natural materials is lower than that of artificial materials since these materials are manufactured with less energy and labor cost. Such kinds of materials which are easy to be locally provided are generally among the renewable resources. Such vegetal materials used in constructions for instance, wood, bamboo, reed, straw, rye stalk, sunflower stalk, mushroom are the natural materials which are quickly gained from renewable sources [33].

Labor intensive materials: Using highly qualified man power in manufacturing materials will reduce the processes based upon industry, and accordingly decrease the energy consumption. Materials manufactured by using renewable energy resources: especially renewable energy resources (solar energy, wind energy, etc.) instead of fossil fuels should be preferred as a primary energy supplier in the manufacturing process. For example, the adobe brick is dried using solar energy after it is molded [33].

Materials consuming less energy during the worksite process: The management of worksite, the need for electricity energy, and machines in operation, heating, and lightening affect the energy consumption of the worksite. As a result of the increase in mechanization in worksites, the electricity consumption has increased considerably as well [31].

Use of durable building materials: Use of durable materials in the buildings makes them more resistant and long-lasting against various factors. This delays or eliminates the need of renewing material or maintenance due to impairment and aging. In this way, it is saved from the energy spent for the material to be used in maintenance or renewing [33].

Building materials with high thermal insulation capacity: With the choice of building materials whose thermal insulation capacity is high, the energy amount that the construction consumes in its usage stage will be decreased. As mentioned as examples are opaque and translucent insulating materials [33].

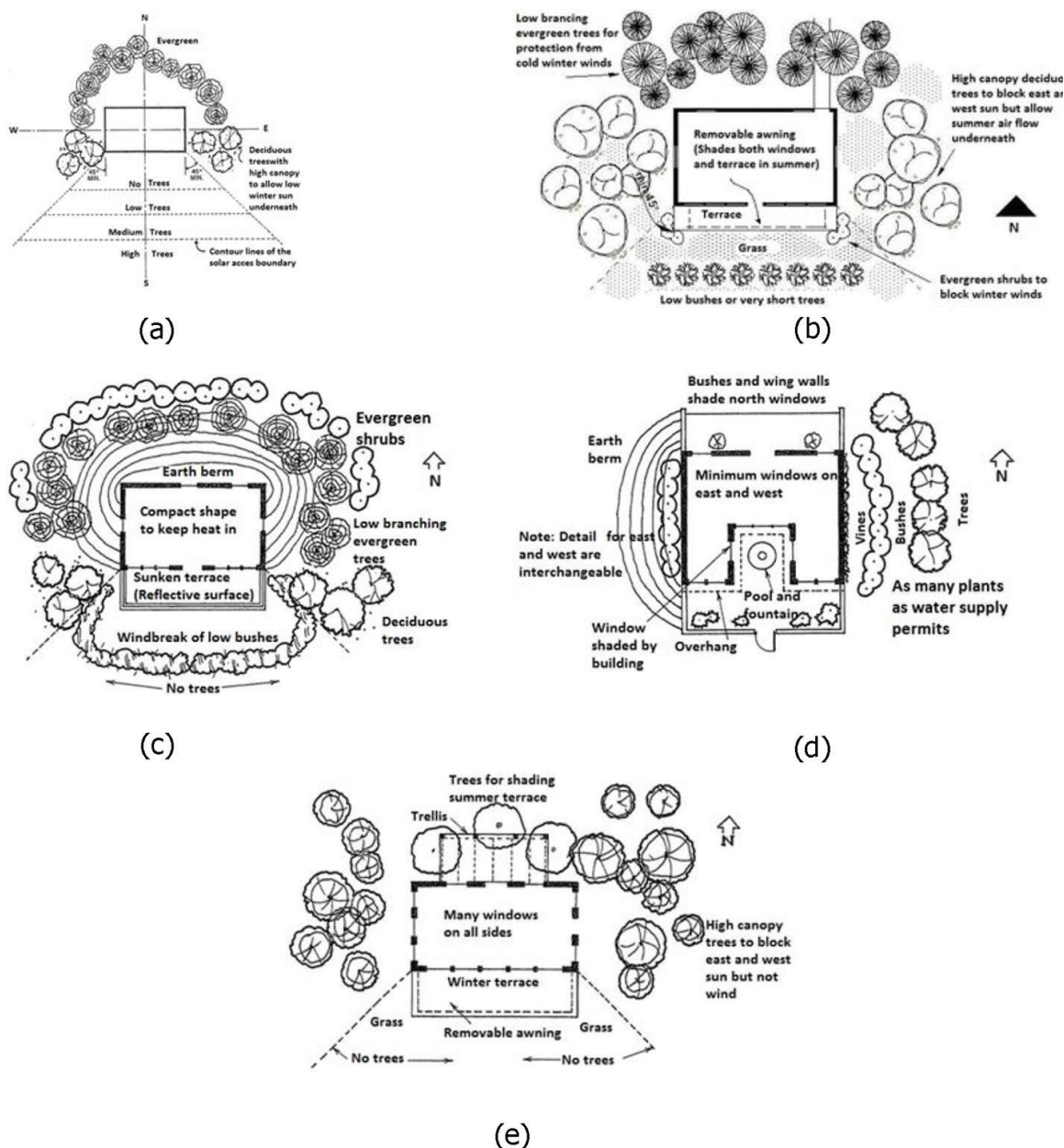
#### *2.1.7. Energy-efficient landscape design*

Through an accurate and conscious energy protected landscape design, it is possible to reduce the energy cost spent for heating and cooling during summer and winter seasons at 30% [34].

The ground flooring of outdoor and grass has a cooling impact via vapor transportation. The materials harboring heat in its body such as asphalt continue to expand heat following sun and they increase night time radiations. So as to reduce the cooling costs spent, using such materials that store heat and reflect lights little or shading them against direct solar rays are among the precautions to be taken [34].



The energy conserving landscape strategies depend on a region. These landscaping strategies are listed by the region and in order of importance as shown in **Figure 6**.



**Figure 6.** Landscaping techniques appropriate for four different climates (temperate, very cold, hot and dry, and hot and humid) [12]. (a) The general tree planting logic for most country [12], (b) landscaping techniques for a temperate climate. The windbreak on the north side of the building should be no farther away than four times its height, (c) landscaping techniques for very cold climates, (d) landscaping techniques for hot and dry climates, and (e) landscaping techniques for hot and humid climates.

Temperate climate: It should maximize warming effects of the sun in winter and maximize shade during the summer. Buildings should be protected away from winter winds. Summer breezes should be directed toward the buildings. Constantly green trees with low branches to

protect them from the cold winter winds on the northern front, low shrubs or trees not high, should be applied on the south front, high body deciduous trees should be placed on the eastern and western facades for block the sun and allowing natural ventilation [12, 35].

Hot-arid climate: It provides shade to cool roofs, walls, and windows. Allows summer winds to access naturally cooled homes and blocks or deflect winds away from air-conditioned homes. North and south sides should avoid forestation, while the eastern and western direction (positioning studies may be substituted), shrubs, vines have been placed on the walls and deciduous trees should be implemented [12, 35].

Hot-humid climate: Channel summer breezes toward the home. Maximize summer shade with trees that still allow penetration of low-angle winter sun. Avoid locating planting beds close to the home if they require frequent watering. Should avoid forestation on the southern front, in the northern front, forestation should be done providing the shadow effect in summer. The eastern and western direction, shrubs, and vines have been placed on the walls and deciduous trees should be implemented [12, 35].

Cool climate: Use dense windbreaks to protect the building from cold winter winds. Allow the winter sun to reach south-facing windows. If summer overheating is a problem, shade south and west windows and walls from the direct summer sun. The north façade is useful in cold climate regions partly raised land application. Northern, eastern, and western fronts in constantly green shrubs and the green, the low branches of trees should be preferred. In the southern wind breaker, low shrubs and grass should be applied. In southeast and southwest direction away from the building, deciduous trees should be used [12, 35].

The ground cover may also be utilized for energy conservation in buildings. Completely or partially buried, construction can moderate building temperature, save energy, and preserve open space and views above the building [36]. If the wall and roof being covered by a layer of earth of substantial thickness sufficient to insulate the dwelling thermally and acoustically and reducing the quantity of energy necessary to maintain the interior of the building comfortable for the occupants even when the atmosphere is extremely hot or cold.

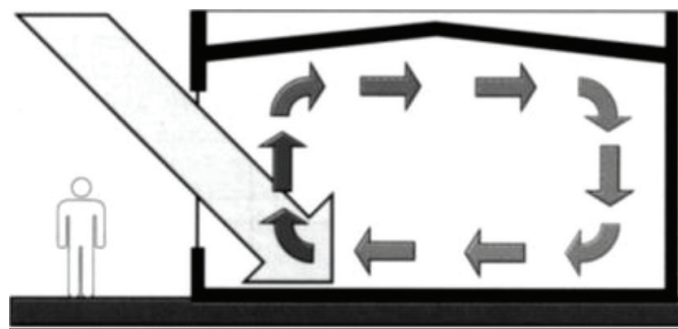
#### *2.1.8. Usage renewable energy resources*

Renewable energy sources (sun, wind, biomass, biogas, geothermal energy, hydro, wood, ocean thermal, ebb and flow, wave, sea flows) are the energy resources that can be used by all living creatures on the earth and accepted as inexhaustible thanks to their continuous renewal. It is possible to benefit from renewable energy resources with passive and active methods.

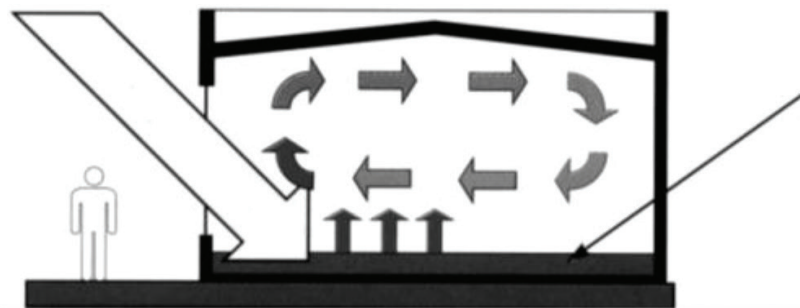
Usage renewable energy resources with passive techniques:

Passive heating: Passive solar heating systems are categorized by the relationship between the solar system and the building. There are three categories of passive solar heating systems: direct gain systems, indirect gain systems, and isolated gain systems [37]. In the passive solar heating system, building elements (windows, walls, floors etc.) collect and store heat and then distributes indoor space.

*Direct gain systems:* The direct gain passive solar building has windows that admit the winter sun directly into the occupied space. These solar gains serve to either meet part of the current heating needs of building or are stored in the thermal mass to meet heating needs that arise later. Most direct gain buildings include: (1) large, south-facing windows (for north hemisphere) to admit winter sun; (2) thermal mass inside the insulation envelope to reduce temperature swings; (3) calculated overhang above the south glass (or other strategy) to shade the glass in the summer while admitting lower angle winter insolation; (4) a means of reducing heat loss at night. In a direct gain building, sunlight is admitted directly to interior through glazing. It strikes massive interior surfaces (typically concrete floor and masonry wall surfaces), is absorbed, and is converted into the heat. Some of the heat from the surfaces is immediately released back into the room interior. The remainder of heat absorbed is conducted into the thermal mass which slowly warms up; later at night, the stored heat is released back to interior as shown in **Figures 7 and 8** [39].



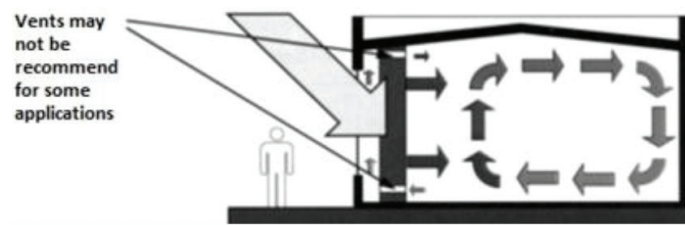
**Figure 7.** Direct gain schematic [36].



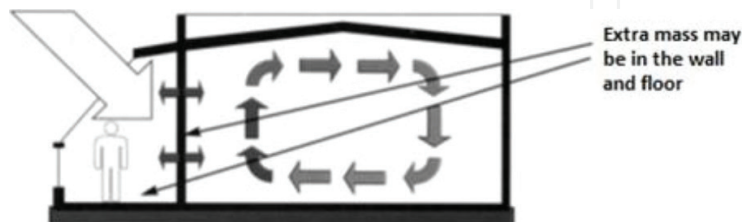
**Figure 8.** Direct gain plus storage schematic [37].

*Indirect gain systems:* An indirect gain passive solar system has its thermal storage between facade and the indoor spaces. Heat is collected and stored in an exterior wall or on the roof (with water or brick/concrete) of a building, and distributed to the indoor as shown in **Figure 9** [37].

*Isolated gain systems:* Isolated gain passive solar concept contains solar collection and storage that are thermally isolated from the indoor space of the building. The most common use in isolated gain systems is a sunspace. Collection and storage are separate from the occupied spaces but directly linked thermally. A sunspace is a room attached to or integrated with the exterior of a building in which the room temperature is allowed to rise and fall outside the thermal comfort zone, as shown in **Figure 10** [37].



**Figure 9.** Indirect gain schematic [37].



**Figure 10.** Sunspace schematic [37].

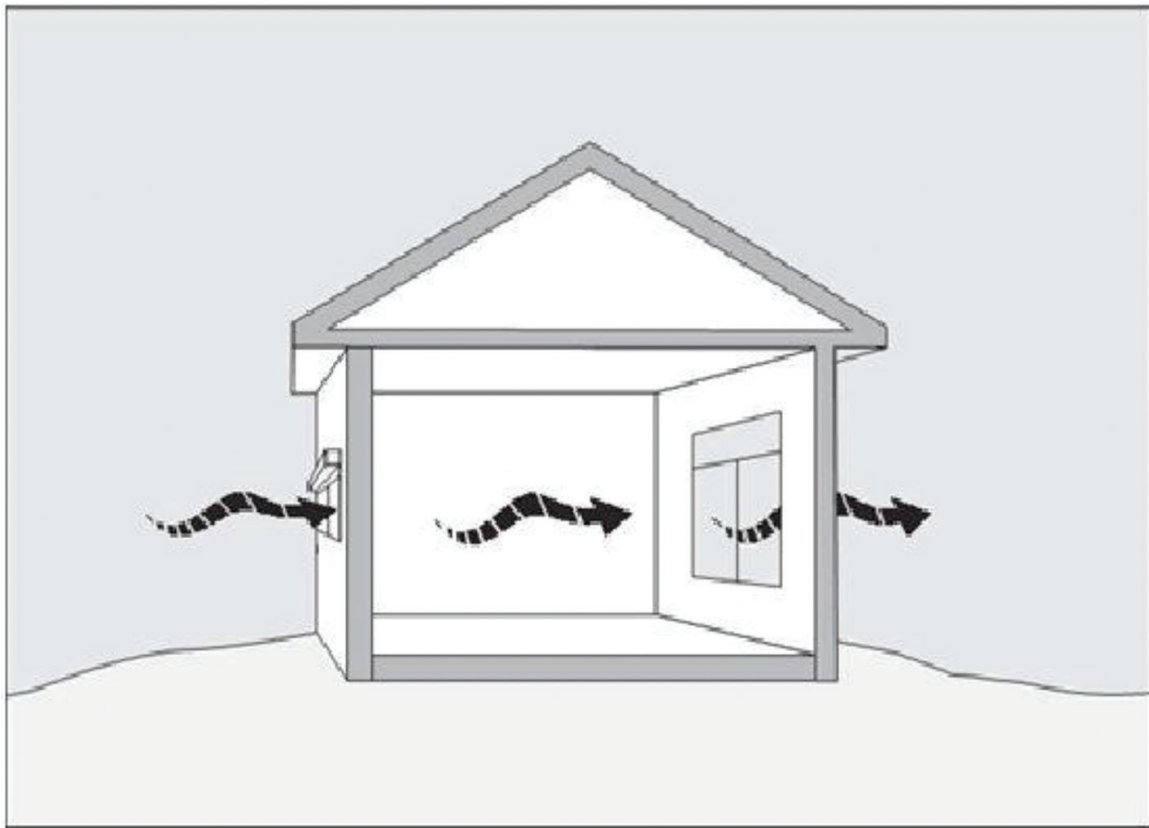
Passive cooling and ventilation: Passive solar heating is divided into categories according to application configuration. On the other hand, passive cooling is better understood as a series of research fields that focus on the basic heat sinks. While this organization is helpful to scientists and inventors, it is a source of frustration for designers and policy makers because so many workable systems involve multiple heat sinks [38]. Nonetheless, this characterization of passive cooling will be described below.

Ventilative cooling: Warm building air and replacing it with cooler outside air. Directing moving air across occupants' skin to cool by combination of convection and evaporation. In passive applications, the required air movement is provided either by wind or by stack effect. In hybrid applications, movement may be assisted by fans, as shown in **Figures 11–13** [39].

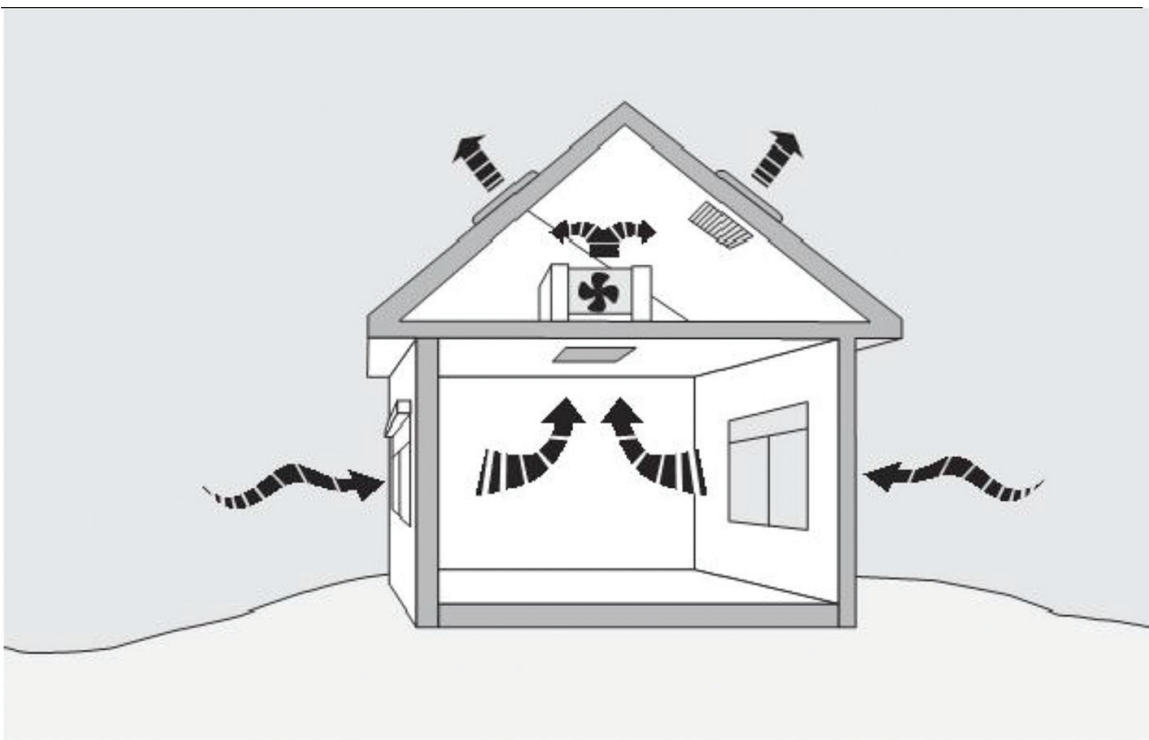
Radiant cooling: All building objects radiate and absorb radiant energy. Building objects will cool by radiation if the net flow the outward. At the night, long wave infrared radiation from a clear sky is much less than the long wave infrared radiation radiated from a building. Thus, there is a net flow to the sky, as shown in **Figure 14** [12].

Evaporative cooling: Water has been used to improve the thermal comfort of buildings with or cascades. Because when water is evaporates, energy is lost from the air and reducing the temperature. When water evaporates, it draws a large amount of sensible heat from its surroundings and converts this type of heat in the form of water vapor. As sensible heat is converted to latent heat, the temperature decreases. This phenomenon is used to cool buildings in two different ways. If the water evaporates in the building or in the fresh air intake, the air will be not cooled, but also humidified. This method is called direct evaporative cooling. If, however, the building or indoor air is cooled by evaporation without humidifying the indoor air, the method is called indirect evaporative cooling, as shown in **Figure 15** [12].

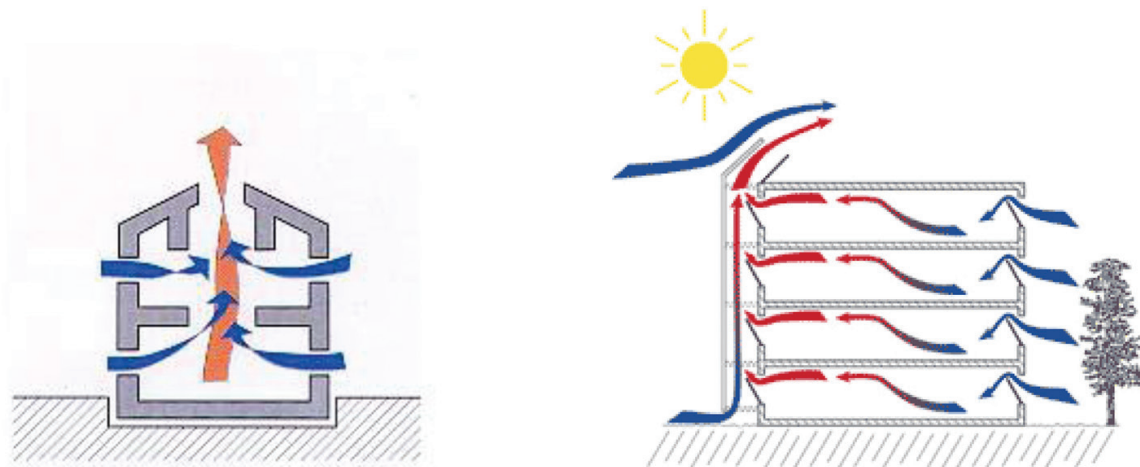




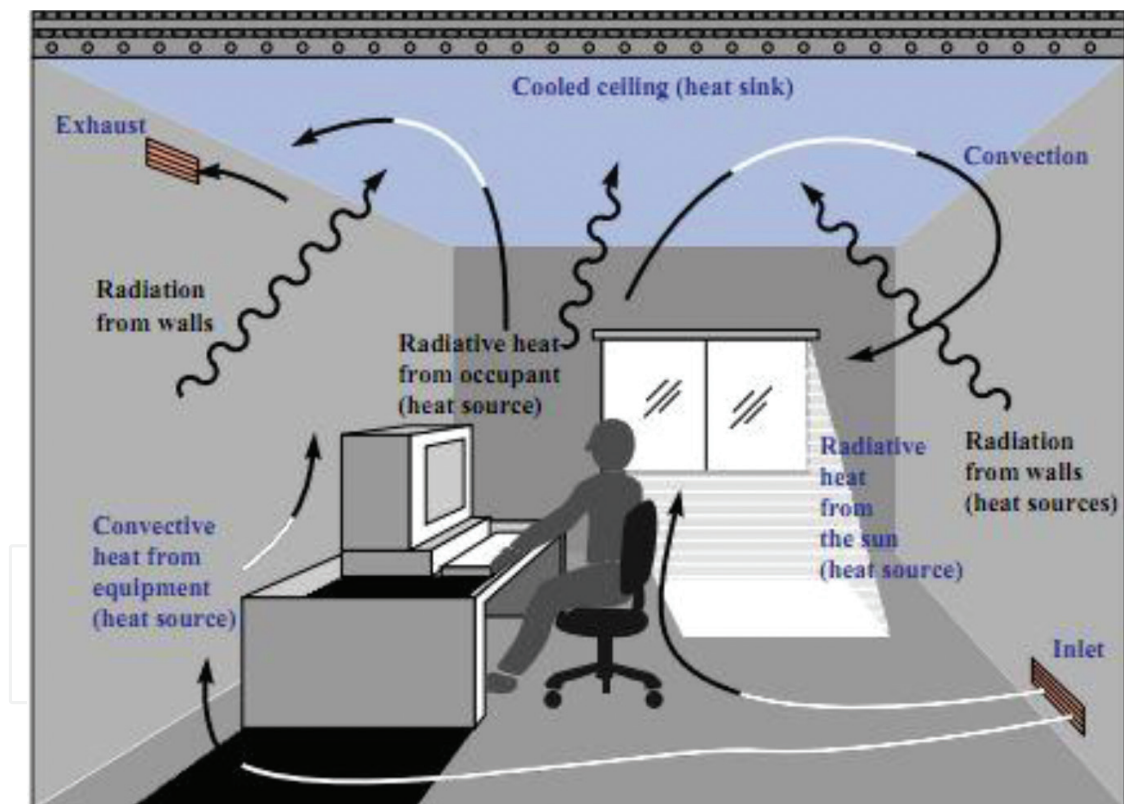
**Figure 11.** Use windows and doors for cross-ventilation [40].



**Figure 12.** A whole-house fan [40].

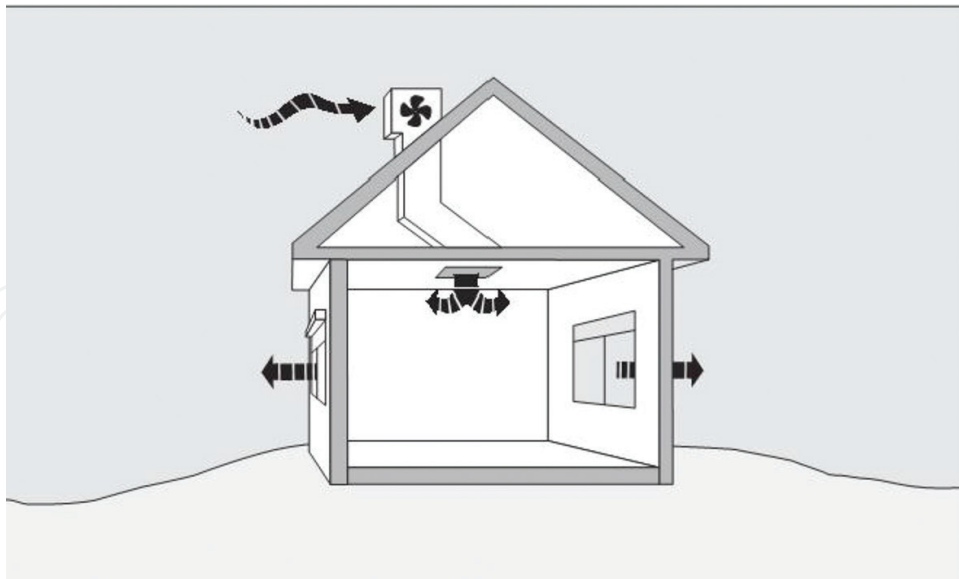


**Figure 13.** Air movement in stack ventilation [41, 42].



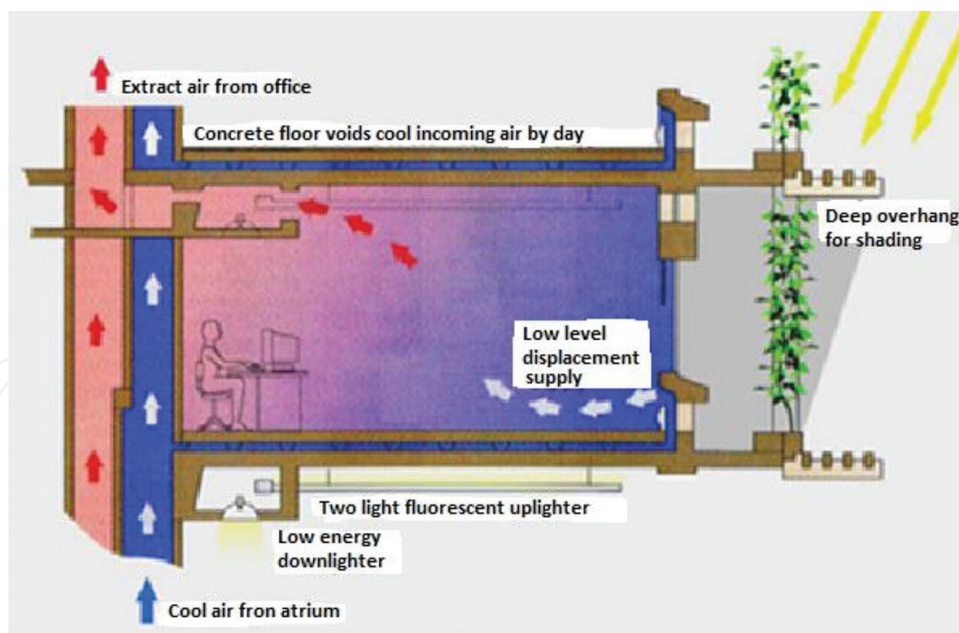
**Figure 14.** Radiant cooling from ceiling [43].

Dehumidification: The removal of water vapor from room air by dilution with drier air, condensation, or desiccation. In the case of condensation and desiccation, dehumidification is the exchange of latent heat in air for the sensible heat of water droplets on surfaces: both are the reverse of evaporative cooling and as such are adiabatic heating processes [39].



**Figure 15.** Evaporative cooling [40].

Mass-effect cooling: The use of thermal storage to absorb heat during the warmest part of a periodic temperature cycle and release it later during a cooler part. Night flushing (where cool night air is drawn through a building to exhaust heat stored during the day in massive floors and walls) is an example of daily-cycle mass-effect cooling, as shown in **Figure 16** [39].



**Figure 16.** Air movement in Eastgate Center Office Building [44].

Usage renewable energy resources with active techniques:

The active use of solar energy systems in buildings: It is possible to produce heat and electricity with solar energy in buildings using such equipment solar collectors, photovoltaic (PV)

panels, and building integrated PV (BIPV). The potential application of PV panels in high-rise buildings is more than the low-rise buildings because of higher neighboring buildings; it gives more possibility for direct solar radiation. Requirements for regulation of large amounts of PV panels are the most important problem. Because it is necessary to maintain aesthetics and PV panel's productivity in buildings[45].

The active systems where solar energy is used are the systems composed of the aggregation of mechanic and/or electronic components that convert solar radiation absorbed via collectors produced for this end into energy in a desired form and permit this to be used in building. Through these systems, solar radiation can turn into heat and electric energy [46]. These systems that transform solar radiations into energy are divided into two according to the energy they produce: solar thermal systems producing thermal energy and thermal electric (photovoltaic) systems (PV systems) producing electric energy. These systems are briefly described below.

**Solar energy thermal systems:** Solar energy thermal systems (effective solar thermal systems) are the aggregation of mechanic and/or electronic components that convert solar radiation into thermal energy via collectors, make it possible to directly use this energy with water, air, and a similar fluid, or make it usable by evaluating it in a storage unit. Solar energy-efficient thermal systems are used for heating pool water, preheating of climatization air and heating environment [46]. The general operation principle of thermal systems is based on collecting heat via collectors, storing thermal energy to be able to use later if needed and distributing it to relevant fields [47].

**Solar water heating systems:** These systems are composed of the elements that transform solar radiation into thermal energy, keep and distribute this heat in an aquatic environment. In contrary to the fact that systems show differences depending on the complexity and magnitude of necessity, all of the solar water heating systems are based on heating water, storing, and distributing it. As the hot water produced with the transformation of solar energy can be directly used for having a bath, laundry, and washing dishes depending on the characteristics of the system, it can also be used for supporting the conventional heating system [46].

**Photovoltaic systems:** The aggregations of the components that produce electric energy via collectors from solar radiation and make this energy usable are called photovoltaic (PV) systems. With simple or complex structuring, PV systems are used to produce electricity in a large number of different fields such as road lighting, lighthouses, vehicles, constructions, and electric power-plants. A photovoltaic system generates electric energy, stores the produced energy for necessary conditions and safely transfers this energy to the areas of usage. By being placed on fronts and roofs of buildings, photovoltaic batteries convert the solar energy coming to these surfaces into electric energy, as shown in **Figure 17** [48].

**The active use of wind energy systems in buildings:** Wind energy is the fastest-growing renewable energy source in the world. Wind energy is a clean fuel source and does not produce atmospheric emissions that cause acid rain or greenhouse gasses. Wind energy is an inexhaustible energy source. More recent developments in this technology have allowed wind turbines to be utilized in building design. Consistent with the high performance approach to building design, the use of wind turbines on high buildings is significantly enhanced by their integration with building architecture [50].





**Figure 17.** Photovoltaic panels integrated into building [49].

When the height of the structure increases the wind without interruption in direct contact with structure, wind speed increases linearly with height and utilizing the turbine at high buildings with this feature it is possible to produce significant amounts of electricity. Implementation of wind turbines in high buildings in the design stage consideration of this parameter is required: site plan layout, wind aerodynamics in building form, local wind pattern, wind speed density, frequencies of the wind speed distribution, and prevailing wind direction [51].

Must be designed taking into account the prevailing wind direction which mass form of the building and placement in the wind turbine, as shown in **Figure 18**. Previous studies show that optimal angle between the prevailing wind direction and wind turbines for maximum efficiency is determined as  $45^\circ$  [45].

Use of geothermal energy in buildings: Geothermal energy is used in heating and cooling in houses, greenhouse cultivation, and agriculture. Geothermal energy systems are applied in three different ways according to application methods such as heat pumps, downhole heat exchangers, and heat pipes. Their common usage in buildings is in the form of heat pipes.

Another form of geothermal energy usage is the methods where earth temperature is used. A little under earth, temperature is always in between 45 and 75 F (7.22 and 23.88°C) depending on latitude [53]. This temperature of the earth can be benefitted via air or water. The air taken through the funnels dug in various depths of earth is transferred into building and indoor is enabled to reach the same level with earth temperature. This application is ensured in the direction of heating in winter and cooling in summer. A similar application is performed to utilize the temperature of underground waters, the water circulated within the building via pipes expands the heat it has into internal volumes [48]. The schematic figure showing these applications is given in **Figure 19**.



**Figure 18.** Wind turbines integrated into building [52].

Use of hydrogen energy in buildings: Hydrogen energy can be used for heating houses, providing hot water, cooking and meeting electricity need. In order to use hydrogen here, we first need to produce it, then store and transfer it. Hydrogen can be produced from such renewable energy sources such as sun, hydroelectric, wind, and geothermal.

Nowadays, among the renewable energy sources, solar-hydrogen hybrid system strikes us as the most productive system. In such a system, there is a need for such constituents as photovoltaic panels, electrolyzer, fuel cell, hydrogen ( $H_2$ ) storing tank, battery pack, and inverter. In solar-hydrogen house energy mechanism, system works as follows [55]:

- with PV panels, electricity is produced from solar energy,
- with electrolyzer,  $H_2$  and  $O_2$  are produced,
- gases are taken into storage tank for heating place and water,
- in winter, by burning hydrogen “flamelessly” with catalytic hydrogen lighter (1.5 kW), the air in the ventilation system is heated,



- if additional electricity is needed, fuel cell runs,
- a part of the heat emerging in fuel cell is used to heat water.

Use of biomass energy in buildings: Biomass is a strategical energy resource, which is renewable and environment friendly, can be grown everywhere, enables socioeconomic improvement, and can be used for power generation and for obtaining fuel for vehicles. Biomass is utilized in the energy sector by being directly burned or its fuel quality is increased with various processes and thus gained alternative biofuels (easily movable, storable, and usable fuels), which are equal to existing fuels.

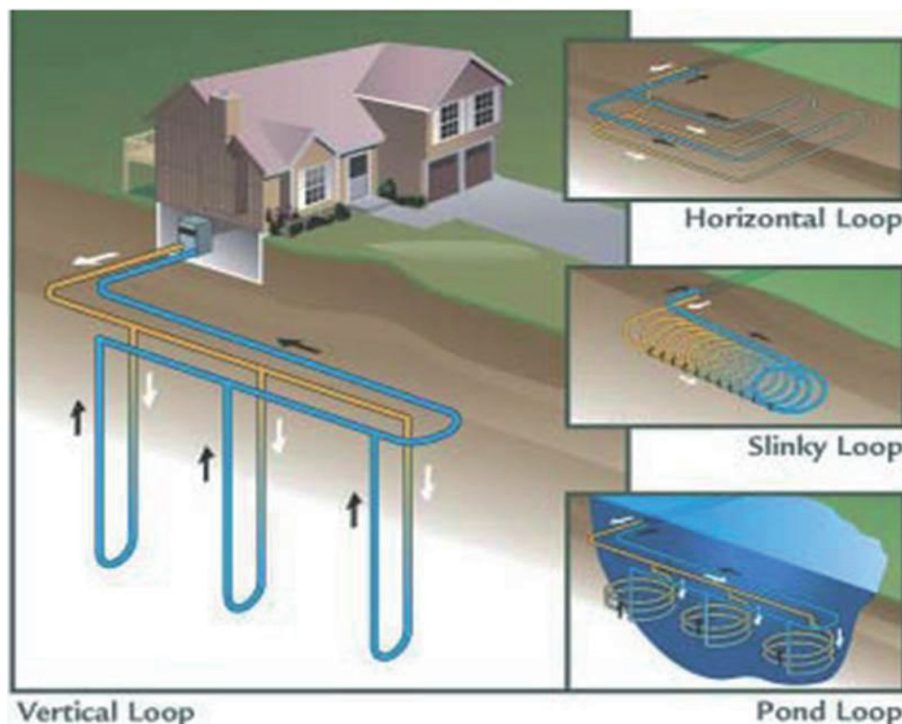


Figure 19. Earth-based heat pipe usage forms [54].

From biomass is produced fuel with physical processes (size reducing-breaking and grinding, drying, filtration, extraction and briquetting) and transformation processes (biomassive and thermochemical processes) [56]. In the houses, biomass is used for biogas power generation adopted with airless incineration, ethanol heating adopted with the pyrolysis method, and hydrogen water heating adopted with the directly burning method [47].

Natural lighting: Natural lighting in buildings is carried out through a most basic windows and skylights. Choice of direction in the windows and roof lighting is important. The most suitable directions for natural lighting are south and north. The north direction is not exposed to radiation, but can always get daylight in the same quality. In the west and east directions, the sun radiates in horizontally and makes it difficult to control. In the south direction, the effect of the sun is permanent and sun rises at a right angle compared to the west and east directions. Therefore, it is easy to control [57].

In order to increase daylight's entrance into the building, light colors should be used on windows' wings that direct the light and light shelves. Moreover, the elements used to reflect light must be made in a position to reflect the light to the ceiling. Wall and ceiling surfaces must be light colored so that the light can be spread [58]. Desirable reflectance according to Illuminating Engineering Society's recommendations: ceilings >80%; walls 50–70% (higher if wall contains window); floors 20–40%; and furniture 25–45% [58, 59].

The proper design and selection of the daylighting systems can help in improving energy efficiency and reducing environmental pollution. Windows, clerestories, and roof monitors when properly designed can provide of the lighting needs without undesirable heat gain and glare. And therefore, electric lights can be turned off or dimmed in day-lit spaces when the target illuminance is achieved by daylighting. Energy savings can only be achieved by implementing light controls, sensors, and light dimmers for the lighting system of those day-lit spaces. The usage of daylight in buildings decreases the electric energy consumption. For instance, it has been shown that artificial lighting of nondomestic buildings represents 50% of the energy consumption in Europe. It also has been shown that it is possible to reduce this consumption by between 30 and 70% by combining the use of artificial and natural lighting. Potential savings depend on orientation, the size and shape of the window, and the shape and surface reflectance of the room [60–64].

Another usage of natural lighting in buildings is the use of the daylighting system. Daylighting is defined as “the combination of the diffused light from the sky and sunlight.” A daylighting system preferred function is to redirect a significant part of the incoming natural light flux to improve interior lighting conditions, therefore located near or in the openings of building envelope. Daylighting systems are divided into two categories: side-lighting and top-lighting. Light can come from many types of glazing configurations, which are either vertical or horizontal and from the side or from the top. Side-lighting, which is more commonly observed, is simply a window opening. Top-lighting is an opening in the ceiling or roof element of the building [60]. Applications of the daylight system are discussed below, as shown in **Figure 20**.

## 2.2. Energy-efficient designing methods in building phase

Building phase includes the construction and usage processes of building. Building phase is possible with preferring building techniques consuming less energy and using energy-efficient equipment. The energy used in construction changes according to building systems. For instance, in a study carried out by Hozatlı and Günerhan, it was established that frame construction consumes less energy than a reinforced concrete frame construction during its life cycle [66]. As the energy consumption of the buildings constructed with different materials changes, energy consumption also changes in the buildings constructed with the same materials. The energy consumption of the commonly used reinforced concrete frame building system was analyzed according to three different building methods as follows:

1. **Conventional frame building system:** The most prominent characteristic of the conventional building system is that the whole of production is implemented in building site thanks to intensive man power. When it is analyzed with respect to energy consumption, the energy consumption of the conventional system is at a low level due to the characteristics of the equipment (concrete mixer, roof crane) used in the stages of concrete production and concrete casting [66].



2. Tunnel form concrete masonry system: Tunnel form masonry system requires a certain preliminary investment. The system is suitable for large scale and permanent productions. Because lifting cranes consuming a lot of energy are used to carry big and heavy forms, energy consumption is high. The task of curing with concrete plant and intratunnel heaters raises the energy consumption of the system [67].
3. Precast construction systems: Since the majority of the processes realized in the building area in other systems are made in the manufacturing plant, energy consumption is very high. In these systems, downloading components from transportation vehicles to worksite, their storage and mounting are performed by lifting cranes. For this reason, at these stages as well, the high amount of energy is consumed. While heavy duty vehicles transporting ready building elements from manufacturing plant to building site lead to problems in traffic, they also increase the consumption of energy [67].

As a result, it can be urged that in a tunnel form, precast framework and precast panel building systems, manufacturing processes create negativities to a large extent in terms of energy consumption and emissions, energy consumption in the conventional systems is quite less compared with these but more negative with respect to the formation of solid waste [67].

As it is understood from the reinforced concrete building system, there are different methods for the same material in the construction of buildings. Such heavy duty vehicles as lifting cranes, concrete pumps, and concrete transit mixers consume the high amount of energy. For this reason, the building methods consuming less energy should be preferred on the condition that no concession is made in the quality of building.

Usage process is the process that consumes most energy in buildings. According to WBCSD (World Business Council for Sustainable Development) report, 88% of the energy consumed in buildings is spent during usage and maintenance [68]. The applications mentioned in designing process gain buildings energy efficiency during usage period. Besides this, the applications below have also the potential of procuring considerable energy saving during usage period.

Supporting multiuse improvement: Sustainable development advocates the combination of house settlement, trading area, office, and retail areas. Thus, people get the opportunity of living next to the places they work and shop. This renders the formation of a community different from traditional suburbs. 24-hour activity potential also makes the land safer [68].

Combining design with public transportation: Sustainable architecture on urban scale should be designed in a way to support public transportation. Thousands of vehicles coming in and going out the land during daily work pressure cause air pollution and traffic jam and they need parking areas [69].

Using energy-efficient bulbs and energy-efficient appliance: For example, the light-emitting diode (LED) is one of today's most energy-efficient and rapidly developing lighting technologies.

Lighting controls: Lighting requirements reply to a building design. The need for lighting, when during daytime, will depend on the window size and placement, and the position of buildings. The need for lighting is decreased by the use of automatic controls, which depend on the orientation of building windows, the supply of daylight, and usage of the room [70].

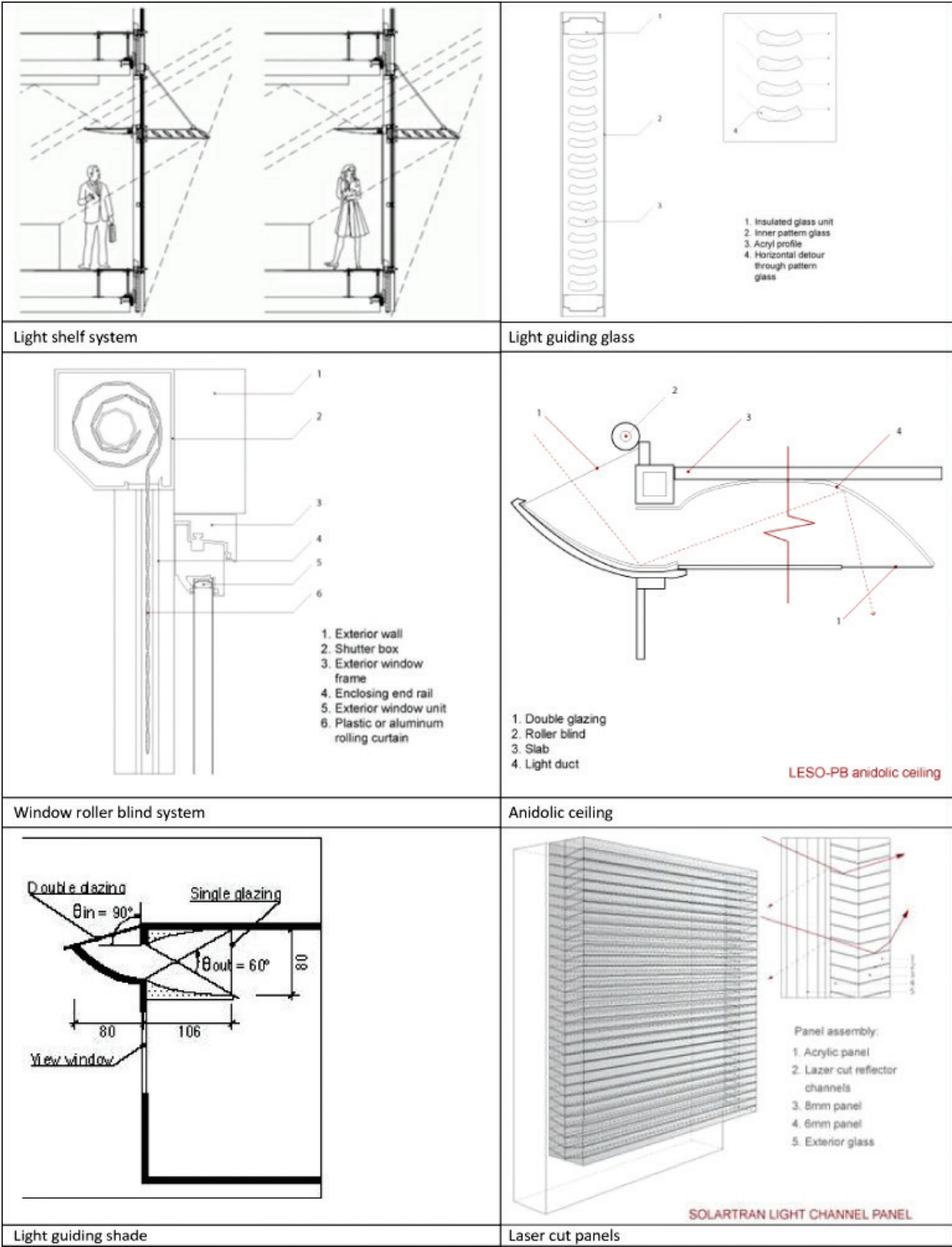


Figure 20. Daylighting systems using direct sunlight [57, 65].

High-efficiency heating, ventilation, and cooling equipment: Heating ventilating air conditioning (HVAC) systems extremely influence energy consumption in buildings. The relationship between building specifications and HVAC systems are: highly efficient building envelopes reduce the need for heating and cooling systems. Good and intelligent designed buildings can reduce the need for HVAC systems. Efficiency improvements in HVAC systems can lead to substantial savings. If, for instance, energy efficiency is improved in a heating boiler or an air-conditioner, total savings will depend on the total need for heating or cooling in the building. In a well-insulated building envelope, the energy needs of the HVAC system are reduced. The building can be separated into thermal zones at suitable dimensions, reducing the need for heating, cooling and ventilation with careful building planning [70].

### **2.3. Energy-efficient methods in postbuilding phase**

The postbuilding phase is the phase when the usage phase is completed. This phase includes the demolition of building, recycling, and destruction of it. In this phase, it is important to recycle the building materials and compositions used in the buildings and reuse buildings. After the functional uses of buildings have been completed, reutilization of them in other functions instead of demolishing them protects such resources as raw material, water, and energy. It should be enabled to reuse the building compositions of the buildings, for which demolition decision has been taken, such as the roof truss, woodworks. Following the saving of appropriate building compositions, recyclable building materials are needed to be separated. In this way, raw material protection is provided for the building material to be reproduced, and thus it is saved from the energy to be consumed while processing raw material.

It is necessary to use machines and equipment as few as possible while demolishing buildings and select equipment procuring energy saving for demolition.

## **3. Conclusion**

Buildings have a huge potential for energy efficiency. To obtain these large potential there is a need to take some regulations and initiatives to improve the efficiency in buildings. Energy consumption in buildings occurs in every phase of building life cycle. However, the important phase is the usage and maintenance process of buildings where energy is consumed most within the scope of life cycle. During the building life cycle, the highest energy consumption occurs during the usage stage. This is because this period is much longer in duration compared to the other stages and the comfort levels necessary for human health and working efficiency need to be provided at this stage. Therefore, in energy-efficient building designs, especially the usage stage should be taken into consideration. In order to reduce energy consumption in the usage process of building, renewable energy sources instead of fossil-based energy sources should be preferred. Importance to the use of renewable energy sources should be given. In particular, the use of active and passive systems should be noted. Energy simulation programs in building design should be used.

Within the scope of this study, energy-efficient strategies described under the titles of the choice of settlement in the prebuilding phase, planning settlement, building form, building organization and planning, building envelope, choice of building material, landscape design, and utilization of renewable energy sources are directed to using less energy or cleaner energy in the usage process of buildings. Examining these strategies, it is clear that cooperation of very different disciplines (architecture, mechanical engineering, civil engineering, landscape architecture, urban and regional planning and interior architecture) is required. For this reason, designing an energy-efficient building is possible with a multidisciplinary study which begins from the emergence of the idea of constructing a building and lasts until the demolition of the building at the end of usage period.

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