Project funded by the EUROPEAN UNION

Black Sea Basin Joint Operational Programme 2007-2013

# BSBEEP

## *Black Sea Buildings Energy Efficiency Plan*

GA1: Knowledge and information collection and dissemination – Analysis of external current situation

**Activity GA1.3**

# Collection of appropriate applied best practices concerning energy efficiency issues and proposals to implement them

# *Black Sea Buildings Energy Efficiency Plan (BSBEEP)*

**Black Sea Basin Joint Operational Programme 2007-2013**

Black Sea Buildings Energy Efficiency Plan (BSBEEP*)* project aims at the establishment of strong regional partnerships and cooperation schemes in Black Sea area through the reinforcement of administrative capacities of local authorities and bodies in a very crucial sector (energy efficiency in buildings) having major environmental and economic impacts locally and globally.

The ultimate goal is to achieve change in the way they treating energy for buildings; facilitating change in the way local societies are acting. Furthermore, the project focuses on the establishment of a knowledge and experience exchange network aiming at the promotion of buildings energy efficiency. The network will engage a wide spectrum of organizations such as local and regional authorities, universities and research centers and NGOs which will help promoting energy efficiency in buildings at local and regional level. Meanwhile it will focus on raising awareness and mobilizing private sector and leverage funds to support future initiatives.

Ten partners are participating in the BSBEEP Project from six different countries; Munipality of Kavala (GR), Municipality of Galati (RO), Municipality of Cahul (MD), Municipality of Mykolayiv (UA), Municipality of Samsun (TR), Municipality of Tekirdag (TR), Democritus University of Thrace (GR), University Dunarea de Jos of Galati (RO), American University of Armenia (AM) and Renewable Resources and Energy Efficiency Fund (AM).

The specific study is one out of five studies, of GA1 of BSBEEP Project, which is a group of activities aiming to identify the external environment that all ten partners are working on (GA1: Knowledge and information collection and dissemination – Analysis of external current situation).

More details about BSBEEP Project are available on its website: **www.bsbeep.com**.

# Table of Contents

# 1. Introduction

Sustainable development is a key element of the European strategy for the 21st century. In his respect, the EU is determined to build a resource-efficient Europe with an increased use of renewable energy sources, a modernized transport sector, energy-efficient buildings and products, and green technologies. In the document "Europe 2020: A European Strategy for Smart, Sustainable and Inclusive Growth", the European Commission has assigned an explicit role to a sustainable energy sector. To reduce carbon emissions, the EU committed to what it has labeled 20-20-20 by 2020:

- Reduce greenhouse gas emissions by at least 20% from 1990 levels by 2020.
- Increase the share of renewable energy sources in energy consumption to 20%.
- 20% increase in energy efficiency

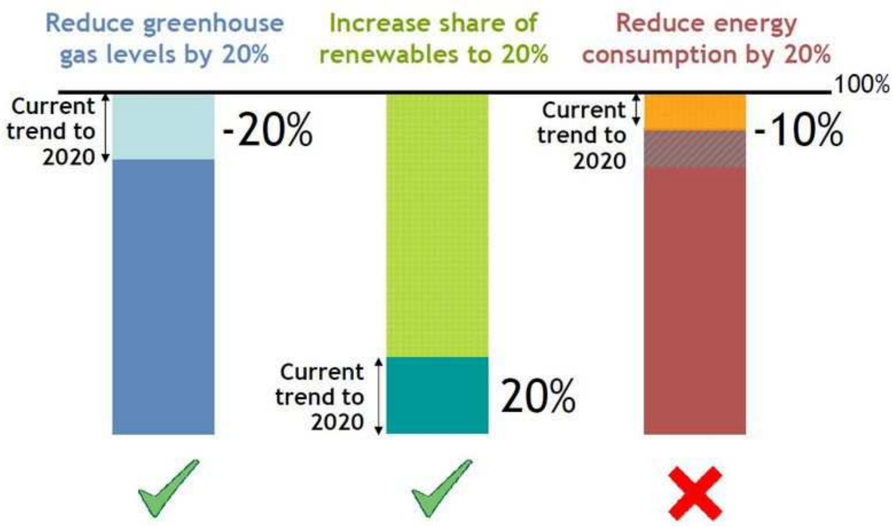



**Figure 1-1:** European Strategy for Smart, Sustainable and Inclusive Growth.

The European Commission (EC) believes that it's on the right way meeting the first two of these goals. But for the third objective the EU is expecting to obtain only a 10% reduction in energy consumption, half the target of 20%.

To get the EU back to the objective for obtain 20-20-20 energy efficiency goal, the European Commission (EC) proposed about a year ago a new Energy Efficiency Directive (EED); first, a legal obligation for all the states member to establish energy saving plans, secondly, the public sector to lead by example, and thirdly, major energy savings for consumers. One of the EED proposal was Annual renovation target of 3% for public buildings above 250 m².

Since buildings account for more than 40 % of the total energy consumption of the European Union, an energy efficiency program for the buildings sector is a crucial step to obtain an energy-efficient Europe. The Directive on the energy performance for buildings was recast in 2010, now are defining ambitious minimal standards for newly built and retrofitted buildings. Still, policies implemented by EU Member

States vary with respect to ambition and efficacy. Yet, good practice examples display options for improvement.

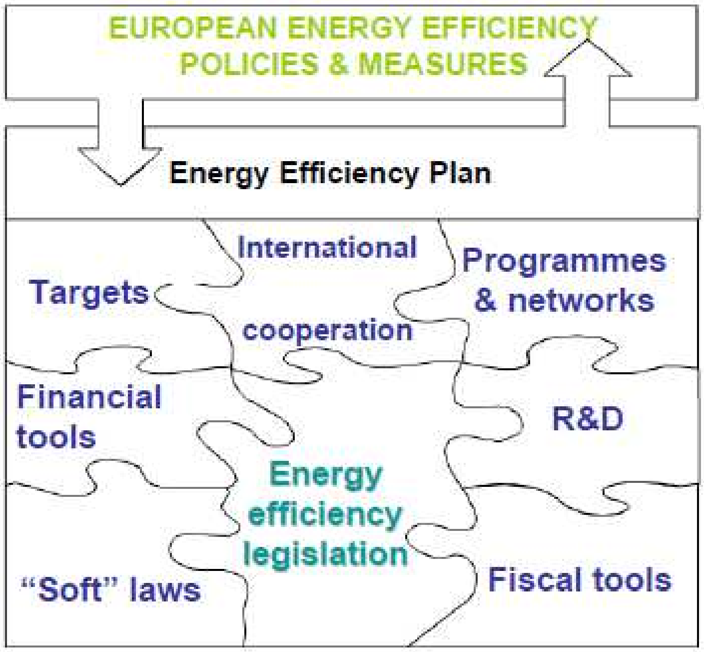



**Figure 1-2:** Energy efficiency plan.

It is very difficult to define the term "best practice". Typically, "best practice" is associated with the use of technologies. But this term can be used loosely to describe implementation of policies and policy packages to reduce energy consumption in buildings.

Energy efficiently means:

- using less energy to achieve the same result;
- using the same amount of energy to obtain a better result;
- the cheapest energy is the saved energy.

EU directives outline the objectives and the expected results from the Member State without telling how to achieve them. After ratification, EU directives are transposed in national law. The Member States are free to choose the optimal way and means to implement the directives. This means that they are not passed as a separate law but the existing legislation is amended or new national legislation created to meet the objectives of the EU directive in the respective Member States. By doing so, the EU respects that each country creates its own regulatory legal framework and needs to overcome individual country-specific challenges. As a result, legal regulations of activities as well as levels for building energy standards to improve energy efficiency and develop energy services considerably vary substantially across EU countries.

This is important for transition countries to note when looking at EU directives. The content, objectives and targets of the directives can be of interest to transition countries. Transition countries should, however, refrain from transferring EU directives 1:1 in national legislation. Instead it's recommended that they rather focus on creating the related legislation in which EU member States embed the EU directives.

Regardless of availability of common European directives, the approaches by different countries to tackling the problems of energy efficiency enhancement considerably vary across the region, and depend on such factors as availability of different incentives within the existing legal and policy frameworks, and terms of project financing.

Buildings are subject to both European and national regulation in the area of energy efficiency, but the requirements of national laws touch only measures, which have an economic sense and have a great public importance. In this context, Germany is a good country example, which has established legislative requirements for energy saving in the housing sector covering heat insulation of pipelines, upper storey, installation of heat meters and thermostatic valves in the heating system. These requirements help implementation of energy saving measures in the housing sector, since these measures do not need the agreement of the owner's majority, premises needed in case of other large-scale repairs.

The knowledge of best available practices is very important because every country must learn from the other countries experience which started earlier a building energy efficiency program. In this way all the countries can benefit from the accumulated experience and avoid mistakes and waste of time and money.

Finland can be considered a good practice example for energy efficiency policy regarding public buildings. Through Finland's measures is the *Local government energy efficiency agreement* in which signatory municipalities are eligible for financial support of energy audits and energy-saving investments. The Finnish policy package also includes minimum energy performance strict standards for retrofitted or newly built buildings owned by the central government.

The best practices are intended to support program administrators and the general remodeling industry in efforts to enhance energy efficiency of the existing housing stock at the time of major renovation.

Retrofitting existing homes for improved energy efficiency is increasingly viewed as a start point of policy initiatives targeting clean energy development and job creation in the construction and building materials manufacturing sectors. However, despite the clear economic and environmental benefits of reducing household energy waste, cost-effective efficiency measures have so far failed to gain widespread acceptance among homeowners. The primary obstacles to widespread adoption of efficiency retrofit measures are not technical. Significant efficiency gains can be achieved through the application of common insulation and weatherproofing techniques, and by replacing inefficient lighting, appliances and HVAC equipment with readily available products. Despite the prospect of reduced household energy bills, homeowner accept of these measures has been hampered by a combination of upfront capital costs, low public awareness, consumer inertia and limited availability of dedicated energy retrofit services.

Building energy efficiency has two components:

1. Active energy efficiency is defined as the result of permanent change by measuring, monitoring and controlling energy usage.
2. Passive energy efficiency is installing countermeasures against heat loss, choice of equipment with low power consumption, etc. The use of performant equipment and devices is vital but not enough. Without proper control, often, these measures only militate against energy losses and the use instead to achieve a real reduction in energy consumption.

When reviewing energy efficiency improvement practices in the housing sector in different countries of the European Union, a number of success factors and important lessons can be identified:

- Political will and commitment are key driving forces to advance housing energy efficiency.
- Target the whole building and one-time renovation.
- Energy efficiency does not have to be expensive.
- Retrofitting of existing buildings has long pay-back periods and requires additional incentives from governments.
- State support measures are important at the transition period.

There are an important number of websites and publications catalogue that promote good practice on energy saving[1, 2, 3, 4, 5, 6, 7]:

- The Energy Saving Trust is the UK's leading impartial organization that help people to save energy and reduce carbon emissions. The Energy Saving Trust does this by providing expert insight and knowledge about energy saving, supporting people to take action, helping local authorities and communities to save energy and providing quality assurance for goods, services and installers.

- The BUILD UP initiative was established by the European Commission in 2009 to support EU Member States in implementing the Energy Performance of Buildings Directive (EPBD). The BUILD UP web portal is intended to reap the benefits of Europe's collective intelligence on energy reduction in buildings for all relevant audiences. It will bring together new practitioners and professional associations while motivating them to exchange best working practices and knowledge and to transfer tools and resources.

[1]http://www.energysavingtrust.org.uk/business/Business/Information/Publicationsand-Report-Library/Publications-and-Case-Studies;
[2]http://www.nrel.gov/docs/fy13osti/57827.pdf
[3]www.hprcenter.org/.../best_practices_white_paper
[4]http://www.buildup.eu/
[5]http://www.sustenergy.org/
[6]http://www.managenergy.net/best_practice.html
[7]http://www.eceee.org/

- The Sustainable Energy Europe Campaign – The European Union created the Sustainable Energy Europe Campaign in 2005 as its major effort to promote energy efficiency and renewable energy sources. Now managed by the EU's Executive Agency for Competitiveness and Innovation (EACI), more than 1 200 energy projects comprise the Campaign. Sustainable Energy Europe is designed to spread best practices in sustainable energy technology, build alliances, and inspire new energy ideas and actions.

- ManagEnergy is a technical support initiative of the Intelligent Energy – Europe (IEE) program of the European Commission which aims to assist actors from the public sector and their advisers working on energy efficiency and renewable energy at the local and regional level.

- The European Council for an Energy Efficient Economy - ECEEE is a non-profit, membership-based European NGO. The goal of ECEEE is to stimulate energy efficiency through information exchange and co-operation.

# 2. Best Available Practices

## 2.1 Bioclimatic design

### 2.1.1 Introduction

Building design from ancient times often relied on ingenious use of forces of nature to create comfortable interior environments. The wind-catchers in desert and hot countries used movement of wind and flow of underground water to cool interior of buildings without expenditure of energy. In increasing lighting flow into rooms, window wall angels were modulated. The massing of buildings and creating narrow alleys to increase shading and wind flow in the summer, esp. in hot climates. In deciding on the location of a building, the southerly exposure to the sun was a key decision factor for going as far back as cave dwellers.

Collectively many of these solutions have come to be known as “passive” solutions or bioclimatic design. That is, solutions that by use of clever and often simple and inexpensive techniques reduce the demand for energy inputs during the operation of a building. These solutions are in contrast to the mechanical solutions such as heating, air-conditioning, and mechanical ventilation units in rampant use, esp. after WWII in Western countries and still spreading rapidly throughout the world.

With increased emphasis on environmentally sustainable architecture, there is a reemergence of interest in such “passive” solutions. The remainder of this module will discuss several of these “passive” solutions, including building orientation, natural ventilation, passive cooling, day lighting, shading, insulation, building envelope design, cool roofs, and so on.

In addition to what will be discussed in the section on bioclimatic building design, there is a number of non-mechanical, passive solutions that improve the thermal, light, and ventilation performance of buildings without expenditure of energy at the operational phase. These solutions have to do with the construction of the building envelope, i.e., the building cladding, the insulation of the walls, roof, and flooring, elimination of thermal bridges, as well as appropriate selection and installation of use of windows and doors. These important solutions are discussed in other parts of this report and not in the bioclimatic section.

### 2.1.2 Building orientation

How a building is positioned in relation to the sun can significantly impact its demand for energy. Many ancient societies understood this. Whenever they had a choice, cave dwellers across the northern hemisphere selected sites with southern exposure. This increased the solar heat gain in the winter while minimizing summer gains. This is how this works.

Because of the slight tilt in the axis of the earth, i.e., 23.5 degrees in relation to the orbit of the earth around the sun, the position of the sun in the sky changes throughout the year. In the summer the sun is at a higher point in the sky than it is in the winter. This shifting solar position is illustrated in the Figure 2.1-1, though the exact angels for the given times will differ depending on exactly where in the northern hemisphere you're located.

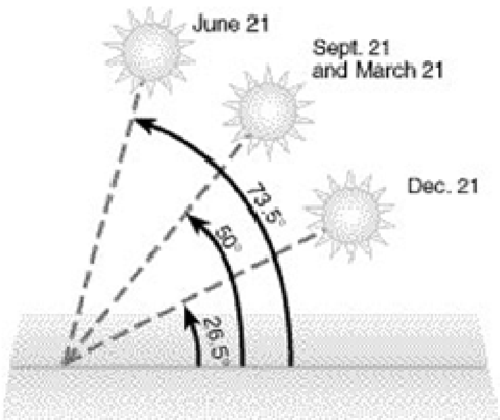



**Figure 2.1-1:** Seasonal change in location of the sun in the Northern Hemisphere (exact angles may change depending on specific location)

Figure 2.1-2 below illustrates the exposure of a modern house at 1pm in the winter, spring, summer, and autumn. In the summer, the eastern and specially the western façade will receive the most exposure to the sun. Thus with the long side of the building facing the south, the surface area with intense western exposure to the sun is reduced. This in turn reduced the need to use energy to cool the building. In the winter, the sun exposure and heat gain that is desired is maximized on the southern façade, reducing the energy need for heating.

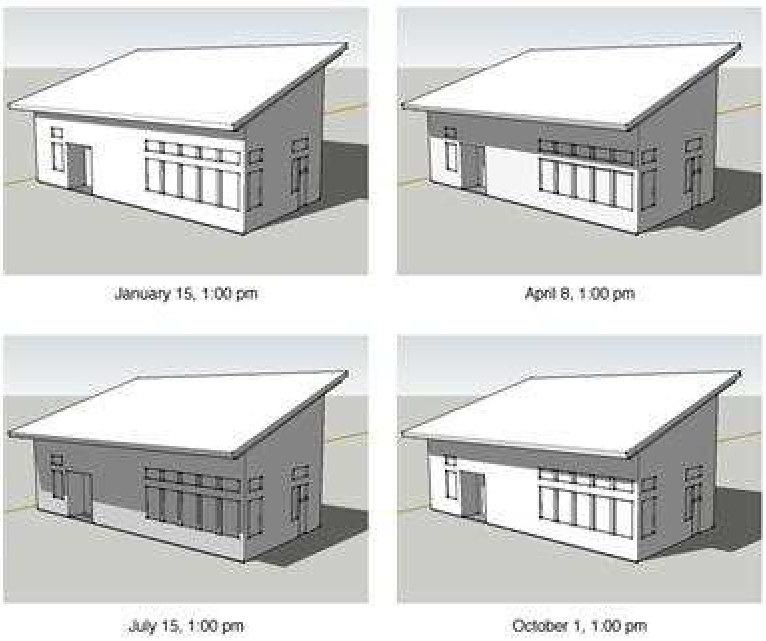



**Figure 2.1-2:** Seasonal change in the location of the sun and impact on shading of the south facing façade in the Northern Hemisphere.

As early as mid-1980s, using computer simulation for prototype buildings across 25 climates in the US showed when the more extensively glazed exposure is oriented to south, total heating and cooling loads are significantly lower than those in the same building oriented east or west.[8] The magnitude of the savings may differ significantly depending on size of the building, amount of glazing, thermal mass[9] of the building envelope, the size of the overhangs, availability of shading such as trees, and so on. Some analysis by local utility companies and municipalities in the US show that southern orientation of buildings can generate savings of up to 20% for heating and up to 40% for cooling.[10]

Many sites may be limited in their southern exposure. The longer side of the land parcel may be north to south, thereby not allowing full utilization of the southern exposure. While this highlights the need for thinking about building orientation at the urban planning and parcelization stage, architects may still have some flexibility in design. They could reduce glazing on the western façade and instead increase glazing and the narrower northern and southern facades. Also some suggest that a variation with an angel of plus/minus 30 degrees from a directly southern orientation will still give you benefits (Figure 2.1-3).[11]

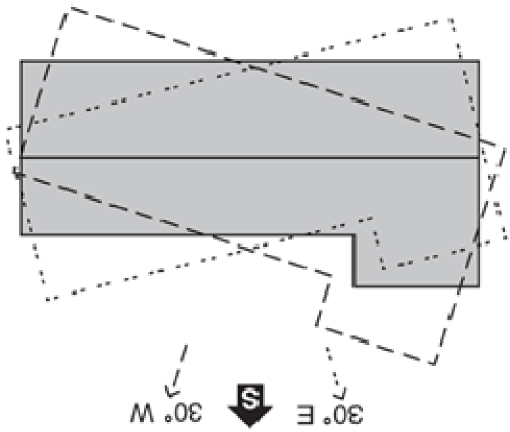



**Figure 2.1-3:** Rotation in orientation that will still offer benefits of southerly orientation.

### 2.1.3 Shading

Shading refers to the intentional creation of shading in hot summer days by structures or plants. This simple and often inexpensive solution can have significant

[8] Brandt Andersson, Wayne Place, Ronald Kammerud, M.Peter Scofield, The impact of building orientation on residential heating and cooling, Energy and Buildings, Volume 8, Issue 3, August 1985, Pages 205-224, ISSN 0378-7788, 10.1016/0378-7788(85)90005-2. (http://www.sciencedirect.com/science/article/pii/0378778885900052)

[9] Thermal mass refers to the mass of a building can flatten out the temperature fluctuations inside the building as outside temperature fluctuates.

[10] Energy Source Builder Vol. III No. 2, April 1991,Iris Communications, Inc.; http://oikos.com/library/solar_site_design/index.html

[11] Passive Solar Home Design, US Department of Energy (April 13, 2012) http://energy.gov/energysaver/articles/passive-solar-home-design

impact on the energy load of the building. Studies have repeatedly shown that shading can significantly lower surface and above surface temperature of an area. Studies from the US show that the temperature of a shaded area can be up to 25 degrees Celsius cooler than a non-shaded area.[12]More recent studies from the UK place the number to up to 20 degrees Celsius.[13]

Trees on the eastern, southern, and western sides of a building will help reduce energy costs. The selection of trees, however, is important. Deciduous trees, trees that shed their leaves in the fall and regain them in the spring, are the ones most appropriate. This is because in the winter months you would like little barrier to sun light (Figure 2.1-4). Trees closer to buildings would also need to be pruned so that the lower parts have few branches and the crown can provide shading for the roof.

Trees that aren't "solar friendly" can still be used. Evergreens can be planted on the northern side of the building. They can also be used on the west side to block the intense summer heat of the setting sun.[14]

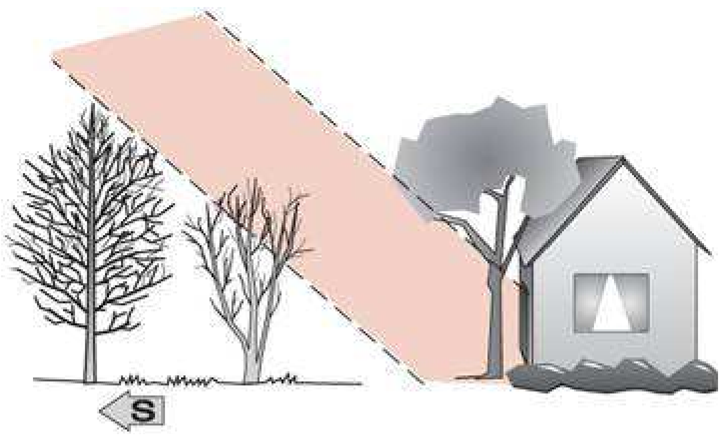



**Figure 2.1-4:** Shading and building orientation.

Building designers should consult with an arborist or a landscape architect to make appropriate tree selection to maximally benefit the building from the shading effect of trees.

Use of plants for shading is common a common practice. In Yerevan and Tbilisi with hot and very sunny summers, a common solution has been planting vines which filter a substantial percentage of the direct sunlight. Grape vines are traditionally used,

[12]U.S. Environmental Protection Agency (http://www.epa.gov/heatisland/mitigation/trees.htm). It is noteworthy that one to two degrees Celsius of this reduction is attributable to evapotranspiration, the process of the tree and the plant released evaporation thereby cooling its surroundings.
[13]D. Armson, P. Stringer, A.R. Ennos, The effect of tree shade and grass on surface and globe temperatures in an urban area, Urban Forestry & Urban Greening, Volume 11, Issue 3, 2012, Pages 245-255, ISSN 1618-8667, 10.1016/j.ufug.2012.05.002. (http://www.sciencedirect.com/science/article/pii/S1618866712000611)
[14]Energy Source Builder Vol. III No. 2, April 1991,Iris Communications, Inc.; http://oikos.com/library/solar_site_design/index.html

though other vines also at times seen (Figure 2.1-5). The advantage of these vines is that they provide shade in the summer and allow light and warmth through in the winter. For pitfalls of improper use of vines or use of damaging vine species refer to your landscape specialist or authoritative information source[15].

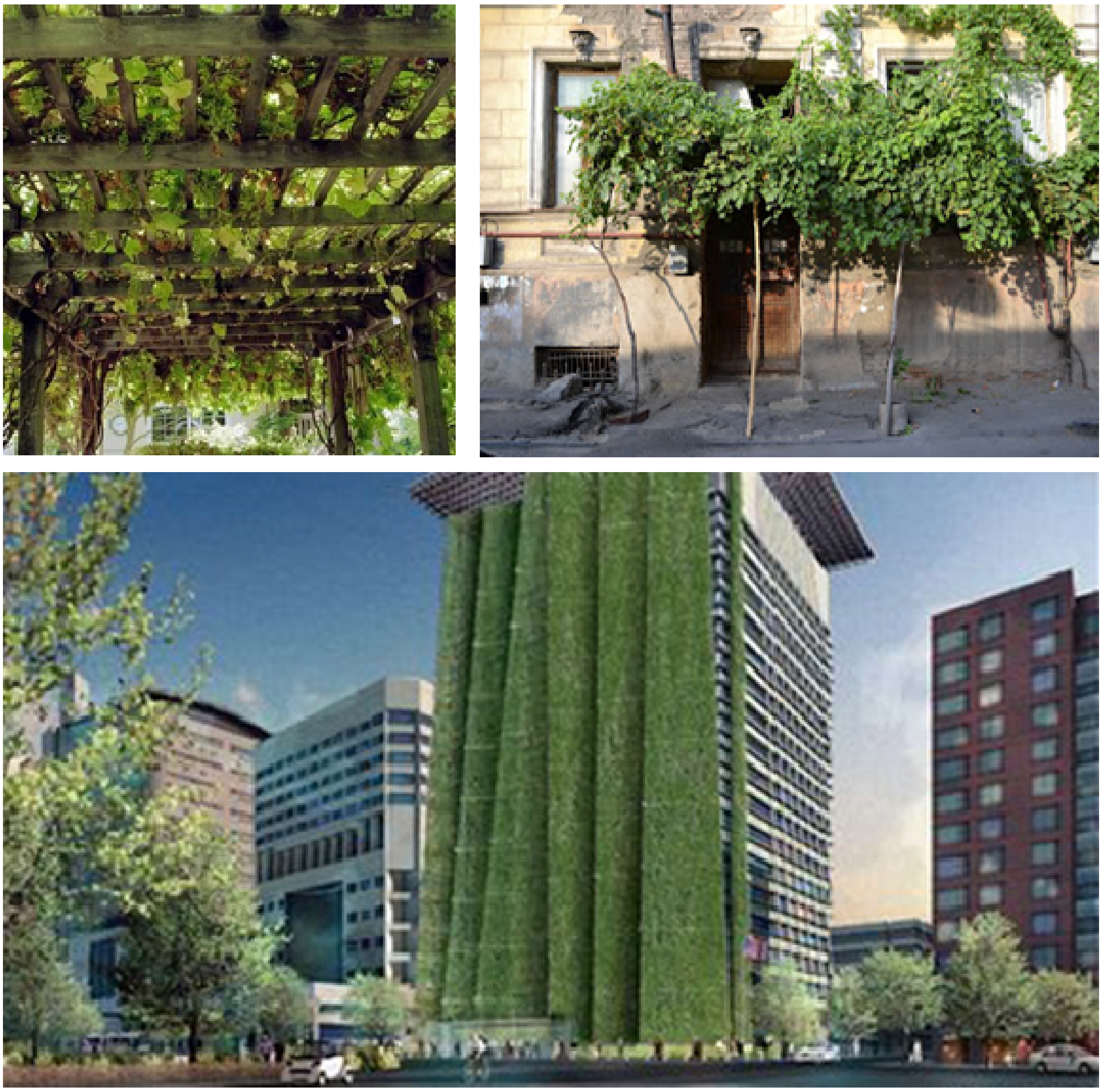


**Figure 2.1-5:** Use of vines for shading is common in the Caucasus including in Yerevan. It is a good practice that can be used to enhance design and building occupant comfort. In the rendering below, the western façade of a US Federal Building in Portland, Oregon has trellises with vine growing on them. For updates see the site for project architect SERA (serapdx.com).

There are physical, structural shading that is also frequently used. Some of these physical shades, such as exterior wooden shutters, are as old as habitable structures. These will be discussed in the day lighting section below, especially in the section called "solar shading devices."

[15]For a very informative discussion of building damage caused by various species of vines see: http://www.fassadengruen.de/eng/uw/climbing_plants/uw/greening/greening/building-damages.htm

As a final note, while curtains and internal shades are also frequently used solutions, from a great energy efficiency perspective, if we want to keep interiors cool, it is best to prevent the heat from entering the building in the first place. It will also help if the side exterior facing side of the curtain is white or a color with a high albedo (see “cool roof” section below for more in-depth discussion of albedo). When trying to keep the building warm, curtains can be very helpful.

### 2.1.4 Daylighting

Lighting is a major expense, especially, for commercial buildings. Using natural lighting during daytime is imminently sensible. Natural lighting also tends to improve psychological wellbeing, increase worker satisfaction levels, as well as reduce visual stress.

To use natural light effectively, however, buildings have to be designed effectively. To have a room or a building where the sun directly shines into room, creating not only excessive heat but also glare that prevents adequate visual performance can only make matters worse for the occupants. On the other hand, having shades and shutting them and turning the lights on during daytime is a result of bad design.

Designing buildings which takes maximal advantage of natural light to produces a diffused and sufficiently bright light is the practice of daylighting. Through daylighting strategies, architects bring natural light as deeply as possible into the building while controlling glare and direct sun. A masterful example of that was Yerevan’s Enclosed Market (Figure 2.1-6).

**Figure 2.1-6:** Yerevan’s Enclosed Market built in the 1950s and designed by architect Grigor Aghababyan was a masterpiece of daylighting.

Another masterpiece of daylighting, though again at a large and iconic scale, is the glass dome at the Reichstag by Norman Foster (Figure 2.1-7). Aside from the poetry of the design, where natural light of the outside world shines on the parliamentary debates and that ordinary citizens walk on top and their representatives down below, the dome cuts down on the use of electricity for lighting as natural daylight shines through the mirrored cone down into the parliament hall. The sun light can be so intense that a screen tracks the sun to soften the glare.

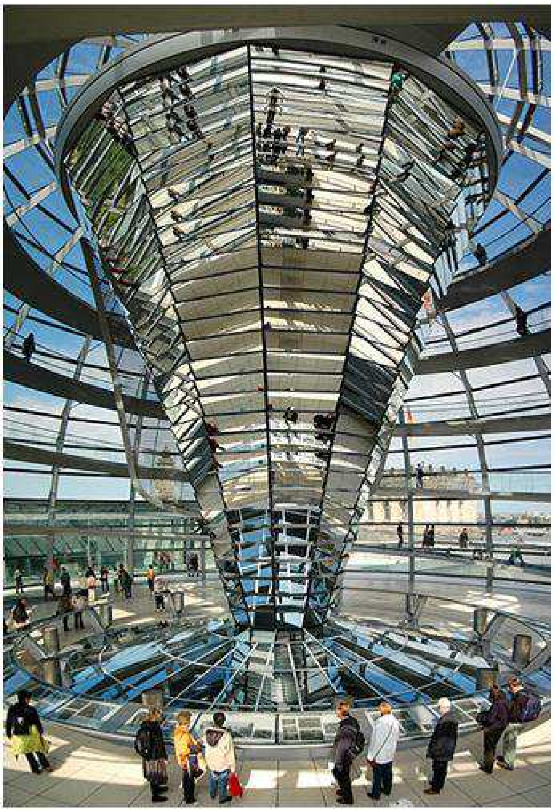


**Figure 2.1-7:** Interior view of the glass dome of the Reichstag in Berlin, Germany by architect Norman Foster. Another iconic masterpiece of day lighting. The dome also allows for natural ventilation from the top of the dome, similar to the Pantheon in Rome.

Aside from the two iconic buildings noted above, daylighting can also be applied to ordinary commercial and residential buildings. There are various approaches and solutions that can be employed to achieve optimal day lighting for a given building. The following are some of these approaches.[16] As you will note some are linked to other "passive" solutions discussed in this Module:

- Daylight-optimized building footprint – maximizing south and north exposure and avoiding the direct eastern and western sun. A room depth of 18-20 meters seems to be maximum for effective day lighting from northern and southern light.

[16]The list is from "Daylighting" by Greg Ander, FAIA, Whole Building Design Guide (August 24, 2012); http://www.wbdg.org/resources/daylighting.php

- Climate-responsive window-to-wall area ratio – balancing the light brought in by glazing with the insulation properties of walls. Even the most high performance windows cannot achieve the thermal performance of walls. The tradeoffs between light and insulation should be balanced.

- High-performance glazing – These would be windows that would allow more light in than heat. Double or triple glazed windows with adequate sealing and construction can perform this role.

- Daylighting-optimized fenestration design – Balancing between clarity of vision provided by window glazing and diffusion of light by the window. Not every part of window needs to offer full view to building occupants. In reducing viewing clarify, glare may be reduced.

- Skylights and tubular daylight devices – Skylights allow ample light to enter a room. The location will impact whether is direct or diffused light. In the summer months it may be source of glare if it’s installed facing east, west, or south and has no shading. It is also a source of heat gain or loss. Therefore it’s use has be considered in the building’s energy and light balance.

- Daylight redirection devices (such as light shelves) – Light shelves are used to block direct sun entering a room while at the same time deflecting it to ceiling of a room which then in turn spreads it throughout the room (Figure 2.1-8).

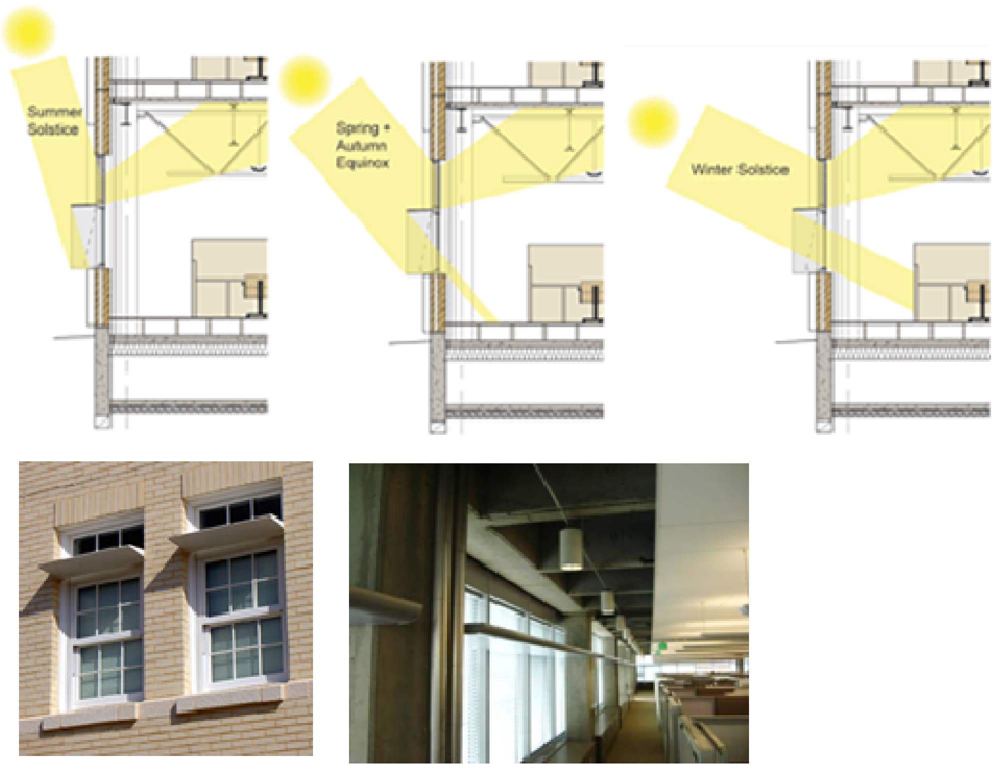



**Figure 2.1-8:** Use of light shelves allows for shading against direct light but reflection of indirect light deeper into the interior space.

- Solar shading devices – There is a wide variety of solutions to solar shading devices. They may include louvers, screens, shelves, or plants. One architectural firm that has used such shading devices to an iconic effect is Morphosis (Figure 2.1-9). There are many more common shading structure that can be integrated into the building design (Figure 2.1-10).

**Figure 2.1-9:**The iconic double skin of Morphosis architectural firm. Pictured is the Cooper Union Building in New York City.

**Figure 2.1-10:** Commonly used structure and architectural elements to provide shade.

- Daylight-optimized interior design – An often overlooked part of daylighting is the furniture design, space planning, and room surface finishes and colors. All these impact the distribution of light within a space (Figure 2.1-11).

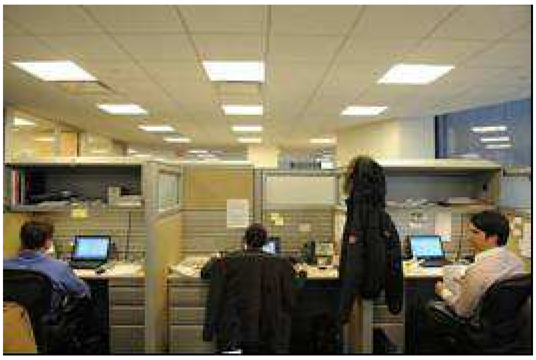



**Figure 2.1-11:** A number of factors impact the movement of light inside a building.

While some architects may have a deep sense of light and how it enters and moves in space, employing many of the solutions above complicates the analysis considerably. To fully understand the impact of all decisions, designers often have to rely on simulation software.[17]To move away from theory and begin designing with daylighting effectively, the student would be well advised to take design studio courses and do individual studies on the subject.[18]

### 2.1.5 Cool roofs [19]

Roofs can be a great source of heat loss from interior of buildings , esp. during cold seasons when you need to maintain the heat inside the building. That is why the insulation requirements of the roofs are generally higher than those of walls.

Roofs can do the opposite in hot seasons. When there is abundant sun, roofs can become a source of heat gain in buildings. In hot summer days, the surface temperature of a black asphalt roof (commonly used in many parts of the world) can reach up to 70 degrees Celsius. The high temperatures on roofs can reduce the comfort of spaces inside buildings that are not air-conditioned. They can significantly increase energy costs for air-conditioning. They may also reduce the service life of the roofing material.

One inexpensive solution is to install cool roofs. Similar to light-colored clothing keeping a person cool on a sunny day, cool roofs use solar-reflective surfaces to maintain lower roof temperatures. Traditional dark roofs can reach temperatures of 70 degrees Celsius or more in the summer sun. A cool roof under the same conditions could stay more than 28 degrees Celsius (Figure 2.1-12).

[17]Christoph F. Reinhart, Jan Wienold, The daylighting dashboard – A simulation-based design analysis for daylit spaces, Building and Environment, Volume 46, Issue 2, February 2011, Pages 386-396, ISSN 0360-1323, 10.1016/j.buildenv.2010.08.001. (http://www.sciencedirect.com/science/article/pii/S0360132310002441)

[18]To start with review the MIT Open Course Ware offering on daylighting: http://ocw.mit.edu/courses/architecture/4-430-daylighting-spring-2012/index.htm

[19] This section relies substantially on U.S. Department of Energy, Energy Efficiency and Renewable Energy, Building Technologies Program's, "Guidelines for Selecting Cool Roofs" (July 2010). At times the text is directly copied. http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/coolroofguide.pdf

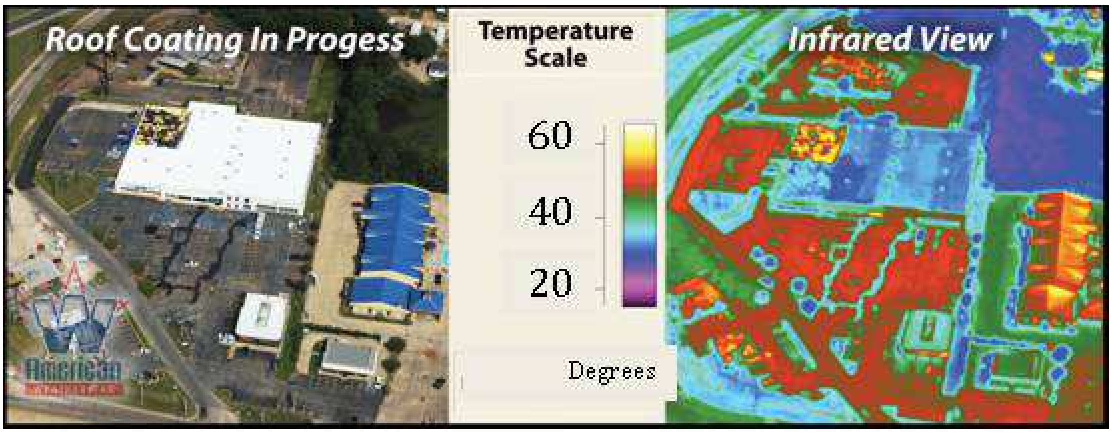



**Figure 2.1-12:** Thermographic view of roof being transformed into a cool roof. Note the top left corner that is not yet fully converted is substantially hotter.

Solar reflectance and thermal emittance are the two key material surface properties that determine a roof's temperature, and they each range on a scale from 0 to 1. The larger these two values are, the cooler the roof will remain in the sun.

Solar Reflectance, also often referred to as the albedo, is the fraction of sunlight that a surface reflects. Sunlight that is not reflected is absorbed as heat. Solar reflectance is measured on a scale of 0 to 1. For example, a surface that reflects 55% of sunlight has a solar reflectance of 0.55. Most dark roof materials reflect 5 to 20% of incoming sunlight, while light-colored roof materials typically reflect 55 to 90%. Solar reflectance has the biggest effect on keeping your roof cool in the sun. For typical reflectance values for different surface materials see Figure 2.1-13. The solar reflectance of roofing products are not typically based on initial values, but rather on 3- year aged values. This is because the reflectance of a surface changes over time, with most rapid change happening in the first 3 years of its use.

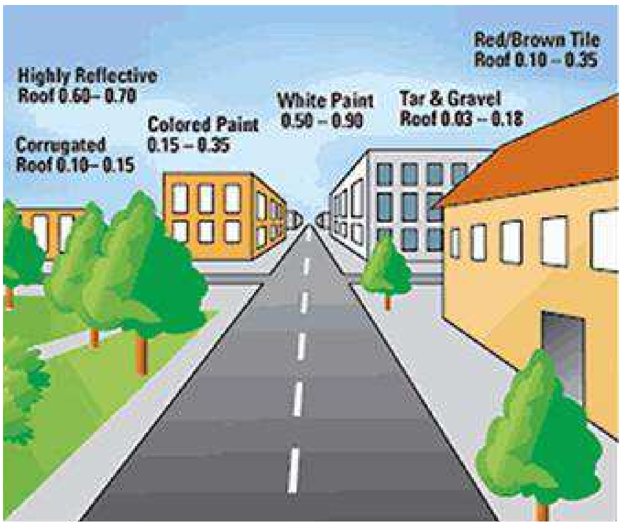



**Figure 2.1-13:** Solar reflectance values of various surface materials.

Thermal Emittance describes how efficiently a surface cools itself by emitting thermal radiation. Thermal emittance is measured on a scale of 0 to 1, where a value of 1 indicates a perfectly efficient emitter. Nearly all nonmetallic surfaces have high thermal emittance, usually between 0.80 and 0.95, that helps them cool down. Bare, shiny metal surfaces, like aluminum foil, have low thermal emittance, which helps them stay warm. A bare metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation.

Solar Reflectance Index (SRI)is another metric for comparing the “coolness” of roof surfaces. It is calculated from solar reflectance and thermal emittance values. The higher the SRI, the cooler the roof will be in the sun. For example, a clean black roof could have an SRI of 0, while a clean white roof could have an SRI of 100. Dark roofs usually have an SRI less than 20.

A roof can qualify as cool in one of two ways. The first way is by meeting or exceeding both the minimum solar reflectance and thermal emittance values. The alternative way is to meet or exceed the minimum SRI requirement. This allows some roofs that have a low thermal emittance and a high solar reflectance (or vice versa) to still qualify as a cool roof.

The threshold levels (i.e., the minimums and the maximums) are set by law or standards adopted by a regulatory agency. Figure 2.1-14 below shows the standards adopted by the California Energy Commission.

| Roof Type | Solar Reflectance [3-year aged] | AND | Thermal Emittance [new or aged] | OR | Solar Reflectance Index (SRI) [3-year aged] |
|---|---|---|---|---|---|
| **Low sloped** | 0.55 | | 0.75 | | 64 |
| **Steep sloped** | 0.20 | | 0.75 | | 16 |

**Figure 2.1-14:** Minimum cool roof requirements set by the California Energy Commission (2008).

To help consumers compare the cool aspects of roof materials and coatings, the Cool Roof Rating Council (CRRC) manages a system for independently evaluating and documenting their properties. Roof products that are tested to CRRC methods receive a performance label (Figure 2.1-15) showing the measured solar reflectance and thermal emittance values.[20]

Because roof material surface properties can change over time due to soiling and weathering, values are measured and reported for both initial and three-year weathered conditions. The label in Figure 2.1-16 shows this product’s solar reflectance has dropped from 0.87 to 0.77 after three years. Most weathering or soiling occurs during the first year or two, and then values tend to stabilize.

[20]NOTE: Any roofing product that is tested by a CRRC accredited laboratory can be listed in the CRRC directory. Being listed does not imply that a product is cool.

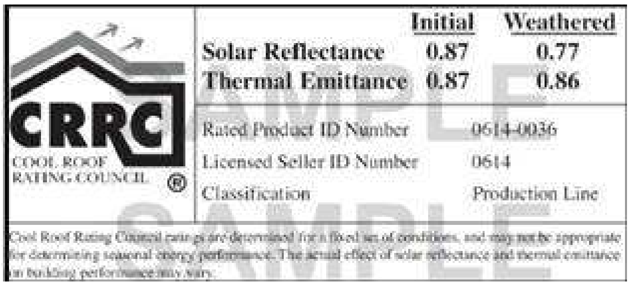



**Figure 2.1-15:** Sample of product labeling by the Cool Roofing Rating Council. Products are rated both for their properties initially and after they are weathered.


**Figure 2.1-16:** Cool roofs do not all have to white. While white has the highest reflectance other hues are also available.

Figure 2.1-17 shows a metallic roof that is dark in color being painted white. Not all cool roofs, however, are white. Although white materials tend to be very good solar reflectors, colored roofing materials, like those shown in Figure 16, can also be made to reflect more sunlight. More than half of the sunlight reaching the earth is invisible to the human eye, and this invisible sunlight heats the roof. A colored surface that reflects much of the invisible sunlight is a called a cool dark color, or cool color. A cool dark color reflects more sunlight than a similar-looking conventional dark color, but less than a light-colored surface. For example, a conventional dark colored surface might reflect 20% of incoming sunlight, a cool dark colored surface, 40%; and a light-colored surface, 80%.

While reducing the roof's temperature with a cool roof can also increase the need for heating during heating seasons, in most climates the cooling advantage outweighs the loss of heat gain during winters. In many climates with snow on the rooftops in the winter, the dark roof advantage is naturally lost.

Finally, aside from building energy efficiency benefits of cool roofs, they are also beneficial environmentally. Roofs can be a contributing factor to the heat-island effect associated with urban areas. Heat-island effect refers to the observed fact that as urban areas develop, buildings, roads, and other infrastructure that replace open land and vegetation, increase the average temperature of the urban area. Surfaces that were once permeable and moist become impermeable and dry. The annual mean air temperature of a city with 1 million people or more can be 1–3°C warmer than its surroundings. In the evening, the difference can be as high as 12°C.

Cool roofs can help reduce heat-island effect and contribute to environmental benefits. Cool roofs can reduce local air temperatures, which improves air quality and slows smog formation. They can reduce peak electric power demand, which can help prevent power outages as well as reduce power plant emissions, including reduction of greenhouse gases such as green carbon dioxide and nitrous oxides, and harmful emissions such as sulfur dioxide and mercury.


**Figure 2.1-17:** White paint being applied to dark metal roof converting it into a cool roof.

### 2.1.6 Green roofs

Green roofs, roofs that are covered by a layer of dirt and vegetation, offer many benefits including filtering of rainwater and air from pollutants, stormwater runoff reduction, reduction of noise pollution, providing food to building inhabitants if clean soil is used, or enhancing biodiversity and habitat creation for urban wildlife.In addition, green roofs also impact the energy use of a building by both reducing the heat gain or loss of a building. They are very effective insulators. In the summer months, green roofs reduce air-cooling loads. In the winter months, they have also been shown to reduce heat loss.[21]

Rigorous studies are not available to compare the energy efficiency of green roofs as compared with cool roofs (see section above for discussion of cool roofs). The accepted wisdom is that cool roofs provide similar energy savings to green roofs, at least in the summer months.

In winter monthsmost likely green roofs perform better, as dirt would have high insulating properties. In the summer months, they both can contribute to the reduction of heat-island effect in urban areas. Cool roofs are less expensive than green roofs. They, however, do not provide the stormwater management, enhanced

[21] http://www.sciencedaily.com/releases/2005/11/051126141309.htm

biodiversity, and filtering benefits associated with green roofs. Cool roofs may be combined with green roofs for optimum use.[22]

There are different categorizations of green roofs. Typically the categorizations are based on the depth of the planter, and the types and intensity of vegetation, and at times its emphasis on biodiversity. The International Green Roof Association categorizes green roofs into three: extensive, semi-intensive, and intensive. Figure 2.1-18 shows some images and presents characteristics of each type of green roof.

Extensive green roof

Semi-intensive green roof

Intensive green roof

| | Extensive | Semi-intensive | Intensive |
|---|---|---|---|
| Maintenance | Low | Periodically | High |
| Irrigation | No | Periodically | Regularly |
| Plant communities | Moss-sedum-herbs and grasses | Grass-herbs and shrubs | Lawn or perennials, shrubs and trees |
| System build-up height | 60-200 mm | 120-250 mm | 150-400 mm;<br>on underground garages >1m |
| Weight | 60-150 kg/m$^2$ | 120-200 kg/m$^2$ | 180-500 kg/m$^2$ |
| Costs | Low | Middle | High |
| Use | Ecological protection layer | Designed Green Roof | Park like garden |

**Figure 2.1-18:** Green roofs are generally categorized into 3 types: extensive, semi-intensive, and intensive[23].

There are a few academic centers in the world that conduct research in the areas of green roofs. Two include Michigan State University (www.hrt.msu.edu/greenroof/) and the British Columbia Institute of Technology, Canada (commons.bcit.ca/greenroof/). But as markets in green roofs develop, most

[22] http://www.mass.gov/eea/agencies/massdep/water/wastewater/green-roofs-and-stormwater-management.html

[23] International Green Roof Association (www.igra-world.com/types_of_green_roofs/); photos from various sources

experience and expertise is accumulating with private companies that are building and learning in the process. In addition to the International Green Roof Association (www.igra-world.com), students can also refer to Livingroofs.org and the European Federation of Green Roof Associations (www.efb-greenroof.eu/).

As a final note on green roofs, it should be noted that like many good architectural ideas, it is not a new innovation.Be it the Hanging Gardens of Babylon (circa 5$^{th}$ century BC), Viking and the medieval Scandinavian rural homes,[24] and the village settlements in Anatolia, roofs with planting have been employed. In fact even today in the Caucasus, structures can be found with the green roof principals employed. Figures19shows a few of these structures.

**Figure 2.1-19:** The photo on top is a structure with a traditional green roof near the Village of Aghtsk in Ashtarak, Armenia. The photo below shows “glkhatouns” in an Armenian village in Alastan, Georgia. Photos: Alen Amirkhanian (Aghtsk, above) and Regis Labourdette (Alastan, below).

[24] http://switchboard.nrdc.org/blogs/kcoplin/green_roof_roots_stumbling_upo.html

### 2.1.7 Natural ventilation

Buildings need ventilation, that is inflow of fresh air and removal of stale air. The staleness can be due to buildup of humidity, perspiration, cooking, smoking, industrial processes, pets, but also breathing by humans. Over time carbon dioxide concentration in enclosed space will increase while oxygen concentrations will decrease.

Building codes typically define ventilation standards. In the US, for instance, most building codes rely on ventilation standards set by ASHRAE Standard 62.1 (indoor air quality for all buildings) and 62.2 (indoor air quality for low-rise residential buildings). These standards are updated every 3 years. In the 21st century, to date updates have been done for2001, 2004, 2007, 2010, and 2013.

These standards determine, for instance, the minimum amount of fresh air that has to be brought into an enclosed space and stale air removed per second per occupant or per second per square meter of space. It also sets other minimums, such as the minimum distance of fresh air intakes from exhaust points.

Building ventilation can take several forms: mechanical or forced ventilation, natural ventilation, hybrid ventilation, and infiltration.

- Mechanical or forced ventilation uses air-handling units that requires the expenditure of energy to circulate air or bring fresh air into interior of buildings and removing stale air or excess humidity out. Most modern commercial buildings rely on such devices for ventilation.
- Natural ventilation uses natural forces of wind and buoyancy of air to move fresh air in and stale air out. No additional input of energy is required for this movement. Natural ventilation is the main subject of this section and more will be discussed later.
- Hybrid ventilation uses a combination of mechanical and natural ventilations. The mechanical is used to either augment the natural ventilation or diminish it, such as when there are strong winds.
- Infiltration or air leakage is the exchange of air between interior or exterior of buildings through cracks in doors, windows, skylights, and the like. It is typically unintentional though some of it is often unavoidable and perhaps even desirable.

Historically buildings were ventilated naturally. In many Western economies, however, mechanical ventilation took on a prominent role, esp. after the second world war. With increasing cost and environmental impact our energy sources, more attention is being placed on natural ventilation. In climates that are suited natural ventilation is estimated to save 10-30% of total energy consumption.[25]

Natural ventilation systems rely on pressure differences that move fresh air through

[25]In the remainder of this section, I've made a significant reliance on "Natural Ventilation" by Andy Walker, National Renewable Energy Laboratory, June 15, 2010 as it appears in National Institute of Building Sciences' Whole Building Design Guide at www.wbdg.org/resources/naturalventilation.php.

enclosed space. Pressure differences can be caused by wind or the buoyancy effect thatdifferences in temperature or humiditycan create. These happen in three ways:

a) Wind can blow air through openings in the wall on the windward side of the building, and suck air out of openings on the leeward side and the roof (Figure 2.1-20).
b) Temperature differences between warm air inside and cool air outside can cause the air in the room to rise and exit at the ceiling or ridge, and enter via lower openings in the wall.
c) Similarly, buoyancy caused by differences in humidity can allow a pressurized column of dense, evaporatively cooled air to supply a space, and lighter, warmer, humid air to exhaust near the top.

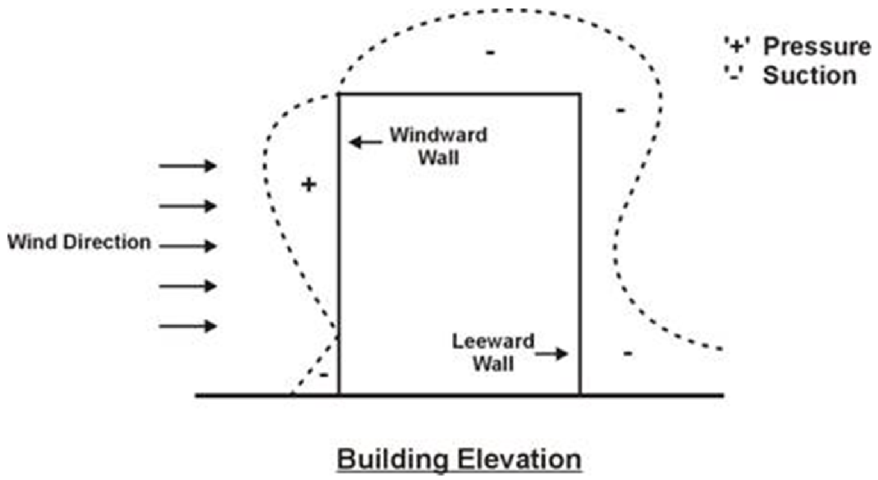



**Figure 2.1-20:** When wind hits a building, that is its windward direction, it has positive pressure. But as the wind “pulls away” from the building, it’s leeward direction, it creates negative pressure (a vacuum) that high pressure air will flow to.

The first principal is used effectively by “wind-catchers” in parts of the Middle East with hot and dry climates. While there is evidence of their use in ancient Egypt, more modern applications were prevalent in Iranian cities, esp. in the more arid parts of the country, and some Arab countries.

The towers that catch the wind are typically four or eight-sided. This enables them to catch the wind from the different directions it may blow. If architects are unable to provide so many openings, they need to have good information on direction of prevailing winds. Access to local meteorological information is critical. They should also ensure that there are no major obstructions to the flow of summer winds. To avoid such obstructions, traditional applications used towers (Figure 2.1-21).

**Figure 2.1-21:** Wind catchers in traditional Iranian cities. Note the four or eight-sided openings to capture wind from different directions. They are also placed on towers to avoid obstructions to wind flow.

Modern applications of the wind catchers are growing. One of the highly references uses is at the Beddington Zero Energy Development (BedZED) in the United Kingdom. Though, this particular solution has a heat-recovery component worked into it, the wind cowls, as they are called, offer passive ventilation. There are also other contemporary projects employing wind catcher solutions. (Figure 2.1-22).[26]

Aside from wind, natural ventilation can result from buoyancy of air, which is caused by difference in air density. The density of air depends on temperature and humidity (cool air is heavier than warm air at the same humidity and dry air is heavier than humid air at the same temperature).

[26]For a thorough discussion of windcatchers and their modern applications see Omidreza Saadatian, Lim Chin Haw,K. Sopian,M.Y. Sulaiman, "Review of Windcatcher Technologies," Renewable and Sustainable Energy Reviews 16 (2012) 1477– 1495

**Figure 2.1-22:** Modern windcatchers. University of Qatar, Doha (top left), BedZED (top right), and Australia (bottom left).

Within the room, both heat and humidity given off by occupants and other internal sources tend to make air rise. The stale, heated air escapes from openings in the ceiling or roof and permits fresh air to enter from lower openings to replace it. This is called stack ventilation and is seen in 19th century buildings. Research by Jane Greenwood on vernacular architecture in Gyumri, Armenia points out the use of these solutions in 19th century residences (Figure 2.1-23).


**Figure 2.1-23:** Research by Jane Greenwood on vernacular architecture in Gyumri, Armenia shows some of the natural ventilation (in photo stack ventilation) used in buildings. Photos by Jane Greenwood.

Stack effect ventilation is an especially effective strategy in winter, when indoor/outdoor temperature difference is at a maximum. Stack effect ventilation will not work in summer unless a chimney heated by solar energy is used.

The solar chimney consists of a black-painted chimney (Figure 2.1-24). During the day solar energy heats the chimney and the air within it, creating an updraft of air in the chimney. The suction created at the chimney's base can be used to ventilate and cool the building below.

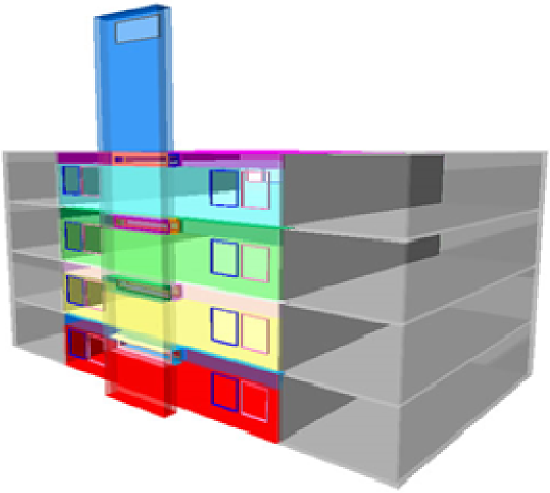


**Figure 2-1-24:** Solar chimneys can enable flow of air even when outside temperature is equal to higher than internal temperature, as they create concentrated hot air that expedites upward flow through the chimney.

This section gave a broad brushstroke of natural ventilation, introducing some of the basic concepts. Architects and builders should familiarize themselves further on this important topic through the readings recommended below.

**2.1.8 Thermal mass: passive heat storage and temperature leveling**

All material have their own rate of heat gain and loss. Copper, for instance, gains heat quickly and loses it quickly. Basalt rock, on the other hand, gains heat slowly and it takes a long time to release the gained heat. This “inertia” of a material to change tempertartue is often described using the concept “heat capacity” (also known as “thermal capacity”). Heat capacity measures the amount of energy needed to change the temperature of a material by a given amount.[27]

The scientific concept of heat capacity is equivalent to the term “thermal mass of a building” that is frequenlty used in architecture and building design. Depending the materials used in a building, the thermal “interia” of a building could be different. Concrete or basalt stone, for instance, take a long time to gain heat and a long time to release that heat. Steel,on the other hand, gain heat quickly and loses it quickly.

Thermal mass of a building can be used to store energy when its not need and release it when its needed. In the process it helps level the internal temperarture of a building throughout the day. When a building structure has large thermal mass, the inside of the building will remain relatively unaffected by the temperature

[27] The section on “thermal mass” has also benefited from contribution of Tigran Sekoyan.

fluctuations outside of the building. In hot summer days, for instance, the building structure with high thermal capacity will protect the inside from heating up too quickly while at night it will loose the heat to the cooler outside temperature, thus keeping the inside temperarture relatively constant.

All matter—be it solid, liquid, or gas—has thermal mass. Some have higher thermal mass than others. The property of the materials that help understand a material's thermal mass is its specific heat capacity.[28] The specific heat capacity of a material is it's heat capacity for a specified mass, say a kilogram. So the specfic heat of concrete is the amount of energy needed to raise the temperature of 1 kilogram of concrete by 1-degree Celsius. The higher the specific heat capacity, the higher the thermal mass of the material (i.e., more energy would be required to change the temperature per kilogram of that material). Table 2.1-1 below summarizes the specific heat capacity of materials used in construction.

**Table 2.1-1**: Specific heat capacity of materials in buildings.

| Material | Specific heat capacity, i.e., watt hours/(kg)(Temp) |
|---|---|
| Copper | 0.11 |
| Steel | 0.14 |
| Cork, straw | 0.17 |
| Mineral wool, fiberglass, foam glass | 0.25 |
| Brick, marble, granite | 0.26 |
| Air (10°C) | 0.28 |
| Gypsum boards | 0.29 |
| Concrete, cement screed | 0.31 |
| Polystyrene, polyurethane | 0.35 |
| Wood, fiberboard and chipboard | 0.65 |
| Water (20°C)* | 1.16 |

*Note: (*) Water has a high specific heat capacity. Thanks to that, water is considered the planet's temperature regulator, slowing warming and cooling.*

Thus architects can impact the energy use of a building by the materials they decide to make the building with. Architects and engineers will have to work together to optimize a building's thermal mass while achieve the aesthetic and cost expectations of the project.[29]

In addition to desiging a building using thermal mass as an energy saving tool, thermal mass of a building can be enhance through the use of the so called "thermal mass activation." Below two increasingly popular thermal mass activation solutions are discussed: concrete-core activation and phase-change materials.

[28]Note that thermal mass is a different concept than thermal conductivity, a concept we've discussed in the module on thermal insulation.
[29]For in-depth discussion of thermal mass visit: http://web.ornl.gov/sci/roofs+walls/research/detailed_papers/thermal/index.html and http://en.wikipedia.org/wiki/Thermal_mass

### *2.1.8.1 Enhancing thermal mass: concrete-core activation*

The thermal mass of concrete structures and exteriors (floors, walls, and roofs) can be enhanced by embedding pipes through them that will carry cool or hot water depending on the season (Figure 2.1-25).

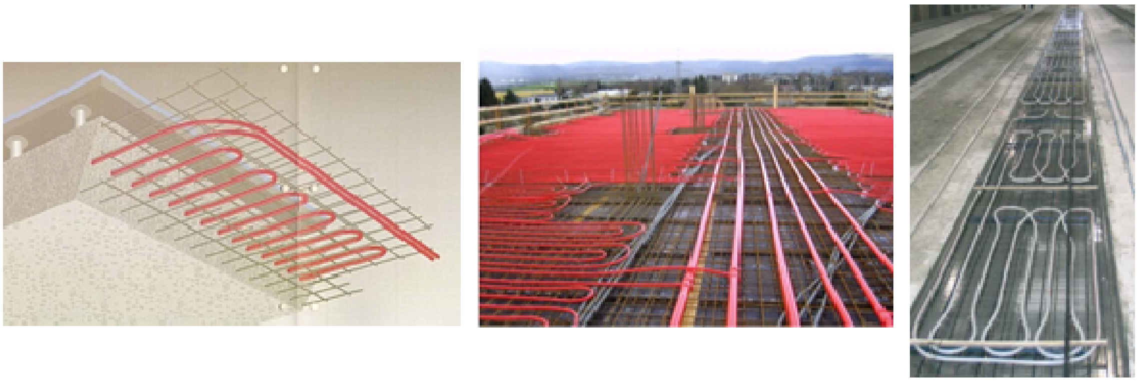


**Figure 2.1-25:**Schematic representation of water pipes in concrete (left); examples of water pipes laid between rebars but before concrete is poured (middle and right)

If water that is cooler than the outside temperarture is run through the pipes (something that is typically done in the summer months), the thermal mass of the piped elements will increase. Similarly, if warmer water than the outside temperature is run through the pipes (something that is typically done in the winter), the thermal mass of the will also increase. In both cases, the temperature of the exterior concrete elements will be more resistant to change. If the water is run through the pipes 24 hours a day, temperature flucuations inside the building will narrow, therefore reducing a building’s need for mechanical heating and cooling (Figure 2.1-26).[30]

[30]Concrete core activation is not the same thing as radiant floor heating/cooling. The main difference is that the concrete core activation system is embedded in structural or floor concrete whereas radiant flooring systems are separate from the structure of a building. They typically sit on top of the floor, separated from the structure by a layer of insulation.

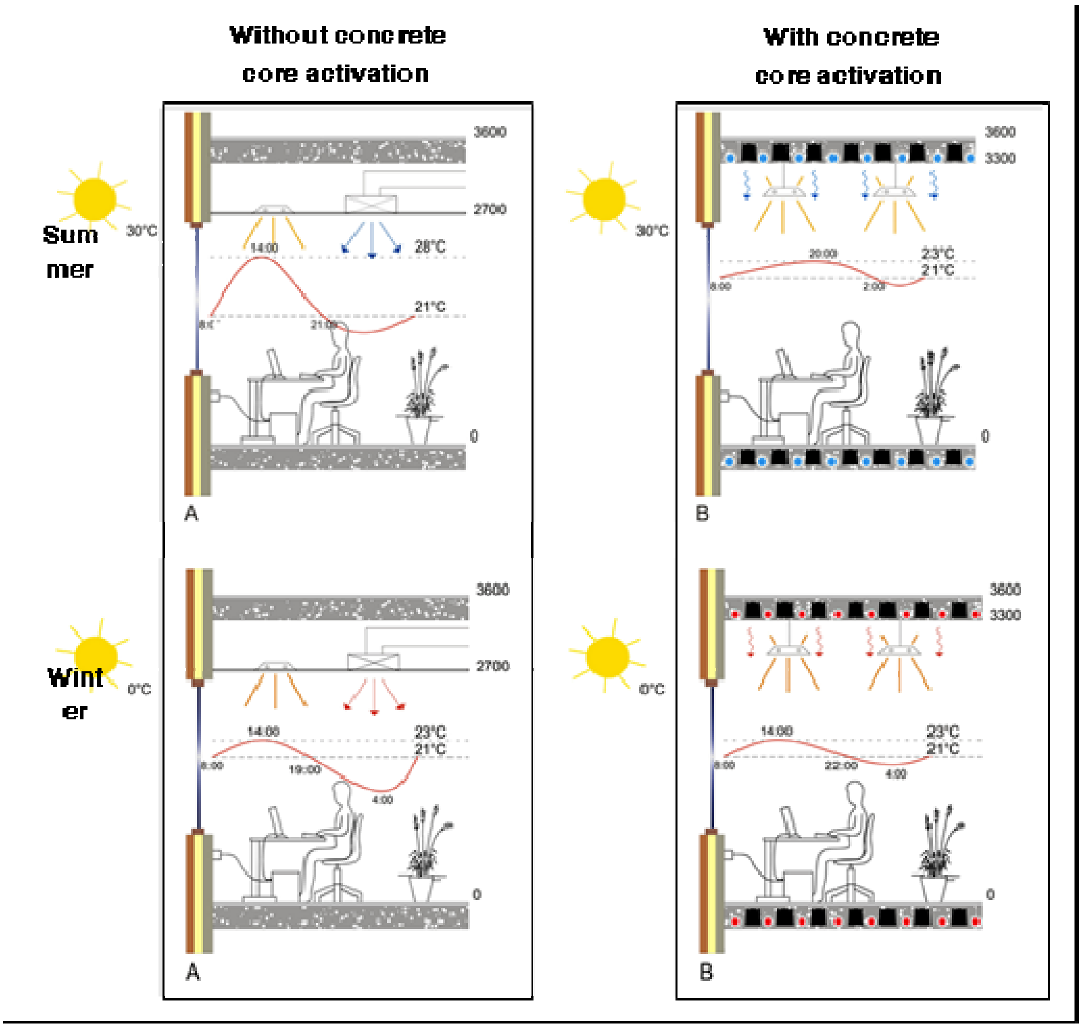



**Illustration Source:** www.airdeck.be

**Figure 2.1-26:** Schematic representation of an office building without (A) and with (B) concrete core activation. Each option is presented for summer and winter conditions. Main impact of concrete core activation is the leveling of interior temperature thus reducing the need for mechanical cooling and heating.

A variation of thermally activated concrete was used during the Roman times. The system was called hypocaust heating system where cavities under floors transported heated air to thermally activate the stone mass. In the early 20th century, a company called Crittall embedded steel pipes in ceilings concrete slabs. The Crittall Ceilings, however, had many problems. As the buildings were not well insulated back then, the pipe diameter was very large. Also condensation was a problem with Crittall's product. In the early 1990s, the Swiss started to reintroduce this technology with substantial improvements. Since then, the application of concrete core activation technology in new building construction has surged. By 2003, more than 30% of the new commercial construction used concrete core activation.[31] Figure 2.1-27 shows images of recently constructed buildings that are using concrete core activation. The

[31]Mauersberger, Frank and Cibis, Dominik, "Energy Efficiency In Commercial Buildings with Concrete Core Activation" (2012). International High Performance Buildings Conference. Paper 64. http://docs.lib.purdue.edu/ihpbc/64

increased popularity of using concrete core activation in new buildings is driven by the energy cost savings during the buildings use and operation.

**Links to architects of buildings above:**www.uytenhaak.nl (top); www.unstudio.com (middle); www.rau.eu (bottom)

**Figure 2.1-27:** Examples of recent buildings using concrete core activation, which is rapidly becoming standard practice in European commercial construction. Exterior on the left and interior on the right.

### 2.1.8.2 Enhancing thermal mass: phase-change materials

In addition to concrete core activation, another approach to enhancing the thermal mass of buildings is by applying phase-change materials (PCMs) to exposed surfaces closest to a buildings source of heat gain or loss. In HVAC applications water has been the most widely used PCM. But water changes phase at 0 degree Celsius. When you want to slow the heat gain of an interior of a building, the PCM that should be used should melt at 20 or 25 degrees. This way it will store the heat impacting the exterior of a building and not allow it to transfer to the interior.

PCMs are used in many industries and products including automative, aerospace, textile, HVAC, and increasingly buildings.It is their application in buildings that interests us most in this section.

To understand PCMs a small bit of physics needs to be reviewed. Energy can be stored in materials both in the form of latent and/or sensible heat. Sensible heat is the energy required to change the temperature of a substance with no phase change. Latent heat, on the other hand, is the heat stored or released when a material undergoes a phase change from solid to liquid, liquid to gas, solid to gas, and vice versa.

If a substance is changing from a solid to a liquid, for example, the substance absorbs energy from the surrounding environment that allows it to spread out the molecules into a larger, more fluid volume while still maintaining the molecular bonds. Likewise, if the substance is changing from gas (which has lower density) to a denser phase such as liquid or solid, the substance gives off energy. Figure 2.1-28, shows the relationship between sensible heat and latent heat when measured against temperature change and heat gain/loss.

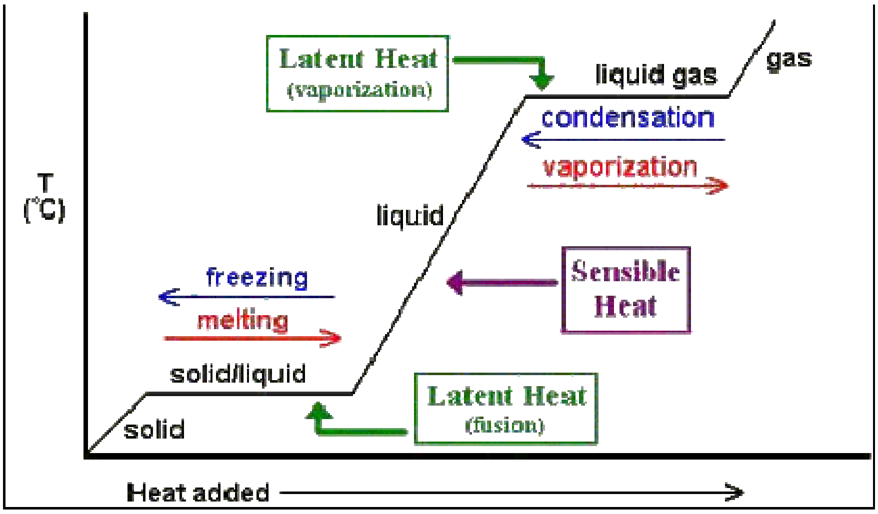
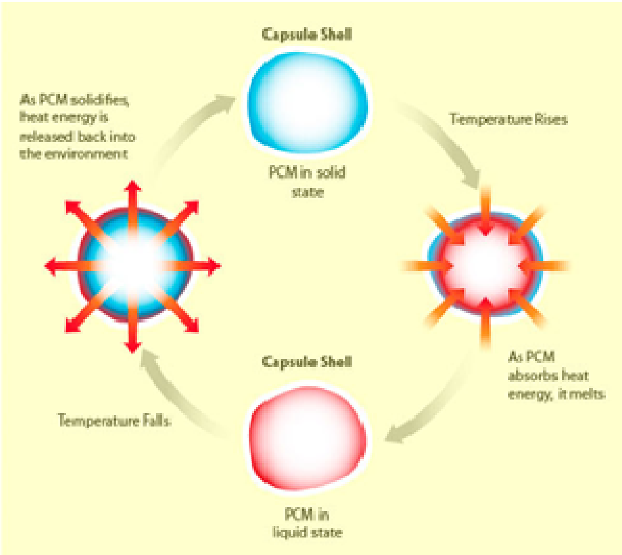



**Figure 2.1-28:** Illustration of sensible and latent heat and their relationship with temperature and heat gain

The latent heat properties of PCM's make them attractive as a heat storage material. PCMs can store several times more heat per volume when compared with sensible heat storage systems (such as stone or water/liquid $H_2O$). For example granite and water can store 50 and 84 mega joules per cubic meter, respectively for temperature change of 20°C. However ice and salts can store 306 and 1500 mega joules per cubic meter, respectively at constant temperature. This storage capacity can be used for many applications such as space heating and cooling. PCMs cover a relatively large range of 0 to about 130 degrees Celsius. But for building envelope applications PCMs are used that change phase from solid to liquid between 20 and 60 degrees Celsius.[32]

Figure 2.1-29 presents a simplified picture of a material's heat gain and loss as it changes phases. When a material goes from solid to liquid, for instance, is absorbs a great deal of heat. As Figure 2.1-29 shows, the heat gain or loss at these phase changes (melting, freezing, vaporizing, or condensing) can occur at a very high rates without any temperature changes. This is a fact that is useful for storing heat when you don't need it and releasing it when you do. PCM applications precisely aim for that.




Source: University of California, Davis; wcec.ucdavis.edu

**Figure 2.1-29:** Simplified picture of heat gain and loss during phase changes of a material.

The fact that PCMs can store large amounts of energy in small volume and mass compared to solutions where sensible energy (such as stone, gypsum board, insulation material, etc.) is used gives them an advantage. For practical reasons, in buildings only the phase change solid-liquid is used, in the range of 20 to 60 degrees Celsius. That is at 20 to 60 degrees the material transitions from solid to liquid, storing lots of heat energy. So when these materials begin to melt at 20 degree Celsius, their temperature stops rising as they begin to store heat. Their temperature can remain constant up to 60 degrees Celsius while continuing to store heat. When exposure temperatures begin to drop and fall below its solidification point, the material begins to change phase back to a solid and in the process releases the heat it had gained to the outside environment.

[32] Many of the facts and explanations are based on the following highly informative document: Haghighat, Fariborz. "State of the Art Review: Applying Energy Storage in Building of the Future" (June 6, 2013). Energy Conservation through Energy Storage Program. International Energy Agency.

PCMs come in a three major categories: organic, inorganic, and eutetics. Organics include paraffin wax, fatty acides, alcohols, and glycols. Inorganic PCMs include hydrated salt, metals and alloys. Eutetics are a mixture of organic and inorganic.

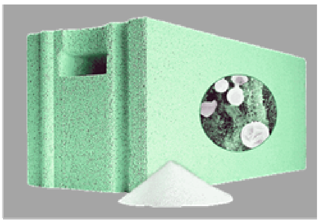
There are several ways in which PCMs can be applied to the building envelope. Some of them are separate elements that are added to the building surface while others have to do with mixing the PCM with the building element. Below are the four broad application types. Figure 2.1-30 gives visual examples of some of the following four types of PCM containment:

- Direct application -- Liquid or powered PCM are added and mixed with materials (gypsum, concrete) during production
- Immersion -- Porous building materials (gypsum board, brick, concrete block, wood, plaster) are dipped into liquid PCM. The PCM is absorbed into the pore by capillary effect
- Macro-encapsulation -- Container larger than 1cm diameter tubes, pouches, spheres (nodules), panels and other receptacles
- Micro-encapsulation -- Containers smaller than 1mm (sometimes the value of 20 μm is given), the PCM is trapped. Powder, microcapsule (mononuclear, or poly-nuclear or matrix).

Today there are a good number of buildings throughout the world that use PCM for enhancing the building's thermal mass. The material is applied to commercial as well as residential buildings.[33]

One demonstration site that shows the potential of this technology in a large scape is the Berlin Botanical Garden. The storage tower in the tropical green house of the botanical garden stores solar heat during the day in the PCM panels on the roof and released at night into the plant area, maintaining a constant daytime and nighttime temperature.

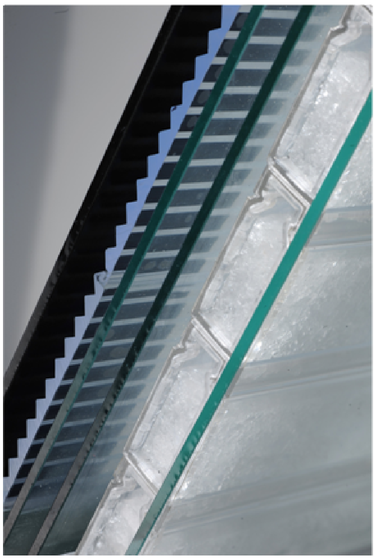
[33]The following site offers good practical examples of the application of PCM solutions to buildings, mostly in Germany: www.bine.info/en/publications/publikation/latentwaermespeicher-in-gebaeuden/



DIRECT APPLICATION -- H+H Deutschland GmbH's CelBloc Plus® has PCM added to the mixture of the concrete block. The powder next to the block is the PMC material. The circular part is a magnification of the composition of the concrete with the white parts representing the PCM particles.

DIRECT APPLICATION -- Dupont™ Energain® are plasterboards that can be applied to walls and ceilings. PCM particles are embedded in the gypsum. Unlike traditional plasterboards which are large and require more than one person to handle, these boards are small and lightweight enough for one person to install. Other companies such as Knauf and BASF also have similar products.


PCM MACRO-ENCAPSULATION -- BioPCmat™ macro encapsulates PCM into pouches connected in long sheets. The sheets can be stapled to walls and ceilings surfaces. They are also sometimes used in the cavities between floors.



PCM MACRO-ENCAPSULATION - GLASSX® crystal is façade element for commercial or residential buildings. It consists of 4 layers of glass. Between the interior 2 layers macro-encapsulated PMC is sandwiched. The exterior two layers have integrated shading. Image to left is the cross section of the product. Below is a building where this façade element has been incorporated. The opaque elements are GLASSX®.

**Figure 2.1-30:** Examples of direct application and macro-encapsulation.

### 2.1.9 Proposal for implementation – Municipality of Yerevan

#### *2.1.9.1 Building selection*

The building which was chosen as the object for this case study, belongs to the American University of Armenia campus, which consists of two buildings – the Main Building and the ParamazAvedisian building. The latter is a modern building, was inaugurated on 1 November 2008, bringing state-of-the-art educational facilities to Armenia and the South Caucasus. ParamazAvedisian building could be a perfect example of energy efficient solutions application.

**Figure 2.1-31**: ParamazAvedisian building.

The building is a five-story, 10 thousand square meters edifice of tufa, basalt, and glass curtain wall, designed to accommodate the latest in video, computer, and telecommunications equipment. It includes large classrooms with central cooling and heating systems, wireless Internet connections, a video conferencing room, a café, a bookstore, a gym, and exhibition space. This building houses all 7 units of the University. The old building, which was originally designed to host the Communist Party of Armenia SSR conferences, is used mainly for administrative and nonacademic purposes after the ParamazAvedisian building was built.

**Figure 2.1-32:** AUA campus.

Though it would be to showcase the modern, innovative solutions that were used in construction of ParamazAvedisian building, but as it already has been almost completely retrofitted energy efficiency-wise, the main building of AUA was chosen for the case study, as a perfect example of a building that has already gone through a number of retrofitting procedures, but there's still room for more.

### *2.1.9.2 Building description*

The AUA main building, also referred to as the Old building, is a modern six-story building at 40 Marshal Baghramyan Avenue in the center of Yerevan, originally constructed as a center for the political education, and was ideally suited for a university and was fully equipped with lecture halls, auditoria, cafeteria facilities, laboratories, library facilities, and offices. Since its founding, AUA has undertaken significant renovations in the building to transform it to a Western-style University, and upgrading its capabilities for hosting multiple conferences and seminars.

**Figure 2.1-33:** Old building.

The architectures that originally designed this building, had a number of energy efficiency solutions in mind. For example, the building is facing strictly south, which on one hand provides a beautiful view of the city in general and one of the city's main avenues in particular, on the other hand most of the building's windows are also facing south and the building is lit with sun light for the most part of the day. Besides lighting, this also helps in cutting down heating costs during winter times. About 70 percent of office and learning space of the building is exposed to natural daylight.

**Figure 2.1-34:** Indicative class.

Main artificial sources of lighting that is used in the building are regular incandescent light bulbs along with fluorescent lamps, compact fluorescent lamps and halogen lamps. The medium energy used for lighting of the main building daily is about 450 kwh.

The natural ventilation of the building was also designed very efficiently. Only 20 percent of the building's space does not have natural ventilation, and is ventilated mechanically, using air conditioners and different types of fans.

The roof of the building is covered with tin, which has high reflective qualities – the reflection rate is around 40 percent. Reflective tin helps keeping the roof cool during hot summer days.

The most modern retrofitting in energy efficiency field was implemented in 2013 by installing a combined heating and cooling system on the roof of the AUA's main building, which is powered by solar panels on the roof. It is the largest project of its kind by the size of power generation in Yerevan so far. Its activation was the culmination of three years of planning and collaboration between the AUA, the Armenian SolarEn company and several foreign partners: the Portuguese DER/INETI, German ISE/Fraunhofer, and Russian InterSolarCenter organizations. Funding of 360,000 Euro was provided by the European Union's INCO-Copernicus program for the design and implementation of the project, supplemented by $40,000 to complete the work from SarkisAcopian, an entrepreneur and benefactor of the AUA and founder of the Acopian Center for the Environment.

**Figure 2.1-35:** Solar panels on the roof.

32 solar heat collectors cover a total area of 64 square meters. The combined system conditions the air in the fifth floor auditorium all year round. The combined system conditions the air in the fifth floor auditorium all year round. The water-heating collectors, desiccant cooling systems, storage tank and management equipment have all been installed on the seventh floor and roof of the building. They produce a combined energy equivalent to 40 kW per hour for water-heating. The solar system has operating modes for different seasons, heating in winter, cooling in summer and refreshing the air all year round. Unlike conventional cooling split systems, it is effective even if windows are opened. As a result, energy consumption in the auditorium reduced by 70 per cent, while the heating and cooling system became 30 per cent more efficient.

#### *2.1.9.3 Identification of feasible interventions*

Feasible intervention 1

The roof of the AUA's main building is covered with reflective tin, as mentioned above. But there is still room to retrofit it by thorough insulation with polyurethane foam. Polyurethane is a closed-cell foam insulation material that contains a low-conductivity gas in its cells. As a result of the high thermal resistance of the gas, spray polyurethane insulation typically has an R-value around R-5 to R-6 per inch[34]. In comparison, blown


**Figure 2.1-36:** AUA building.

[34] R-value is the term given to thermal resistance to heat flow. The higher the R-value of an insulation product, the more effective the insulation properties.

fiberglass typically has an R-Value of only R-2 to R-4 per inch. Such type of insulation, besides preventing heat losses in winter and overheating in summer, also protects against moisture, which provides the benefit of reducing the chance of harmful mold and mildew. Eliminating mold growth reduces the likelihood of rotting wood in a home, and allergic reactions to mold spores. In addition to building temperature and moisture control, spray foam insulation is also used to reduce noise.

Feasible intervention 2

Another feasible interventions is the total upgrade of the building's lighting. The regular incandescent light bulbs along with fluorescent lamps, compact fluorescent lamps and halogen lamps that are currently used in the AUA's main building should be replaced with LED lamps, which have a lifespan and electrical efficiency that is several times better than incandescent lamps, and significantly better than most fluorescent lamps, with some chips able to emit more than 100 lumens per watt. Like incandescent lamps and unlike most fluorescent lamps (e.g. tubes and compact fluorescent lamp (CFL)), LED lights come to full brightness without need for a warm-up time; the life of fluorescent lighting is also reduced by frequent switching on and off. Such intervention would help AUA save both energy and money for bulb replacements, as LED lamps average lifespan is approximately five times longer than of CFL lamps, and fifty times longer than of incandescent lamps.

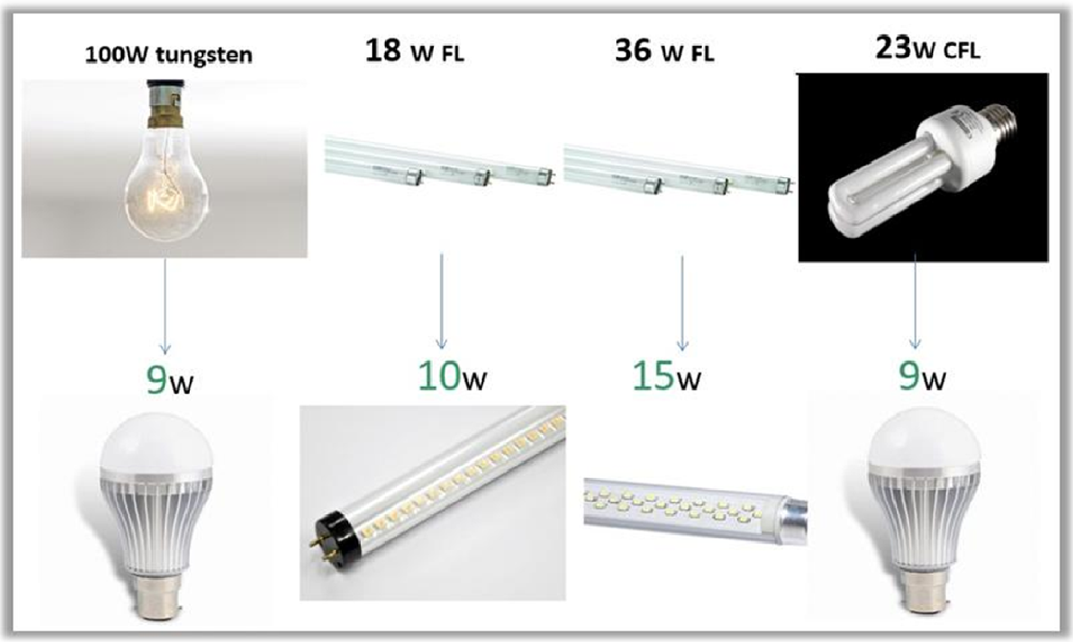



**Figure 2.1-37:** Replacement of regular with LED lamps.

### *2.1.9.4 Drafts of scenarios for energy retrofitting interventions*

Insulating the AUA main building's roof with polyurethane foam is a relatively easy retrofitting intervention. There will be no need for evacuation or any special permission from the city hall. The roof is easily accessible for constructors and the main preparative work needed is to remove unnecessary objects such old furniture pieces and to free space for insulation works. So the following steps are needed to implement this retrofitting intervention:

1. Develop and sign a corresponding contract with licensed construction workers.
2. Clean up the area under the main building roof and prepare it for insulation works.
3. Provide workers with necessary conditions, such as electricity access, etc.
4. After insulation works are complete, perform a quality check, involving independent experts in the field.

Another scenario is also very simple, but significantly cheaper. Replacing the lamps to more energy efficient ones is a very basic procedure. Most of the proposed LED lamps can be easily installed in regular lamp sockets, so in most cases that upgrade procedure come down to a mere replacement of a light bulb. The necessary steps to implement this retrofitting intervention are:

1. Purchase 300 LED lamps of different power.
2. Develop a schedule – when and where to replace the lamps, based on the University's work schedule.
3. Replace the lamps according to the plan.

### *2.1.9.5 Drafts of scenarios for budget*

High budget: upgrading making the roof of the AUA's main building. The surface of the roof is about 3500 square meters. The insulation with polyurethane foam costs 5000 AMD (about 12 USD) per square meter including labour. The total cost of the roof insulation will make 17.500.000 AMD (about 42500 USD).

**Table 2.1-2:** Low budget- upgrading the lighting of the AUA main building.

| Type of the lamp | FL | LED | FL | LED | CFL | LED | Bulb | LED |
|---|---|---|---|---|---|---|---|---|
| Power | 18W | 10W | 36W | 15W | 23W | 9W | 100W | 9W |
| Quantity | 84 | 84 | 38 | 38 | 38 | 38 | 140 | 140 |
| Daily Energy consumption (kwh) | 36 | 20 | 33 | 14 | 21 | 8 | 86 | 30 |
| Yearly energy bills ($) | 1007 | 559 | 911 | 379 | 582 | 228 | 2307 | 808 |
| Annual savings ($) | 447 | | 531 | | 354 | | 1499 | |
| Investment ($) | 2016 | | 1463 | | 1140 | | 4200 | |
| Payback period (year) | 4.5 | | 2.8 | | 3.2 | | 2.8 | |

## 2.2 Renewable energy systems integration

### 2.2.1 Introduction

Black Sea Basin and Europe have the unique opportunity to leap into a new economic era of innovation. The successful economies of the next decades will be those which decrease resource use and greenhouse gas (GHG) emissions while creating new businesses through technology leadership, technology deployment and increasing employment.

The transition to a renewable energy, resource efficient economy is a tremendous chance to boost economic growth and create new jobs while securing environmental protection and mitigating climate change through to 2020. The 2009 Climate and Energy Package and its binding renewable energy targets have provided the energy sector with the necessary stability and predictability.

There is a clear international consensus of the importance of such targets: the number of countries worldwide with renewable targets more than doubled between 2005 and 2012. Due to the early adoption of legally binding EU and national targets, including national action plans and administrative reforms, Europe has achieved a share of 12.5% renewable energy in its energy mix with year-on-year growth in 2010 at its highest level since 1990.

However, the key driver of the current European renewable energy framework, its binding targets, expires in 2020. As a consequence, the European commission expects renewable energy annual growth to slump from 6% to only 1%, resulting in the 2050 de-carbonization objective not being met. Business as usual is therefore not an option.

The European commission's Energy roadmap 2050 identifies renewable energy, energy efficiency and infrastructure as "no-regrets" options - in any given scenario they are critical for de-carbonization towards 2050. It emphasizes a high penetration of renewable energy beyond 2020 as a pre-requisite for a secure, zero-carbon energy system. It also recognizes that increased investments in high added value renewable energy and efficiency equipment could constitute a major opportunity for the EU manufacturing industry to create growth and jobs.

At the end of 2012, the council acknowledged the need for ensuring continuity and stability for Europe's renewable energy sector by calling for a solid and effective post-2020 policy and gave a mandate to the European commission to work on a new renewable energy framework; work which began with a Green Paper and public consultation in March, 2013.

This paper sets out a number of reasons why an integrated renewable – greenhouse gas – energy efficiency 2030 policy approach with an ambitious and binding renewable energy target yields more benefits for European citizens and industries than a one-legged policy based on a supposedly “technology-neutral” GHG-only approach.

Enabling the sustainably usage of systems by using renewable energy resources, by causing minimum pollution for the environment, by making no concessions to comfort requirements, with minimum operating costs.

An integrated climate and energy framework:
- Renewable Energy Integration
- Energy Efficiency in Buildings
- Greenhouse Gas Emission

**2.2.2 Solar photovoltaic renewable energy systems**

***2.2.2.1 Photovoltaic Cell Technology***

Solar Cells (Photovoltaics)

Solar cells are semiconducting devices which convert solar radiation into direct current electricity. Solar cells can generate electricity under all kinds of light. Their surfaces are formed in squares, rectangles, and circles. Solar cells’ surface area is generally around 100cm$^2$, and their thickness is between 0,2 mm to 0,4 mm. Solar cells are devices which convert light energy into electric energy in accordance with the conservation of energy law, but they do not have energy storage capabilities. When the light source disappears, the electric energy generated by solar cell is also cut. If the electricity is planned to be used throughout the night, an electric storage battery should be added to the circuit. There are a lot of materials used in manufacturing solar cells, but silicon is the most widely used one (Figure 2.2-1). Silicon is the most used material in the world, after oxygen. Silicon is non-poisonous. The cells do not use any sorts of fuel during the energy conversion; and the more light they receive, the more energy they generate.

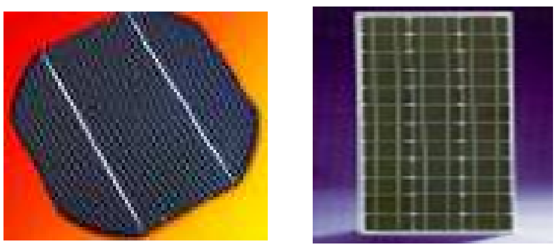


**Figure 2.2-1**: Solar Cells Made of Silicon.

Sunlight, which is the fuel of the solar cells, is probably the only source of fuel in the world which is abundant and free. Depending on the structure of the solar cell, solar energy can be converted into electric energy with a 5% to 25% efficiency (41% efficiency was reached under laboratory environment by using a light concentrator). In order to increase power output, a large number of solar cells can be connected to each other in series or in parallel and mounted on a surface. This type of structure is called a module or a solar panel (Figure 2.2-2). When modules are connected to each other in series or in parallel, they can generate electricity starting from a couple of watts to megawatt.

**Figure 2.2-2:** Solar Modules of Different Sizes.

Theory of Solar Cells

At the present time, transistors used in electronics and semiconductors used in the production of rectifier diodes key materials of solar cells. In order to use semiconducting materials as solar cells, they have to be doped either n-type or p-type. Doping is the process of control ledly adding the desired dope additive into the intrinsic semiconductor. Whether the acquired semiconductor is n-type or p-type depends on the dope additive. In order to obtain an n-type silicon from the most common solar cell material which is silicon, an element from the 5th group of the periodic table, for example phosphorus, is added to the silicon. As there are 4 electrons in the outer orbit of silicon and 5 electrons in the outer orbit of phosphorus, the excess single electron of phosphorus “donates” an electron to the crystal structure. For this reason, V. group elements are called “donors” or “n-type” additive.

Types of Solar Cells

Among the many substances that show semiconducting properties, silicon, cadmium sulphide, gallium arsenide, and cadmium telluride are among the most suitable ones for manufacturing solar cells. Solar cell technology is a very rich field in terms of used materials and manufacturing methods. In addition to these materials which are already being used in solar energy production, a lot of materials are also being studied and worked on.

Basically, types of solar cells are as follows:

- Mono Crystalline Silicon
- Poly Crystalline Silicon
- Thin Film

Works and studies have been intensified on solar cells which have easier and cheaper production technologies that can replace the traditional Si solar cells which are introduced to commercial environment in the last years.

These are technologies such as photoelectrochemical poly crystalline titanium dioxide cells, polymeric plastic cells and quantum solar cells which have energy bandwidth and are produced in such a way that they can adopt to different wavelengths of the solar spectrum. If we try to write down the structure and properties of the used solar cells;

Mono Crystalline: 24% efficiency in laboratory conditions and above 15% efficiency in commercial modules can be reached in the solar cells which are produced from mono crystalline silicon blocks which are first expanded and then sliced into very thin layers that are 200 micron thick. Poly crystalline silicon solar cells produced by slicing cast silicon blocks can be manufactured cheaper but they have less efficiency. Their efficiency is 18% in laboratory conditions and around 14% in commercial modules.

Poly Crystalline: With this material, 25% and 28% (with optic concentrator) efficiency can be reached under laboratory conditions. 30% efficiency was reached with multi-junction GaAs cells which are produced by using other semiconductors. GaAs solar cells are used in space
applications and in systems with optical concentrators.

Thin Film Solar Cells: There are three types under this category.

- Amorphous Silicon: Efficiency levels of these non-crystalline allotropic Si cells are around 10% in laboratory conditions and around 5% to 7% in commercial modules. At the present time they are generally used in smaller electronic devices as power sources. Amorphous silicon solar cells' another possible important application is predicted to be the their use as external protective coatings in buildings by integrating them as semitransparent glass surfaces while using them as energy generators at the same time.
- Cadmium Telluride (CdTe): It is predicted that CdTe, a material which has a highly crystalline structure, will drastically lower the production costs of solar cells. 16% efficiency can be reached in laboratory type small cells and around 7% efficiency can be reached in commercial type modules.
- Copper Indium Diselenide (CuInSe2): With this polycrystalline cell, 17,7% efficiency was reached under laboratory conditions, and 10.2% efficiency was reached in a prototype module designed for energy production.
- Cells With Optical Concentrator: 41% efficiency levels were reached by using devices with lenses or reflectors that can intensify the incident light by 10 to 500 times. Concentrators are made from simple and cheap plastic materials.

#### *2.2.2.2 Characteristics of solar panels*

Characteristics of solar panels should be known well in order to get maximum efficiency in production as the cost of the production of electrical energy per kW with these systems is more than the electrical energy produced by using other resources such as water petrol, and coal. Tag values of solar panels are determined following the experiments conducted by manufacturers under 250 panel temperatures and when radiation intensity is 1000 W/m$^2$. Output characteristics of the panels vary depending on the production technique, ambient temperature, etc. In determining characteristic values, Figure 2.2-3 is used for voltage output (VO), and Figure 2.2-4 is used while measuring the short circuit current (Ik). Figure 2.2-5 is used to see the changes under load.

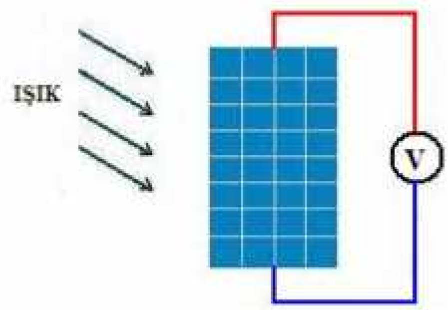



**Figure 2.2-3:** Short Circuit Measuring of the Module

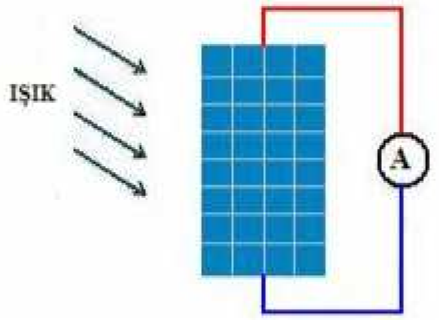



**Figure 2.2-4:** Measuring the Voltage Output of the Module

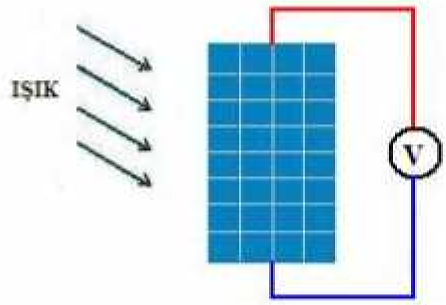



**Figure 2.2-5:** Measuring Module's Current Potential Fluctuation under Load

When the load is changed from minimum to maximum in the circuit shown in Figure 2.2-5, the current - potential fluctuation will be like as shown in Figure 2.2-6. Besides, the current – potential curve of a 100 cm$^2$ PV is given in Figure 2.2-7.

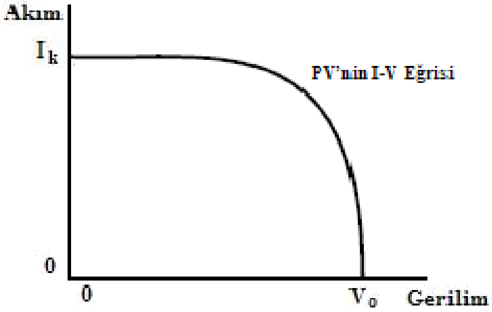



**Figure 2.2-6:** Current – Potential Curve of a 100 cm2 PV

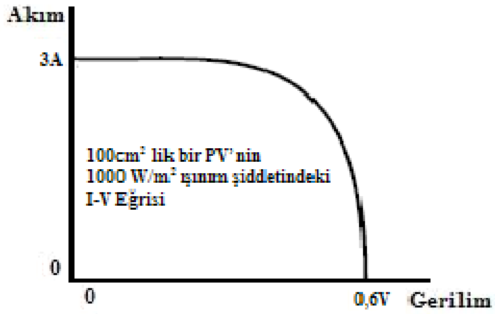



**Figure 2.2-7:** Current– Potential Curve of PV

As it can be understood from the current – potential curve, in the event that values for either the current or the potential or both of them are zero means that the power output of the PV will also be zero. When the curve that gives the values of current x potential is drawn in the current – potential curve, the power – potential (P-V) curve is obtained (Figure 2.2-8).

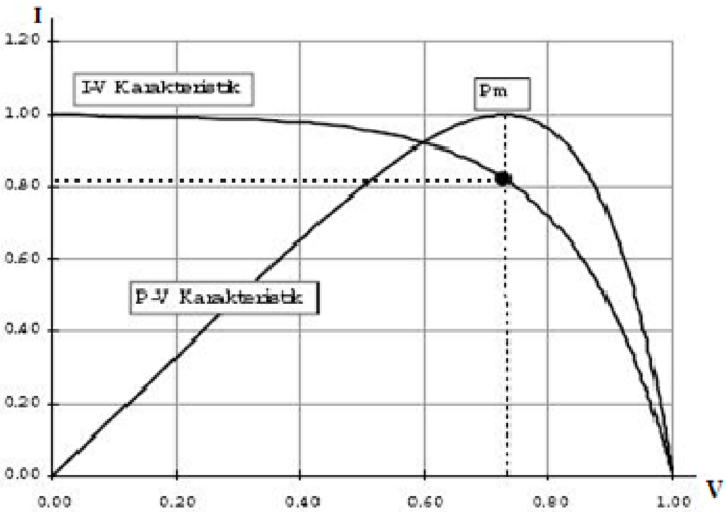



**Figure 2.2-8:** I-V and P-V Curves Shown Together

Knee zones of the I-V curve are the maximum power points. This point is called PMPP (Maximum Power Point). PMPP points with different radiation intensity forms in a certain line (Figure 2.2-9).

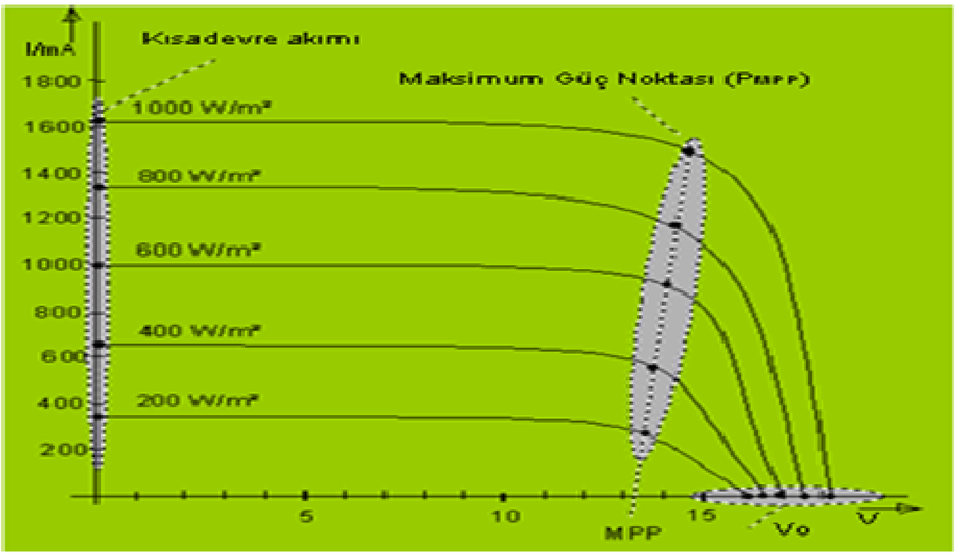



**Figure 2.2-9:** Maximum Power Points for a Sample PV in Various Radiation Intensities

Each and every solar cell has a unique V-I curve and therefore a V-P curve. The current (IN) and potential (VN) values that create the module's maximum power point under load are the values that have been acquired under laboratory conditions and given by the producing company. One of the quality indicators of the module is the efficiency factor and it is shown with the letter "e" (Figure 2.2-10) formulized as follows:

$$e = \frac{P_N}{P_{max}} = \frac{V_N \text{ x } I_N}{V_o \text{ x } I_K}$$

It is a quality indicator of the module when the efficiency factor is high.

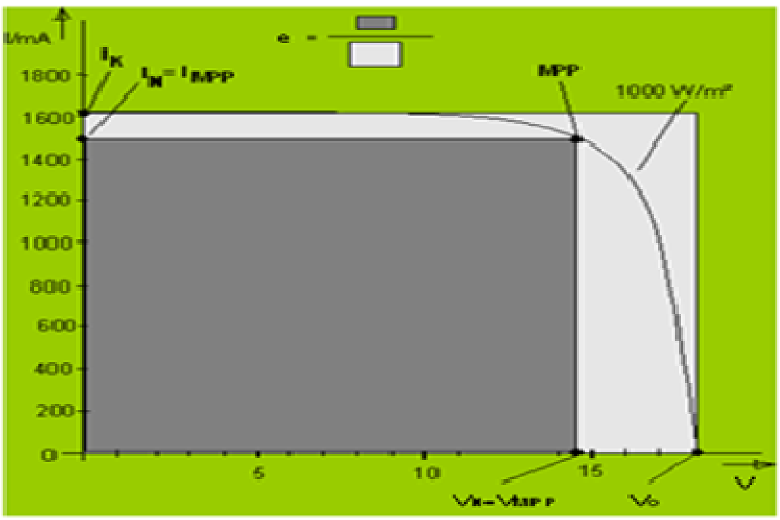



**Figure 2.2-10:** Presentation of PV Efficiency Factor

<u>Example</u>

If, for SM20 module VN =14,6 V; IN = 1,5 A; Vo =18,2 V; IK = 1,62 A;

PN = 14,6 x1.5 = 21,9 W
Pmax = 18,2 x 1,62 = 29,5 W
e= 21,9 / 29,5 = 0,74

Module temperature is one of the affecting factors for current and potential values of the modules (Figure 2.2-11). As the module temperature rises, output voltage value decreases. At the same time, the rising in of the temperature creates an increase effect in the current but the effect of the temperature is more effective on the potential. The decrease in the potential creates a decrease in the power output of the module. Cold and sunny environments (winter sun) are the most suitable environments for solar cells.

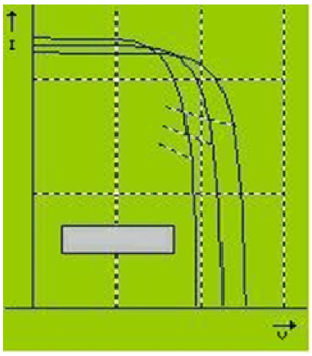


**Figure 2.2-11:** The Change in the PV's Current – Potential Value with Temperature

The position of the load is also one of the factors affecting the utilization ratio from the sun. If the load's V-I change curve and the module's V-I curve are in accord with each other, then our utilization ratio from the sun increases. If the V-I curve of our load passes from the PMPP point, then this is the most ideal situation. If shadow falls on a cell in a module, then the flow capacity of that cell reduces and in turn the flow capacities of all of the other cells are limited with the cell on which the shadow falls (Figure 2.2-12).

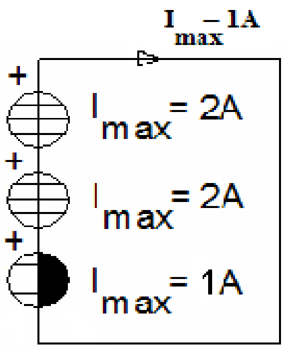



**Figure 2.2-12:** Decrease of Flow Capacity in the Cell on Which Shadow Falls

<u>Hot Spot Effect</u>

The cells in the microstructure of the modules are connected in series. When shadow falls on a module, the cells that are affected by the shadow act like a load and current is passed through them by the other cells that generates voltage and because of the voltage heat is released on the module.

This is called the hot spot effect. A by-pass diode is used to prevent any damage to the cell caused by the released heat. When a cell is under shadow, the by-pass diode turns on and passes the circuit current through itself and, as the current does not pass through the cell, no damage is inflicted (Figure 2.2-13, 2.2-14, and 2.2-15).

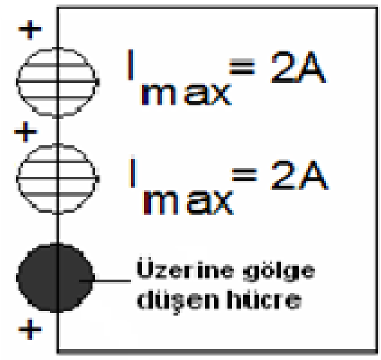



**Figure 2.2-12:** A Cell under Full Shadow

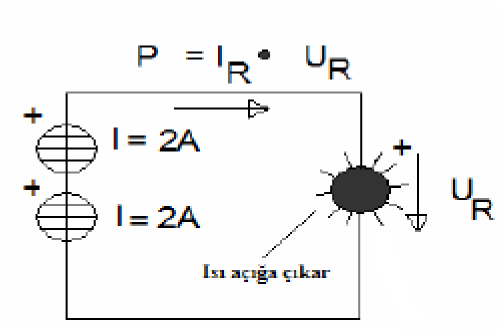



**Figure 2.2-13:** Cell Displaying Load Properties

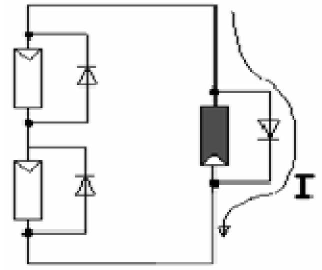



**Figure 2.2-14:** Connection of the By-Pass Diode

<u>Cell Connections</u>

Cells are connected in series to increase the voltage rating inside a module (Figure 2.2-16). In order to increase the flow capacity, the cells are connected in parallel (Figure 2.2-17).

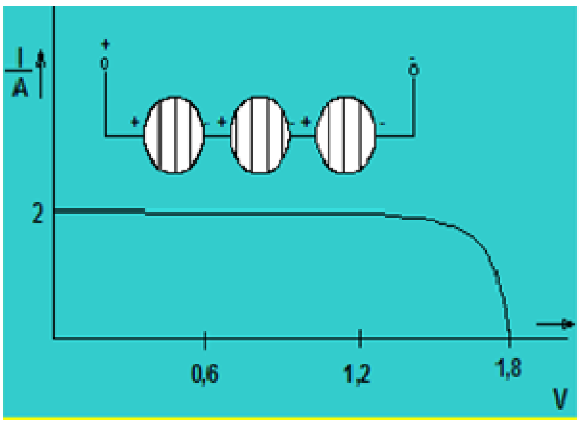



**Figure 2.2-15:**Serial Connection of 0,6 V Cells

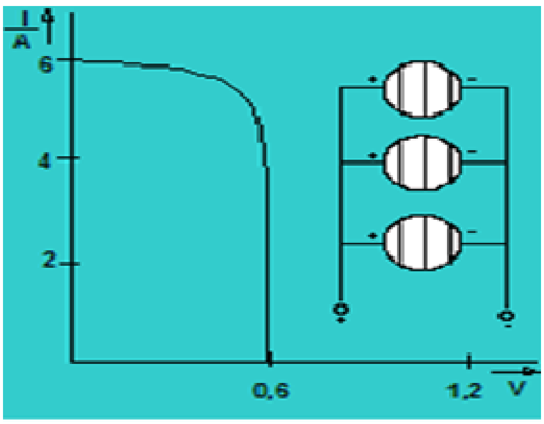



**Figure 2.2-16:** Parallel Connection of 2A Cells

In addition to the by-pass diodes used to protect the modules from the hot spot effect, line diodes must also be serial connected to the module in order to protect the system from reverse voltages (Figure 2.2-18). In selecting this diode, schottky type diodes must be chosen as they have low voltage drop.

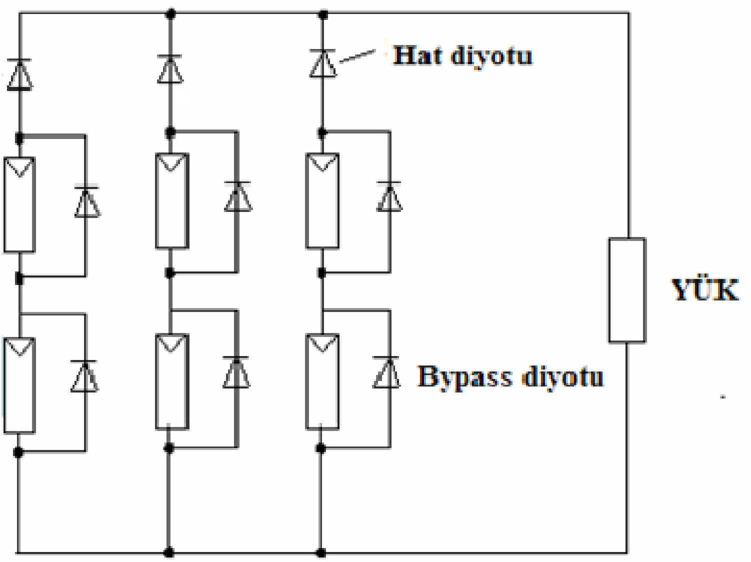



**Figure 2.2-17:** Serial Connection of Diodes in Module Groups

### *2.2.2.3 Equipment used in photovoltaic (PV) systems*

Regulators Used in Photovoltaic Systems

They are used for charging the battery or the battery group with the voltage generated by the solar cell (Figure 2.2-19). While performing this task, they also protect the system when a spike occurs in the voltage by reverse operating the system and preventing the passage of current through the module. They are divided into two categories, being series regulator or parallel regulator, in accordance with the connection of the switching element in their design to the load.

- Series PV Regulators
- Parallel PV Regulators

**Figure 2.2-18:** Examples for Regulators Used in PV Systems

Series PV Regulators: These are the regulators where the switching element is serial connected to the load (Figure 2.2-20). Voltage on the load is managed by controlling the resistance value of the semiconducting switching element. They are simple structured and therefore their costs are low. They are used in low power systems. Since transistors are generally used as switching elements, switching losses are high. As the charging current increases, the losses on the transistor also increase. Because they are mostly produced simple structured, when the battery voltage drops excessively, they cannot cut out the load from the circuit.

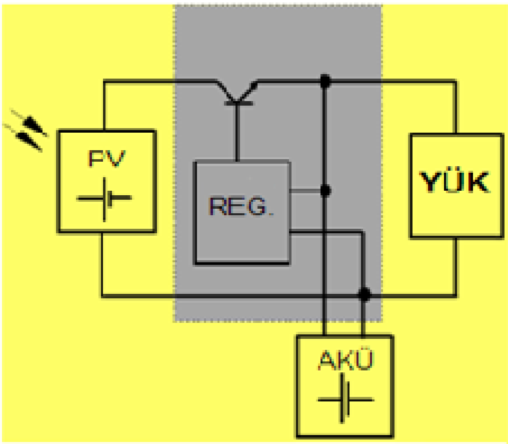



**Figure 2.2-19:** Structure of Series Regulator

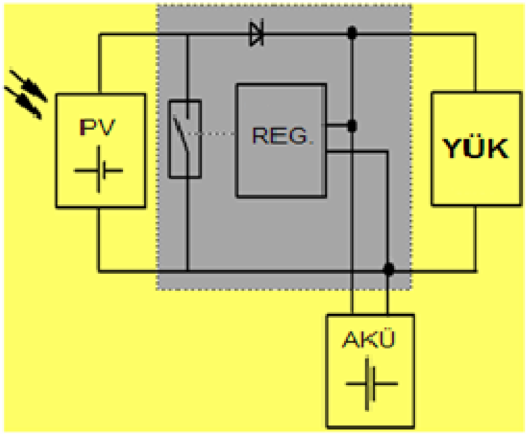



**Figure 2.2-20:** Structure of Parallel Regulator

Parallel PV Regulators: These are the regulators where the switching element is serial connected to the load (Figure 2.2-21). Current and potential value is provided by changing the resistance value of the semiconducting component. In these regulators the voltage drop on the semiconducting component does not change the resistance value on the load, which is one of the disadvantages of the series regulators.

Properties that have to be present in a series or parallel regulator system (Figure 2.2-22) are as follows:

- The battery should be able to control the voltage level and it should be able to cut off the charge when the battery is fully charged.
- When the battery voltage drops below the limit value, the regulator should be able to cut off the load from the circuit.
- It should not allow the battery voltage to feed the PV in reverse direction.
- It should be protected against overvoltage and over-current.
- It should have automatic battery voltage (12 / 24V) recognition capability.
- It should have charge state indicator.
- It should have a battery type setting (acidic – gel).
- It should have aural warning and load shutdown indicator properties.

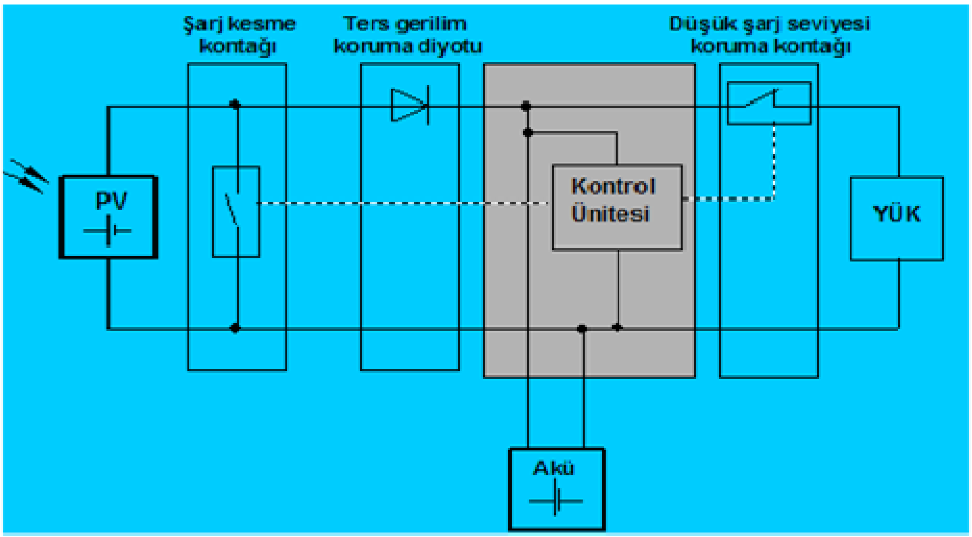



**Figure 2.2-21:** Structure of an Ideal Regulator

<u>Inverters</u>

They are the devices that convert the direct voltage generated in the solar cells into square wave, trapezoidal wave, or sinusoidal voltage (Figure 2.2-23). The voltage type at the inverter outlet varies according to the place of use. In low power systems generally inverters with square wave or trapezoidal wave outputs are used. As for the systems which are connected to a grid, inverters with sine output are used. Their structure basically consists of a switching element and a voltage forming circuit (Figure 2.2-24). There are inverters that have input voltage between the range of 12V and 800V.


**Figure 2.2-22:** Examples of Inverters Used in PV Systems

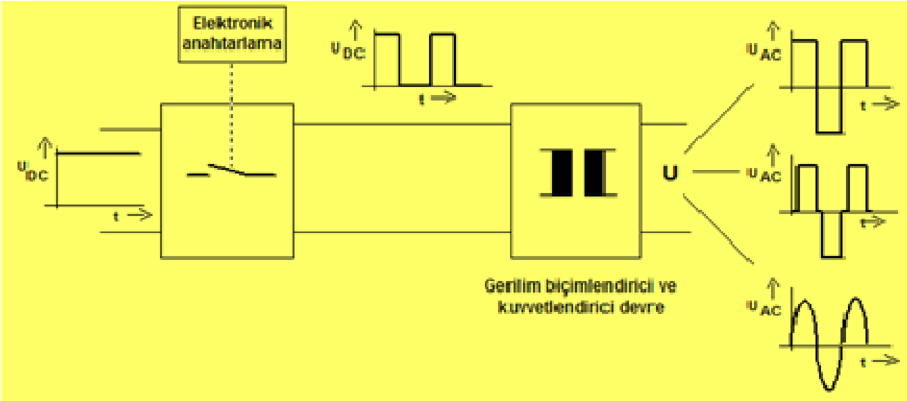



**Figure 2.2-23:** Structure of an Inverter

With the RS 232 port which is found on certain inverters, a connection with a computer can be established and system information can be obtained (Figure 2.2-25). Especially in the inventers that are used in grid-tied PV systems, power and generated electrical energy values can be read from the screen located in the device (Figure 2.2-26). Input voltage value (total voltage acquired from the modules) and power of the inverters selected for the PV system should be suitable for the modules.

**Figure 2.2-24:** RS 232 Port on an Inverter

**Figure 2.2-25:** Computer Connection of the Inverter

As described in article 2, the MPP point of a panel changes in regard to radiation intensity and module temperature. In order to ensure an efficient energy generation, invertors that use Maximum Power Point Tracking (MPPT) technique in the PV outlet should be preferred (Figure 2.2-27).

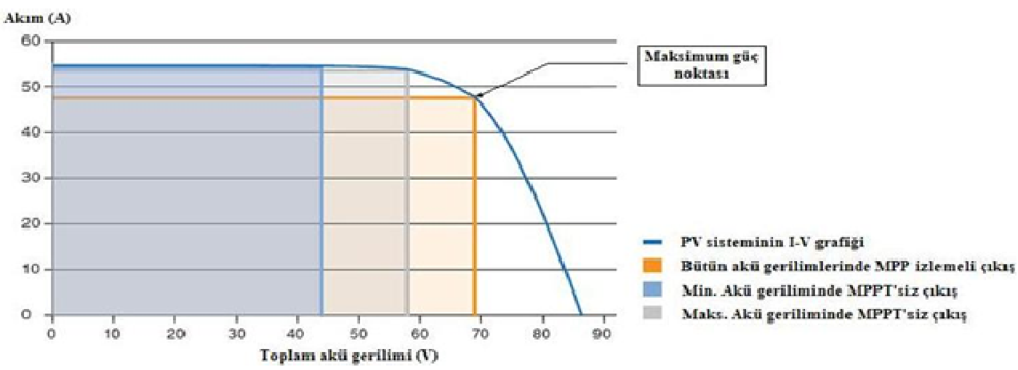



**Figure 2.2-26:** Graphic Comparing MPPT Inverters with Classic Inverters

Following methods are used in inverter controls:

- Indirect control
- Direct control

The indirect control method is a procedure based on guessing the MPP point with mathematical methods by using the V0, IK, radiation intensity, and module temperature values from the tables prepared by the manufacturers with the help of experiments depending on the PV characteristics.

Indirect Control Method:
Basically, there are 2 methods:

1. Constant Voltage Method:
Vo open-circuit voltage rating is taken as reference. Research has shown that VMPP voltage is a linear function of Vo voltage. This rating generation method is about 73% to 80% of the average Vo voltage in the poly crystal modules, depending on the factors like the environmental conditions. In more general words,

k = VMPP / Vo ≅ constant; as the k constant does not change here, the VMPP voltage can easily be found with the help of the open circuit voltage (Vo). Constant voltage method is a quite simple, cheap and practical procedure which does not require complicated circuits. However, the fact that the panel is disconnected from the circuit during the measuring process is one of the disadvantages.

2. Constant Current (Short Circuit Current) Method:
It is performed with the same logic behind the constant voltage method, however in this method current is used as reference. IMpp has a proportional relation with IK. Even if this value changes depending on the environmental factors and production technique, the maximum power point current is approximately 85% of the short circuit current. In more general words;

IMpp = k2 x IK even though being simple structured is one of its advantages, the fact that the panel is disconnected from the circuit during the measuring of the current and deviation from the actual values due to panel pollution are the disadvantages.

Direct Control Method:
PV voltage and/or current values are used in this method. It is tried to capture the optimum point by changing the working points. The following procedures are used in the direct control method:

1. Change and Observe Method:
It is the most used method. PV output power is constantly observed, the control variable is changed with reference to current or voltage and the effect of this change on the power is controlled. Operation is resumed at the point where the power is at maximum.

2. Increasing Conductivity Method:
The ratio (curve) of system power to the system voltage is constantly controlled. The point where the curve is $0^0$ is the MPP point and the inverter resumes working at this point.

DC/DC Converters:
DC/DC converters are used in PV systems in order to convert a DC level into another DC level. Safe operating range is very important in inverters and converters. If we separate the circuit designs according to safety level, there are basically 2 types of convertors.

- Insulated Converters
- Non-insulated Converters

Insulated Converters: They are the inverter types in which the isolation between the load, grid, and the energy producing panels are provided by using a transformer.

Advantages of insulated converters;

- They are safer in terms of load.
- In the event that the switching element is short circuited, they do not transmit voltage to the output
- They can be made in high powers.

Disadvantages of insulated converters;

- They are heavier then the non-insulated converters with the same power.
- Their costs are higher.
- Their efficiency levels are lower than the non-insulated converters.

Non-insulated Converters: They are the converters that transform the input voltage and transfer it to the output without using a transformer.

Advantages of non-insulated converters;

- They are cheap due to the fact that they are simple structured.
- They have high efficiency levels.

Disadvantages of non-insulated converters;

- They are not suitable for high powered systems.
- As there isn't an electrical insulation between the load and the switching element, their safety is low.

An ideal inverter should possess the following properties.

- The frequency and amplitude of the output voltage must be steady.
- The harmonic it creates in the systems that feed the grid must be lower than 5%.
- It should be able to work between the range of cosφ (+0,8…-0,8) power factor in order to run inductive and capacitive loads.
- It should be protected against reverse voltage.

- It should be able to offer protection against high voltage and over current.
- It should meet the electromagnetic compatibility standards.
- In the systems that feed the grid, it should cut off the flow of energy when there is no voltage on the line.
- It should be protected against water and moisture.

Batteries

Batteries are used as storage units in the systems with solar cells. Another function of the batteries is that they make the voltage steady in the system. Generally lead-acid or gel batteries are used. Dry batteries are not preferred because of the memory effect.

Fundamental concepts about batteries:

Depth of Discharge: If a lead-acid battery is used in a way to discharge it to 80% to 90% of its capacity, then its life will seriously shorten seriously. The way to prevent is to determine the energy needs and thus determine the capacity of the batteries above this need. The less a battery is discharged, the longer life it will have.

Environmental Conditions: Ambient temperature in which the batteries are used is one of the factors that determine the life of the batteries. Batteries sustaining ambient temperature below or above the ideal operating temperatures which are in the range of 20°C to 25°C have reduced life time.

Battery cycle count: A battery's life span is limited with a certain number of charges-discharges, even if all the conditions are ideal. Even though this number may differ in different brands and models, it is approximately around 1000. Battery life time will inevitably shorten in a system where power failures happen very often and where the batteries engage and disengage on a daily basis.

Storage: If the batteries are going to be stored for a long time, they have to be charged at certain periods ( 3 months – 6 months), otherwise sulfating will occur due to the ongoing reactions in the battery and the anode caps and cathode cups may become unusable. The capacity change of batteries in accordance with charge count is given in Figure 2.2-28, and the discharge time in accordance with the current draw is given in Figure 2.2-29.

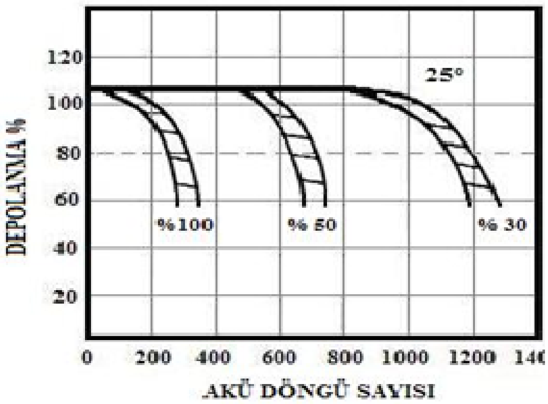



**Figure 2.2-27:** Capacity Change In Accordance With Charge Count

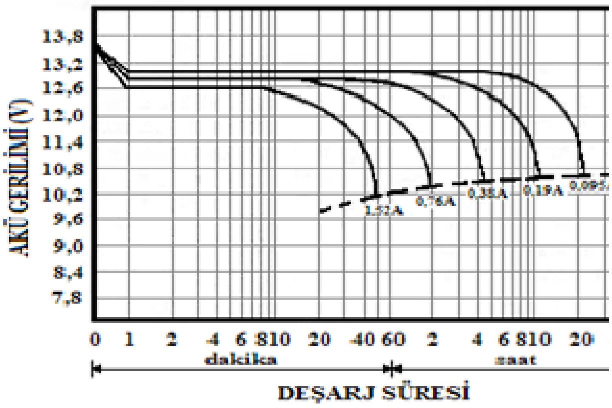



**Figure 2.2-28:** Discharge Time In Accordance With Current Draw

Capacity in Batteries: The energy that can be given in the discharge process of the battery is called the capacity of the battery.

The capacity of a battery is expressed as (Ah) = Ampere x Hour.

Electrical isolation of the connections of a battery should be done well in order to prevent short circuits. One of the contributing factors on battery life is the intensity of the charge-discharge current. Charge currents with very high values cause high gassing that cannot be absorbed by the battery. This, in return, causes a rise in the internal pressure and the gas is discharged from the valve. For this reason, the number of electrolytes diminishes and eventually finishes. Therefore, during battery charge, charging current values should not be exceeded above the recommended values. Heavy currents also affect the service life of batteries. When discharged with heavy currents excessive sulfating (PbS04) occurs in the negative plaque. This shortens the service life of the battery.

Meters

They are the devices that show the energy received from the grid and given to the grid in the grid-tied PV systems. Connection of the meters can be done in 2 ways (Figure 2.2-30).

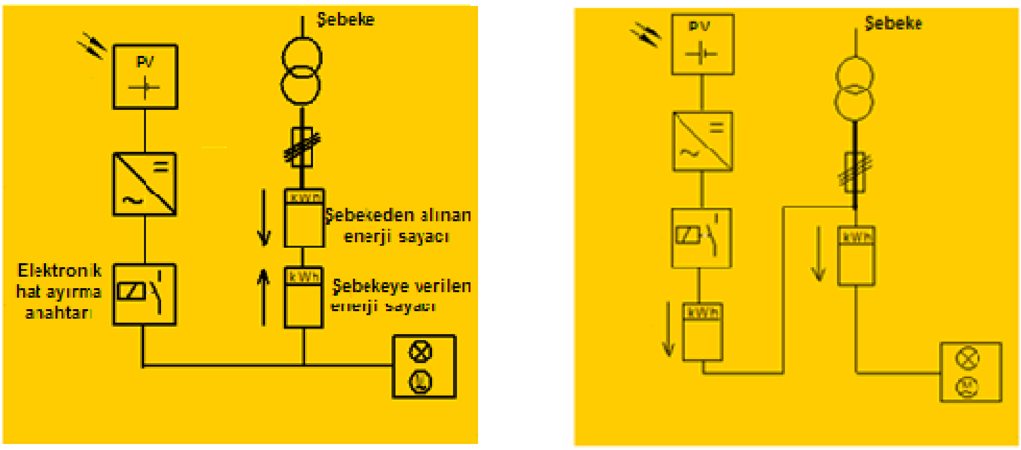



**Figure 2.2-29:** Connection Types for Meters

The usage of inverter and meter together is given in Figure 2.2-31, and reverse meters (electronic meters that can automatically detect the energy exchange with the grid) are given in Figure 2.2-32.

**Figure 2.2-30:** The Usage of Inverter and Meter Together

**Figure 2.2-31:** Reverse Meter

### *2.2.2.4 Categorization of Solar Cell Systems*

We can divide the PV Solar Cell Systems which are used to generate electrical energy in buildings into two categories in regard to their working specifications: off-grid and grid-tied.

<u>Off-Grid Systems</u>

These systems are generally used in remote regions far from the residential areas and in areas where the electric grid is not available. The cost of extending the reach of the electrical grid to these regions is more than the setup costs of photovoltaic systems. Off-grid systems are divided into three categories depending on the type of generated electricity. These are, DC systems (Figure 2.2-33), AC systems (Figure 2.2-34), and AC-DC hybrid systems (Figure 2.2-35). PV systems which offer both DC and AC voltage usage are called hybrid systems.

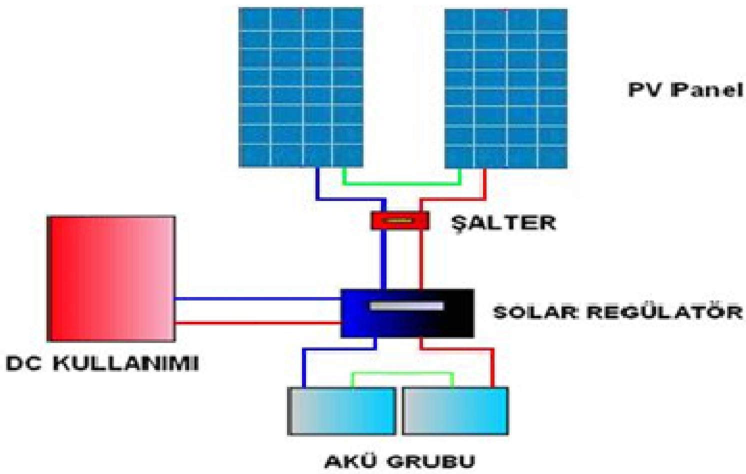



**Figure 2.2-32:** DC Off-Grid PV Systems

DC off-grid PV systems are small but powerful systems. The generated DC voltage can either be directly used, or can be used to power other devices with different voltage levels by using converters.

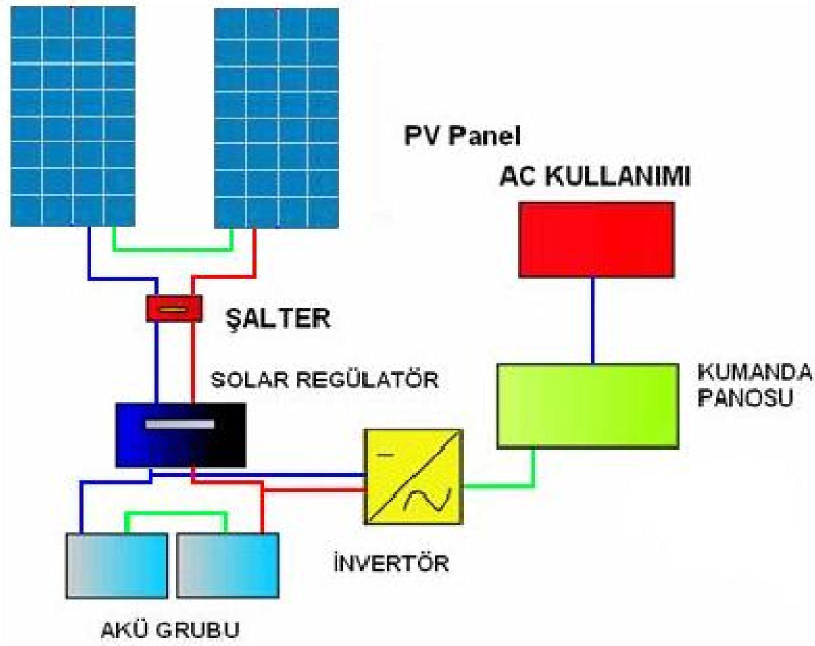



**Figure 2.2-33:** AC Off-Grid PV Systems

In the off-grid systems, inverters are used for AC voltage usage. The devices that we use must be energy efficient, by this means the service times of the batteries will extend and the setup costs will reduce with the choice of smaller and powerful inverters.

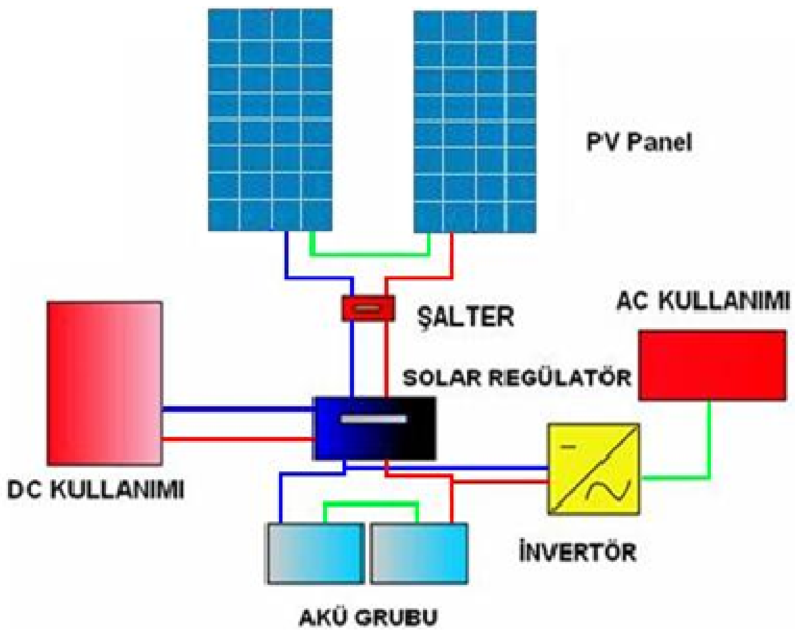



**Figure 2.2-34:** DC and AC Off-Grid PV Systems

Grid-tied Systems

The surplus energy generated in buildings in which a grid-tied system is installed can be used to support the local energy needs. PV grid-tied power systems (Figure 2.2-36) have become popular in recent years. Users install these systems on building roofs or surfaces. These systems are typically in the range of 1kW to 50kW and the generated electrical energy can be given to the grid with the application of a reverse meter.

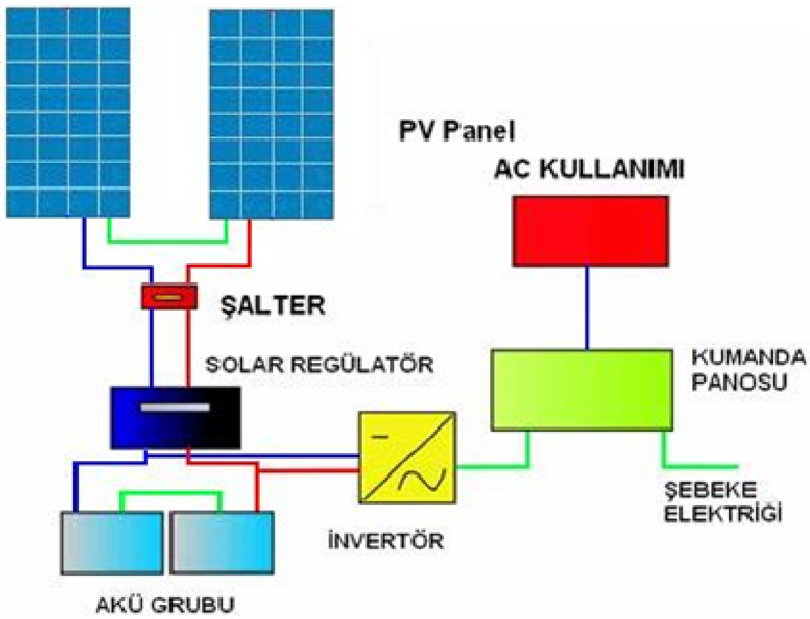



**Figure 2.2-35:** PV System Connected to the Grid

In the systems that have been described so far, the module connection is generally series (Figure 2.2-37) and the total voltage generated by the modules can be calculated by multiplying the number of modules by the voltage of one module.

$$V_T = V_M \times n$$

VT : Total module voltage
VM : Voltage of one module
n : Number of modules

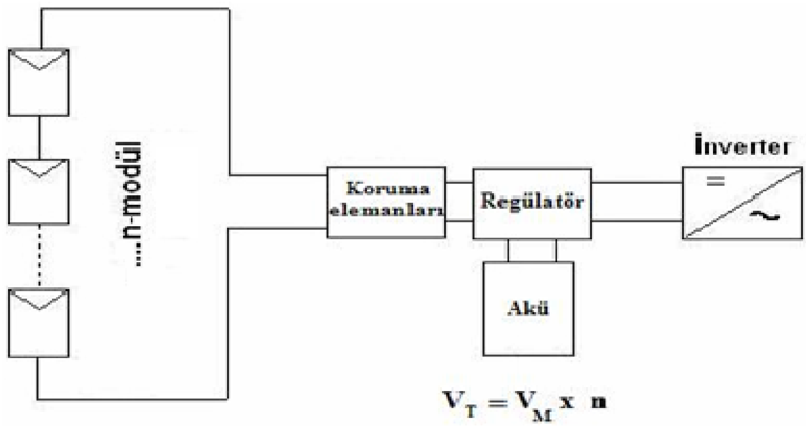



**Figure 2.2-36:** Increasing the Total Voltage by Connecting the Modules in Series

Although it is a rarely encountered concept, the module groups can be connected in parallel (Figure 2.2-38). With the parallel connection, the current value is increased.

$I_{DC} = I_G \times n$

IDC : Total current
IG : Current passing through a module group
n : Number of module groups

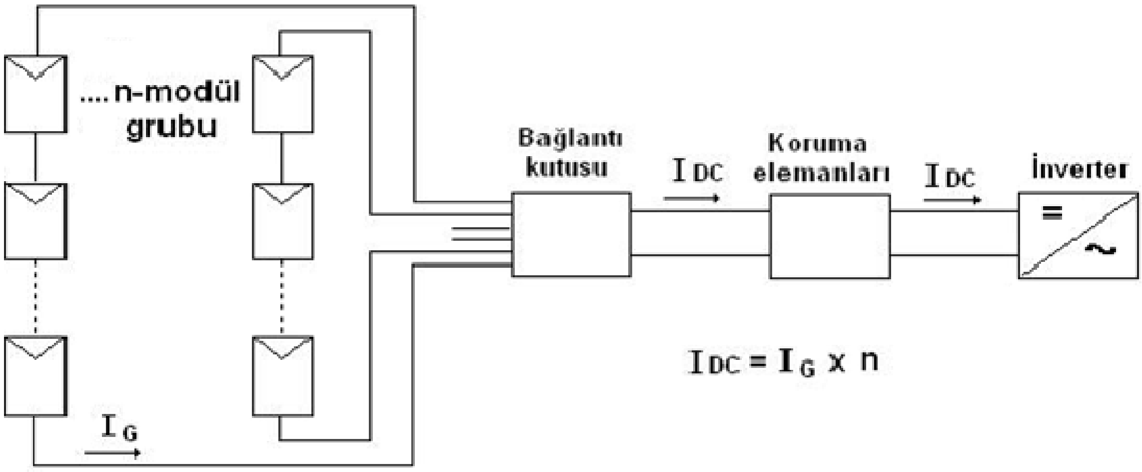



**Figure 2.2-37:** Increasing the Current by Connecting the Module Groups in Parallel

### *2.2.2.5 Installation of Photovoltaic (PV) Systems*

Points to Take Into Consideration in PV Installation

The following points should be taken into consideration in order to run the system we have installed efficiently and properly for long years: Shadows cast by obstacles should be taken into consideration. Shadows that fall on modules cause that module group to lose efficiency and sometimes cause them to entirely cut-out from the circuit (Figure 2.2-39). When preparing the module layout plan, the inclination of sun beams should be taken into consideration. 21st of December is the date when the sun beams reach the earth in the most inclined angle. Angle of inclination (α) varies with the current region. In the meantime, nearby trees or projected windows can also cast shadows. These also should be taken into account while preparing the layout plan.

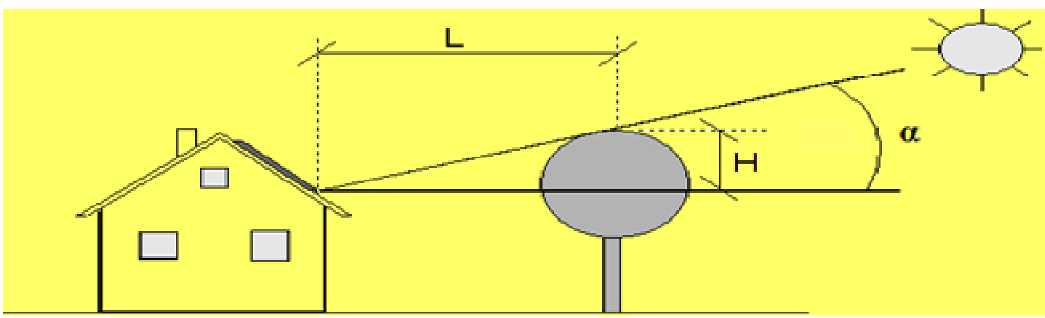



**Figure 2.2-38:** Shadows Falling on to Modules Because Of Obstacles

Following method can be applied in order to control the shadows falling on to modules because of obstacles:

If the distance between the module and the obstacle (L), is higher than the H / tan α value, then the shadow will definitely not be cast because of an obstacle (L > H / tan α). Attention should especially paid to the distance between the modules, especially in facilities built on level surfaces.

In the layout of the modules, the coming sun rays should not be blocked by the previous module. The minimum distance required to prevent modules from blocking each other's sun rays (Figure 2.2-40) is calculated with the following formula:

$$A = \left[\frac{\sin \alpha}{\tan \beta} + \cos \alpha\right] \cdot L$$

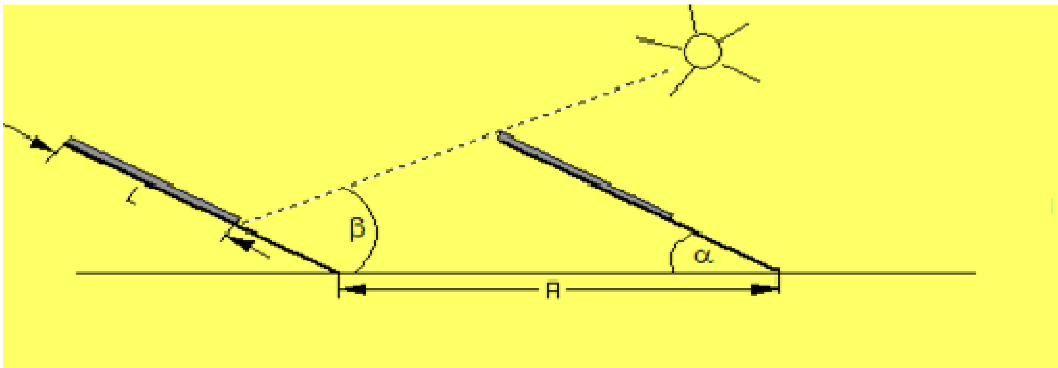



**Figure 2.2-39:** The Distance Required to be Kept between Two Modules

Grouping of the modules should be done with regard to shadow position. While the modules are being grouped, it should be ensured that modules belonging to the same module should be installed into the possible shadowy locations (Figure 2.2-41). Otherwise, more module groups that are installed into the shadowy area might be disabled.

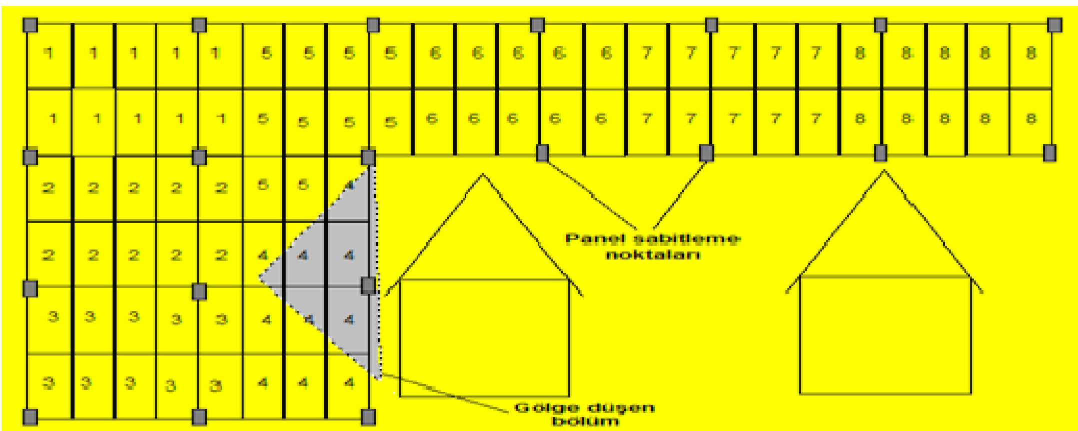



**Figure 2.2-40:** Installing The Same Group Into the Possible Shadow Zone

Modules with different properties should not be used together in the same group. Modules in a group are generally connected in series. If there is a module with different properties in the group, the efficiency of the group might change as the characteristic features of the modules will be different from each other. In this regard, all the modules in the same group should be the same.

The cables used in the installation should provide the proper conditions. The following points should be taken into consideration in the selection of cables and connection elements used in the solar cell systems (Figure 2.2-42).

- They should be resistant to UV rays.
- They should have high mechanical endurance.
- They should be made of material with low specific resistance.
- Their section should be suitable for the current value that will pass through the system.

**Figure 2.2-41:** Cables and Connection Elements Used in the Module Installation

Building PV Facilities

The installation of the modules varies by the structure of the module, dimensions, and the place where the installation will be done. A basic installation of an off-grid PV system is done as follows.

1) The module is chosen by its type, power, voltage and tolerance value (Figure 2.2-43 and Figure 2.2-44). For the same power value, we have to choose a polycrystalline module which has a bigger area instead of a mono crystalline module. In addition, a low tolerance value is a desired feature.

**Figure 2.2-42:** The Module Selected For Installation

**Figure 2.2-43:** Junction Boxes of the Modules

2) Following the selection of the module, the needed number of modules is determined

$$n = \frac{P_G}{P_M}$$

n : Number of modules
PG : Needed power
PM : Power of one module

3) In the roof surface, roof tiles are removed from the area needed for the modules (Figure 2.2-45).

**Figure 2.2-44:** Clearing the Required Area for the Modules

4) Backup strips are screwed on the strips in order to build up elevation. During the installation, screws should be used instead of nails, in order to prevent the strips from cracking.

5) Module fastening metal rods (Figure 2.2-46) are screwed down from the right and left sides of the area cleared for modules being just about 27 cm inside.

**Figure 2.2-45:** Module Fastening Rods

6) There are sockets on the module fastening rods that enable the connection between each other. These sockets are first cross combined and then aligned by turning, and then assembled.

7) Plastic insulating mold is placed to prevent water intrusion inside the roof (Figure 2.2-47).

**Figure 2.2-46:** Finished Installation of the Insulating Molds

8) Installation of the modules are done (Figure 2.2-48). After the module installation is finished, the remaining areas are covered with tiles. Following the tiling, the module installation process is completed and wiring works begin.

**Figure 2.2-47:** Finished Module Installation

9) First of all, the wiring inside the roof is done. Afterwards, regulator (Figure 2.2-49) and inverter (Figure 2.2-50) wiring is completed. The input voltage rating of the inverter must be compatible with the total module voltage. Inverter selection must be done in accordance with the module voltage at the temperature rating of -10.

**Figure 2.2-48:** Regulator Wiring

**Figure 2.2-49:** Inverter Wiring

10) The installation is completed by wiring the battery, fuse, and overvoltage protection relay (Figure 2.2-51 and Figure 2.2-52).

**Figure 2.2-50:** Battery and Regulator Wiring

**Figure 2.2-51:** Fuse and Overvoltage Protection Relay

There are different installation techniques other than the PV installation system described above. If we give a few examples of these techniques; there are roof tile systems and rail systems specially designed for PV installation. Some images regarding these systems are given below (Figures 2.2-53 to 2.2-56).

**Figure 2.2-52:** Special Roof Tiles for Rail Installation

**Figure 2.2-53:** Screwing the Roof Tiles

**Figure 2.2-54:** Installation of the Rail

**Figure 2.2-55:** Finished Module Installation

### 2.2.3 Solar (thermal) renewable energy systems

#### *2.2.3.1 The Importance of Solar Energy*

In order to stop global warming and maintain the habitability of the earth for all living creatures, the amount of $CO_2$ that is produced on earth at the present time should be reduced. Things that can be done to reduce the $CO_2$ levels:

- Fossil fuel consumption should be reduced, and the following topics should be emphasized as a replacement for fossil resources in energy production:
- Solar and wind energy usages should be generalized and popularized,
- The current forest levels in the world should be increased,
- The usage of machines, devices, equipments, and apparatus that consume less energy,
- Heat and energy losses in buildings and installations should be reduced through insulation.

In the light of all the issues mentioned above, in our day, solar energy water heating systems are the most economical and most commonly used type of solar energy. With the amount of hot water provided by a solar energy water heating system which has only two flat solar collectors of good quality, the usage of approximately:

- 3000 kg wood

- 765 kg heating oil
- 1088 kWh electrical energy
- 720 kg LPG
- 960 m$^3$ natural gas
- 2200 kg local – Soma type coal
- 1480 kg import hard coal

as fuel will be avoided, along with the $CO_2$ that would be emitted by using these sources as fuel. When a kilo of hard coal is burnt, approximately 3-4 m$^3$ smoke is produced and nearly half of it is $CO_2$. Considering this fact, a two collector solar water heating system prevents the emission of 4,000 - 5,000 m$^3$ smoke and 1,600 – 1,800 m$^3$ $CO_2$ into the atmosphere. In addition to this, besides $CO_2$, the emission of $SO_2$, $NO_x$, dust and particulates into the atmosphere is also prevented.

Approximately, 3% to 5% of the energy used in residences and 3% to 4% of the energy used in industry is spent for hot water. In accordance with this conclusion, 6% to 9% of the energy consumed in Turkey is used for hot water. In addition to the fact that the operating costs of solar energy water heating systems are almost nonexistent, the biggest cost is the initial investment cost. The initial investment costs spent for solar energy water heating systems are paid off in a short span of time, and these systems continue to provide hot water over the course of many years at no cost. In terms of meeting energy needs, benefiting from solar energy is largely widespread in countries especially like, China, France, Greece, Israel, Italy, Japan, Korea, Portugal, Spain, Turkey, and U.S.A. Earth's insulation map is given in Figure 2.2-57.

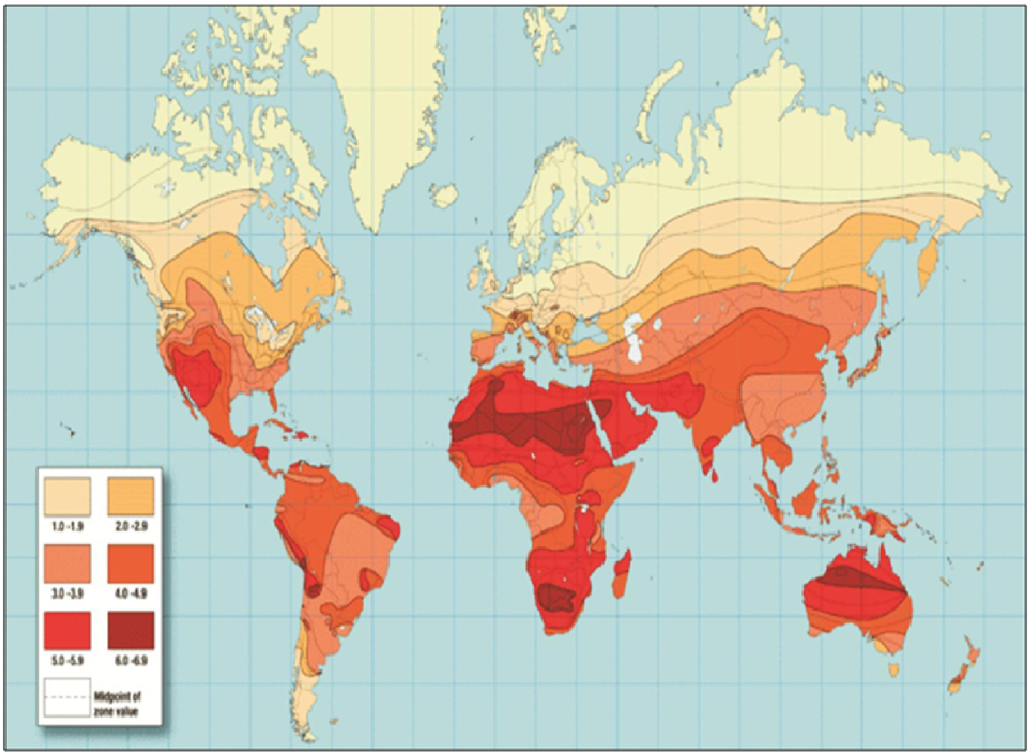



**Figure 2.2-56:** Earth Insulation Map

Thanks to government incentives, benefiting from solar energy has recently become widespread in countries such as Austria, Denmark, Germany, Netherlands, and Sweden although they are not located inside the solar belt. These listed countries such as Denmark, Germany, Netherlands, and Sweden, due to their geographical locations, can only receive a small amount of solar radiation when compared to other countries.

In contrast with this fact, these countries are on the course of supplying a great portion of their energy shortage from the sun. In Figure 2.2-58, radiation levels per square meter per annum in Germany and Turkey are specified. Earth radiation levels in regard to weather conditions are separately given in Figure 2.2-59. In Turkey, Southern Anatolia Region, Mediterranean Region, and the southern parts of the Aegean Region can be specified as the regions where insulation levels are highest. Nevertheless, despite the fact that they have fewer insulation levels when compared with the above mentioned regions, Central Anatolia, Central Aegean, Eastern Anatolia, Marmara, and the Black Sea Regions also have a very high potential for solar energy usage.

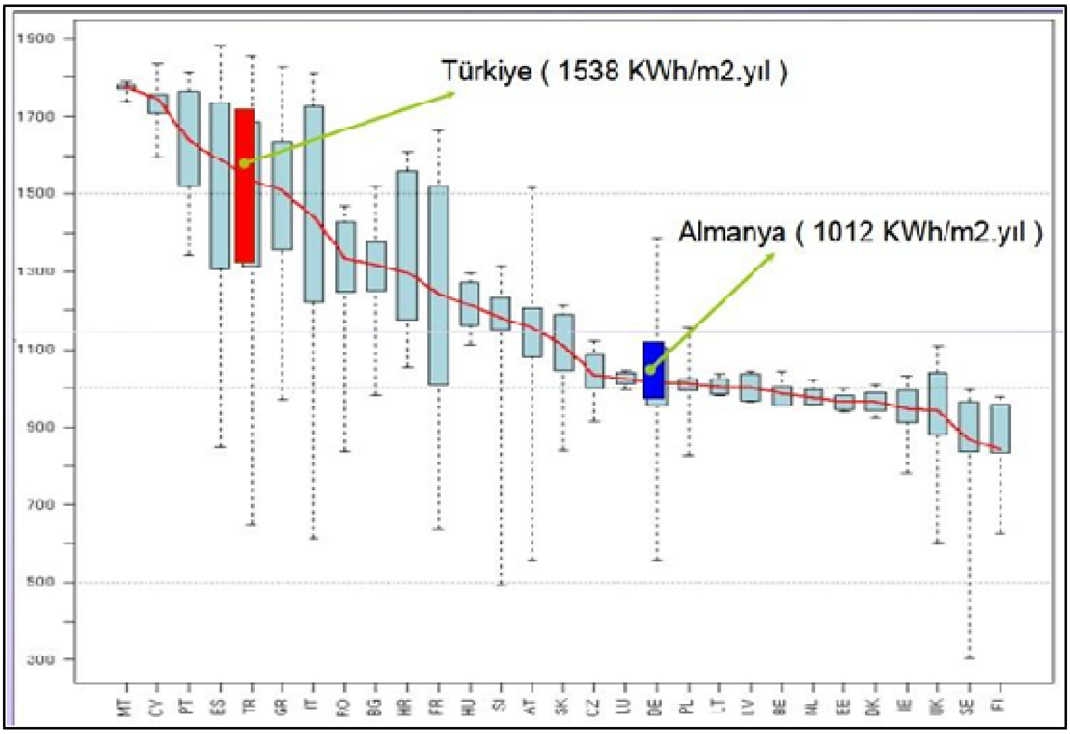



**Figure 2.2-57:** Annual Solar Radiation Levels per Square Meter in European Countries


**Figure 2.2-58:** Earth Solar Radiation Levels in Regard to Weather Conditions

### *2.2.3.2 Hot water preparation systems*

It is possible to classify solar energy (hot water) systems in two major categories.

Systems with Natural Circulation

Solar energy systems with natural circulation are systems where the circulation of heating fluid (closed-loop) or the fluid that will be heated (open-loop) (which is inside the system and ensures that heat is transported), between the solar collector and the storage capacity occurs automatically, without the need for any operating mechanism such as a pump.

The fluid inside the solar energy system becomes less dense because of the heat energy collected from the sun with the help of a solar collector and then starts to move upwards in the system. The cooler fluid (water or water + antifreeze mixture) which has higher density and is located in the storage capacity flows downwards and is collected at the bottom of the system and applies a natural driving force to the hot fluid which has lower density and thus circulates the fluid inside the system.

This condition originates from the density difference between the heating and cooling of the fluid located inside the system. This movement ensures a daily circulation of 8 – 10 between the solar collector and the storage.

These systems can be collected under two topics.

- Systems with Heating Fluid (Closed-Loop Systems)
- Systems without Heating Fluid (Open-loop Systems)

Only systems with heating fluid and their sub branches are analyzed in this study.

Systems with Heating Fluid (Closed-Loop Systems)

There are two different loops working independent of each other in the solar energy using natural circulation hot water preparation systems with heating fluid (closed-loop). The first loop is the heating fluid loop between the solar collector and storage capacity's outer wall, and the second loop is the hot water usage loop where the cold water coming from the public water system is stored and then utilized after heated up.

The fluid (water or water + antifreeze mixture) inside the Heating Fluid Loop transfers the solar energy received from the sun to the cold water coming from the public water system which is stored in the solar energy storage located inside the usage water loop with the help of the wall (heat exchanger) in the solar energy storage capacity, and thus the usable hot water can be provided.

The fluid inside the heating fluid loop (closed-loop) consists of a mixture of water and antifreeze in appropriate proportions, depending on the regions where there is the risk of freezing which generally occurs in the winter months. The percentage of the antifreeze which has to be added into the water that circulates in the closed-loop changes from cities to cities and districts to districts depending on the region where the system is used. Systems with Heating Fluid (Closed-Loop) are divided into two categories.

*Float Systems*
In Closed Loop Float Systems, there is a cold water reservoir located on top and a hot water reservoir located at the bottom. There is a floater inside the cold water reservoir. The floater is connected to the municipal cold water inlet inside the cold water reservoir. The decreasing water inside the reservoir is replenished by way of the floater.

In these type of systems, the reservoirs where the usage hot water is stored and the walls that transfers the heat do not work under pressure. For this reason, the design and the thickness of the reservoir and the thickness of the wall is between 0,50 mm and 0,70 mm. They are manufactured in such a way that they can only withstand the static pressure of the usage water contained in the reservoir. Systems with vertical reservoirs or double reservoirs can be given as examples for float systems.

**Figure 2.2-59:** System with Double Reservoirs

Systems with double reservoirs (Figure 2.2-60) are natural circulation systems like systems with vertical reservoirs (Figure 2.2-61). When the solar energy reservoir is observed from the outside, two flat reservoirs which are independent from each other are seen. The reservoir in the top contains cold water whereas the reservoir at the bottom contains hot water. Cold water coming from the municipal water system goes to the reservoir at the top at first. Water intake is controlled with the help of a floater. When hot water is used, a cold water flow from the upper reservoir to the lower reservoir occurs. In the lower reservoir, besides the inner wall, there is also an outer wall. There is heating fluid which is heated up in the solar collector inside this wall. The heating fluid transfers the received heat energy to the usage water stored in the lower hot water reservoir with the help of the floater and the lower reservoir starts to warm up. Thus, hot water is acquired through the solar energy system.

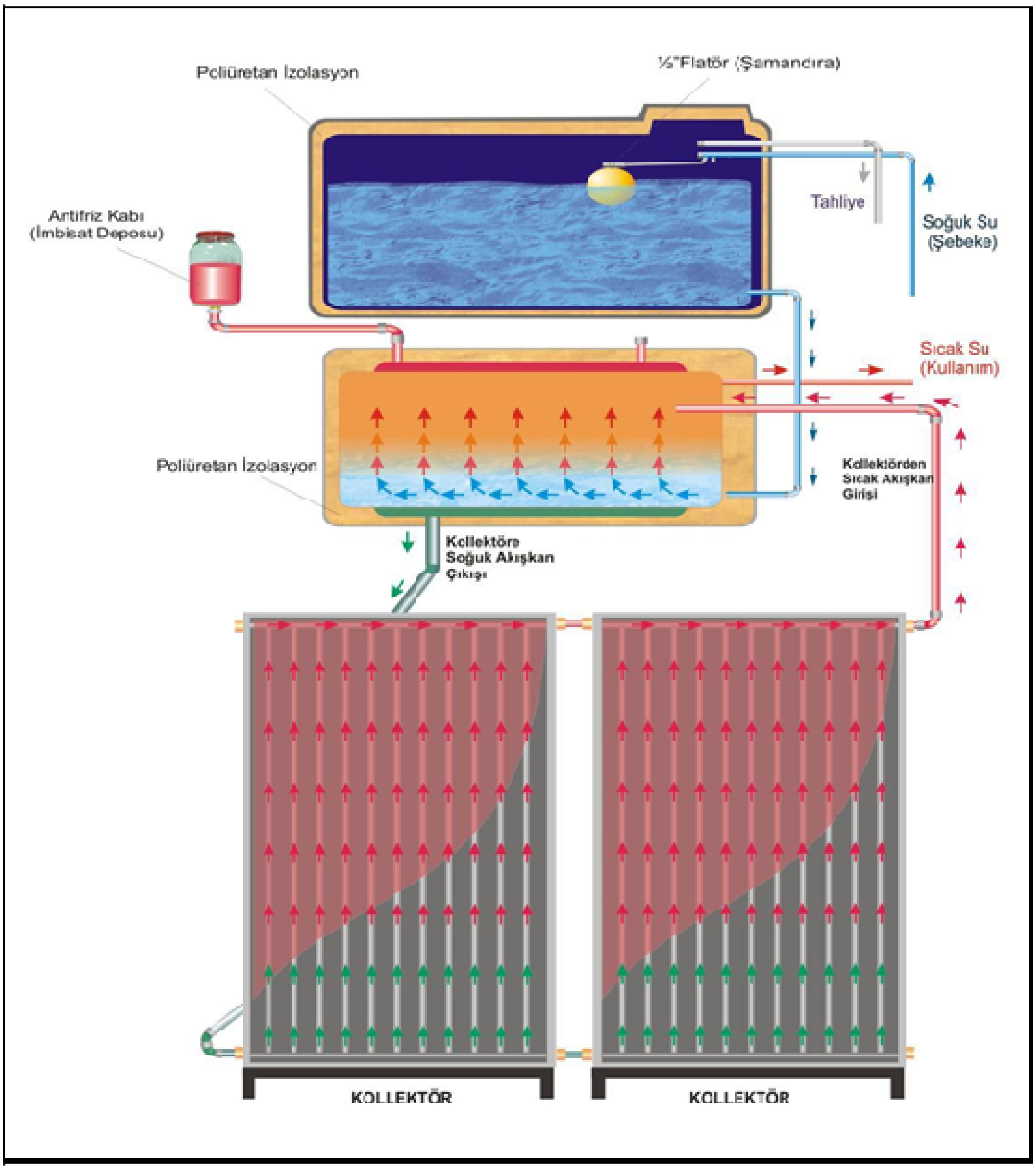



**Figure 2.2-60:** Details for the System with Double Reservoirs

*Pressure Systems*

In Closed Loop Pressure Systems cold water supply is directly fed into the hot water reservoir from the municipal water supply by using pressure and an additional float reservoir is not used. Therefore, the system reaches the municipal water pressure levels even before it starts to work. And when the system starts to work, the pressure level increases as the temperature level increase. In accordance with the closed-cup principal, as the pressure increases the temperature of the water inside the reservoir reaches higher values when compared with the other float systems. These types of reservoirs are the ones that work under pressure. Because of this reason, the design of the reservoir and the sheet thickness of the body is 2,5 mm or more. Details of a closed-loop reservoir (Figure 2.2-62) and the details of an open-loop reservoir (Figure 2.2-63) are given below.


**Figure 2.2-61:** Details of a closed-loop reservoir

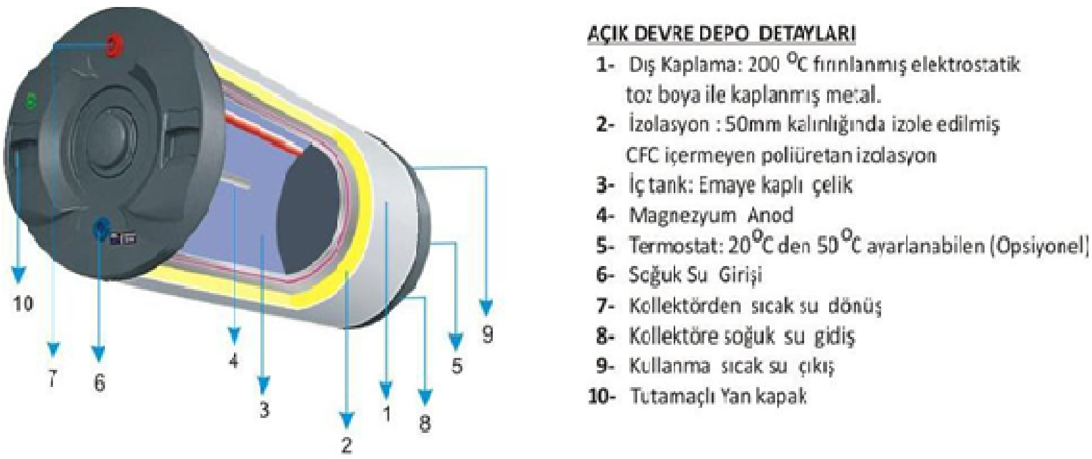



**Figure 2.2-62:** Details of an open-loop reservoir

The heating fluid circuit in these systems that work with natural circulation can both work under pressure closed to atmosphere (Figure 2.2-64 and Figure 2.2-65), and also open to atmosphere (Figure 2.2-66 and Figure 2.2-67). Generally closed systems are very common and widely used in abroad whereas open to atmosphere systems are widely used.

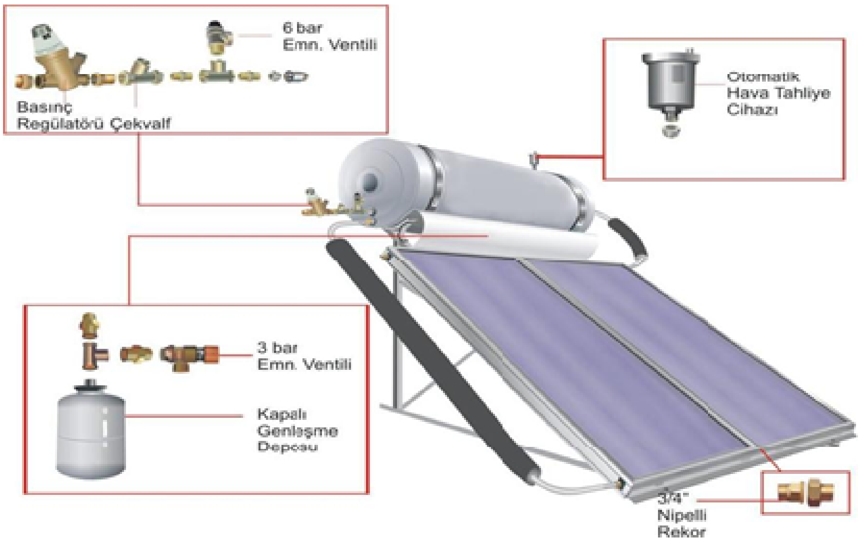



**Figure 2.2-63:** Closed Loop System (Closed to atmosphere)

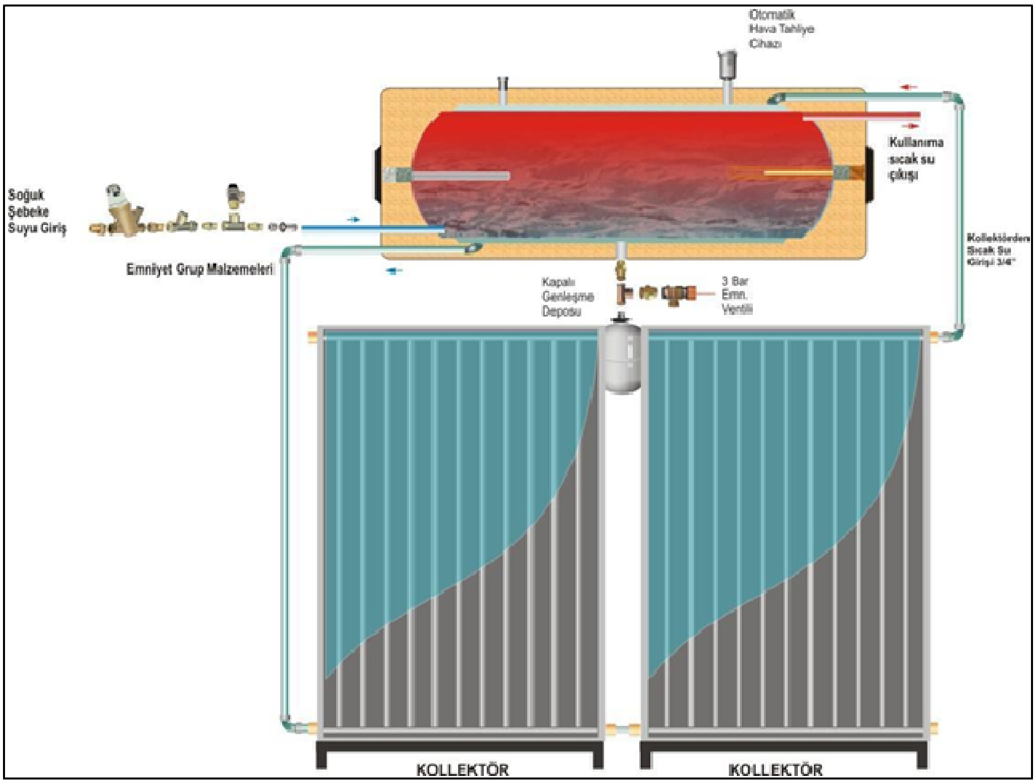



**Figure 2.2-64:** Closed Loop System (Closed to atmosphere)

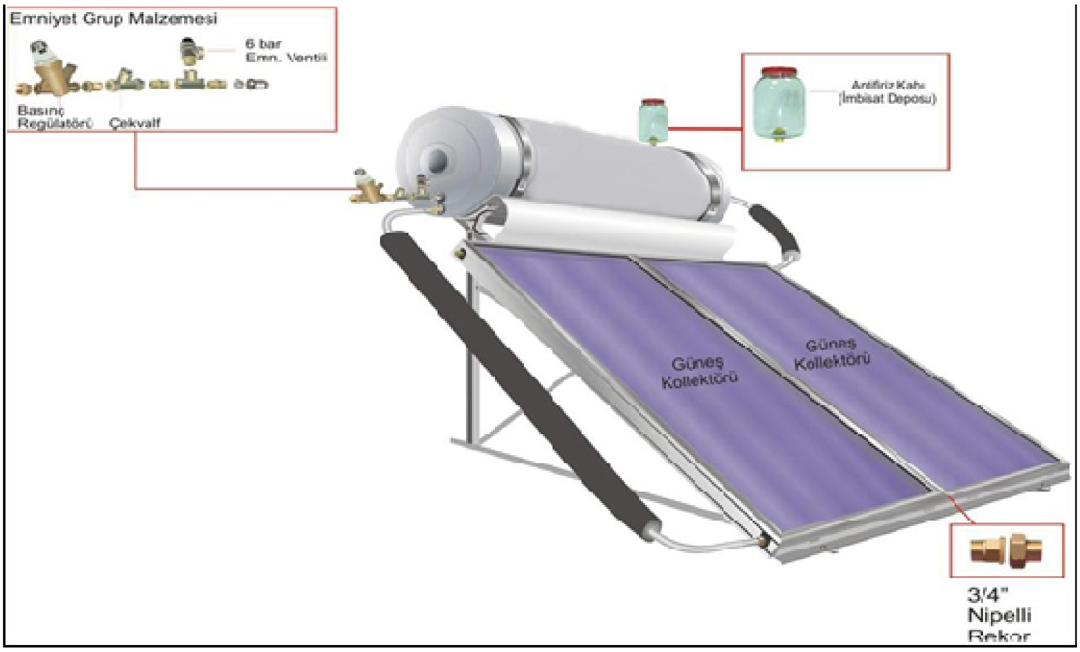



**Figure 2.2-65:** Open Loop System (Open to atmosphere)

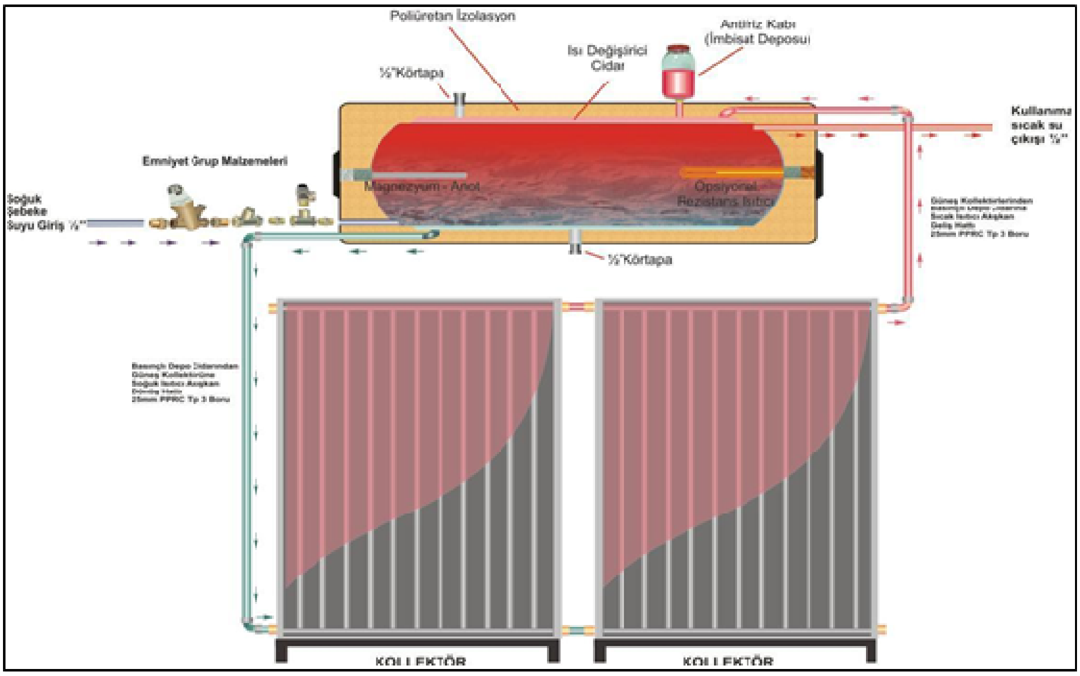



**Figure 2.2-66:** Open Loop System (Open to atmosphere)

Forced Circulation Systems

Solar energy systems with forced circulation create the circulation with a heating fluid pump which is located inside the system and enables the transport of heat. By this means, the storage capacity does not have to be located at a higher location then the solar collector like the ones in natural circulation systems. The storage capacity can be located at the desired height and even be located below the collector.

Forced circulation systems are more efficient then the natural circulation systems. As the flow rate and speed of the fluid that circulates in the collector can be controlled, the solar collector and system efficiency of these systems are higher. We can analyze forced circulation systems in two groups (Figure 2.2-68).

Local (Individual – Domestic) Forced Circulation Systems
Solar powered hot water preparation systems with local forced circulation can also be evaluated in two categories. These categories are the systems with one coil or the systems with two coils.

**Figure 2.2-67:** System with Local Forced Circulation

*Single Coil Solar Powered Hot Water Preparation Systems with Forced Circulation:*
Single coil solar powered hot water preparation systems with forced circulation are solar energy systems in which only a solar energy system and an additional resistance is used to obtain usable hot water.

In the general sense, the system equipment consist of a solar collector, a single coil fast boiler, a pump assembly which enables the circulation of the heating fluid between the collector boiler, and an automatic control device which controls the pump assembly by activating the assembly when the solar energy is sufficient and deactivate the assembly when the solar energy is insufficient (Figure 2.2-69).

The way the system works is as follows: the circulation pump activates and the boiler starts to heat up when the collector heat sensor unit reaches and passes the preset differential temperature that we have set in the automatic control unit before the boiler temperature sensor does. Otherwise, the circulation pump deactivates. In cases where the solar energy is insufficient, the resistance (heater) activates and production of the usage hot water is accomplished. The temperature of the usage water depends completely on the requirements of the user.

As these systems are generally built in the closed atmosphere category and the heating fluid (water + antifreeze mixture) circuit is also allocated, they can be used in all sorts of climate conditions.

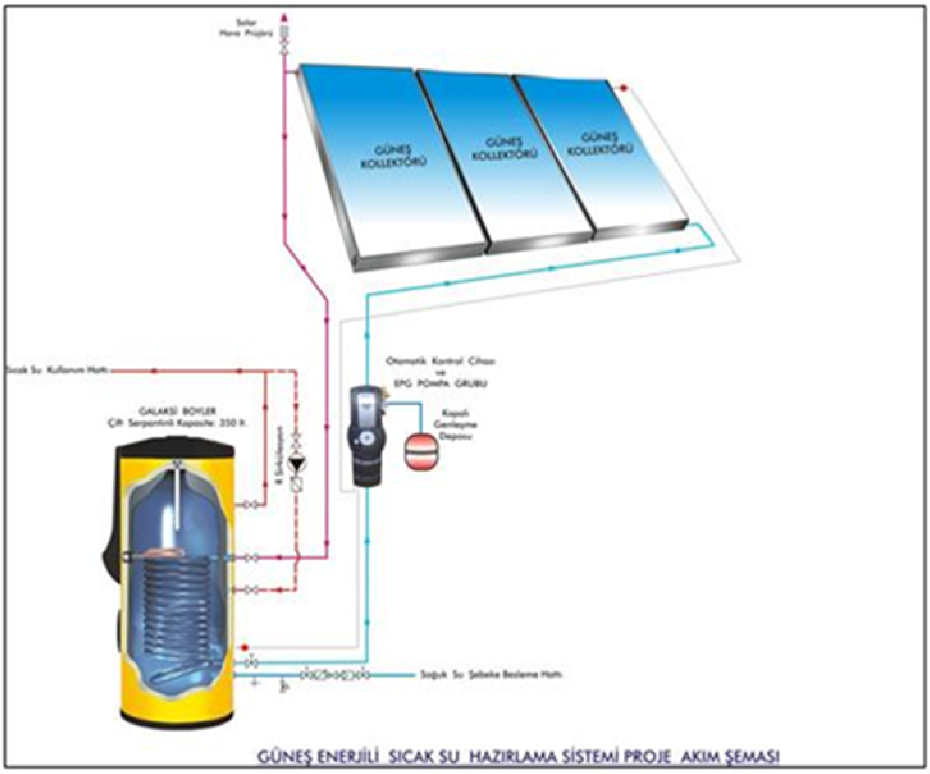



**Figure 2.2-68:** Single Coil Solar Hot Water Preparation Systems with Forced Circulation

<u>Double Coil Solar Powered Hot Water Preparation Systems with Forced Circulation:</u>
Double coil solar powered hot water preparation systems with forced circulation are the solar energy systems where both solar energy and the boiler heating system are used in order to produce usage hot water.

In the general sense, the system equipment consist of a solar collector, a double coil fast boiler, a pump assembly which enables the circulation of the heating fluid between the collector boiler, a pump assembly which enables the circulation of the heating fluid between the boiler, boiler heating system and an automatic control device which controls both of the pump assemblies by activating the assembly between the collector boiler when the solar energy is sufficient and deactivate this assembly when the solar energy is insufficient while activating the pump assembly in the boiler heating system.

The way the system works is as follows: if the solar collector temperature sensor is more than the preset differential temperature that we have set in the automatic control unit before the lower sensor, then the circulation pump between the collector boiler activates and the boiler starts to heat up. Otherwise, the circulation pump deactivates. In cases where the solar energy is insufficient, if the boiler temperature sensor is higher than the differential temperature set in the automatic control unit, then the circulation pump between the boiler is activated and the usage hot water is provided (Figure 2.2-70). The temperature of the usage water in double coil systems depends completely on the requirements of the user, just like it is in the single coil systems.

Double coil systems are generally assembled closed to atmosphere and the heating fluid (a mixture of water and antifreeze) is used, therefore they can be used in all sorts of climatic conditions.

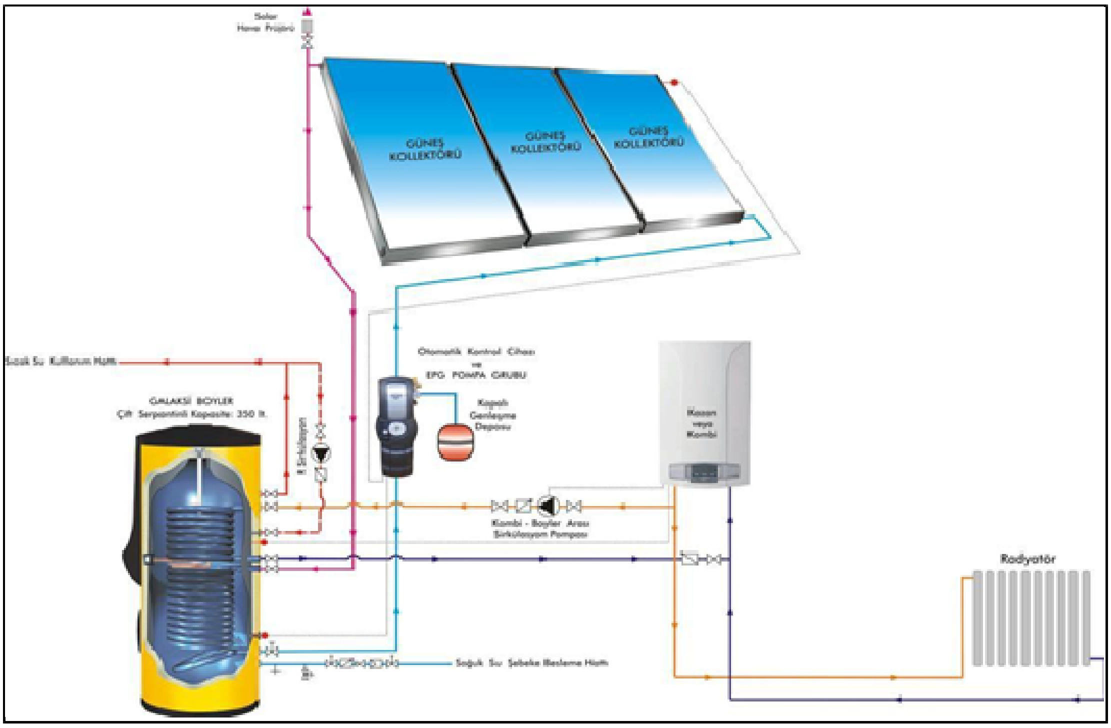



**Figure 2.2-69:** Double Coil Solar Hot Water Preparation Systems with Forced Circulation

### *2.2.3.3 Industrial Type Forced Circulation Systems*

Industrial type solar powered hot water preparation systems with forced circulation are used to meet the hot water needs of big facilities such as hotels, holiday villages, hostels, schools, dormitories, guesthouses, recreational facilities, leisure centers, hospitals, factories, business centers, dining halls, commercial laundries. Radiation values, temperature of municipal water, and the consumption amount of water related to temperature are the basic values in the sizing of the industrial systems. The size of the system that will be set up can be determined according to the user's desired months. In the systems which are set up based on the annual averages, 100% or more of the facility needs are met between April and October, and on other months an optimum utilization is achieved with preheating. Industrial systems (Figure 2.2-71) are given below.

Details and the topics such as calculating the technical estimates and project designing of the components such as solar collector, circulation pumps, hot water storage units (boilers), diameter of pipes, plate heat exchangers, closed expansion tank which are all used in the industrial type solar powered hot water preparation systems with forced circulation will be examined in detail in the chapter named “Project Designing Technical Estimates of Hot Water Preparation Systems with Solar Energy”.

**Figure 2.2-70:** Industrial Systems

### *2.2.3.4 Solar Collectors*

Appliances of different types and forms which collect solar energy and transfer it to a fluid in the form of heat are named as solar collectors. It is possible to categorize solar collectors in three groups with regard to manufacturing form.

- Flat Solar Collectors
- Vacuum Tube Solar Collectors
- Parabolic Solar Collectors

<u>Flat Solar Collectors</u>

This is the most commonly used solar collector type in the domestic applications (Figure 2.2-72). The fact that they have a planar profile makes them easier to transport, assemble and manufacture. Solar collectors of solar energy systems can work in three operation modes: low flow, high flow, and matched flow.

**Figure 2.2-71:** Flat Solar Collector

The system generally consists of the below mentioned parts and equipment (Figure 2.2-73).

1) Absorber plate (panel)
2) Cover coat (glass)
3) Isolation
4) Case (Frame) - Lath
5) Seal (rubber section)
6) Manifold gasket
7) Bottom plate

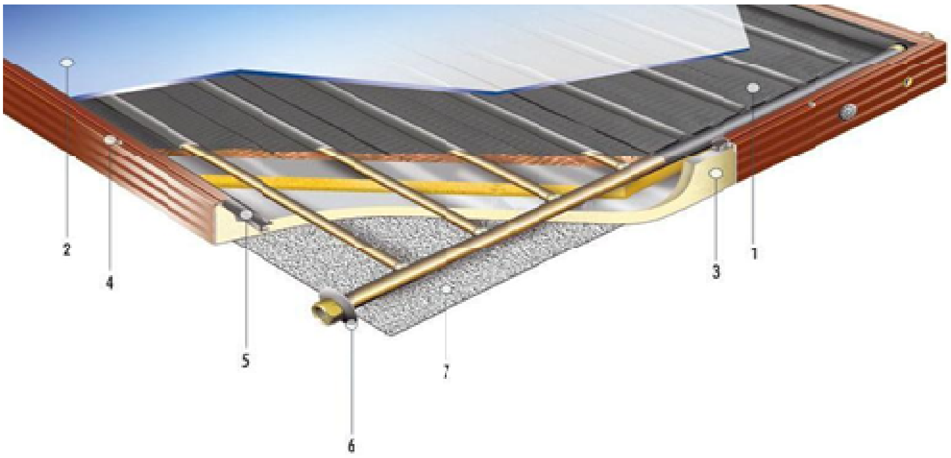



**Figure 2.2-72:** Equipment That Forms a Flat Solar Collector

1-<u>Absorber plate (panel)</u>
It is a part that absorbs the solar rays and is made of high conductivity material which has ducts in it. The absorber plate converts solar radiation into heat and enables the transfer of this heat to the heating fluid (water, water + antifreeze, etc.) and thus causes the heating fluid to heat up. Generally, the absorber plates

are manufactured from copper or aluminum as their conductivity and usability are high.

2-Cover coat (glass)

Transparent materials are used as cover coat in order to reduce the heat losses that will happen through heat convection and heat radiation from the collector to the surrounding in addition to the protection of the collector from the external effects.

At the present time, cover coats, which have high light transmittance and high resistance against the pressure that develops inside, that will transmit solar rays to the absorber area at the base with minimum reflection and with a very high percentage are used in the solar collectors.

3-Isolation

The isolation in the solar collector is used to preserve the heat energy that is transmitted to the heating fluid inside the absorber plate. Glass wool, rock wool, or monobloc cast rigid polyurethane foam which does not contain CFC and is not harmful for the ozone layer are used as insulating material in the collectors.

4-Case (Frame) - Lath

Case (Frame): It is the protective and connecting component used to protect the parts such as the absorber plate that constitutes the collector in which the heating fluid circulates, transparent glass cover, and insulating material from the atmospheric effects. Due to the fact that it is always in contact with external factors, this component is made from corrosion-resistant material. Generally materials such as aluminum, galvanized sheet, etc. are used, and the assembly of the case is done by welding to form a monobloc.

Lath: It is the part that has the same properties with the collector frame and is the piece which enables the changing of the glass with ease where necessary. It offers full water tightness and is aesthetic-looking.

5-Seal (rubber section)

It offers water tightness, is resistant against outer environment effects and the harmful ultraviolet (UV) rays which comes with the solar radiation, and is made of long life EPDM rubber.

6-Manifold gasket

It offers water tightness, is in a form that prevents the heat bridge between the panel and the case, is resistant against outer environment effects and UV rays, and is made of long life EPDM rubber

7-Bottom plate

It is made of aluminum, galvanized sheet, etc. and protects the material inside the collector against the external effects.

Vacuum Tube Solar Collectors

In this type of collectors (Figure 2.2-74) the air between the two telescopic glass tubes is vacuumed and the heat transfer is prevented from giving off to the outer environment. There is a pipe or heat-conveying copper bars in the middle of the interior glass tube. Solar radiation is transformed into heat with the help of these pipes or bars and thus the heat transfer is provided. A great number of vacuum tubes are generally imported from countries such as China.

**Figure 2.2-73:** Solar Collector with Vacuum Tube

<u>Parabolic Solar Collectors</u>

Parabolic solar collectors (Figure 2.2-75) are used in high temperature applications, in the condensation thermal systems. Condensation solar energy systems produce high temperature steam by directly utilizing solar radiation and are used in electricity production. Reflecting surfaces located in the inner side of the parabolic profile collectors focus the solar rays into a black absorbent pipe located at the focus. Electricity is generated from the steam which is produced by the heat gathered in the liquid that is circulated inside the absorbent pipe. Parabolic dish systems which are another type of condenser systems follow the sun in two axes and focus the sun rays into the focusing area. As for central receiver systems, an area consisting of mirrors named heliostat which are capable of individually focusing, reflects sunlight onto a heat exchanger which is mounted on a tower and thus they create condensation.

**Figure 2.2-74:** Parabolic Solar Collector

### *2.2.3.5 Installation angles and types of mounting*

Determination of Solar Collector Deflection Angles

In the North Hemisphere in which our country is also located, solar collectors are mounted facing the south. Although it changes with the seasons, solar radiation is at its highest levels, effect and quantity at around 10:00 – 11:00 in the morning and at 15:00 – 16:00 in the afternoon. It's possible to get maximum efficiency from the collectors between the specified hours by mounting the solar collectors facing south.

In terms of received radiation amount, it doesn't make a difference that can be considered important if the collectors face 10-15° southeast or 10-15° southwest. On the other hand, it is beneficial to place the collector considering the peak use period of the hot water produced in the solar energy system. For example, in a hotel where the peak use period is afternoon and evening hours, its beneficial to place the collectors facing 10-15° southwest in terms of getting more hot water from the system. Correction factors in accordance with solar collectors' angle of inclination and angle of deflection from the south are given in Figure 2.2-76.

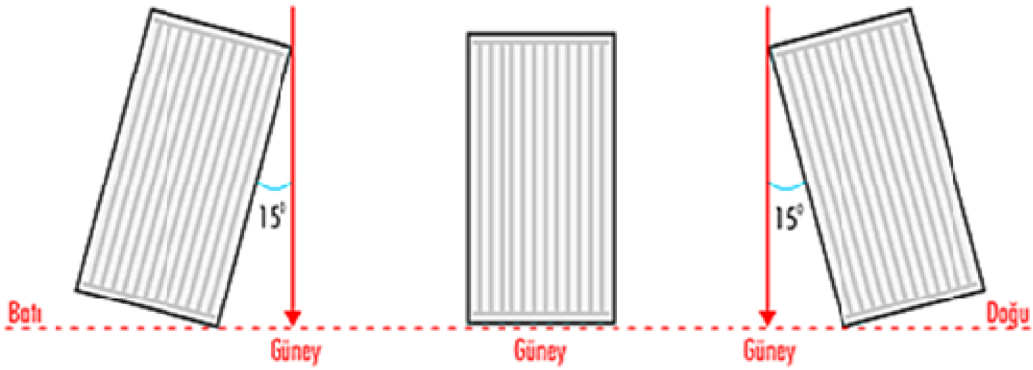



**Figure 2.2-75:** Collector Angle In Reference to Directions

Collector Installation Angles

In determining the angles, the most practical method is the calculations of the latitude values of the current location and the season in which the system will be used mostly. If the solar energy water heating system will be used year-round, then the collector's angle with the ground plane should be the same with the latitude of the location where the installation is done.

In relation to the aimed summer or winter season of the installation of the solar energy water heating system; the following should be based on for the ideal angle:

- the ideal angle for the summer season should be -15 degrees to the latitude of the location,
- the ideal angle for the winter season should be +15 degrees to the latitude of the location.

Determination of the Distance between the Collector Groups

If a more precise calculation is desired in terms of solar collector placement; solar radiation reaches our earth at its lowest angle on 21st of June for the south, and 21st of December for the north hemisphere. The dates where solar radiation reaches our earth at its highest angle are the exact opposite of these dates. Zenith angle (Figure 2.2-77) is at the median all over the earth on 21st of March and 21st of September. This date is the time and angle of the peak point of solar movement:

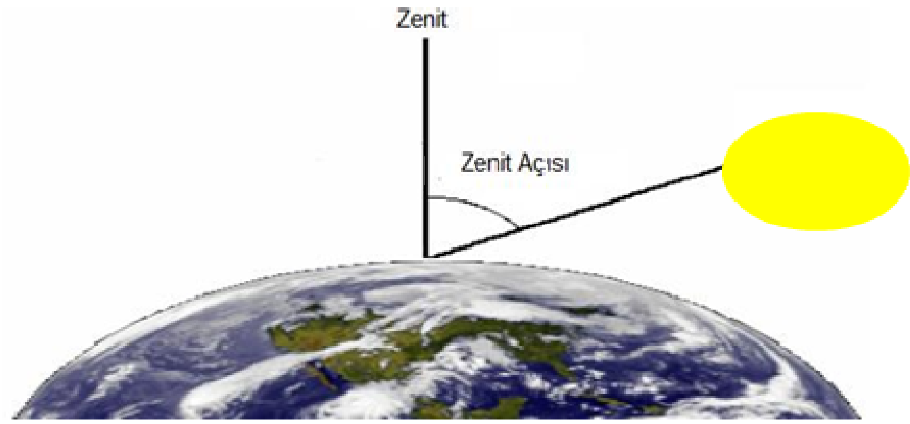



**Figure 2.2-76:** Zenith Angle.

Zenith angle changes between +23.5° and -23.5° for summer and winter seasons. Distance b between collector rows where collector height is a, is calculated with the following formula: In

b = a / tan α

In order to ensure that the collectors (Figure 2.2-78) shade each other when the incidence angle of the sun is at its lowest, the distance should be calculated as follows:

a= 90° –latitude–23,5°

Examples:
For Istanbul, 41° k.e.
b= a/tan α = a / tan (90° –41° –23,5°) = a / 0.45 = 2.09 a

For Kayseri, 35° k.e.
b= a/tan α = a / tan(90° – 35°–23,5°)= a / 0.6 = 1,66 a

In Istanbul, the necessary distance between the borders should be 2,09 times the collector height. As for Kayseri, it is approximately 1,66 times. As the contribution of the winter months to the yearly solar energy efficiency is not much, it doesn't cause much loss in performance if this distance is heated a little less.

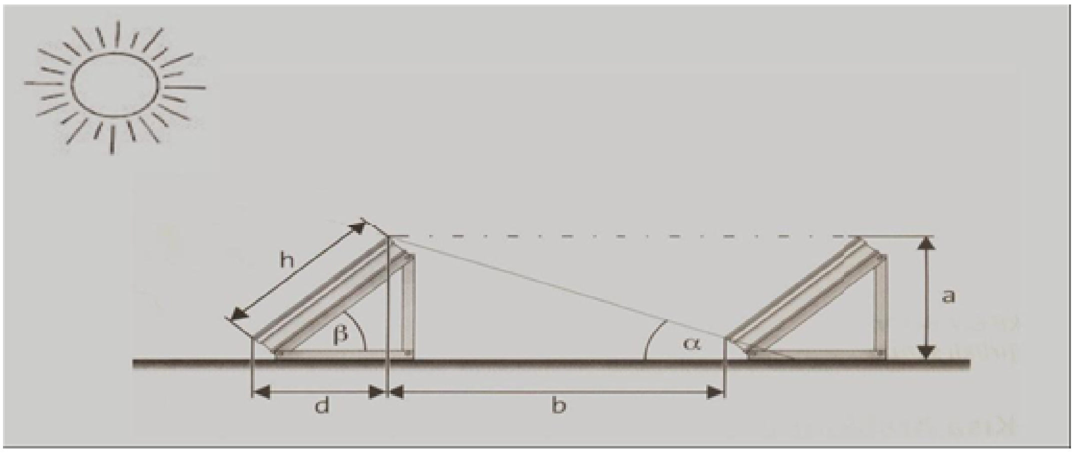



**Figure 2.2-77:** Shadowing Distance between Two Solar Collectors.

<u>Solar Collector Installation Types</u>

*<u>Installation on Flat Roofs</u>*
On the installation on flat roofs, angle and direction of the collector can be optimum arranged by using a suitable table. The required distance to prevent the collector rows from casting shadows to each other depends on the installation angle and local conditions (the season where the sun is at the lowest level).

The installation shown on the figure is an application done in a hotel (Figure 2.2-79). As the roof is flat, a concrete work was conducted at first, and after then the collectors were installed.

**Figure 2.2-78:** Application of Solar Collectors on Flat Roofs.

Space requirement may be a problem when the system that will meet the hot water needs gets bigger. In such cases, flat roofs that are supported in wide gaps are constructed. Besides, very heavy and expensive substructure bearing supports are needed for the roofs where the installation will be done. An application of this kind of application in industrial systems is given in Figure 2.2-80.

**Figure 2.2-79:** Solar Collectors With Bearing Substructure Applications.

*Installation on Tiled Roofs*

Installation on tiled roofs can be done in a couple of different ways. The properties of the roof are the key element in determining the way of installation. Collector installation procedure on a tiled roof can be done either on top of the roof or inside the roof. The only difference between these two methods is the mounting locks. In either method, the collector can be mounted to the roof with zero gaps. Various installation applications are given in Figure 2.2-81.

**Figure 2.2-80:** Collector Installation Methods That Can Be Applied On To Tiled Roofs.

*Installation of Collectors on Facades*

If a suitable place is not available on the roof, a search for an alternative place to install the collectors starts. Facades may be suitable for this (Figure 2.2-82). The potential difficulties at this point may be overcome by using a vertical type assembly set.

In the mid-latitudes, the amount of radiation falling on a vertical surface is about 70% of the radiation falling on an optimum slope. This ratio is lower in equatorial regions. For this reason, in the event that a suitable place is not available or a vertical installation is preferred for the appearance, the solar energy efficiency lowers. If the solar energy system is used as support for space heating in winter, the energy that is produced in summer creates plus value and the standstill times will shorten. When the collectors are vertically installed on top of each other, the different static pressure which develops in regard to the locations of the collectors has to be regulated. This circumstance has to be taken into account in selecting a collector. As there generally are windows or balconies between the collector rows that are mounted on facades, the fact that more piping will be required has to be taken into consideration. Flat collectors can be installed on facades in an inclined way and be used as a shade or an additional roof. They can also be fully integrated into the facades. Suitable evaluation systems for installation are provided by producers. Collectors mounted on facades lower the heat insulation needs, but they cannot be entirely used as a replacement for heat insulation.

**Figure 2.2-81:** Collector Application on a Façade.

<u>Mounting Kits for Load Bearing Elements of Solar Collectors</u>

The load bearing abutments and tables are manufactured from specially developed aluminum, etc. materials. It is possible to find kits on the market that will be suitable for all installation types. These installation can be seen in detail in Figure 2.2-83. Solar collector mounting kits are divided in 5 basic categories. These can be classified as follows:

- Mounting kits to be used on the installations done on the roof
- Mounting kits to be used on the installations done inside the roof
- Mounting kits for flat roofs
- Vertical type mounting kits
- Mounting kits for low angle roofs

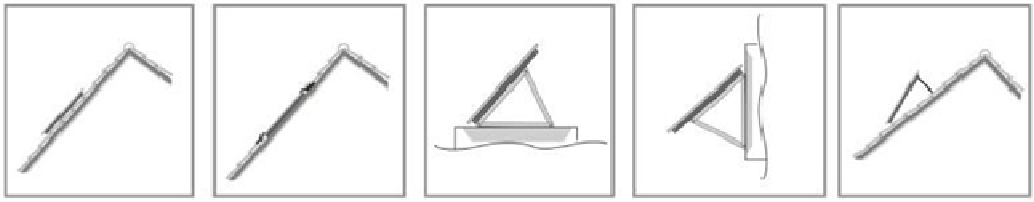



**Figure 2.2-82:** Mounting Kits.

### *2.2.3.6 Technical Calculations*

The Importance of Calculation

When it is decided to install a solar energy hot water system, the next step is the calculation. Calculation plays an important part in the system installation. Because, each of the processes like the number of collectors to be installed, the size of the storage tank, etc. are determined after calculations. In order to calculate, accurate information is needed. If we take information such as daily water requirements, the number of people living at the location, etc. into account; we can say that our calculations may be done correctly.

In general, the following topics should be known before starting the calculations: the intended use of hot water, the desired hot water temperature, the number of people that will be using the water, the efficiency of the collector to be used, the area to be used to install the collectors, general system efficiency, and solar radiation amounts of the location where the solar energy system will be installed.

Determining Total Heat Requirement

In order to determine the number of collectors that will be needed for the location, which is our primary objective, we have to determine the heat requirement of the location.

This requirement can be calculated with the formula

$Q = m \times cp \times \Delta T$

which shows the material's direct proportion change between heat and temperature. If we explain the unknowns in the formula respectively;
Q = Daily needed total thermal load (kWh/ day)
m = Total amount of hot water to be used at the location (lt)
cp = Water's average specific heat capacity between 0°C-100°C (0,001163 KWh/kgK)
ΔT = Desired water temperature – Municipal water temperature (°C)
In the application of this formula, both the customer requests will be taken into account, and data will be taken from certain tables.

Determining the Month to be Calculated

Range of use of the system is important for the calculation that will be done. Namely; if the system will be constantly used throughout the whole year, including summer and winter, then it is better to make the calculations based on April. As the seasons change, the cities do not have a fixed municipal water temperatures for each month. In order to prevent this, if the system will only work in summer then July or June; if the system will work only in winter, then December and January; and if the system will work four seasons, then April will be taken as base in determining the municipal water temperatures.

Determining Total Water Requirements

In order to determine total water requirement that will be spent, total number of people living at the location has to be known. After this information is obtained, the amount of water that might be used daily per person and the number of people are multiplied and thus “m” is found. Total daily water consumption = Number of People x amount of water a normal person consumes (lt). Details for average water quantity used in certain building types and temperatures are given in Table 2.2-1.

**Table 2.2-1:** average water quantity used in certain building types and temperatures.

| Location | Consumption (lt) | Temperature C |
|---|---|---|
| 2 Star Hotel | 50-75 | 45 |
| 3 Star Hotel | 75-100 | 45 |
| 4 Star Hotel | 100-150 | 45 |
| 5 Star Hotel | 150-200 | 45 |
| Pantion | 35-50 | 45 |
| Sport Complex | 30-50 | 40 |
| Hospital | 35-50 | 55 |
| Dormitory | 50 | 45 |
| Apartment (high comfort) | 100-200 | 55 |
| Apartment (normal comfort) | 75-100 | 55 |
| Refectory | 15-20 | 55 |
| Factory (hand wash) | 15-20 | 50 |
| Factory (shower) | 50 | 50 |
| Restaurant | 20-30 | 55 |
| Holiday Village | 200-250 | 45 |
| Laundry | 15-25 | 50 |
| Bath | 300-500 | 55 |
| Swimming Pool | 30-50 | 50 |

Although consumption amounts in locations where hot water is used are connected with the life standards, habits, cultural and educational levels of the people living in the location; the most important parameter is the income levels (Table 2.2-2).

**Table 2.2-2:** Water Consumption Amounts With Reference to Distribution of Income.

| Economic income level | Hot water consumption per capita (liter/day, person) |
|---|---|
| Low income group | 30 - 50 |
| Middle income group | 50 -70 |
| Upper income group | 70 - 90 |
| The highest income group | 90- 150 |

Specific Heat Capacity of Water

It is the quantity of heat that has to be given to or taken from the matter in order to change the temperature of the unit mass of matter by 1°C and it is a differential feature of the matter. Specific weight of water changes in regard to the desired unit type. As we will do our calculation in kW, the average specific heat of water should be 1,163 Wh/kgK = 0,001163 KWh/kgK.

ΔT Determination

The last data required to determine the total heat requirement is temperature differences. The thing we have to know in here is the municipal water temperature of the city where the system will be installed. After the desired value is obtained from 55, this value is subtracted from the requested temperature. In this way, the ΔT value is determined.

Determination of the Number of Collectors

We can determine the number of collectors after we determine the heat requirements. The formula needed for this is:

$$\text{n (Kollektör Adeti)} = \frac{\text{Q (Gerekli Isıl Yük)}}{\text{A (Alan)} \times \mu\text{k (kollektör)} \times \mu\text{s (sistem)} \times \text{I (Işınım Miktarı)}}$$

The Q in the Formula is the daily needed thermal load that we have determined above. If we explain the other unknowns in the formula respectively:

n = total number of collectors that is needed for the system which we will try to determine by calculation.

A (Area) = The net area of unit collector to be used.

µk (collector) = It is the collector efficiency. Different types of collectors have different efficiencies. The efficiency of the collector that will be used will be written here

µs (system) = It is the system efficiency. It is generally around 90% to 95%. It may show a change in accordance with the system size.

I = Solar radiation value (kWh/$m^2$-day). This value is given in Figure 2.2-56 for each city (on monthly basis).

When all these values are used in the above given formula, the number of collectors needed for the system can be calculated. The calculation of the storage tank is not analyzed in this study. Manufacturer publications can be consulted for this topic.

### 2.2.4 Heat pump renewable energy systems

<u>What is a Heat Pump?</u>

Heat pumps are thermodynamic systems in which heat transfer occurs from a lower temperature heat source to a higher temperature heat source (Figure 2.2-84).

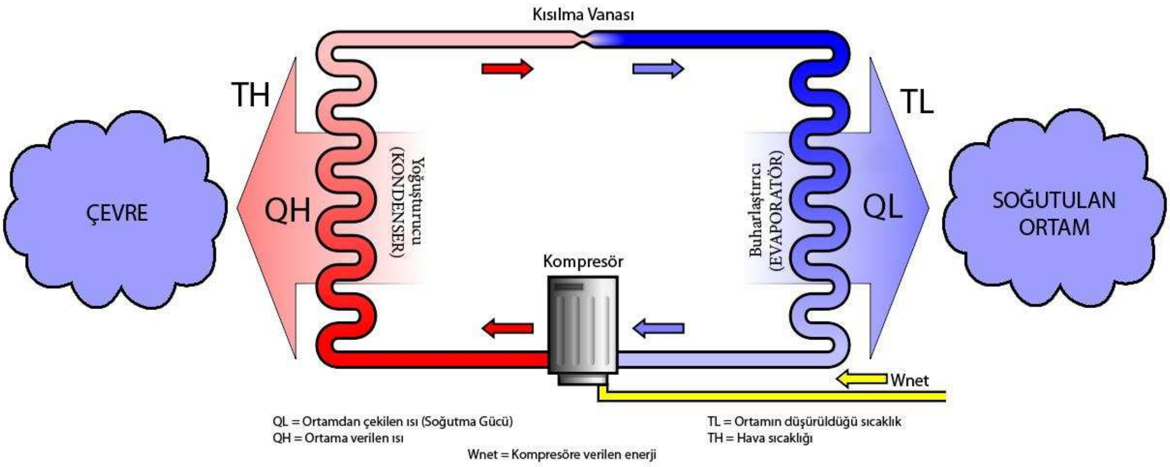



**Figure 2.2-83:** Working Principle of a Heat Pump.

Heat pumps have become the most asked and wanted devices of the recent times as a result of usability for both heating and cooling purposes in a single device, for being more functional in comparison with the traditional methods, for achieving considerable economy in energy consumption, for having a compact structure, and for enabling high control opportunities.

When considered from thermodynamic aspects, heat transfer from a lower temperature source to a higher temperature environment is only possible through the existence of a secondary source of energy. Heat pump types in accordance with this heat transfer are as follows;

- Vapor compression cyclic heat pump
- Absorption heat pump
- Adsorption heat pump
- Gas cycle heat pump
- Steam jet heat pump
- Stirling cycle heat pump
- Resorption heat pump
- Rankine / vapor compression cycle heat pump
- Thermoelectric heat pump.

Among these, vapor compression cyclic heat pumps and absorption and adsorption heat pumps which operate on thermal energy are used. We can mention the working principle of absorption and adsorption heat pumps briefly.

Absorption chiller main principle, is based on the principal of heat extraction from the lower energy leveled source by force of boiling low temperature water or in other words “evaporation” of low temperature water (Figure 2.2-85). System consists of 4 main components and 2 pumps.
These are: 1- Evaporator, 2- Condenser, 3- Absorber, 4- Generator
The pumps are: 1- Solution pump, 2- Refrigerant pump

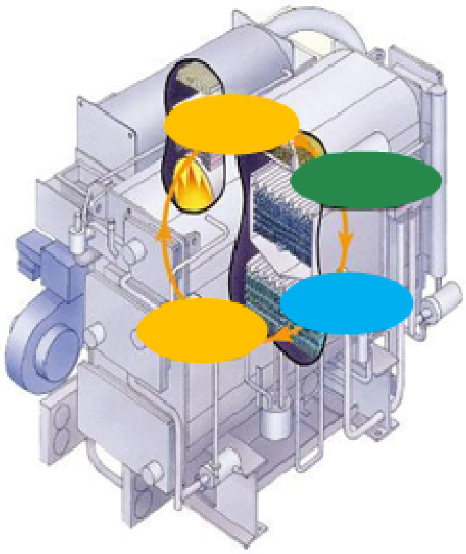


**Figure 2.2-84:** Absorption Chiller.

The system works way below atmospheric pressure. These devices work in vacuum. Water absorbing element of the system, in other words the absorbing element which gives the system its name is lithium bromide (a type of salt) and water is used as refrigerant. We can explain the system in regard to flow order.

- “Solution” is LiBr (Lithium bromide) salt.
- “Refrigerant” is water.
- “Rich mixture” (strong solution) is the solution with high salt ratio.
- “Poor mixture” is the solution with more water in the water – salt ratio

1. Generator
The solution coming to the upper side generator through the pre-heating heat exchanger by means of the solution pump is heated at elevated temperatures by means of the steam/hot water battery located in this section (at this point solar energy, waste heat, natural gas, or flue gas is used) and a portion of the water it contain evaporates and leaves.

The leaving water - refrigerant vapor pass through the condenser section, and the remaining solution with increased Li – Br ratio becomes a strong solution, and is then moved again to the heat exchanger and cooled by the poor mixture which is pumped into the generator from the absorber, just like itself.

2. Condenser

The refrigerant vapor coming from the generator flows through the eliminator where it is condensed by the battery containing cooling water which is sent from the cooling tower located in this section and is collected in the built-in bottom pan in water form.

3. Evaporator

The refrigerant liquid accumulated in the condenser is sprayed on to the cooler battery by means of nozzles. The low pressure (6 mm Hg) at this receptacle causes the water particles to evaporate at temperatures such as 3 - 4 ˚C. The cooling process is done by extracting the heat of the fluid (chilled water) passing through the cooling battery with the effect of evaporation. Water particles (refrigerant liquid) that do not evaporate are collected in the pan located at the bottom of the evaporator and sent to the nozzles again with the help of a pump (refrigerant pump). In this way, the refrigerant which does not evaporate is used again.

4. Absorber

The intermediate concentrated Li-Br solution which comes from the generator and is cooled a little in the heat exchanger is sprayed through the nozzles located at this section. The sprayed Li-Br particles create an extra vacuum effect in the evaporator by drawing and absorbing the water vapor from the evaporator into the absorber. The water vapor drawn into the absorber section is condensed by the cooling water battery found in this section (the water coming from the cooling tower is first sent to the condenser, and then to the absorber). At the bottom side of the absorber, it becomes poor mixture by mixing with Li-Br. Thus, the starting point loop is reached.

In the Adsorption Cooling Systems, pores of substances such as active carbon silica gel absorb huge amounts of gas. Adsorption cooling systems have been developed by benefiting from these properties of solids such as these (Figure 2.2-86).

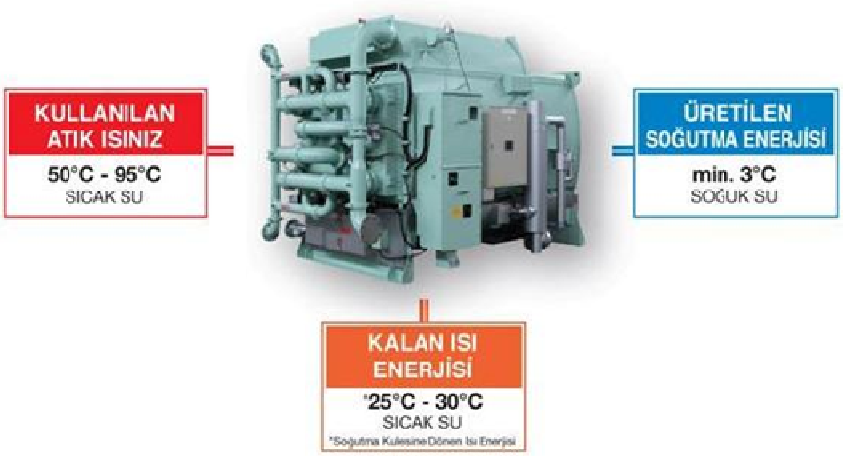



**Figure 2.2-85:** Adsorption Chiller.

The system consists of a boiler (and an absorber at the same time), a condenser, and an evaporator. In this system there is silica gel, instead of water, inside the boiler that will ensure ammonia absorption. There are electric heaters and cooling coils inside the boiler. With the heating of the boiler, silica gel also warms up and the ammonia it has absorbed evaporates and leaves the body of the silica gel. When a certain pressure is reached, it opens the discharge valve and passes to the condenser. In here, the ammonia liquefies by giving off heat and flows inside to the condenser. After a while, the float inside the condenser rises and shuts off the electric heater circuit. Cooling water valve is opened and the heater starts to cool down. When the electric heater is off, the ammonia which evaporates by absorbing heat from the environment starts to be absorbed by the silica gel in the boiler which acts like an absorber. Thus, the evaporation of ammonia will be easier due to the pressure drop inside the cooling boiler. The formed ammonia steam opens the suction valve and returns to the absorber again. After a while, the fluid level inside the evaporator drops and the float closes the cooling water valve and activates heating circuit. The circulation continues in this manner.

### *2.2.4.1 Components of heat pumps*

Heat pumps consist of four main components.

- Condenser: It condenses the refrigerant in gaseous phase into the liquid phase again and transfers to the heating installation.
- Compressor: It increases the pressure of the refrigerant.
- Expansion Valve: It reduces the pressure of the refrigerant.
- Evaporator: Evaporates the refrigerant. Transfers the heat from the heat-conveying liquid to the refrigerant circuit.

Heat pump flow diagram is given in Figure 2.2-87.

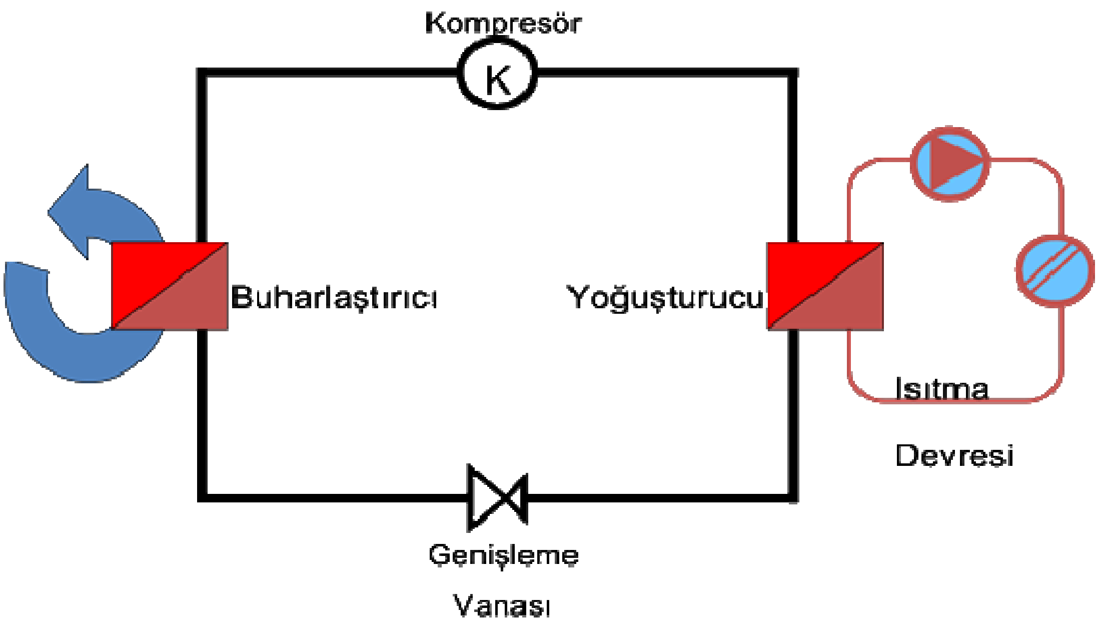



**Figure 2.2-86:** Heat Pump Flow Diagram.

Compressors

It is the equipment which works like a pump in order to circulate the refrigerant in the refrigerant circuit (Figure 2.2-88). The low temperature and low pressure refrigerant is evaporated in the evaporator and the refrigerant steam is compressed in the condenser up to the pressure level where it can easily transit to liquid phase.

**Figure 2.2-87:** Compressor.

Compressors are classified in accordance with their compressing methods. They can be divided into two classes, being volumetric compressing and centrifuge compressing. In volumetric compressing, we see piston compressors, rotary-piston compressors, scroll compressors, and screw compressors. In centrifuge compressing, we see single-stage and multi-stage compressors. Compressors are also categorized according to their structures. There are three categories, which are open type compressors, semi-hermetic compressors, and hermetic type compressors.

*Classification of Compressors According to Compressing Methods*
Compressors are generally classified according to their compression methods.

a. Piston Compressors

Piston compressors are composed of cylinders, pistons, and valves. Compression is achieved by the reciprocating motion of the piston inside the cylinder. The valve controls the gas that enters and exits the cylinder. During the intake stroke of the piston, the low pressure refrigerant is pulled through the intake valve. The valve can be located on the piston or the cylinder head. During the delivery stroke, the piston coolant compresses the refrigerant and pushes it to the delivery valve. It is generally installed on the cylinder head.

b. Rotary Compressors

There are three types of rotary compressors:

- Rotary-piston

- Slide valve
- Swing

Even though rotary compressors are used in very big compound compression systems' low pressure section as booster compressors, they are generally used in household cooling applications, freezers, and air conditioners.

Working principle of a rotary-piston type is as follows: as the rotary-piston (rotor) is rotating together with the cylinder by touching the circumference of the cylinder, the stationary blade compresses the refrigerant. Center of the shaft is the same with the cylinder. But the center of the rotary-piston (axis) is placed eccentrically to the shaft. In this way, the rotary-piston contacts the cylinder while rotating. In a rotary-piston type compressor, the suction and delivery rooms are divided by a spring loaded divider blade.

The working principle of the slide valve type is as follows: multiple blades rotate with the cylinder while they contact the circumference of the cylinder together with the rotary-piston. In this way, the refrigerant is compressed. In the slide valve type compressors, the rotor rotates around its own axis but the axes of the rotor and the cylinder do not coincide with each other. The rotor has two or more slide blades and these settle on the cylinder with the centrifugal force effect. In a two bladed compressor, the displacement in each rotation is divided into twin cross scan areas. In a four bladed compressor, the compressor displacement is divided into four cross scan areas. From this important point forth, the displacement stage of a compressor increases in direct proportion to the number of blades.

As it is not necessary, an intake valve is not installed in both types of rotary compressors and the gas intake of the compressor is constant. For this reason, vibrations are at the lowest levels.

When compared with piston compressors, rotary compressors are more compact, simpler structured, and have less components. Additionally, efficiency values of rotary compressors are much higher. However, precision must be ensured and abrasion should be prevented during the production of the rotary compressor's components. In the past, the most used rotary compressor type was the rotary-piston rotary compressors. But, in the last years, the new swing type is developed and the usage area of rotary compressors has considerably expanded.

By means of the joined blade and piston of the swing rotary compressor, gas escape from the high pressure side to the low pressure side is prevented and the compression ratio in the high pressure side is retained.

c. Scroll Compressors

Scroll compressors consist of two spirals of which one is fixed and the other revolves around. Aeriform refrigerant is sucked towards the compressor around the spirals and is compressed with the decrease of the area which circles the spirals enclosing the gas and is sent to the system through the outlet line in the center.

d. Screw Compressors

Screw compressors consist of rotors that have male and female cogwheels. Refrigerant is compressed when the single screw rotor and two cogwheels engage and run. In screw compressors the compressing process is done in three stages: suction, compressing, and delivery. In order to reduce gas flow resistance, gas is sucked, compressed and delivered in the direction of the shaft.

e. Centrifugal Compressors

Centrifugal compressors consist of a blade and spiral. The blade revolves around 10.000 rpm. Centrifugal compressors are like centrifugal pumps in terms of construction. The fluid enters from the midsection of the fan (wheel) and is scattered around the fan by the centrifugal force. Thus, the fan blades rotate in high speed and pressure is generated. The kinetic energy of the gas flow coming out of the fan is converted to pressure in the diffuser blades or in a worm. Centrifugal compressor can be produced with a single cogwheel if the pressure stage is low but these type of compressors are generally multi staged. Centrifugal compressors work in 70% to %80 adiabatic efficiency.

*Classification of Compressors According to Their Structure*

a. Open Type Compressors

Open type compressors are driven by external power through the instrument of a v-belt or direct connection. For this reason, one end of the drive shaft project from the compressor body. By installing a seal which is named shaft seal into the place where the shaft goes through, gas escape from the compressor housing or inward air flow if the crankcase pressure is lower than the atmospheric pressure, is prevented. Even if the designers constantly develop better seals, housing hole can always be a source of escape.

In order to protect from refrigerant leakages, the motor and the compressor are often installed into the same housing. In addition, open type compressors can easily be dismantled for control and maintenance. By this means, worn or damaged parts can easily be replaced. Open type compressors are generally used in low temperature applications.

b. Semi-Hermetic Type Compressors

The compressor and the motor are installed and connected into the same body. The cap of each section is reinforced with bolts. There is no need for a seal as the possibility of a gas leakage is out of the question.

c. Hermetic Type Compressors

The compressor and the motor are installed and connected into the same body and hermetical sealing is ensured by welding. When compared with semi-hermetic type compressors, hermetic type compressors are perfect in terms of air tightness. Low capacity piston-compressors and rotary compressors are generally produced hermetic type. In these compressor types, the whole compressor has to be replaced in case of a malfunction.

Another subject about compressors that has to be emphasized on is that the compressors can work with inverter systems.

*Inverter Compressor Systems That Work in Partial Load*

a. What is Inverter Technology?

Devices that can transform direct current (DC) into alternate current (AC) are called "inverter systems". Their frequencies and voltages can be adjusted independent of each other.

The location's peak cooling load is calculated by heat gain calculation and the capacity is determined in accordance with this calculation. However, the system generally works in partial load during the cooling season. Inverter compressor system working in partial load works more efficiently than the classic on-off controlled systems.

In the classic compressors, the compressor rotation is firm. The compressor works in firm capacity. The compressor stops when the preset temperature is reached in the conditioned location. The start-stop of the compressor is the mode of operation of classical systems. It is not possible for the compressor to control the ambient temperature precisely by manner of start-stop at the same capacity. Due to the fluctuations in the room temperature, deviation from the comfort requirements occurs and energy consumption increases. Inverter compressors can modulate their capacities. Inverter technology adjusts the compressor revolution by changing the frequency of the constant-frequency electricity coming from the grid. With inverter compressors, the conditioned location's temperature can be stabilized by a ± 0,5°C precision. There are no deviations in the comfort requirements. Electricity consumption is approximately 30% lower when compared with the classical compressor systems.

Evaporator

It's the equipment that transforms the fluid coming from the expansion valve in liquid form into the vapor phase by passing a heat source over.

Condenser

This is the equipment in which at one end the fluid which is compressed and increased in temperature transfers its heat to the fluid at the other end (Figure 2.2-89).


**Figure 2.2-88:** Condenser.

Expansion Valve

It's the valve that makes the fluid to change its phase in accordance with its passage type (Figure 2.2-90).

**Figure 2.2-89:** Expansion Valve.

Refrigerants

In accordance with European Community specifications, the usage of HCFC type refrigerants is forbidden. For this reason, heat pump manufacturers use R-407 C, R-417 A, R- 421 A and R – 410 A as alternative refrigerants.

### *2.2.4.2 Heat sources used in heat pumps*

Ambient Air

Air is the most easily accessed, and is the most preferred heat source in heat pumps as it is easy to use and economic. But air has some disadvantages when used as a heat source. The fact that it does not have steady temperature, the fact that air temperature drops significantly in continental climates especially in winter times and even during daytime are some of these disadvantages.

Soil

The fact that soil temperature does not show much change throughout the year (Figure 2.2-91) when compared with air allows their usage in continental climates. Specifications such as composition, density, and moisture content of the soil and application depth of the pipes affects system choice. When soil is used as source, investment cost increases. Heat pumps using soil as source are generally used in detached buildings and especially in villa-type houses and in various commercial and corporate buildings due to the need for free soil area and the high initial investment costs.

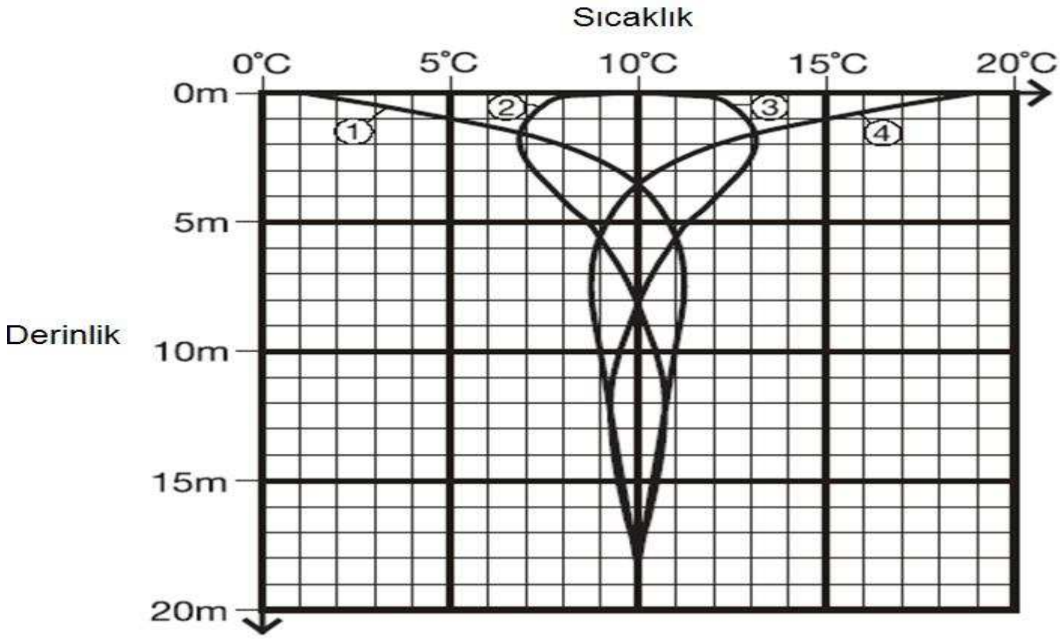



**Figure 2.2-90:** Temperature Changes of Soil Throughout the Year.

Surface Waters

Big water sources such as seas, lakes, ponds, etc. are used as surface waters. Systems using these types of sources have lower costs. One of the biggest problems about these systems is the need for permissions to use these sources and thus the problems encountered with the local authorities can cause an issue. While a secondary heater is sometimes needed when using water sources, the biggest problem with water resources is that the source temperature can drop to temperatures around 0 °C.

Underground Waters

The fact that there aren’t many changes in temperatures in underground waters makes this source attractive. The disadvantage here is that another pump is needed to get this source to the heat pump and that pump also has its own energy requirements. The quality of the underground water also affects the system and if there isn't a readily available well at the location the drilling of a new well will also bring extra costs. If these disadvantages can be minimized as much as possible, the fact that water temperature is around 5-10°C and higher temperatures can be reached by drilling deeper throughout the year makes this source a good one.

Exhaust Air

In house or small business applications where ventilation is done, the used air can be used as a source in heat pumps. The hot water need in the system can be met by the warm air that will be passed on to the heat pump.

Waste Liquids

Waste water disposed from geothermal facilities, refined or unrefined sewage, industrial waste fluids, waters such as cooling water used in industrial facilities can be given as examples for these types of heat sources. The advantage of these waters is that they can be at high and constant temperature. The disadvantage is that there can be changes in the quantity of these sources and therefore storage is needed and this in return increases the costs. Besides, the pump that will pump water from this storage into the heat pump will also have its own energy requirements.

#### *2.2.4.3 Types of heat pumps*

Water/Soil Source Heat Pumps

The energy stored in soil or water is directed to the interior of the building with the help of the laid pipe system and a pump (Figure 2.2-92). This energy is transferred to the fluid inside the heat pump. The pressure and the temperature of the fluid is increased by means of the compressor located inside the heat pump and this energy is then transferred to the water that is circulating inside the indoor heating installation by the heat pump (Figure 2.2-93).

Subsoil pipe line contains a heat transfer fluid which consists of water and glycol. The energy found in soil or water is transferred to this fluid. After this transfer, the temperature at the pump inlet of the water source heat pump is around 0 °C. When this fluid meets the refrigerant inside the evaporator, the heat transfer occurs inside the heat pump. When the refrigerant enters the evaporator, its temperature is -10°C. The refrigerant starts to boil when it reaches 0°C. After the evaporator, it passes through the compressor and turns into gas phase. The temperature of the fluid in the gas phase reaches to 100°C in the compressor as its pressure is increased. This gas is sent to the condenser by the compressor. In the condenser, it transfers its energy into the water in the heating installation and thus heating water at 55°C is obtained. This heated water is sent to systems like radiators, under-floor heating, and boilers by means of a pump and used there. As the fluid inside the condenser looses energy, it becomes cold. In the meanwhile, the pressure of the fluid is still high. The fluid is quickly depressurized in the expansion valve and is liquefied. In order to recollect the energy stored in water or soil, source water is divided again from the heat pump. At this point the temperature of the source water is -3°C. In this way, the cycle is completed. An example of a Water/Soil Source Heat Pump is given in Figure 2.2-94.

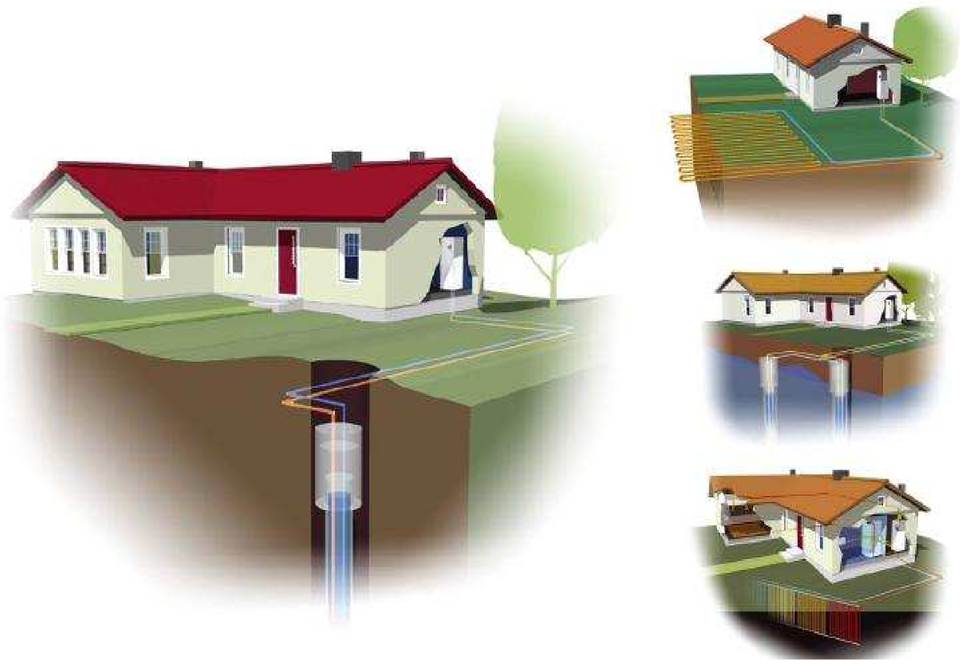


**Figure 2.2-91:** Application Examples for Water/Soil Source Heat Pumps.

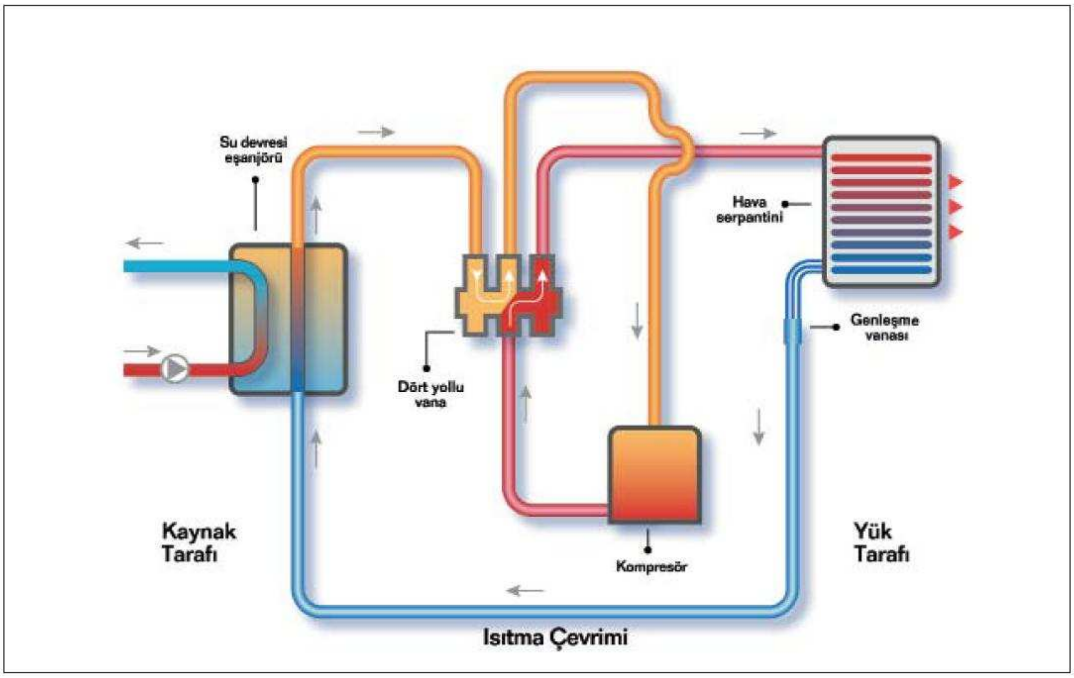



**Figure 2.2-92:** Working Principles of Water/Soil Source Heat Pumps.

**Figure 2.2-93:** Soil Source Heat Pump.

Source side of the soil source heat pumps can be considered to be a deep well, laying, or a water source. When soil is used as heat source, it has been observed that the watery clay layer is the most efficient heat source. Throughout the year, heat absorbing capacity in a single installation can be considered as 10-35 W/m$^2$ soil area. The energy that we can absorb from the soil reduces if the soil has very high amount of sand. In other words, it is best if the soil analyzed by an expert and necessary reports are prepared in order to calculate how much and what type of energy we will receive from the soil. The regeneration of the soil from which heat is extracted, will be ready until the next heating period thanks to increased solar radiation and rains.

While calculating the under-soil collector area thermal characteristics such as the capacity of the soil layer and the coefficient of thermal conductivity depend on the composition of the soil. Heat storage characteristics and thermal conductivity coefficients increases when the amount of water and minerals in the soil increases and when the amount of pores in the soil decreases.

| | |
|---|---|
| Dry sandy ground | 10-15 W/m$^2$ |
| Wet sandy ground | 15-20 W/m$^2$ |
| Dry clayey ground | 20-25 W/m$^2$ |
| Wet clayey ground | 25-30 W/m$^2$ |
| Underground water bearing ground | 30-35 W/m$^2$ |

When underground water is used as heat source, a lift and force well must be prepared. The quality and temperature value of the water is very important in here. This water source is not directly fed into the heat pump, as it necessarily is cutout from the cycle by using a stainless steel heat exchanger.

When selecting the water/soil source heat pump system, the needs of the building should be specified in the first place. After the needs are determined, the building heating and cooling loads that has to served by the water/soil source heat pump system must be specified. After that, the necessary series of analysis are performed to decide the source to be used at the area where the installment will be set up. If as a result of these series of analysis it is determined that the heat pump meets all of the requirements, then the planning is done accordingly. If zoning or rate of meeting the requirements in their entirety is low, then boiler reinforcement should be considered and the planning and system design is done accordingly.

A plant layout example for a water/soil source heat pump can be examined below (Figure 2.2-95). With this heat pump, heating in wintertime, cooling in summertime and running hot water heating with the support of solar energy in general can be done. After the essential requirements are determined, the main equipment is chosen according to the system requirements.

As it can be seen in the example system given below for heat pumps, when choosing the pump between the source and balance tanks of the heat pump, attention should be paid to the minimum water discharge that has to pass through the heat pump, and that the selected pump can meet this minimum requirement. In addition, when choosing a boiler for the system, attention must be paid to select a boiler specifically manufactured to be used in a heat pump or to select a boiler which has a large serpentine area and has reinforcing electric heating on it.

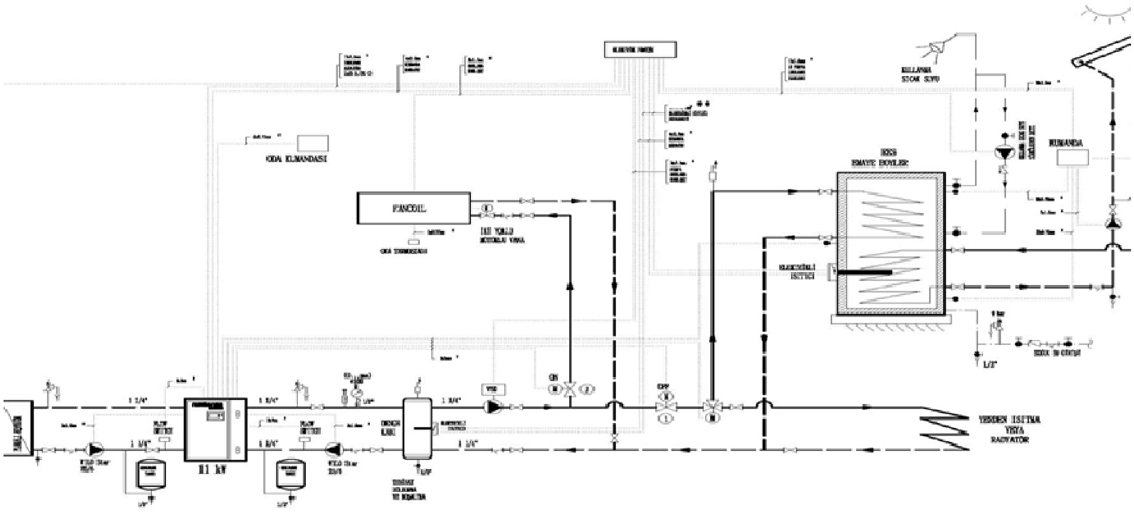



**Figure 2.2-94:** Sample Water/Soil Source System.

Air Source Heat Pumps

They are the devices that can use the energy in the ambient air for heating or cooling in location. These devices can transfer the energy they obtain into the water or air in the load side. Air conditioners are actually air-to-air heat pumps. The air-to-water heat pumps, on the other hand, can provide a comfortable heating with under-floor heating or radiators as they transfer their energies into the water at the load side. And when used for cooling purposes, they can easily allow fan coil cooling or under-floor cooling on the condition that the relative humidity is suitable. Air source heat pumps are designed as split or monobloc (Figure 2.2-96). In monobloc systems, all of the system components are located completely outside. In split type heat pumps, the external unit which has the components of the refrigerant cycle (Figure 2.2-97) is installed on the outside of the place whereas the internal unit which has the water circuit heat exchanger, pump expansion tank and control system (Figure 2.2-98) is installed inside the location.

**Figure 2.2-95:** Sample Monobloc Heat Pump.

**Figure 2.2-96:** Split Type External Unit.

**Figure 2.2-97:** Split Type Internal Unit.

Air source heat pumps have some advantages. In addition to being easy to mount, they do not require high cost drills or installations. Their external units can be mounted to the desired location closed to the building and they take very little space. Ventilation is not required in the place where the interior unit is installed. They can be installed in the desired locations inside the place as there is no need for a chimney. With a good automation, they stabilize the temperature of the location by using inverter technology. When compared with the boiler systems, they do not need maintenance and they do not have problems such as sound. The most important feature of these systems is that they do not emit carbon dioxide.

Operation of an air source heat pump is as follows (Figure 2.2-99). When the refrigerant which has lower temperature and pressure passes through the evaporator located in the external unit, it extracts heat from the ambient air which has higher temperature. After the temperature and the pressure of the heat conveying fluid is increased while it passes through the compressor, it is sent to the water circuit heat exchanger. In here, the heat of the high temperature fluid is transferred into the water which is in the installment. Thus, the obtained heating water is sent to the radiator, under-floor heating or boiler circuit by means of a pump and the requirements are met.

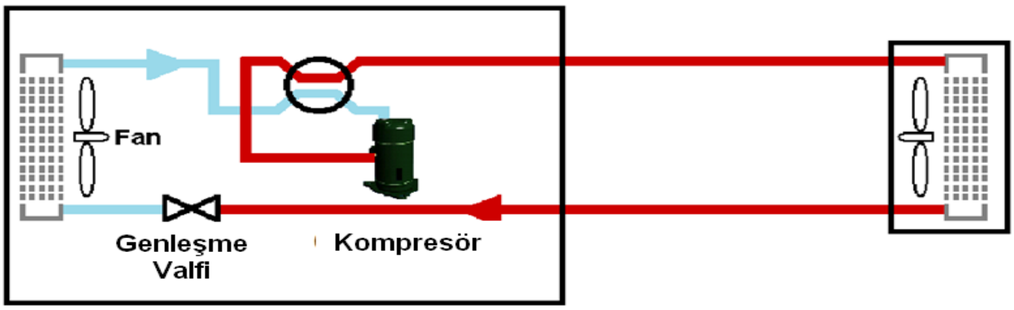



**Figure 2.2-98:** Working Principle of Air Source Heat Pump.

In the cooling process, the refrigerant cycle is reversed with a four-way cock and the heat extracted from the interior is transferred to the outside air through the exterior unit. Again, fan coils are preferred in cooling process, also under-floor or ceiling cooling methods can be used.

As inverter technology can be applied to air source heat pumps, an inverter device should be preferred. Accordingly, the compressor rpm in the heat pump is adjusted by the device in accordance with the user's requirements and thus the maximum possible performance is achieved at all times during operation. The fact that it works without start-stop is important for economy. Besides, for this reason, it gives an advantage in terms of compressor service life and maintenance requirements. Due to the fact that less heating is required when the exterior temperature rises up, interior unit decreases the exit water temperature and thus the efficiency of the heat pump increases.

High-volume boilers are needed in air source heat pumps due to the fact that the device capacities and exit water temperatures are low. In addition, because the serpentine's heating surface is big, it has to be backed up with an electrical heater from time to time.

*Why should air source heat pumps be used;*

1. High efficiency, less energy consumption, and lower bills for the users.
2. It's expected that natural gas prices will rise faster than the electricity prices.
3. Operating expenses of heat pumps are lower than other systems.
4. They are the best solutions for regions where natural gas is not available.
5. Their usage is less risky in regions with high earthquake risk.
6. It's an advantage that in addition to heating, they also offer cooling.
7. The fact that they can be used in upstate residences is a huge advantage.
8. They can offer even a bigger advantage if PV solar panels are used to generate electricity to be used in these systems.

Below there is an installation diagram of an air supply monobloc heat pump (Figure 2.2-100) given as example. Again, all the components are used in the system. Hot water is supported by solar energy. Cooling in indoors is done by fan coils whereas for indoor heating, a radiator system with enlarged heating surface which is compatible for 55°C or an under-floor heating system is preferred.

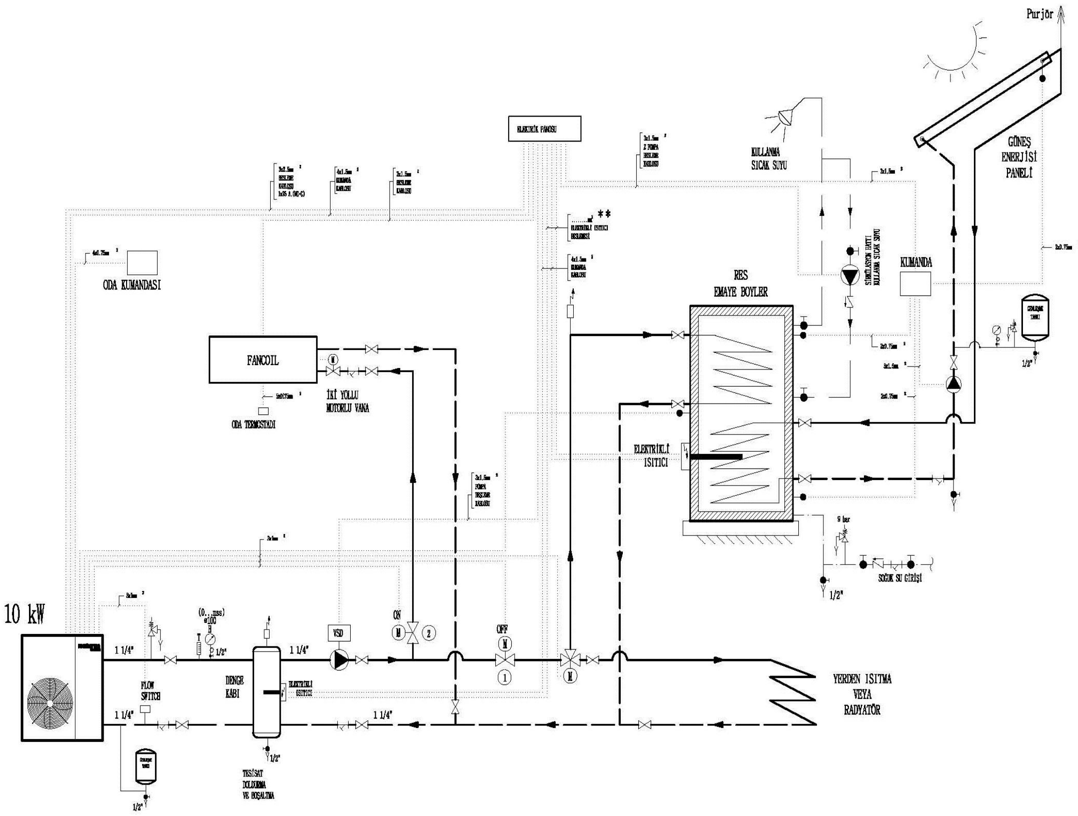



**Figure 2.2-99:** Installation Diagram of a Monobloc Heat Pump.

<u>Water-To-Air Heat Pumps</u>

In the heating operation of all water-to-air heat pumps, the heat in the source side is transferred to the refrigerant cycle, and then to the air by the load. In the cooling operation, the heat sucked by the load is passed to the water in the closed circuit by the refrigerant cycle. One of the biggest advantages of using devices of this kind is that while heating is done at one side of the place, cooling can be done in another part if needed. For this reason, this has become a highly selected option in especially shopping malls.

Compressor, water circuit heat exchanger, air serpentine, expansion valve, four-way cock, fan and fan motor, drain pan, and safety equipment stands out as the main components of a water-to-air heat pump (Figure 2.2-101).

Heating and cooling loads should carefully be specified in designing a heat pump system of this type. In shopping malls, hotels, or places like production facilities, the building is generally divided into zones and the heating and cooling loads of these zones are calculated separately. In buildings, people, computers, lighting, etc. create cooling load in the core zones in wintertime, whereas in the perimeter zones heating demand occurs due to the heat losses. In the transitional periods, the perimeter zones which receive solar radiation and core zones demand cooling whereas other zones may require heating or they may just have fresh air loads. In selecting the device; device water discharge, inlet air and water temperatures and air flow must be determined. Device air intake temperature is the location air return temperature, or if there is, the temperature of the combination of fresh air and return air. If the fresh air will be conditioned before it enters the device, this will have to be taken into consideration in the capacity calculations.

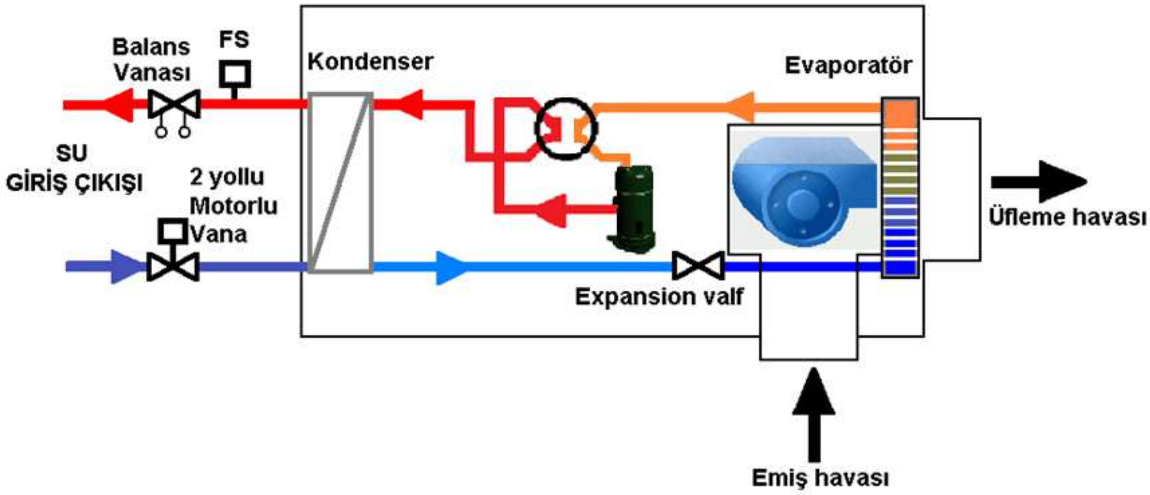



**Figure 2.2-100:** Working Principle of Water-to-Air Heat Pump.

There is a simplified system diagram given below where you will find how many different systems can be applied to a building which is designed as a tower office with its lower floors designed as a shopping mall (SM) (Figure 2.2-102).

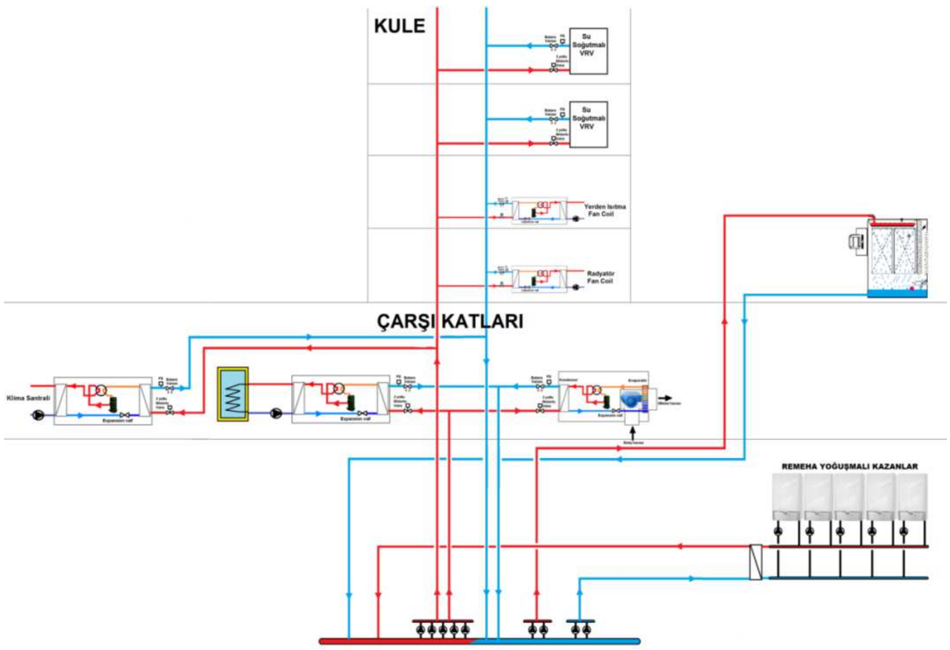



**Figure 2.2-101:** Example SM System Diagram.

Swimming Pool Heat Pumps

Outdoor air used as source. In the load side, pool or sea water can be used (Figure 2.2-103). The distinguishing characteristic of this type of heat pumps that separates them from other devices is that they have specially designed titanium heat exchangers (Figure 2.2-104).

**Figure 2.2-102:** Swimming Pool Heat Pump.

**Figure 2.2-103:** Titanium Heat Exchanger.

By this means, the pool heating can directly be done without the need for additional devices. Titanium heat exchangers are used so that the device is not affected by chlorine and water hardness. In this way, the device can have a long service life.

In our country, swimming pool heating systems generally use fossil fuels. As electricity is used in this heating system, it will have the advantages that the other heating pumps have. Besides, when system costs are calculated, the usage of this type of heating pump will be advantageous as there will not be a need for an additional installation room, and a chimney. The pools where high temperatures are not required will reach the desired values at low temperatures. As low temperatures will create the most ideal working condition for heat pumps, the COP values will be high. There is an example installation diagram of a swimming pool with pool heating pump (Figure 2.2-105).

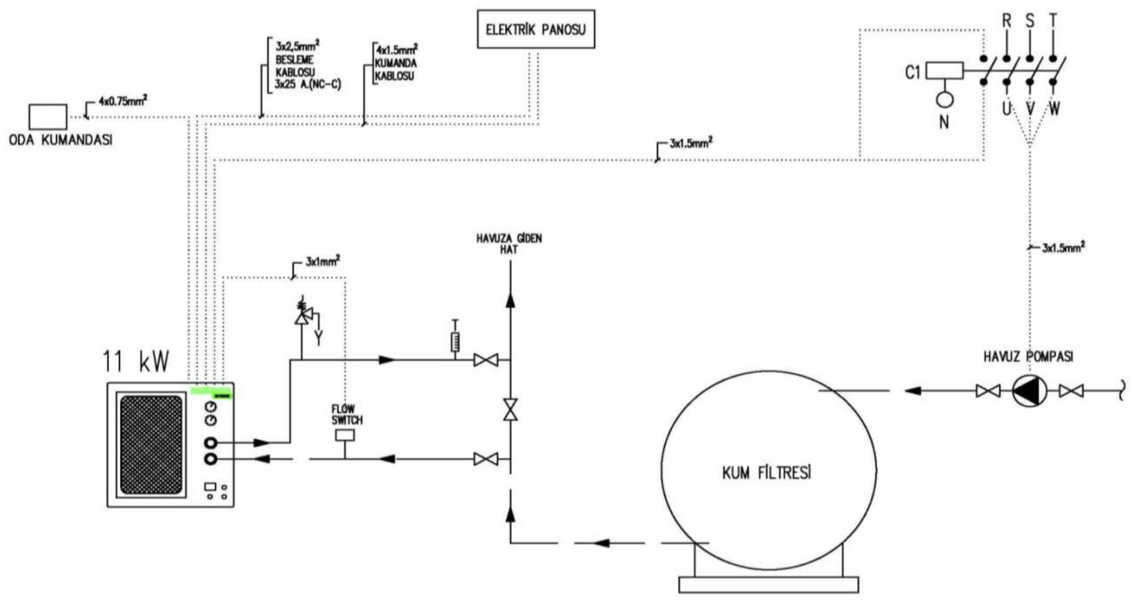



**Figure 2.2-104:** Example Swimming Pool Heating Pump System Diagram.

### *2.2.4.4 Selection of heat pump system*

Below, the selection of a heat pump is described in the simplest term without giving too many theoretical information. There are some points to be taken into consideration in determining the capacity of a heat pump:

- Weather conditions of the place where the system will be installed,
- The system to be installed (under-floor heating, radiator, fan coil),
- After the capacity of the place to be heated is determined, the device that will give that capacity at minimum conditions should be selected.
- When calculating the heat loss of a location, the system to be chosen won't affect this calculation.
- In other words, if the capacity needed for the location is 8 kW; this means that your energy requirement is 8kW whether you use natural gas or heat pump.

For example; Let's say that we have a house that has a heat requirement of 8 kW. When choosing a heat pump for this place;

- We must find out the average winter temperature of the place.

- Then, we must find out the capacity that the device gives at that temperature value and at 55°C exit water.
- If the capacity output of the device does not meet our requirement, the difference is compensated with an electric heater.
- If the difference is too much, then the next capacity level is selected.
- Another important point to pay attention is the selection of the heating systems.
- As the heat pumps give a maximum of 55°C, the system should be designed accordingly.
- Its not needed to heat water up to 90°C in order to heat a location.
- If the right equipment is chosen, a 55°C exit water will be enough to warm the place.
- For these reasons, when choosing a heat pump, we will have the most efficient working conditions if the selection is done as follows:
- Heating = Under-Floor Heating
- Cooling = Fan Coil
- If the heating will be done by radiator;
- In the selection of the radiators, the values at 55°C exit water temperature must be taken into account and selection should be done accordingly.
- Heat pumps are devices that work in 5°C temperature difference.
- Accordingly, the Pump and Pipe Diameter is bigger than the classic systems.
- This must be taken into account when doing the calculations.
- In order to ensure hydraulic equilibrium in the heat pump systems, accumulator tank equilibrium receptacle must be used.
- We can think of accumulator tanks as “source of energy”.
- In heat pumps, 5 liters per kilowatt are obtained in average.

Heat Pump System Field Applications

*Application - I*

Structure : 54 Apart Rooms, 4 Stars, Summer Hotel
Location : Marmaris
Equipment : 35 Pieces of Solar Collector
1 Piece of 85 kw Water-to-Water Heat Pump
3 Pieces of 3000 Liter Twin-Serpentine Boiler

*Application Details*

By the reason of very high fuel costs, the hotel has consulted an installation company and asked for a study on what to do. During the estimating, it has been confirmed that in order to meet the hot water demands, the hotel has installed a LPG fueled steel hot water boiler installment into the boiler room and is obtaining usage hot water through the boiler + plated heat exchanger and 3 accumulator tanks. In addition, it has also been confirmed that the Hotel has been using a 300 kW capacity chiller in order to meet its cooling requirements. In the light of this information, the required feasibility studies were conducted and the below given installment diagram and information is given.

The scripting of the installment diagram is as follows. It has been decided to use a water-to-water heat pump for hot water needs and a system that uses solar energy. In addition, it has been considered that a little more storage should be done in order to benefit from solar energy in the maximum possible way. The chiller used for cooling has one collector. A line is taken from the chiller collector and sent to the water-to-water heat pump. This means that the source of the heat pump is the water of the chiller collector. When the heat pump activates, it will cool the water it takes from the collector by 5 °C and then will send it back to the collector. Accordingly, the chiller will save on energy by this temperature difference. It has been planned that when the need for usage hot water arises, first of all solar energy will activate, and if it won't be able to meet the demand then the heat pump will activate. In hot water generation, nearly 45% of hot water production is done achieved with the support of solar energy. Into the bargain, despite the fact that equipment consuming additional electricity were installed, the electricity consumption of the hotel remained the same and the LPG consumption was reduced by 73%.

It has been estimated that, with current fuel prices, the total investment will be amortized in approximately 2 seasons.

*Application - II*

Structure : 90 Rooms, 4 Stars, Summer Hotel
Location : Marmaris
Equipment : 3 Pieces 17 kw Air-to-Water Heat Pump
4 Pieces 2000 Liter Twin-Serpentine Boiler

*Application Details*

The hotel is using diesel fueled steel boiler in order to meet its hot water needs. As a result of the conducted feasibility study, a solution has been generated, which is installing an air source heat pump instead of the boiler (it has been confirmed that the hotel spends around 32.000 TL for fuel in one season for hot water). In addition, the accumulator tanks of the old mechanic system are changed with twin-serpentine boilers. That way, hot water production has begun by means of the heat pump (where the solar energy also contributes to in sunny weather). Following this transformation, the information obtained from the hotel stated that the fuel expenses of 32,000TL turned into an electricity consumption which costs 6.000 TL. In the meetings, the need for cooling in the dining hall was also reported. For that, the cold air coming out of the heat pump was transferred into the dining hall with the help of prismatic channels and the cooling requirement of that zone was met while the heat pump was working to produce hot water, the cold air coming out have met the requirement free of charge.

*Application – III*

Structure : Building
Location : Balıkesir
Equipment : 28 kW 3 pieces air-to-water heat pump

***Application Details***

The application was done in a newly constructed building located in Balıkesir (Figure 2.2-106). 3 pieces of air-to-water heat pumps are used in order to meet the building's heat requirements, and the system was designed to work with cascade logic.

**Figure 2.2-105:** Heat Pump System.

### 2.2.5 Geothermal heat renewable energy systems

#### *2.2.5.1 Introduction to geothermal heating module*

Geothermal is the hot water, steam, and gasses which contain chemicals and is formed by the heat accumulated in the various depths of geothermal crust. Geothermal energy involves directly or indirectly benefiting from these geothermal sources and the energy that is generated from these sources. Geothermal energy is a new type of renewable, sustainable, inexhaustible, cheap, safe, eco-friendly, local, and green type of energy.

The fact that geothermal energy is a renewable, sustainable, inexhaustible, cheap type of energy is an advantage for countries such as Turkey who are lucky in terms of geothermal energy. It offers huge advantages thanks to the following reasons: it is clean and eco-friendly; it causes almost zero emission as it does not use combustion technology; it offers ideal conditions for multi-purpose heating applications in residences, agriculture, industry, greenhouse heating, and similar areas; it is independent from metrological conditions such as wind, rain, or sun; its ready for use property; it is very cheap when compared with fossil energy or other energy resources; exploratory shafts can be directly converted into production facilities and sometimes to reinjection areas; contrary to hydroelectric, solar, wind, fossil energy, facility area needs stay at minimum levels; due to its locality it's import and export is not affected by factors such as international conjuncture, crises, and wars; as it does not have problematic issues in transportation to residences as in fuel-oil, diesel fuel, coal, and wood; its ease of use in settlements.

*How Can We Ensure That the Geothermal Energy Systems are Renewable?*
Geothermal reservoirs created by rain, snow, sea and magmatic waters as they feed the porous and fissured rock masses, can be renewed as long as the underground and reinjection conditions continue to exist. They are not affected by transient atmospheric conditions. However, in drilled productions in geothermal reservoirs, it is compulsory to avoid dumping the geothermal fluid into the environment and in regard to feeding the reservoir it is compulsory to re-inject the fluid back into underground when their functions are over. Reinjection is a legal obligation in many countries.

*Places of Use for Geothermal Energy Sources*
Primary places of use for Geothermal Energy

- Electric energy generation,
- Heating/cooling applications such as central heating, central cooling, greenhouse heating, etc.,
- Industrial applications such as process heat supply, and drying applications,
- Production of chemical substances and minerals such as carbon dioxide, fertilizer, lithium, heavy water, hydrogen, etc.,
- Hot spring use in thermal tourism,
- Culture fishing at low temperatures (up to 30°C),
- Production of mineral containing drinking water and similar applications.

### *2.2.5.2 Geothermal energy systems*

Critical Factors and Definitions for Application

Some of the critical factors that have to be taken into consideration in the application of geothermal energy systems are discussed in this chapter.

*Crustation Problem:*
It is one of the most important problems of geothermal systems. If this problem cannot be solved, production may frequently have to be suspended for cleaning and clearing the blockages. As the heat transfer coefficient will drop a lot, the efficiency may also reduce.

Geothermal fluids, due to the compositions they contain, may mostly cause lime ($CaCO_3$) and sometimes silica ($SiO_2$) crustations as a function of their acidity (pH) or may show a corrosive effect. These crustations may occur inside the drill pipes, inside the separator, on heat exchanger plates, on turbine blades, and in transmission pipes. In drill operations conducted in thermal areas where the water contains more than 350 ppm $SiO_2$, $SiO_2$ crustation occurs inside the pipes in the event that the temperature drops below a certain limit. $CaCO_3$ crustation is observed in every thermal area where the source water's pH is between 6 and 8 and Ca++ ion concentration reaches several ppm. The reason for this is that when the well starts production, the pressure and therefore the $CO_2$ partial pressure drops and in such a way to fit into the new pressure balance condition.

It is the pH rise and forming of water soluble $CaCO_3$ chemical salt and leaving the liquid medium through gas loss from the liquid medium to the atmosphere with $CO_2$ loss. Some measures are taken against this case. Of course, the simplest of all these measures is to suspend the production from time to time and do a mechanical cleaning. Another measure is to constantly keep the wellhead pressure above a certain level. Of course, this means to reduce production and well efficiency.

Another method that will prevent inner-well crustration is to inject $CO_2$ inside the well under a certain pressure (with a compressor). Another method which has been developed in the recent years and widely used is to inject chemical substances called "inhibitor" inside the well in certain amounts on the ppm level. The formula of these inhibitors are kept secret by the producing companies. In order to prevent the possible negative effects such as crustration, corrosion, etc. that might occur inside the haulage drifts which are located outside of the well; the thermal energies of the geothermal fluid is transferred into the usable waters inside the heat exchangers.

*Corrosion Problem:*
This problem increases the cost as it makes the special selection of the materials of the system components obligatory. Some geothermal fluids are, on the contrary to the information given above, aggressive; meaning they have acidic character and can corrode materials used in the system such as concrete, metals, mortars, etc.

In order to prevent this, an inhibitor that will remove the aggressive characteristics of the geothermal water must be used, use of corrosion-resistant materials such as titanium alloys and plastics should be preferred, and the use of buried metallic elements should be avoided and if there is a necessity to use buried metallic elements, then cathodic protection should be applied. Another solution alternative is that, instead of directly using the geothermal fluid, the heat energy can be transferred to nonaggressive water through a heat exchanger.

*Heat Loss During Transmission:*
As the distance between the geothermal well and the area of utilization is generally long, heat loss during the energy transmission can be high. The heat lost in the pipes that transfer the geothermal fluid from the wellhead to the turbines, and radiators, etc. in the residences should be minimized with good insulation. Pre-insulated pipes should be used, and there should be leak monitoring and control systems in the buried lines.

*Well Depth:*
Selection criteria are important if a pump will be used for the well (Figure 2.2-107). The depth of the well in meters, the static and dynamic water levels should be known and if there is need for dosing, the quantities of the dosing should be known and it shouldn't mixed.

**Figure 2.2-106:** Pump Station.

*Well Discharge Rate and Temperature:*
The material specifications of the selected system components and device types are important for the system design. The optimum discharge rate that can be obtained from the well (Figure 2.2-108) should be known, and system designs should be done accordingly. The discharge rate and the temperature of the well should be confirmed only after the system has been working in the determined/planned discharge for at least 15 days.

**Figure 2.2-107:** View of a Well.

*Flash Point:*
The point where the water – vapor balance is disrupted and flash vaporization starts as a result of the pressure drop on the fluid that travels from the reservoir to the surface is described as Flash Point. This phenomenon is seen in high temperature fields.

*Dosing Depth:*
It is important for a healthy dosing. It represents the depth where the dosing head lowered. This depth should sufficiently be below the flash point.

*Vapor Fluid:*
In addition to the two phases that comes from the well, which are vapor and water, there are also uncondensed gases inside this fluid. The most common ones are $H_2S$, $CO_2$, and methane.

*Power Plant Types:*
In our day, the most preferred plant types are: binary and flash types (double, triple) technologies. The aim is to reach the technology which can make the most efficient production at every temperature (>15°C in our day) and pressure. Organic Rankine Cycle (ORC); is the energy production method where the vapor of an organic based fluid is used the turn a specific turbine (Figure 2.2-109).

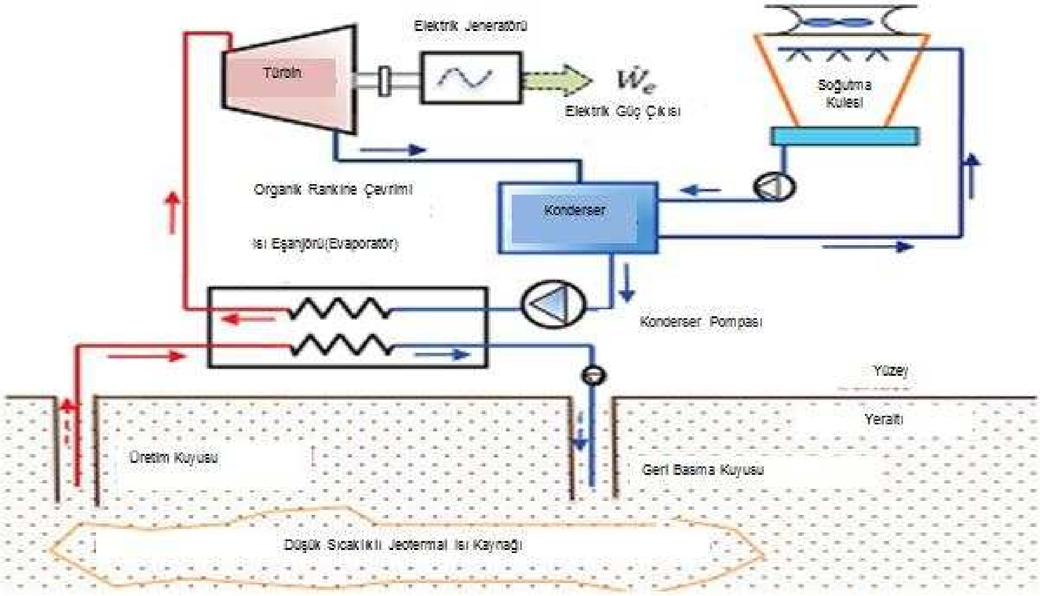



**Figure 2.2-108:** ORC Diagram.

*Reinjection:*
In accordance with the regulations and also as a technical requirement, a fluid whose energy is transferred is reinjected to underground. This process is called reinjection (Figure 2.2-110).

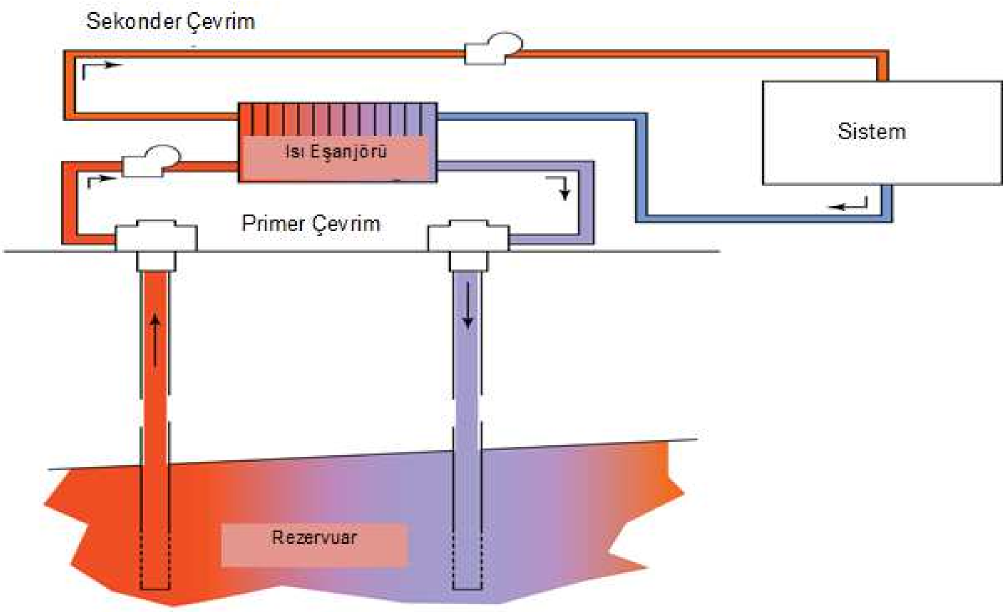



**Figure 2.2-109:** Reinjection Diagram.

*Production Well:*
The wells that provide the necessary fluid for the plant are called production well (Figure 2.2-111). All plants may need one, or more wells depending on the discharge, temperature, and pressure.

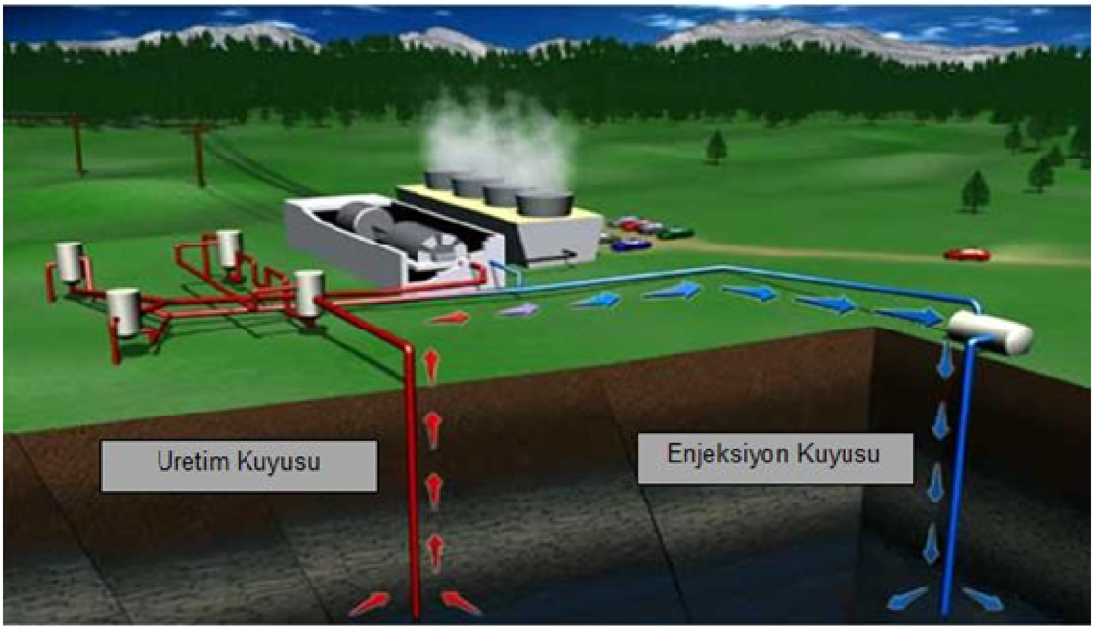



**Figure 2.2-110:** Production Well Diagram.

Some Devices Used in Applications

Some of the critical factors that have to be taken into consideration about the devices that are frequently used in the application of geothermal energy systems are discussed in this chapter.

*Separator:*
Geothermal fluid reaches the separator first (Figure 2.2-112). Here, the liquid and steam phases separate. Steam phase can feed a steam turbine or it can be used in a different manner. If the steam or waste gases are not required to be used or improved, the steam is directly released to the atmosphere.

**Figure 2.2-111:** Separator.

*Capillary Tube:*

It is used in the inhibitor dozing system. It is a metal or plastic based thin pipe used to dose the chemical which is needed in the wells (Figure 2.2-113). The rupture risk due to long length, in accordance with the selected system and temperature, should be taken into consideration and safety coefficients should also be considered.

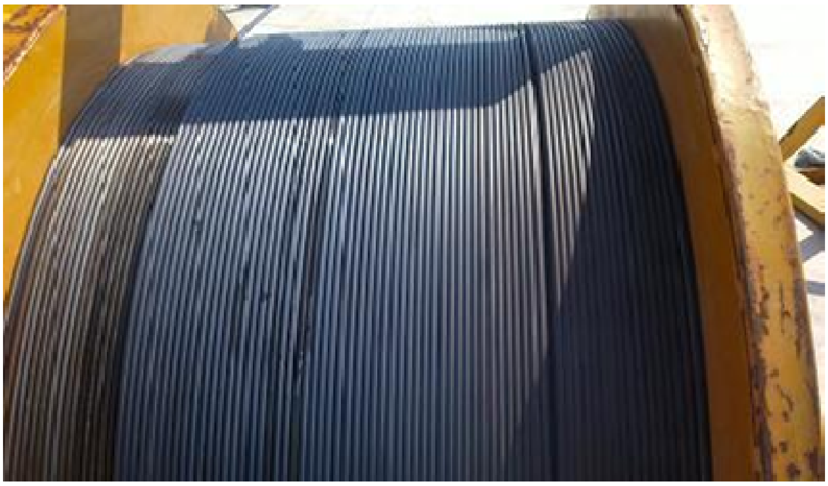


**Figure 2.2-112:** Capillary Tube.

*Dosage Head:*

It is used for inhibitor dozing. It is the head located at the far end of the capillary tube where the chemical is transferred into the well. In diameter, it is much wider than the capillary. There are grooves on it that ensure the chemical spills outside (Figure 2.2-114)

**Figure 2.2-113:** Dosage Head.

*Wellhead Equipment:*

It is important for the system design. It involves all the equipment found in the wellhead such as drum, pulley, lubricator, wellhead valve, dosage skid (Figure 2.2-115).

**Figure 2.2-114:** Wellhead Equipment.

*Wellhead Valve:*
It serves as the flow control valve (Figure 2.2-116). It is the main valve that engages and disengages the well. It is the first equipment that the fluid meets when it reaches the surface.

**Figure 2.2-115:** Wellhead Valve.

*Horizontal Production Valve:*
It is necessary for the regulation of the production discharge. It is the valve where the adjustments are made in order to obtain the discharge expected from the well and specified in the project. It is fixed at the point when the needed discharge for the plant is obtained (Figure 2.2-117).

**Figure 2.2-116:** Horizontal Production Valve.

*Weir:*

It is necessary for the measurement of the well discharge. It is the apparatus where the quantity of the well fluid is tested and measured (Figure 2.2-118). It is used to calculate the discharge in a canal from the water level where the dimensions are specified.

**Figure 2.2-117:** Weir.

*Accumulator Tank:*

It is the tank in which the liquid phase coming from the separator is stored before the plant (Figure 2.2-119). Its level should always be controlled.

**Figure 2.2-118:** Accumulator Tank.

*Transfer Pump:*

It is needed for the fluid transfer. They are the production or plant pumps which are used in the surface in systems such as separators or valves to pump the liquid which sustains pressure loss into the plant (Figure 2.2-120).

**Figure 2.2-119:** Transfer Pumps.

*Plant Filters:*

They are the filters used to prevent the particles that might come from either the line or from the wells at the plant entrance from damaging the system (Figure 2.2-121).

**Figure 2.2-120:** Plant Filters.

*Inhibitor:*

They are the chemicals used to stop or minimize the possible corrosion and/or deposit risks in the wells (Figure 2.2-122). Their working mechanisms may vary in accordance with their active agents.

**Figure 2.2-121:** Inhibitor.

*Plate Heat Exchanger:*

It ensures the heat transfer between different fluids (Figure 2.2-123). By this means, we can protect a large part of our geothermal system from the aggressive crustation effect.

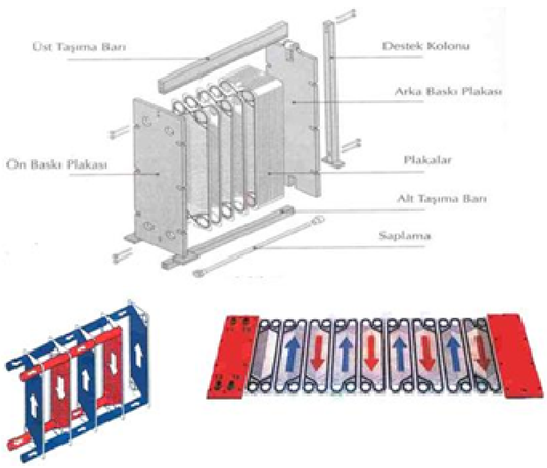



**Figure 2.2-122:** Plate Heat Exchanger.

Plate heat exchangers are equipments which can achieve fast and high efficiency heat transfer between two fluids (without mixing then) with the same or different properties. Based on their area of usage, there are 3 types of plate heat exchangers: sealed, soldered, and welded steel. As sealed type heat exchangers are the most commonly used heat exchanger type, this heat exchanger type is generally called plate heat exchangers. With their special seal structure which directs the flow and ensure leak-tightness, the fluids entering inside the heat exchanger efficiently materialize heat transfer without mixing with each other. The red colored flow is called the primary cycle, and the blue colored flow is called the secondary cycle.

*Pre-Insulated Pipe:*

Pre-insulated pipe system is an interconnecting pipe system. The area between the fluid carrier pipe and HDPE casing is filled with polyurethane foam. The leakage monitoring and control system constantly measures and observes the resistance of the copper cables which are buried inside the polyurethane foam.

This system alarms when the humidity rate that might enter/leak from the surroundings or carrier pipes passes the predetermined rates and enables the identification of the leak point precisely.

Certain types can survey 4x5000 meter long alarm cable. In addition, the system can be connected to the central computer system and recordings and controls can be carried out from the system (Figure 2.2-124).

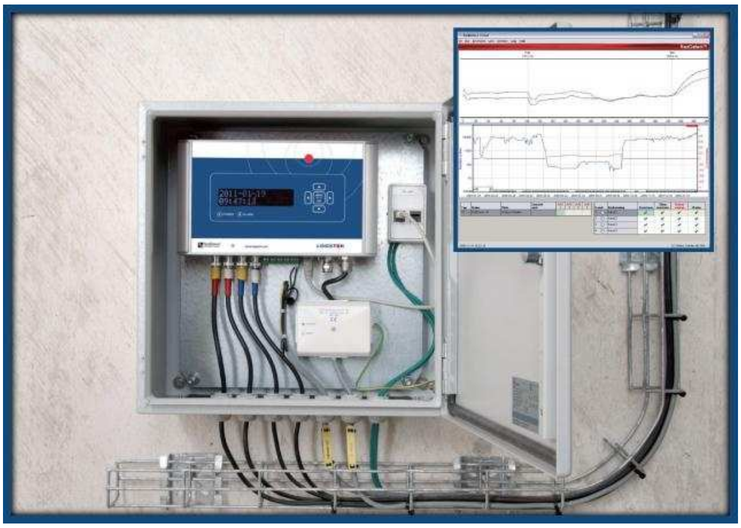


**Figure 2.2-123:** Control System.

### *2.2.5.3 System flow diagrams examples*

In this section, some flow diagrams about the usage of geothermal energy is given (Figures 2.2-125 to 2.2-127).

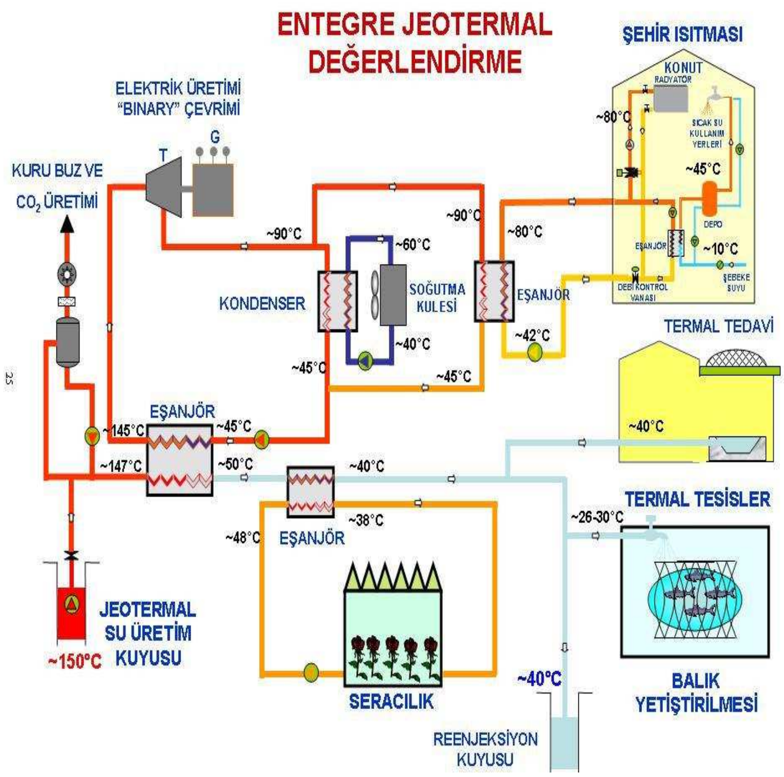



**Figure 2.2-124:** Integrated Usage Diagram of Geothermal Energy.

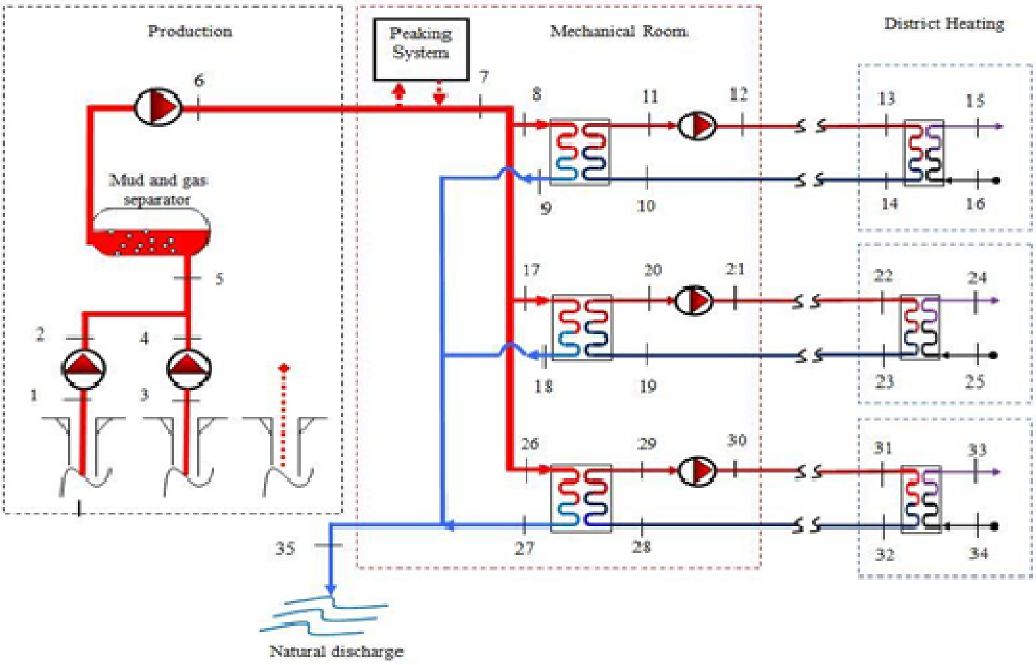



**Figure 2.2-125:** Diagram of a Different Application of Geothermal Energy.

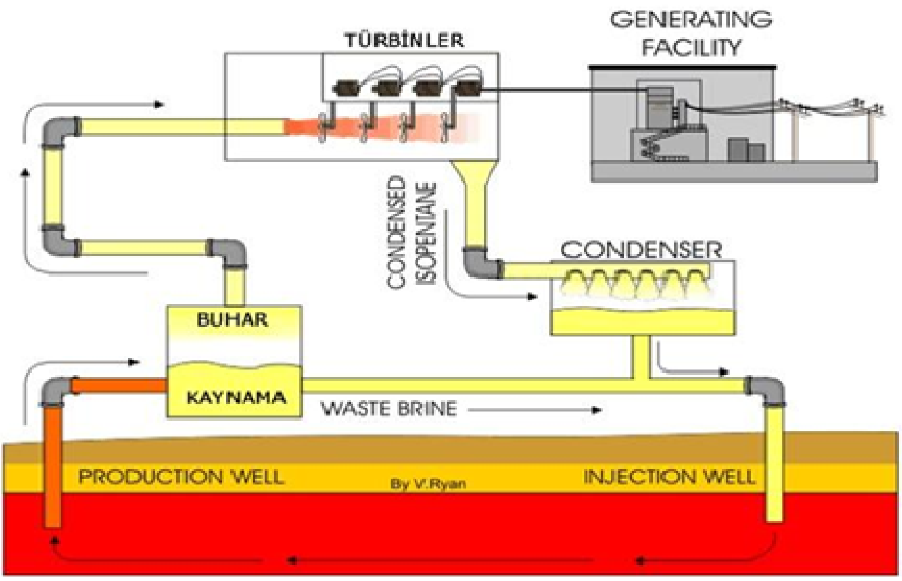



**Figure 2.2-126:** Application Diagram Showing the Main Components of Geothermal Energy.

### 2.2.6 Proposal for implementation – Municipality of Samsun

Samsun Medical Park Hospital building has been selected as a reference building for the implementation proposal of energy efficiency in buildings by Samsun Metropolitan Municipality for the following reasons:

- The hospital building attracts so many people on daily basis with its nonstop service all around the year.
- The potential energy upgrade of the hospital building will be used as example of good practice in terms of energy efficiency in public, municipal and private buildings.
- The study preparations for upgrading the energy efficient potential of the building may raise the awareness among the people living in Samsun.
- The study prepared about the implementation proposal of energy efficiency in hospital building and the pilot projects will be implemented in the Blue Lights Training, Recreation and Rehabilitation Center and Technopark will contribute to the strategy of Samsun Metropolitan Municipality's on using energy efficiently.
- The buildings of Blue Lights Training, Recreation and Rehabilitation Center and also the Samsun Technopark present significant renewable energy system integration needs. Therefore, there is a noticeable potential of improvement in terms of using energy efficiently and integration of renewable energy systems.

Renewable Energy System Integration will be also implemented by Samsun Technopark within their own administration building located at 19 University Campus by using solar photovoltaic electricity energy system and also ground source heat pump energy system.

Another RES integration will be implemented by SMM by using again solar photovoltaic electricity energy system by Blue Lights Training, Recreation and Rehabilitation Center-Camp.

Executive Summary

The study providing observations and recommendations on the energy efficiency of Samsun Medical Park Hospital building has been realized within the scope of BSBEEP Project, which is conducted by Samsun Metropolitan Municipality. The study has been realized under the leadership of Chamber of Mechanical Engineers of Samsun by participation of 15 mechanical engineers registered to the chamber.

The Samsun Medical Park Hospital building examined within the project is comprised of 3 blocks. It has been identified that the Block A and B function in an integrated way into updated technologies whereas the Block C, which was erected subsequently, still functions with old technology. Therefore, It has been determined that energy consumption of the Block C is high while energy saving is low.

It has been identified that natural gas boilers for heating used at block A and block B for the purpose of efficient energy use and regaining saving potential are not condensing boilers.
It has been recommended that coal boiler at block C is inefficient and should be replaced by condensing natural gas boiler, split air conditioners in the buildings should be replaced by inverter VRF air conditioning systems, thermostatic valves should be used and the building should be insulated.

The Samsun Medical Park Hospital building is comprised of blocks A,B and C. Works accomplished at block A and B are represented as positive examples while the things required at block C are represented as negative.

Aiming in our country to preserve native resources, reduce import energy demand and by way of using less fuel to minimize negative effects of harmful emissions to the environment released as a result of combustion , the results of the demonstration project realized by using energy efficiently in building are planned to be released to the public and popularised.

Purpose of the Study

It can be summarized as;

- Integrated technologies located in the Block A and B are demonstrated,
- Energy efficiency measures in the Block C are implemented and
- Optimization results for energy efficiency are introduced to public so as to encourage taking measures of energy efficiency in existing buildings in our country.

Current Situation of the Building

*Block A and B*
Closed construction area : 16.539 $m^2$
Total acreage : 3.991 $m^2$
Number of floors : 2 basements, ground floor, 8 regular floors and 1 penthouse
Climate conditions : Area 2, Samsun, Turkey
Heating and Cooling System : will be specified in detail thereinafter.
Insulation : insulated building , nonetheless exterior coating is required.
*Block C*
Closed construction area : 1.044 $m^2$
Number of floors : basement, ground floor and 4 regular floors

The Equipment Used And The Measurements Taken In The Study

1. Flue gas temperatures of boilers and $O_2$ percentage of flue gas were measured by "Flue Gas Analyzer" and boiler efficiencies were accordingly identified.
2. One of the parameters to determine air quality is $CO_2$.
3. Heat loss from the exterior surface of the building was displayed by "Thermal Camera"

Systems used in the Buildings
*Block A and B*
Heating installation : 1.044 KW x 2 boilers with burner
Cooling installation : 1.077 KW x 2 chiller cooling groups
Ventilation and Air conditioning : 25 fresh air conditioning plants
*Block C*
Heating system : 200 KW coal fired boiler and radiator core system
Cooling installation : 40 split air conditioners with 2.500 W cooling capacity and 6 free-standing saloon type split air conditioners with 4.300 W cooling capacity

Energy Consumption and Costs

- Natural gas consumption at block A and B: Natural gas costs for heating in 2012-2013 is 194.000 TL.
- Coal consumption in block C: Approximately 9 tons of coal for heating was used in 2012-2013.

General Findings and Suggestions

*Block A and B*
Walls, Ceilings and Windows
- It has been noticed that there is high level insulation of floor, ceiling and windows at the current building. Measurement by thermal camera could not be performed because of exterior coating.

- It has been confirmed that high-insulating materials like PVC, gas concrete, reinforced concrete, marble and lamella suspending ceilings are applied.
- If the building had not been insulated at all, up to 65% saving could have been achieved by means of insulation.

Automatic Temperature Control

- Since automation system exists, there are thermometers measuring indoor temperatures and indoor units are set to optimum temperatures. Those temperatures can be followed from the main and the individual panel, and can be set by authorized personnel.

Insulation of Installation

- It has been confirmed that hot water pipes, valves and flanges are insulated.
- Due to the fact that loss of heat from an uninsulated valve connector is equal to loss of heat from a 2.5 meters long uninsulated pipe with the same diameter; and loss of heat from an uninsulated flange is equal to loss of heat from a 0.6 meters long uninsulated pipe, insulating uninsulated valves and flanges along with uninsulated pipes contributes to the energy efficiency and saving.

**Figure 2.2-127:** Boiler Room.

- Pipes in the boiler room and flue gas ducts are heat insulated.

Flue Gas and Combustion Efficiency

- According to flue gas measurements , 146⁰ C flue gas temperature, 10% CO2 percentage, 3% O2 percentage ve 94% net efficiency have been calculated.
- 3% oxygen percentage, which is the optimum level, confirms that high energy is not emitted to the atmosphere.
- In proportion to a non-condensing boiler ,the highest efficiency level was identified.
- Nonetheless, utilising a condensing boiler ,it is possible to keep the flue gas temperature at 45⁰ C . The gap of 100⁰ C means 5% saving amount.
- As it is, last year heating system consumed natural gas of 190.000 TL. Under the same conditions replacing the current boiler with a condensing boiler may provide 9.500 TL annual saving.

- At first sight it does not seem plausible to completely replace the system with condensing boiler by means of annual saving amount. However, factors like selling off the existing boiler for a good price may make the amortization period feasible.
- Surplus heat emitted from the flue can be recovered by means of an additional economizer. This amount of investment is feasible with regard to amortization period.
- Replacing the existing two-staged burners with modulated burners will decrease the number of switches. Accordingly, combustion efficiency and energy efficiency will improve. Nonetheless saving amount will be about 1%.

**Figure 2.2-128:** Flue Gas and Combustion Efficiency in Boiler Room.

Pumps

- The circulation pumps in the boiler rooms operate 24 hours a day during winter heating season.
- So as to reduce the electricity consumption of the existing pumps, variable speed energy efficient pumps that operate depending on heating necessity were preferred.

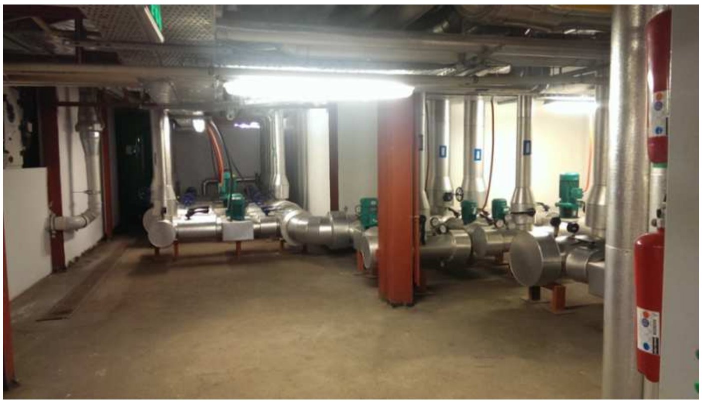


**Figure 2.2-130:** Pumps in Boiler Room.

Maintenance and Control

- Hospital has a well-disciplined and qualified technical team headed by a very experienced director of technical services.

- All periodic maintenances are listed and a significant amount of budget is spent for periodic controls and maintenances.
- Thanks to the digital tracking system, each year up to 4%-13% wasting due to losses has been prevented since the establishment of the hospital.
- It has been identified that 560 fan coil units operating at the hospital causes 23% energy waste due to sedimentation, and the system has been cleaned.

Actions for Electricity Saving in Lighting

- Lux values measured at the hospital are in compliance with regulations.
- Light bulbs whose lifespans ended ,even if they continue lighting, have 30% less luminance. The hospital's technical service management is attentive to this issue while replacing light bulbs.
- Windows are kept clean, because dirty windows prevent daylighting.
- Dusty armatures, which absorb a significant amount of light, are periodically cleaned.
- White paint was preferred as wall color since lighter colors reduce the need for lighting.
- If the lighting armatures are to be replaced, the most efficient lighting armatures and light bulbs of the present time are preferred.
- Electrical heaters are not used.
- Dormant computers, copy machines, printers and other office devices are shut down.

Other Energy Saving Points

- Fresh air plants: 100% fresh air supply is a burden for the facility. Saving can be increased by mixed air supply. However, they take no chances for it is a health care facility. Although the regulations allow operating with 20% mixture, 100 % fresh air supply will continue.

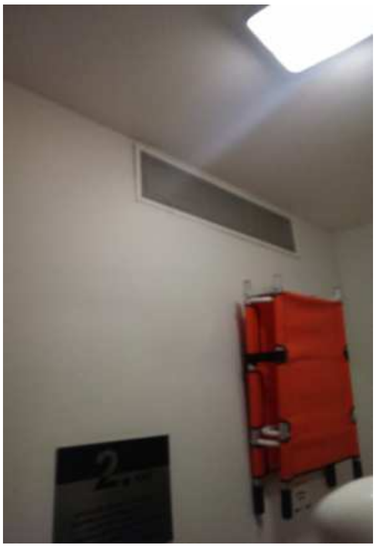


**Figure 2.2-129:** Fresh Air Plants

- All the fans are inverter-equipped
- Cooling pumps are inverter-equipped
- Cogeneration has been applied several times, but not preferred afterwards.
- Humidification system is not be activated unless compelled. Infections may cause.

*Block C*

Walls, Ceilings and Windows

- It is recognized that the building is not insulated.
- The uninsulated building has caused heat loss. Heat loss calculations have been made depending on the recommended insulated system and the differences between the uninsulated and the insulated models have been presented;
- The components calculated as uninsulated are as follows:

**Table 2.2-3:** The components calculated as uninsulated.

| Wall Material | Thickness (m) | The Coefficient of Thermal Conductivity (W/mK) |
|---|---:|---:|
| Plaster | 0,02 | 0,87 |
| Filled Brick | 0,19 | 0,58 |
| Plaster | 0,03 | 1,4 |
| **Concrete Material** | | |
| Plaster | 0,02 | 0,87 |
| Colon-Beams | 0,2 | 2,1 |
| Plaster | 0,03 | 0,87 |
| **Base Materials** | | |
| Tile and Mosaic Floorings | 0,02 | 1,4 |
| Screed | 0,05 | 1,74 |
| Leveling Concrete | 0,02 | 1,74 |
| Lean Concrete | 0,1 | 1,1 |
| Rubble Stone | 0,15 | 0,7 |
| **Roof Materials** | | |
| Plaster | 0,02 | 0,87 |
| Concrete | 0,12 | 2,1 |

- annual energy consumed in the uninsulated model;

**Table 2.2-4:** Annual energy consumed in the uninsulated model.

| Months | Heat loss | | | Heat gains | | | KKO | Gain Utilization Factor | Heating Energy Needs |
|---|---|---|---|---|---|---|---|---|---|
| | Specific Heat Loss | Temperature Difference | Heat Losses | Internal Heat Gain | Solar Heat Gain | Total | | | |
| | $H=H_i+H_v$ | $T_i-T_d$ | $H(T_i-T_d)$ | $\Phi_i$ | $\Phi_g$ | $\Phi_t=\Phi_i+\Phi_g$ | $\Upsilon$ | $\eta_{ay}$ | $Q_{ay}$ |
| | (W/K) | (K,°C) | (W) | (W) | W | (W) | (-) | (-) | (kJ) |
| **January** | 4.314 | 16,1 | 69.451 | 7.034 | 2.070 | 9.103 | 0,13 | 1 | 156.431.580 |
| **February** | 4.314 | 14,6 | 62.980 | 7.034 | 2.536 | 9.570 | 0,15 | 0,999 | 138.474.424 |
| **March** | 4.314 | 11,7 | 50.470 | 7.034 | 3.072 | 10.105 | 0,20 | 0,993 | 104.803.784 |
| **April** | 4.314 | 6,2 | 26.745 | 7.034 | 3.072 | 10.106 | 0,38 | 0,929 | 44.985.629 |
| **May** | 4.314 | 1 | 4.314 | 7.034 | 3.585 | 10.619 | 2,46 | 0,334 | 1.992.414 |
| **June** | 4.314 | $T_d$ High | (-) | 7.034 | 3.753 | 10.787 | (-) | (-) | |
| **July** | 4.314 | $T_d$ High | (-) | 7.034 | 3.659 | 10.693 | (-) | (-) | |
| **August** | 4.314 | $T_d$ High | (-) | 7.034 | 3.480 | 10.513 | (-) | (-) | |
| **September** | 4.314 | $T_d$ High | (-) | 7.034 | 3.032 | 10.065 | (-) | (-) | |
| **October** | 4.314 | 4,9 | 21.137 | 7.034 | 2.541 | 9.574 | 0,45 | 0,89 | 32.699.685 |
| **November** | 4.314 | 10,5 | 45.294 | 7.034 | 1.960 | 8.994 | 0,20 | 0,994 | 94.241.214 |
| **December** | 4.314 | 15,2 | 65.568 | 7.034 | 1.819 | 8.852 | 0,14 | 0,999 | 147.021.420 |

Total $Q_{year} = \sum Q_{month}$ = 720.650.151.kJ
$Q_{year}$ = 0,278 * 1/1000 * 720.650.151 = 200.341 kWh

- the components calculated as insulated are as follows;

**Table 2.2-5:** The components calculated as insulated.

| Wall Material | Thickness (m) | The Coefficient of Thermal Conductivity (W/mK) |
|---|---|---|
| Plaster | 0,02 | 0,87 |
| Filled Brick | 0,19 | 0,58 |
| Plaster | 0,03 | 1,4 |
| Thermal Insulation Material | 0,05 | 0,031-0,040 |
| Plaster | 0,008 | 0,3 |
| **Concrete Material** | | |
| Plaster | 0,02 | 0,87 |
| Colon-Beams | 0,2 | 2,1 |
| Plaster | 0,03 | 0,87 |
| Thermal Insulation Material | 0,06 | 0,0310,040 |
| Plaster | 0,008 | 0,3 |
| **Base Materials** | | |
| Tile and Mosaic Floorings | 0,02 | 1,4 |
| Screed | 0,05 | 1,74 |
| Leveling Concrete | 0,02 | 1,74 |
| Lean Concrete | 0,1 | 1,1 |
| Rubble Stone | 0,15 | 0,7 |
| **Roof Materials** | | |
| Plaster | 0,02 | 0,87 |
| Concrete | 0,12 | 2,1 |
| Thermal Insulation Material | 0,12 | 0,04 |

- annual energy consumed in the insulated model;

**Table 2.2-6:** Annual energy consumed in the insulated model.

| Months | Heat loss | | | Heat gains | | | KKO | Gain Utilization Factor | Heating Energy Needs |
|---|---|---|---|---|---|---|---|---|---|
| | Specific Heat Loss | Temperature Difference | Heat Losses | Internal Heat Gain | Solar Heat Gain | Total | | | |
| | $H=H_i+H_v$ | $T_i-T_d$ | $H(T_i-T_d)$ | $\Phi_i$ | $\Phi_g$ | $\Phi_t=\Phi_i+\Phi_g$ | $\Upsilon$ | $\eta_{ay}$ | $Q_{ay}$ |
| | (W/K) | (K,°C) | (W) | (W) | W | (W) | (-) | (-) | (kJ) |
| January | 1.648 | 16,1 | 26.538 | 7.034 | 2.070 | 9.103 | 0,34 | 0,946 | 46.470.271 |
| February | 1.648 | 14,6 | 24.066 | 7.034 | 2.536 | 9.570 | 0,4 | 0,919 | 39.580.489 |
| March | 1.648 | 11,7 | 19.286 | 7.034 | 3.072 | 10.105 | 0,52 | 0,852 | 27.680.171 |
| April | 1.648 | 6,2 | 10.220 | 7.034 | 3.072 | 10.106 | 0,99 | 0,636 | 9.823.546 |
| May | 1.648 | 1 | 1.648 | 7.034 | 3.585 | 10.619 | 6,44 | (-) | |
| June | 1.648 | $T_d$ High | (-) | 7.034 | 3.753 | 10.787 | (-) | (-) | |
| July | 1.648 | $T_d$ High | (-) | 7.034 | 3.659 | 10.693 | (-) | (-) | |
| August | 1.648 | $T_d$ High | (-) | 7.034 | 3.480 | 10.513 | (-) | (-) | |
| September | 1.648 | $T_d$ High | (-) | 7.034 | 3.032 | 10.065 | (-) | (-) | |
| October | 1.648 | 4,9 | 8.077 | 7.034 | 2.541 | 9.574 | 1,19 | 0,57 | 6.793.829 |
| November | 1.648 | 10,5 | 17.308 | 7.034 | 1.960 | 8.994 | 0,52 | 0,854 | 24.952.100 |
| December | 1.648 | 15,2 | 25.055 | 7.034 | 1.819 | 8.852 | 0,35 | 0,941 | 43.350.398 |

Total $Q_{year} = \Sigma Q_{month}$ = 198.650.804 kJ
$Q_{year}$ = 0,278 * 1/1000 * 198.650.804 = 55.225 kWh

- As it is seen, the uninsulated model consumes 200.341 kWh annually, while the insulated model consumes 55.225 kWh annually. There is a gap of 72.5% saving.

Automatic Temperature Control - Thermostatic Radiator Valve

- Block C is heated by radiators. According to our findings thermostatic radiator is used.
- Decreasing indoor temperature $1^0$ C means approximately 6% saving. Since overheating indoor spaces may cause loss of savings, thermostatic radiator valves should be used.

Insulation of Installations

- Boiler room is located in the basement in the building. Rather than the heat loss resulting from pipe insulation in the boiler room, the situation of the boiler itself is more striking.
- Heating pipes are generally embedded in concrete inside the walls.

Flue Gas And Combustıon Efficiency

- According to flue gas measurements , $45^0$C flue gas temperature, 1% $CO_2$ percentage, 20% $O_2$ percentage and 82% net efficiency have been calculated.

**Figure 2.2-130:** Flue Gas And Combustion Efficiency.

- When the measurement values are examined, it becomes clear that there are remarkable problems in the system.
- Besides the fact that $45^0$ C flue gas temperature is the desired value, it proves that the heat of the boiler cannot be emitted well.
- 1% CO2 percentage and 20% O2 percentage confirm that there are excessive oxygen in the boiler which means that the boiler keeps getting air from everywhere. This indicates that the fuel cannot be used efficiently.
- Heating system in the building is 200 KW coal fired boiler. In 2012-2013 approximately 9 tons of coal was used.


**Figure 2.2-133:** Heating system in the building.

- If the boiler room is equipped by 2 condensing cascade combi even in its uninsulated condition, approximately 30% saving is estimated thanks to natural gas efficiency, saving resulted from condensed flue gas, electricity saving in circulation pump and automatic by means of outside air temperature sensor.
- Amortization period may sound feasible again in long term. For heating, 9 tons of coal x 700 TL= 6.300 TL have been spent. If 30% saving is achieved, the hospital can annually benefit 1.890 TL from the change of system.
- Components like two cascades, flue, valve group, natural gas installation, insulation labor cost, expansion tank, balance tank may cost about 33.000TL depending on brand and labor cost. In this circumstances the amortization period is 17 years.
- The facts that the building is rental and the hospital may move to a new building make this idea a malinvestment.
- When the insulated model is imagined, it provides 72.5% saving. It means that approximately a 55KW boiler is sufficient.
- It is obvious that installing 55KW condensing kombi system costs less than 33.000 TL. Thus, the amortization period may be shorter than 10 years.

Pumps

- The circulation pumps in the boiler rooms operate 24 hours a day during winter heating season.
- So as to reduce the electricity consumption of the existing pumps, variable speed energy efficient pumps that operate depending on heating necessity should be preferred.

Actions for Electricity Saving in Lightening

- Light bulbs whose lifespans finished ,even if they continue lightening, have 30% less luminance. This should be taken into consideration while replacing light bulbs
- Windows should be kept clean, because dirty windows prevent daylighting.
- Dusty armatures, which absorb a significant amount of light, should be periodically cleaned.
- Lighter colors will reduce the need for lightening.

- If the lighting armatures are to be replaced, efficient lighting armatures and light bulbs should be preferred.
- Measures should be taken so as not to use electrical heaters.
- Dormant computers, copy machines, printers and other office devices should be shut down.
- Broken ballasts should be replaced by electronic ones.

Cooling System

- At Block C, there are 40 console type 2,5 KW split air conditioners and 12 free standing saloon type 4,6 KW air conditioners for cooling.
- Total installed power is 155,2 KW cooling load.
- None of the air conditioners has inverter technology.
- Inverter air conditioners make 40 % more saving
- Rather than a single split air conditioner, central system VRF air conditioner would be more feasible in terms of saving, space occupied and visual appearance.
- 45-50% more saving than the current air conditioner system would be achieved by VRF air conditioner system .
- 160KW VRF air conditioner system costs $ 95.000. In today's currency rate($=2,24) it costs about 213.000.
- 40 split air conditioners (40 x 1.100 TL = 44.000 TL), 12 free standing air conditioner (12 x 3.000 TL = 36.000 TL) cost 80.000 TL in total.
- 40 split air conditioners (40 x 1.600 TL = 64.000 TL), 12 free standing air conditioner (12 x 3.600 TL = 43.200 TL) cost 107.000 TL in total.
- Let's assume that a split air conditioner consumes 1.200 W per hour. If it operates 12 hours per day and 6 days per week, it consumes 1.200 x 12 x 6 x 4= 345.600 W= 345,6 KW electricity, which costs 122 TL
- Since there are 52 air conditioners ( values averagely stated as 13.000 btu), it means a monthly bill of 52 x 122= 6.344 TL. 6.344 TL x 6 months=38.064 is the annual bill cost.
- If split air conditioners spend 38.064 TL, VRF system can spend 19.000 TL while inverter air conditioners spend 22.800 TL.
- Split air conditioners cost 80.000 TL, while VRF air conditioner system costs 213.000 TL. The gap is 133.000 TL. Amortization period may last 133.000 /19.000= 7 years.
- Split air conditioners cost 80.000 TL, while inverter air conditioners cost 107.200 TL. the gap is 27.200 TL. Amortization period may last 27.200 /22.800= 1,2 years.
- Replacing the system initially with inverter air conditioners rather than split air conditioners seems feasible.

Ventilation System

- There is no existing ventilation system at the Block C.
- According to the measurements, there is 1500 ppm $CO_2$ in the indoor air.
- For healthy conditions, this amount is required to be less than 1000 ppm.

Results of the Study
This study done in company with the Chamber of Mechanical Engineers has displayed two major differences;

- Block A and B are equipped by the newest technologies, whereas there are old technologies at the Block C.
- The most significant advantage of this study is to let us see the advantages of replacing systems such as used in the Block C with the systems such as used in block A and B.

Major differences

*Insulation*
Thanks to the insulation at the Block A and B, it has been identified that up to 60-70% saving to the general consumption is achieved.
*Heating system*
It has been observed that saving up to 30-35 % can be achieved thanks to the components of correctly chosen fuel type, boiler type and boiler room.
*Cooling system*
It has been observed that saving up to 50% can be achieved thanks to central cooling units with inverter technology rather than split air conditioners.
*Ventilation system*
It has been observed that getting the humidity and $CO_2$ in the building under control, a healthy indoor environment can be achieved.
*Lighting and electrical systems*
It has been observed that electricity saving can be achieved thanks to appropriate components and lighting equipment, without using electrical heater.
*Periodic Control and Maintenance*
It has been observed that the technical team is qualified, monthly maintenances achieve annual savings of up to 25%, and 4% annual minimum optimization has been achieved.

# 2.3 Insulation

## 2.3.1 Introduction

Insulation is the most effective way to improve the energy efficiency of a home or a building. Insulation of the building envelope helps keep heat in during the winter and out in summer to improve comfort and save energy. Insulation could add additional benefits such as acoustics and waterproofing. Effective draught proofing, moisture control and ventilation are important at design stage.

The appropriate level of insulation intervention will depend on climate, building construction type, and whether auxiliary heating and/or cooling is used. Insulation reduces heat flow and is essential to keep a building warm in winter and cool in summer. A well insulated and well designed building will provide year-round comfort, decreasing energy costs. This, in turn, will reduce greenhouse gas emissions.

Climatic conditions will influence the appropriate level and type of insulation. Passive design techniques must be used in conjunction with insulation. For example, if insulation is installed but the building is not correctly shaded, built up heat can be trapped in by the insulation creating an 'oven' effect. Air tightness of a building is important, as draughts can account for up to 25 percent of heat loss in winter.

Ensure proper ventilation in buildings where fossil fuels are burned as an energy source. Certain types of insulation can assist with weatherproofing and control moisture problems such as condensation. Some types of insulation also have soundproofing qualities. Some products are environmentally friendly and contain recycled material.

An un-insulated home is subject to considerable winter heat losses and summer heat gains. The term 'insulation' refers to materials or a combination thereof which provide resistance to heat flow.

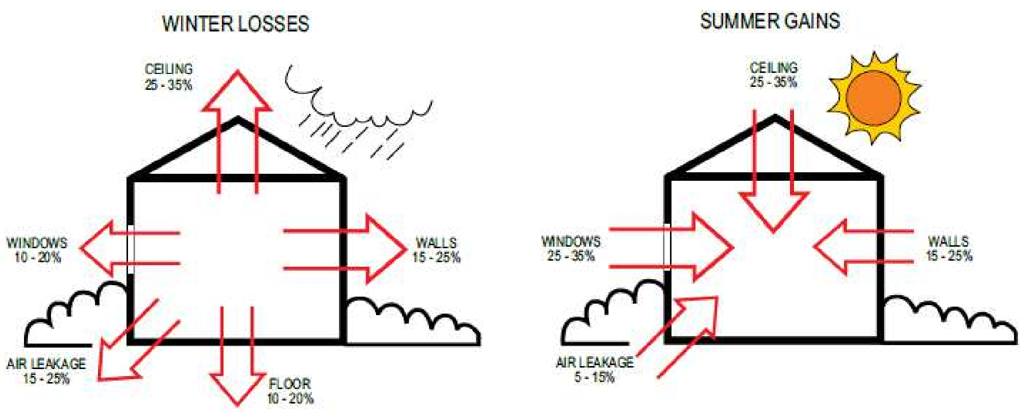



**Figure 2.3-1**: Sources of winter heat losses and summer heat gains.

When these materials are installed in the roofs, ceilings, walls, and floors of a building, heat flow into and out of the building is reduced, and the need for heating and cooling is minimized. Although ceilings and walls may be insulated, heat loss will still occur in winter if there are large areas of unprotected glass or through fixed wall vents, gaps electric light entry points and cracks around external doors and windows. Appropriate internal window coverings (e.g. lined drapes with pelmets) and draught proofing are vital to complement insulation. Insulation should always be coupled with appropriate shading of windows and adequate ventilation in summer. Without shading, radiant heat entering the home through the windows will be trapped inside by the insulation and cause discomfort.

### 2.3.2 Measurement of insulation performance

The thermal performance of all components and systems except windows and doors is expressed in terms of R-Value; for windows and doors, performance is expressed in terms of U-Value. Insulation materials are rated for their performance in restricting heat transfer. This is expressed as the R-Value, also known as thermal resistance. The R-Value is a guide to its performance as an insulator-the higher the R-Value, the better the insulation (i.e., resistance to heat flow) it provides.

R-Values are expressed using the metric unit's $m^2.K/W$, where:

- $m^2$ refers to one metre squared of the material of a specified thickness;
- K refers to a one degree temperature difference (Kelvin or Celsius) across the material;
- W refers to the amount of heat flow across the material in watts.

Use the nominal R-Values as listed by the manufacturer on the packaging of the insulation to determine the performance. Products which have the same R-Value will provide exactly the same insulating effect as each other, provided they are correctly installed. The higher the R-Value the more effective the insulation. Products must be installed in accordance with the manufacturer's specifications.

The information available on the product data sheet and/or label must include the R-Value and whether it must be installed professionally or DIY. Ensure that it suits your particular application. Ask if performance guarantees and/or test certificates are available.

Material R-Values – the thermal resistance values of bulk/mass type insulation are measured on the product alone according to standards.

System R-Values – the thermal resistance value of reflective insulation is calculated based on standards and depend on the product being installed as specified in accordance to manufacturer's specifications. This is known as a system R-Value which incorporates air spaces.

Composite R-Values - the thermal resistance values of composite insulation products are measured by testing the composite product as a unit according to standards.

Direction of heat flow effect
R-Values can differ depending on the direction of heat flow through the product. The difference is generally marginal for bulk insulation but can be pronounced for reflective insulation. Up R-Values describe resistance to heat flow upwards (sometimes known as 'winter' R-Values). Down R-Values describe resistance to heat flow downwards (sometimes known as 'summer' R- values).

What is a U-Value?
Sometimes insulation or systems are rated in terms of its thermal transmittance (U-Value), rather than it R-Value. The U-Value measures the transfer of heat through a material or a building element (thermal transmittance), whereas the R-Value measures the resistance to heat transfer. U-Values are often used in technical literature, especially to indicate the thermal properties of glass and to calculate heat losses and gains.

The U-Value is the reciprocal of the R-Value, R=1/U or U=1/R. For example, with an R-Value of 2.0, the U-Value is ½ or 0.5.The U-value is expressed using the metric units ($W/m^2.K$) where:

- W refers to the amount of heat transmitted across the face or through the material in watts;
- $m^2$ refers to one meter squared of the material of a specified thickness; and
- K or 'degree Kelvin' refers to each °C temperature difference across the face of the materials or through the material.

A smaller U-Value results in lower heat flow, and therefore less heat loss. Higher U-Values mean greater heat loss.

What is an Overall R-Value?
The overall R-Value is the total resistance of a building element or system combination. It takes into account resistance provided by construction materials used in a wall or ceiling, internal air spaces, thermal bridging, insulation materials and air films adjacent to solid materials. Each of these components has its own inherent R-Value, the sum of which provides the overall R-Value.

What is Intervention or Added R-Value?
The intervention added R-Value or added thermal resistance is the value of the insulating material alone. This is the term most used when buying thermal insulation. The manufacturer should provide the R-Value of the insulation on the packaging. Some products will have a higher R-Value for a specified thickness. For example, a 70mm thick extruded polystyrene board and 100mm thick glass wool blanket may have the same apparent R-Value.

Reflective insulation requires that air spaces are positioned correctly within the building system to be effective, reflective membranes cannot have an R-Value without the air space or air spaces.

To compare the relative performance of bulk and reflective insulation membranes, the resistance of such membrane in combination with air space(s) must be calculated. Reputable manufacturers can supply this information. The effectiveness of reflective insulation installed on horizontal or sloping surfaces may eventually be reduced due to dust build-up, which reduces reflectivity, thereby increasing absorption.

What is the difference between R-Value and Total R-Value?
The R-Value is the material thermal resistance, i.e. product only whereas the Total R-Value describes the total thermal resistance of the system to heat flow provided by a roof and ceiling assembly (inclusive of all materials and air films), a wall or a floor. These values are calculated from the resistance of each component, including the insulation. Total R-Values are the best indicator of performance, as they show how insulation performs within the building envelope.

What is Thermal Bridging?
Thermal bridging is the transfer of heat across building elements, which have less thermal resistance than the added insulation. This decreases the overall R-Value. Wall frames and ceiling beams are examples of thermal bridges, having a lower R-Value than the insulating material placed between them. Because of this, the overall R-Value of a typical ceiling and/or wall is reduced.

### 2.3.3 Building envelope

The envelope of a building includes all the outer surfaces of the building that separates the indoor area from the following:

- Outdoor air;
- ground;
- auxiliary constructions that are not heated;
- other buildings separated by joints.

The envelope offers the structural support to walls and roofs, protect against the deterioration, offers the possibility to use the daylight, protect against the rain and snow, etc. For a good outcome of energy efficiency measures, it should be considered all the elements of the envelope. In practice, it is not that simple since each element should correspond to different requirements (transparency, mobility, mechanical characteristics).

In other words, the role of the envelope is to separate the indoor controlled environment from the outdoor environment. In order to maintain the required indoor conditions, the flows of heat, air and humidity should be controlled.

#### *2.3.3.1 Building envelope and heat flows*

Existence of a heating system that would ensure enough heat for the building represents one of the most important conditions to maintain the temperature in the building during the winter season. An important condition for achieving indoor comfort is to equip the building with a heating system which will provide heat during the cold season. The heat supplied should be maintained inside the building, so that the power consumption of the heater to be minimum. But characteristic of heat transfer (or heat, popularly called "heat transfer") is that it is generated by any difference in temperature and can occur in any direction.

Many people may think that because hot air rises, most heat is lost through the roof. This is not necessarily true. The heat "streaming" of any surface hotter to one cooler, either up or down or sideways. A heated chamber placed over an unheated garage will lose heat through the floor. Similarly, heat loss can occur through walls - underground or above ground. It is the role of the building envelope to control the flow of heat between the inside and outside environment.

The mechanisms (or ways) of heat transfer are thermal conduction, heat convection and thermal radiation. The flow of heat through the envelope can be achieved by one, two or all three ways.

The conduction of heat arises in stationary environment (solid, liquid or gaseous) by transferring energy from microscopic particles of component (molecule, atom) with high speed to the low speed as a result of collisions inherent in the particles. As a result, better heat conduction is achieved through the solid and liquid than in the gas, where the particle density is low. Heat insulating materials are often porous, air-filled spaces, thereby reducing the flow of heat through the envelope. Property material to transfer heat by conduction is called thermal conductivity, and its values are dependent on temperature. The literature values or expressions are presented for calculating the thermal conductivity of most materials used in engineering.

Thermal convection occurs between a surface and a fluid in motion, achieved by the combined action of thermal conduction through the fluid and of the overall macroscopic motion of the fluid. The latter is largely responsible for the transport of energy between the surface and microscopic fluid. In an uninsulated room, e.g. air "collect" heat from the hot wall, then runs, reaching the cold wall where it is lost. A part of the heat is transferred as a result of hot air with cold air mixing.

There are two types of thermal convection: forced convection when the fluid motion is imposed by mechanical means (pumps, ventilator etc.) or remote natural (wind); and natural convection when the fluid motion arises naturally from differences in density caused by differences in local temperature (fluid warmer climbs and cold descends, forming the so-called convective currents).

Thermal radiation is energy emitted in the form of electromagnetic waves due to changes in body electronic emitter configuration. The thermal radiation occurs at any level of the temperature and, unlike the conduction and convection, requires no carrier medium. There are situations in which thermal radiation is small, even negligible, in comparison with other modes of transfer (at low and medium temperature differences), or situations where thermal radiation is dominant (large differences in temperature, and incident radiation from sun, or at night to atmospheric space removed).

Years ago, when the types of insulation were extremely limited, as insulation efficiency was its thickness. Today, coatings are chosen according to their thermal resistance, defined as property, by analogy with the electrical resistance of a conductor.

A thermal insulation works well if properly mounted in the attic, basement and exterior walls. Although the technology is relatively complex installation and site specific and is not subject of this paper, it may indicate the following general recommendations:

- insulation must fill the space completely and evenly. All portions blank or corners will allow the emergence of thermal convection, able to by-pass complete insulation;
- thermal bridges should be avoided wherever possible. As the name implies, the thermal bridge is a portion of the tire to lower heat resistance conductive, thereby allowing transfer of heat through the soft portion (e.g., a beam on the wall). When insulation is applied over one side of the thermal bridge, it acts as a barrier, blocking the flow of heat;
- insulation thickness should have allowed the size and space when made of soft, porous, it must have the proper density to form the required thermal resistance.

Thermal insulation size is chosen based on several factors:

- standards in thermal rehabilitation of buildings may include specifications on insulation thickness to be added;
- the condition and thickness of existing insulation thickness and type of insulation required to be added;
- the way who the house is built basically determines how much insulation can be added.

#### *2.3.3.2 Building envelope and humidity*

Humidity causes crumbling concrete, wood rot, peeling paint, plaster can damage and destroy carpets. In all its forms, humidity is a major cause of destroying the building. Humidity can occur in the form of solid, liquid or vapor. The moisture source may be external, as in the ground water, ice, snow, rain, fog and the surface discharge; or it may be internal, in the form of vapor produced by the occupants of the building (through breathing) and their activities (washing, cleaning, cooking), or by using humidifiers systems.

The building envelope is penetrated by the humidity through different modes:

- Water is leaking from the roof or window glass by gravity;
- apillary afford water movement in all directions, creating the effect of blotting; capillary action depends on the presence of very narrow spaces

encountered winding overlapping or porous materials (such as concrete and soil);

- Water vapor can cross the materials and diffusion. This is caused by the presence of a difference in water vapor pressure and the resistance of the material traversed this difference;
- airflow through the tire performs a simultaneous movement of moisture. The air always contains a certain amount of water vapor, the higher as the higher is the air temperature.

By comparison, the flow of air through a small crack in the tire carrying about a hundred times more moisture than diffusion through the building envelope materials. Water vapor condenses when it becomes a problem and become liquid water, i.e. condensation. This happens at a relative humidity of 100%, the air cannot encapsulate water vapor. A typical example is the condensation formed on the windows. When indoor air comes into contact with the cold glass, its temperature decreases and with it the ability to incorporate air humidity; as a result, some of the water vapor in the air condenses and is deposited on the glass. If the window is less than zero, humidity becomes lodged in ice. A single glass window is cooler than the one with two glasses, so that condensate can form even in case of low indoor humidity.

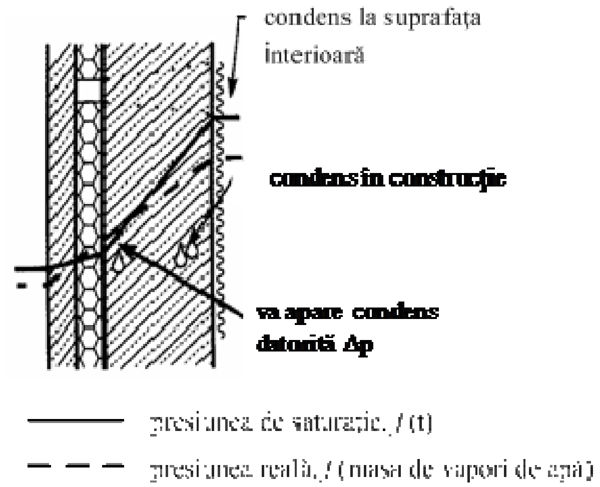



**Figure 2.3-2**: Condensation on envelope wall.

Condense usually appears in rooms with higher humidity, such as kitchen. The control of humidity flow through the envelope is very important to ensure the comfort and sustainability of the buildings. Building elements such as leaks, roof, basement and hydro-insulation protects the building against liquid water. Controlling the flow of water vapor protects the building structure and provides comfortable indoor humidity levels.

The humidity control is accomplished in three ways, called strategies:

- construction techniques that keep moisture away from the building structure;
- decreasing the production of moisture;

- evacuation of excess moisture outside.

Even seemingly dry houses without roof leaks or seepage in the basement, may have problems with moisture, because moisture sources are not always obvious:

- occupants and their activities;
- windswept rain on walls;
- wet basements;
- moisture stored in be building materials and finishes.

A family of four persons can produce about 63 liters of water per week by current domestic activities. When hydro-insulation of the basement do not exist or is damaged, the water seeps through the foundation soil by capillary effect and evaporate on the surface of walls and floor. And finally, during the wet season, rainy, building materials and furnishings absorb moisture, which then releases it during the cold season.

### *2.3.3.3 Building envelope and air flows*

The exchange of air in the tire is a major source of heat loss. Since warm air can contain large amounts of water vapor, the air flow is also the principal means by which moisture passes through the tire. In winter conditions, air is forced through the building envelope. The air carries out heat and humidity, and the air is dry and creates currents get uncomfortable.

In order for the air to pass through tire building, there must be an empty space (a hole in door, opened window, a slit) and a pressure difference between the inside and the outside of the tire. The pressure difference can be caused by any combination of:

- wind;
- temperature difference leads to the phenomenon of thermal stratification vertical chimney cunocut effect;
- equipment with burners or fan vents.

Detailed explanation of these effects following recipes:

- effect of wind occurs when the wind blows toward the building, and the point of impact with the wall kinetic energy is converted into potential energy pressure (applied here the well-known Bernoulli's law). In this way, the air pressure increases on the windward side, and the air is forced to enter the building. On the other hand, the air pressure on the opposite side of the building decreases due to air entrainment by wind side of the building, and the air in the building is forced to go outside;
- layering effect occurs in homes heated, where the warm air of lower density, climb and relax, creating at the top of the building a greater pressure. The air escapes out through cracks in the ceiling and cracks around windows on the upper floors. With the lifting of warm air to the bottom of the building creates a slight vacuum that force outside air to penetrate inside any leak or opening the envelope;

- the effect of combustion and ventilation equipment and facilities with due process of burning a fuel, either wood, oil or natural gas. Combustion process requires more air to allow oxidation of combustible chemicals, for which they provide ways to ensure that excess air (eg fans, chimney or properly). Open stoves or fireplaces must evacuate gases, harmful to health, and once they are evacuated and more air. It must be replaced to maintain the air pressure inside, so that by the tire, gets fresh air from outside. For this reason, the rooms feature fireplaces, stoves or air currents more intense than others.

Air flow through the building envelope can contribute small kitchen or bathroom fans, bigger fans of the central vent grills located on stoves, clothes dryers, or other existing ventilation fans in the building.

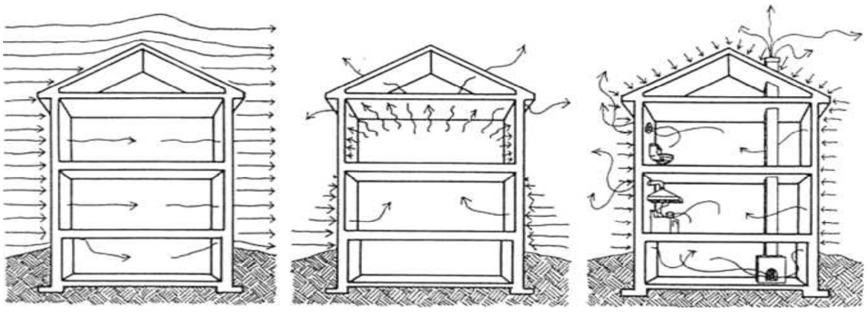



**Figure 2.3-3**: Air flow through the envelope (wind effect, thermal stratification, burning and ventilation effect)

Controlling interior and exterior air flow provides many advantages, such as:

- Saves money and energy;
- building more comfortable without cold spots and drafts;
- Building materials protection against damage caused by moisture;
- an increase of comfort, health and protect, eliminate clogged exhaust air and excess air and ensure necessary to achieve safe combustion processes;
- building cleaner and quieter.

Air flow control involves three simple activities to be carried out at once:

- Prevent uncontrolled leakage of air through the tire;
- Provide fresh air and exhaust air discharge;
- Ensure the flue and combustion air necessary equipment burners in the house (fireplaces, stove, hot water boiler).

To be effective, insulation must still include small air spaces. Therefore, it must be protected against the wind blowing from the outside, but also against air leakage from the inside.

### *2.3.3.4 Building energy efficiency issues*

Civil buildings, the main user which is people, can be divided into three categories: residential buildings, homes, hotels:

- individual - single family homes, coupled lined;
- buildings with several apartments, multi-storey apartment block;
- public and tertiary buildings (buildings other than dwellings destination);
- hospitals, nurseries, clinics;
- buildings for education (nurseries, kindergartens, schools, colleges, universities), sports;
- social and cultural buildings (theaters, cinemas, museums);
- public (shops, retail, firms, offices, banks) and industrial buildings.

Buildings other than the dwelling destination are divided by mode of employment continued occupancy buildings with discontinuous employment and after class thermal inertia in buildings inertia class high, medium or low. Civil buildings function is to create comfortable indoor climate regardless of season. In this sense, the building blocks that make up the tire of such buildings must be designed to ensure proper conditions for indoor Hygrothermal comfort, acoustic, visual light, olfactory-tract. The notion of comfort should suggest creating an appropriate conduct normal life.

Hygrothermal comfort translates into levels of temperature and humidity bearable. He performed with energy consumption for space heating is used (in winter) or cooling of (summer). For this reason, hygrothermal comfort component is directly related to the notion of building energy efficiency in the sense that it seeks to achieve the minimum energy consumption.

State of thermal comfort in a room is done provided that at least 90% of users can indicate if you would prefer a warmer or colder environment. Identifying the performance requirements associated with the thermal comfort requirements of users is done by analyzing both objective aspect relates to the need to maintain the internal temperature of the human body around 37oC, and the subjective as it relates to metabolism, thermoregulatory system and sensitivities of each organism.

The level of thermal protection of buildings that make up the existing stock of buildings corresponds independent structural system used specifications and calculate requirements imposed by standards and hygro-thermo-technical. So according to each generation of such standards and specific technological level that period, there groups of buildings with the same level of thermal protection, regardless of the materials used for the building envelope composition.

A well-insulated house is comfortable, quiet and accumulate less dust and pollen inside. Any activity to improve the building keep in better shape, prolonging life and increasing its value. Contribute to larger scale investment and saving primary energy resources and to reduce environmental pollution by emissions inherent in energy production.

The tire is "coat" that separates the inside from the outside of the building at a gradient with a temperature difference of 5 ° C. The envelope consists of outer walls (opaque, glazed curtain), roof (type terrace or inclined flat surfaces, with spaces designed for living or not) and the floor above the basement or on the ground floor. Regarding the thermal insulation should be considered and other technical elements, such as temperature difference inside - outside (winter through heat loss, excessive summer heat) to draw the tire (construction system, types of materials) energy loss through thermal bridges, energy loss through glazing.

### 2.3.4 Roof insulation

An effective rehabilitation cannot be done if you do not mind the roof, especially if it is the top floor of a block. In determining the thermal rehabilitation solutions take account the degree of deterioration of existing coatings, waterproofing and insulation. There are times when both the state seal, as well as the insulating layer are not adequate.

It becomes more complicated when the thermal framing or system that supports the roof and the roof itself should be rehabilitated. First of all, a specialized technical expertise is required depending on the base on the destination space as framing (attic or mansarde) and the required level of thermal insulation. For bridges that do not require conditioning, thermal rehabilitation is achieved by insulation floor bridge: peel and leveled substrate, apply vapor barrier, insulation is applied, apply a thick layer separation (polymer sheet or geotextile).

Styrofoam panels contain an additive that prohibits lighting in the event of accidental fires. The panels are still combustible and if exposed to direct intense flame can burn quickly. All combustibility characteristics presented in literature Dow, based on the results of tests on a small scale and do not always reflect the reaction of the material under actual fire. Rules on building fire performance are set by national standards. Styrofoam panels can be cut easily using simple tools such as: fine-toothed saw, read, etc.

**Figure 2.3-4**: Styrofoam panels.

The panels are resistant to contact with most building materials such as asphalt dust, glue, cement, plaster, gypsum, alcohols, acids and bases. Some organic materials such as solvents, paint thinners, acetone, toluene, ethyl acetate, etc.., Damage resulting XPS panels soaking narrowing (contraction) and even dissolution, which may cause drastic decrease in performance. For support, we recommend the use of solvent-free adhesives. Compatibility with polystyrene foam should be defined by the manufacturer of adhesives before starting work.

Roofs, especially flat roofs are the building elements mostly exposed to the heat. That's why, a right structural composition plays a determinant role for the life of the roof. Flat roofs offer architectural options: can be used as a terrace, parking place or roof-garden. In case of slope roofs, the waterproof film is placed above the heat insulation; the upper layer of the film is subject to the weather factors and mechanical impacts, which lead to increased risk of losing the tightness.

In case of inversed roof (IRMA system), the sequence of layers is changed:

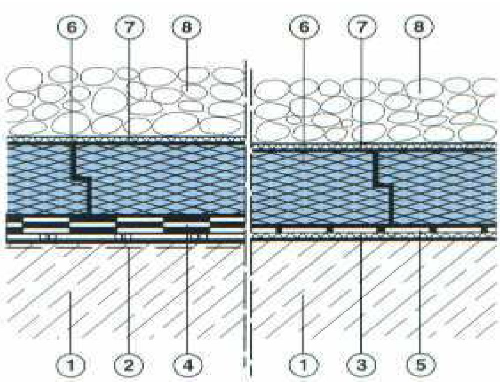
- Heat insulating panels are placed above the water insulation, which offer a lasting solution.
- Waterproof film is protected from the heat impacts and UV radiation,
- Film is not exposed to mechanical impacts,
- The lifetime of the film is increased.

'Inversed' roof with gravel protection

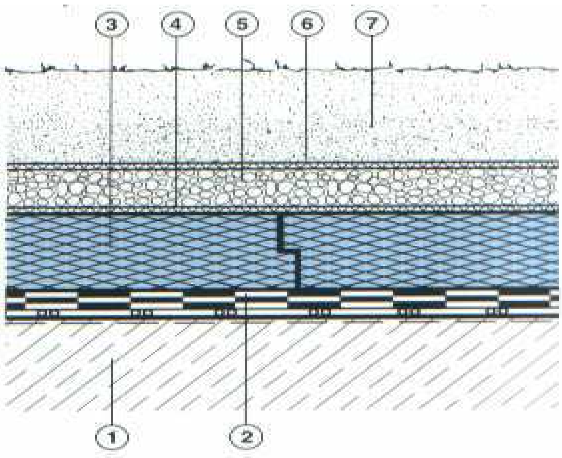
In case of construction a seandard plane 'inversed' roof – unused – a layers of min. 5 cm of gravel is applied above the heat insulation. This has the role of ballast and protection against UV for insulating panels Roofmate, which are placed above the waterproof film. Between the gravel layer and heat insulation, a separation film is placed that allow the diffusion without retaining the water, and creating cohesion between the insulating panels. Along the edge of the roof, it is recommended to place a bigger quantity of ballast.

'Green' roof

In case of garden-roofs, all advantages of the inversed system are applied, which lead to increased security through the installation of Roofmate panels above the film. Above the isolation the following layers are placed: separation layer, drenage layer (i.e. gravel), filtering layer, soil substrate.




1. Sloped concrete roof
2. Bitum film base
3. Protection/separation layer
4. Bituminous enveloping film
5. Polymer/plastic enveloping film
6. Roofmate SL insulation
7. Geotextil separation layer (e.i. Typar)
8. Gravel ballast (min.5 cm, granulation 16/32)




1. Sloped concrete roof
2. Waterproof film
3. Roofmate SL insulation
4. Separation layer (i.e. Typar geotextil)
5. Drainage layer (i.e. gravel)
6. Filtering layer (geotextil)
7. Soil

### 2.3.5 Walls insulation

Approximately 20% of the total heat loss of a single family home can occur through uninsulated walls. These spaces should be insulated to reduce energy consumption, to increase the indoor climate comfort and to prevent condensation on the surface of the walls. Insulation is useful even in case of non-heated buildings, the areas that have contact with the soil. Thus, in the event of a conversion, comfort and efficiency can be achieved without requiring additional insulation works. Based on physics rules, the insulation of walls on the outdoor side is the solution for preventing the risk of indoor condensation on the inside structure surface.

Efficiency of base exterior insulation should not be deteriorated under long-term exposure to humidity and soil pressure. In order to ensure a long-term function of the insulation material it is recommended to be taken into account the following requirements:
1) Compression durability (nominal value): ≥ 0.30 N/mm2 (300 kN/m2)
2) Compression durability for long-term tasks: ≥ 0.11 N/mm2 (110 kN/m2)
3) Water absorption by immersion term (28 days): ≤ 0.5.% Vol
4) Water absorption by diffusion term (28 days): ≤ 3.% Vol
5) Freeze durability / thaw: Water absorption after 300 freeze cycles/thaw: ≤ 1.% Vol
6) Reduction of compressive strength after 300 freeze cycles / thaw: ≤ 10.%.

Polystyrene panels of extruded insulation, ensures an external insulation of the basement wall and at the same time protect the waterproofing membrane

Mechanics. Approximately 35% of heat is lost through the walls of a room outside, which means higher heating costs. If external insulation wall being solid, heat builds up in the room and serves as a balancing element.

In summer, when house are very hot, well insulated exterior wall maintains an average temperature in the apartment. Even building overall strength will be greater, because it reduces the stress caused by temperature between the parties and the supporting construction.

Installing a vapor barrier on the inside wall is required in the following situations: the use of materials based on mineral wool insulation, the insulation inside of a concrete wall, the subsequent isolation of the walls of the basement when there is a high degree of moisture premises (in the bathroom or kitchen).

The walls are plated with polystyrene plates available in different thickness (the thicker the better), that stick with an adhesive similar to that used when installing tiles after fixing from place to place with special support and covered with plaster mortar.

Interior with expanded polystyrene insulation is about the same, but besides the gains relatively easy mounting and that does not reduce much of the space in the room, has a number of disadvantages. First wall inclinations and does not correct the resulting surface is very resistant. Secondly, the radiators in the room should be moved inward and anchors should be large enough to go through the insulation and to be catch to the concrete.

Insulation indoor wallboard and mineral wool is more complicated. Plasterboards are installed on a grid made of special profiles, fastened to the wall. A layer of mineral wool is fixed between the wall and supporting grid. Its absence leads to cooling of the walls, so that the time appears on the plaster mold. After fixing plates over joints apply adhesive tape (prevents cracks), then this is finished with gypsum plaster.

The advantages of this system are: it can be used where ceiling can correct the imperfections of verticality of the walls, the radiator pipes can hide behind the wall, the wall is more resistant, even only can hang drywall meaningful tasks using special anchors. Whatever method is chosen by the insulation of exterior walls of the house, the results to be meaningful, they need to be taken into account and change existing windows.

There are basically three types of insulation:

a) <u>exterior insulation</u>

Execution: the exterior walls are plated with Styrofoam boards, available in different thicknesses (1, 2.5, 5 cm, how much thicker the better). it sticks to the outer wall with an adhesive (similar to the mounting tiles if you want), is fixed in place with some special supports in place, then it is covered with plaster mortar.

Advantages:

- Concrete wall is less exposed to temperature variations, the whole time the interior temperature (therefore more protected time);
- No loss of interior space of the room

Disadvantages:

- More difficult to perform, especially if you live on the ground or 1st floor;
- Facade looks funny with a thicker wall and possibly another color in your apartment right;

b) <u>exterior insulation with polystyrene</u>

c) <u>inner insulation with plasterboard and mineral wool</u>

Execution: the plasterboards are fixed on a 'grid' made of special profiles, fastened to the wall. Before fixing tiles, a mineral wool layer is fixed between the wall and the grid.

Advantages:

- Also run relatively easily and quickly; can be isolated and ceiling;
- Can correct the imperfections of flatness (verticality) of the walls;
- The radiator pipes can hide behind the wall (I rebuilt the vertical columns and connections to radiators pexal, starting from the neighbor below, pexal that I hid behind the wall's True that I kind of tremor bottom couple of days when I refilled the heating, but it seems that installers were craftsmen);
- Also can recover (through the 'back' ceilings and plasterboard walls) wiring;
- The wall is more resistant, even only can hang drywall meaningful tasks using special anchors - Dacian is something really hard right can be fixed in an upright vertical profile of 'grid' support;
- The finish is high quality and very fast with very little effort - basically, outside plastering with responsibility joints between boards, just give the washable, because the wall is flat nature of gypsum board

Disadvantages:

- Loss of space in the room (about 7-8 cm for each profile wall insulated with 30 mm mineral wool 50 mm and 12.5 mm plate).

**2.3.6 Floors insulation**

When choosing a flooring insulation must be taken into account:

- condition and irregularities of the concrete floor
- the need to isolate and improve the acoustic of the floor
- the need to heat the floor (especially important if the case of basements and ground floor rooms)

- insulation resistance on weight (durability, increases the life of the floor)
- protects the floor against moisture and decay caused by fungus and mold

Heat transfer via the ground floor uninsulated or unheated rooms, is the cause of significant heat loss. Besides reducing heat loss, insulation of floors enables effective use of thermal energy stored in the floor.

The energy savings can lead to reduced costs, while helping to protect the environment. Proper insulation of floors helps significantly increase overall comfort. Floor insulation materials are subject to long-term static and dynamic - the main demands are: compressive strength and minimal deflection under load; necessary demands, keeping the High performance insulation even in wet conditions and mechanical impact.

Based on the same principle of reversed insulation floor mate and Obsolete INS plates are used also for foundation insulation where there is water pressure in the soil. This creates an overall thermal protection of construction elements in direct contact with the ground.

### 2.3.7 Windows as insulation element

The windows must meet standard requirements that take into account natural lighting through an orientation optimal sunlight, indoor air ventilation, heat and sound insulation. They are made of wood (simple, different species or laminated), metal (steel, aluminum), plastics, and as components shows a fixed part (heel), some furniture (frames) and hardware (sash clamp heel, closing, clamping in a certain position for ventilation and air refresh). Due to the materials used and size the windows are areas of loss of faster and larger amount of heat (losses arise through transparent surface through opaque elements of these components and leaky joints, often by gap between the window frame and itself). Enhancement wooden windows the idea is that they resist heat loss from inside to outside in winter and heat coming from the outside in the summer (this means to increase the thermal resistance of the window).

**PVC window - 3 rooms**

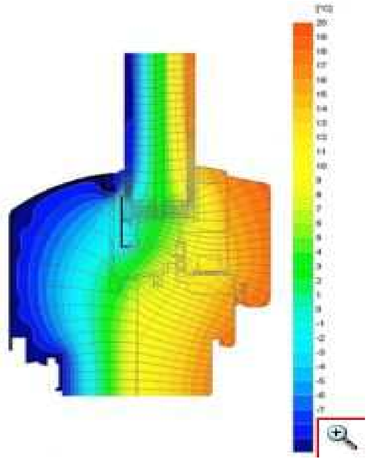
**PVC window - 5 rooms**

**PVC window - 6 rooms**

**Figure 2.3-5**: 3 types of PVC windows.

Attractive design of window glazing is given rounded edges. They are recommended for villas, holiday homes due to depth, the maximum number of rooms 6 and the window with triple glazing. Thanks to the collaboration with major companies that produce windows and doors, the possibility arose designers to diversify and to harmonize their design. Among the technical features we expose the defining ones:

- thermal insulation Uf = 1,1 W/m2K;
- sound insulation up to protection class 6;
- burglary proofed resistance class 3;
- tightness against drafts and air currents to request group C.



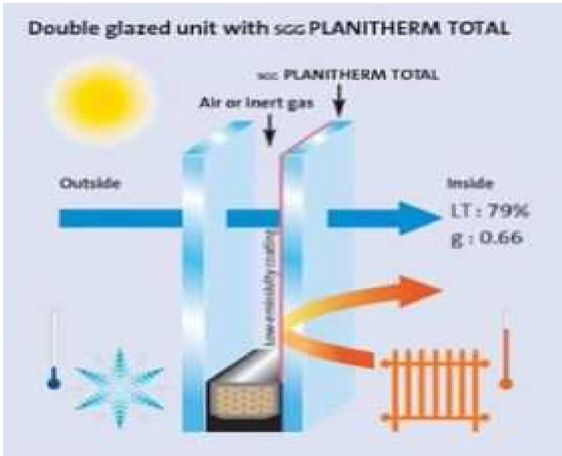



**Figure 2.3-6**: Double glazed PVC window

Quality for PVC double glazed windows, regardless of the type of glazing used, thus sealing the nature of gas inserted in glazing cavity, the number of sheets used, the thickness of the insulating glass package. Are so many variables that actually give the glazed noise, thermal insulation capacity, dimensional stability of PVC windows, double glazing parameters which define the category in general.

For energy saving capacity systems with double glazed PVC have become in recent decades a basic element in building a house. Although the surface of glazed PVC windows is generally 10-12% of the outer surface of a building, heat loss through PVC double glazing is more than 40%. Given that 80-85% of the surface is covered with a PVC window glazing, clearly shows the importance of using an insulating glazing.

Thus, if for a window named double glazed windows consists of two sheets of ordinary float glass with a thickness of 24 mm, the heat transfer coefficient is k = 2.8 W/m2K, when using a Low-E insulating glass air, k = 1.4 W/m2K when using gas reaching the coefficients of up to 1.1 W/m2K.

### 2.3.8 Proposal for implementation – Municipality of Cahul

In order to examine the applicability of building insulation in municipal buildings, a case study was developed and is analyzed in the specific section. The Kindergarten no.14 “Spicusor” in Cahul, was selected as a reference building. The specific building was chosen given the following reasons:

- Kindergarten no.14 is visited by a large number of children, thus a potential energy retrofit of the building could be used as a promotion example and awareness raising for children and their parents and also a better tool of communicating the municipal efforts on improved energy efficiency and implementation of EE related strategic documents.
- This building needs significant thermal insulation measures, thus there is a noticeable potential of improvement. Moreover, a complete lack of building envelope insulation was observed.

### *2.3.8.1 Current situation of the building*

In order to evaluate the interventions proposed for the energy upgrade of the Kindergarten no.14 in Cahul, an initial energy audit of the building was performed, based on guidelines of the current Moldovan legislation and the application of MS Excel software. In this section, an analytic description of the building is provided in terms of prevailing climate data, topography, building use profile, building envelope and availableelectromechanical systems, in order to estimate its energy footprint/characteristics.

*Climate data and topography*

Cahul town is a settlement in Cahul Rayon located at 45.9075 latitude, 28.1944 longitude and 52 m latitude above the sea. This settlement is subordinated to the Cahul Rayon administration. According to 2004 census, the population of the town is 35488 citizens. Distance to Chisinau is 131 km. The climate is characteristic to southern climate zone, where the region is considered the most dry and hot in the country, while the temperatures are 2-3 degrees higher in comparison with other regions.

**Table 2.3 -1:** Climate data of Cahul.

| *AIR TEMPERATURE (monthly and annual average)* | | | | *ATMOSPHERIC PRECIPITATIONS (monthly and annual quantity)* | | |
|---|---|---|---|---|---|---|
| | | | *Celsius degrees* | | | *millimeters* |
| | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 |
| ***Monthly*** | | | | | | |
| January | -4,2 | -2,2 | -2,0 | 35 | 36 | 60 |
| February | 0,1 | -2,9 | -7,8 | 43 | 14 | 46 |
| March | 4,8 | 4,4 | 5,0 | 29 | 11 | 14 |
| April | 11,6 | 10,1 | 13,7 | 23 | 53 | 30 |
| May | 17,2 | 16,6 | 18,7 | 82 | 47 | 77 |
| June | 20,7 | 20,3 | 23,3 | 121 | 92 | 29 |
| July | 23,2 | 23,4 | 26,4 | 146 | 41 | 45 |
| August | 24,9 | 22,2 | 24,0 | 25 | 25 | 57 |
| September | 17,1 | 19,9 | 19,7 | 31 | 3 | 30 |
| October | 8,6 | 10,0 | 13,9 | 80 | 33 | 46 |
| November | 11,1 | 3,0 | 7,3 | 20 | 0 | 23 |

| | | | | | | |
|---|---|---|---|---|---|---|
| December | -0,7 | 2,8 | -2,0 | 64 | 16 | 138 |
| ***Annual*** | **11,2** | **10,6** | **11,7** | **699** | **371** | **595** |

*Cahul has a* ***humid continental-type*** *climate with four distinct seasons.*
*http://www.statistica.md/category.php?l=ro&idc=99&*


**Figure 2.3-7:** Topography of the Kindergarten no.14 building.

**Figure 2.3-8:** General view of the building.

*Use profile and thermal zones*

The Kindergarten no.14's represents a typical design of 8 blocks building complex, where 7 two stored blocks are used for dormitories and one-stored central block used for administration, kitchen, sport and art activities. All blocks are connected with one-stored corridors making the complex as one building. The whole complex has basement. For the estimations, it was considered that the whole complex is one thermal zone, since the surface of the parts of the buildings that could perceived as different thermal zones (e.g. ground floor) was less than 10% of the total area of the building.

The basic characteristics of the buildings and the desired operating conditions/use profile are summarized in Tables 2.3-2 and 2.3-3. respectively.

**Table 2.3-2:** Basic characteristics of the building.

| Characteristic | Value |
|---|---|
| Type of use | Kindergarten |
| Total heated area [$m^2$] | 5,860 |
| Total area of external walls [$m^2$] | 2,425 |
| Total area of windows and doors [$m^2$] | 437 |
| Total volume [$m^3$] | 13,300 |
| Heat capacity [kW] | 300 |

**Table 2.3-3:** Use profile.

| Characteristic | Value |
|---|---|
| Operating hours | 8 |
| Days of operation | 5 |
| Months of operation | 12 |
| Heating period | 15/10 to 31/3 |
| Average indoors heating temperature [°C] | 16-18 |
| Designed indoors heating temperature [°C] | 22 |
| Designed outdoor temperature [°C] | -16 |
| Daily consumption of hot water [$m^3$/day] | 5.73 |
| Average designed temperature for hot water [°C] | 55 |
| Average annual temperature of cold water supply system [°C] | 15.2 |

*Building envelope*

The thermal properties of the building envelope were analytically estimated. The R-values of all building components are summarized in **Table 2.3-4**.

The architectural elements of the building are the following:

- external walls are made of limestone with 500 mm width with no insulation;
- sloped roof for 7 blocks and plane roof for central block with poor roof floor insulation;
- non-heated and non-insulated basement (neither the base neither the floor), which has no usage value to the kindergarten, except for the storage needs;
- total area of external walls is 2,425$m^2$ ;
- external windows and doors are double glazed with wooden frames with a total area of 437 $m^2$.

**Table 2.3-4:** R-values of main building components.

| Building component | R-value [in (m²·K)/W] |
|---|---|
| Walls | 0.647 |
| Roof | 0.583 |
| Floors | 0.801 |
| Windows | 0.330 |

*Electro-mechanical systems*

*Ventilation system*

The ventilation of the building is carried out mechanically by the central ventilation system (Figure 2.3-9)

**Figure 2.3-9:** Ventilation system of the building.

*Heating system*

The heating of the building is performed with the application of a two gas boiler (120+150 kW) with an efficiency of 90% (Figure 2.3-10). The insulation of the distribution network is insufficient (estimated thermal distribution losses coefficient ≈ 90%).

**Figure 2.3-10:** Heating system of the building (gas boiler, internal radiators).

*Cooling system*

Kindergarten was not supplied with cooling system and no cooling equipment was installed at the kindergarten premises.

*Lighting system*

The building is illuminated using conventional fluorescent lamps and incandescent lamps in building rooms.

**Figure 2.3-11:** Lighting system of the building.

*Summary of energy consumptions of the building*

The total annual primary energy consumption per end use and energy consumption per fuel type is presented in Table 2.3-5.

**Table 2.3-5:** Energy consumption per fuel – current situation [2013].

| Month | Electricity | Natural gas, | |
|---|---|---|---|
| | kWh | m3 | kWh |
| January | 8960 | 8 | 75 |
| February | 6900 | 13996 | 130863 |
| March | 5640 | 12226 | 114313 |
| April | 6980 | - | |
| May | 4100 | - | |
| June | 4280 | - | |
| July | 4600 | - | |
| August | 3420 | - | |
| September | 3020 | - | |
| October | 5440 | 2107 | 19700 |
| November | 7640 | 9115 | 85225 |
| December | 1020 | 15343 | 143457 |
| | 62000 | 52795 | 493633 |

### *2.3.8.2 Intervention analysis*

In order to identify energy efficiency improvement measures for the building, the efforts were focused on the measures for heat insulation of the building envelope which include the following:

- insulation of external walls with extruded polystyrene XPS100;
- insulation of roof floor with mineral wool of 200mm width;
- insulation of non-heated basement floor with extruded polystyrene XPS100;
- replacement of external windows and doors with PVC framed windows and doors with 3 chambers.

The Table below includes the basic information for the above mentioned measures.

**Table 2.3-6:** Heat losses through building envelope elements.

| Building component | Calculated heat losses before interventions, W | Yearly heat losses, kWh/year | Calculated heat losses after interventions, W | Yearly heat losses, kWh/year | Savings, W | Yearly savings, kWh/year |
|---|---|---|---|---|---|---|
| **External walls** | 122154 | 258570 | 25516 | 54010 | 96638 | 204560 |
| **Roof** | 155330 | 328797 | 26341 | 55758 | 128989 | 273039 |
| **Floor** | 76859 | 162691 | 16828 | 35622 | 60030 | 127070 |
| **Old wooden external windows and doors** | 50321 | 106518 | 24067 | 50943 | 26255 | 55575 |
| **TOTAL** | **404664** | **856577** | **92752** | **196334** | **311912** | **660243** |

**Table 2.3-6:** Costs and savings estimation.

| Measure | M.U. | Value | Costs EURO/u.m | Savings, MWh/year | Investment, th. EURO | PayBack period, years | Savings CO2, tone/year | Savings Gas, th. $m^3$/year | Savings, th. EURO/year |
|---|---|---|---|---|---|---|---|---|---|
| Insulation of external walls (including basement) | sqm | 2425 | 48 | 204,6 | 116,4 | 11,8 | 41,3 | 26,50 | 9,91 |
| Insulation of roof floor | sqm | 2650 | 38 | 273,0 | 100,7 | 7,6 | 55,2 | 35,37 | 13,22 |
| Replacement of windows and doors | sqm | 437 | 130 | 55,6 | 56,8 | 21,1 | 11,2 | 7,20 | 2,69 |
| Insulation of basement floor | sqm | 2700 | 38 | 127,1 | 102,6 | 16,7 | 25,7 | 16,46 | 6,15 |
| **Total:** | | | | **660,2** | **376,5** | **11,8** | **133,4** | **85,53** | **31,97** |

### *2.3.8.3 Assessment of interventions and conclusions*

Building envelope thermal insulation has a positive impact on reducing the energy consumption of the building. However various factors must be assessed in order to make a final decision regarding the adoption or rejection of specific intervention proposals. As a final statement it could be inferred that the interventions examined have a great potential of energy saving while being cost-effective. All above estimations have a relative character and are based on the data received from the building manager and partially completed with data from other sources – technical documentation of the building and geo-informational site www.geoportal.md.

# 2.4 Energy efficient lighting

## 2.4.1 Introduction

More than 150 years ago, inventors began working on a bright idea that would have a dramatic impact on how we use energy in our homes and offices. This invention changed the way we design buildings, increased the length of the average workday and jumpstarted new businesses. It also led to new energy breakthroughs from power plants and electric transmission lines to home appliances and electric motors.

**Figure 2.4-1:** Different types of light bulbs.

Like all great inventions, the light bulb can't be credited to one inventor. It was a series of small improvements on the ideas of previous inventors that have led to the light bulbs we use in our homes today. Long before Thomas Edison patented - first in 1879 and then a year later in 1880 - and began commercializing his incandescent light bulb, British inventors were demonstrating that electric light was possible with the arc lamp[35].

By October 1879, Edison's team had produced a light bulb with a carbonized filament of uncoated cotton thread that could last for 14.5 hours. They continued to experiment with the filament until settling on one made from bamboo that gave Edison's lamps a lifetime of up to 1,200 hours -- this filament became the standard for the Edison bulb for the next 10 years. Edison also made other improvements to the light bulb, including creating a better vacuum pump to fully remove the air from the bulb and developing the Edison screw (what is now the standard socket fittings for light bulbs).

The next big change in the incandescent bulb came with the invention of the tungsten filament by European inventors in 1904. These new tungsten filament bulbs lasted longer and had a brighter light compared to the carbon filament bulbs. By the 1950s, researchers still had only figured out how to convert about 10 percent of the energy the incandescent bulb used into light and began to focus their energy on other lighting solutions.

[35]The history of the Light Bulb, available at,http://www.energy.gov/articles/history-light-bulb

By the late 1920s and early 1930s, European researchers were doing experiments with neon tubes coated with phosphors (a material that absorbs ultraviolet light and converts the invisible light into useful white light). These findings sparked fluorescent lamp research programs in the U.S. These lights lasted longer and were about three times more efficient than incandescent bulbs. The need for energy-efficient lighting American war plants led to the rapid adoption of fluorescents, and by 1951, more light in the U.S. was being produced by linear fluorescent lamps.

It was another energy shortage -- the 1973 oil crisis -- that caused lighting engineers to develop a fluorescent bulb that could be used in residential applications. In 1976, Edward Hammer at General Electric figured out how to bend the fluorescent tube into a spiral shape, creating the first compact fluorescent light (CFL).

One of the fastest developing lighting technologies today is the light-emitting diode (or LED). A type of solid-state lighting, LEDs use a semiconductor to convert electricity into light, are often small in area (less than 1 square millimeter) and emit light in a specific direction, reducing the need for reflectors and diffusers that can trap light. They are also the most efficient lights on the market. Also called luminous efficacy, a light bulb's efficiency is a measure of emitted light (lumens) divided by power it draws (watts). A bulb that is 100 percent efficient at converting energy into light would have an efficacy of 683 lm/W. To put this in context, a 60- to 100-watt incandescent bulb has an efficacy of 15 lm/W, an equivalent CFL has an efficacy of 73 lm/W, and current LED-based replacement bulbs on the market range from 70-120 lm/W with an average efficacy of 85 lm/W.

To make LEDs an option for general lighting, researchers next had to focus on improving the efficiency of LEDs -- which in the beginning were no more efficient than incandescent bulbs. In 2000, the Energy Department partnered with private industry to push white LED technology forward by creating a high-efficiency device that packaged LEDs together.

Today's LED bulbs are also six to seven times more energy efficient than conventional incandescent lights, cut energy use by more than 80 percent and can last more than 25 times longer. Taken together, these advancements have led to rapid deployment in the past of couple years in both commercial and residential applications. In 2012 alone, more than 49 million LEDs were installed in the U.S. -- saving about $675 million in annual energy costs-- and as prices continue to drop, LEDs are expected to become a common feature in homes.

### 2.4.2 General lighting information

Lighting upgrades can significantly reduce energy use (by up to 82% depending on the purpose and type of the building). There are two general types of upgrades: a retrofit and an entire luminaire replacement. A retrofit changes only part of an existing luminaire system, such as lamp or control gear. The other option is to replace the entire luminaire with a new luminaire. The decision will depend on a number of factors. Generally, retrofitting requires less upfront capital and can be easily installed, but installing a new luminaire is often more cost effective in buildings that contain older equipment. Full replacement can also be economical where improvements in technology have led to reductions in price[36].

Energy efficient lighting often has a significantly lower heat load than traditional lighting, which means that less energy is required to cool a space. Upgrading lighting can reduce the amount of energy used by heating, ventilation and air conditioning (HVAC) systems.

There is no substitute for good lighting design, which focuses on light quality as well as light quantity. The environment is lit for people so lighting should be both functional and attractive. Understanding some basic lighting concepts can help when designing energy efficient lighting solutions.

- **Luminous flux**: the light produced by a light source (typically a lamp) is measured in lumens (lm). If light is directed towards a surface, rather than scattered and uncontrolled, the light level will be higher on the surface. This is called luminous flux or light intensity and is measured in candela (cd).

- **Illuminance** is the light arriving at a surface and this is measured in lux. Illuminance does not take into account how the surface will respond to the light, only how much gets there. The luminance of a surface is measured in candela per square metre ($cd/m^2$), a white wall will reflect a lot of the light directed and will effectively become a light source, while a black wall will not reflect much light.

- **Luminaire:** also referred to as light fitting or fixture, including the lampholder and lamp.

- **Lampholder:** part of the luminaire that provides electrical connection to the lamp and holds the lamp in place.

- **Lamp**: the light source mounted within a luminaire.

- **Control Gear**: converts the energy supplied to the building into a form that best suits the light source. Include starters and ballasts.

Lighting suppliers most commonly use lumens (lm) as the defining characteristic of the light source. When selecting a luminaire we need to understand how much of the produced light will enter the space and where it will land. When comparing technologies, resist any encouragement from suppliers to focus only on lumens produced. Lighting design software will take into account all areas of light performance.

[36]Energy Saver, energy efficient lighting, Technology Report, Office of Environment and Heritage, Sydney, Australia

Most luminaires consist of a lamp, lamp holder and control gear. The luminaire will also have a means of getting as much light as possible to leave the luminaire and travel in the required direction. This could involve reflectors, louvres, lenses or diffusers. There are thousands of different lamp holders, tens of thousands of different luminaire types, and even more types of lamps. Most common energy efficiency technologies will be analyzed for households and commercial use in separate sections.

### 2.4.3 Energy efficient lighting technology for households

Since widely used old technology lighting will be compared with energy efficient lighting options we have to start with incandescent lighting solutions. The characteristics of commonly used standard light bulbs are;

*Incandescent Light Bulbs*

Incandescent lamps are often considered the least energy efficient type of electric lighting commonly found in residential buildings. Although inefficient, incandescent lamps possess a number of key advantages--they are inexpensive to buy, turn on instantly, are available in a huge array of sizes and shapes and provide a pleasant, warm light with excellent color rendition. However, because of their relative inefficiency and short life spans, they are more expensive to operate than newer lighting types such as compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs).

Since 1 September 2009, household lamps produced for the EU market need to fulfill minimum energy requirements. Conventional incandescent and halogen bulbs which cannot meet these requirements were gradually phased out from the EU market until late 2012.

From September 2009, non-clear (frosted) lamps will need to be of A-class standard according to the EU's lamp energy label. Only compact fluorescent lamps and LED lamps can achieve such high efficiency. All the more inefficient non-clear types will disappear.

Meanwhile, inefficient clear (transparent) lamps will also be gradually phased out. The process began in September 2009 when equivalents of clear incandescent bulbs of 100W or more were required to be of C-class standard, phasing-out incandescent 100W light bulbs. This limit was moved down to lower wattages gradually until 2012 (75W in 2010, 60W in 2011, 40W and below in 2012)[37].

[37]Energy Efficient Lighting, available at, http://eartheasy.com/live_energyeff_lighting.htm

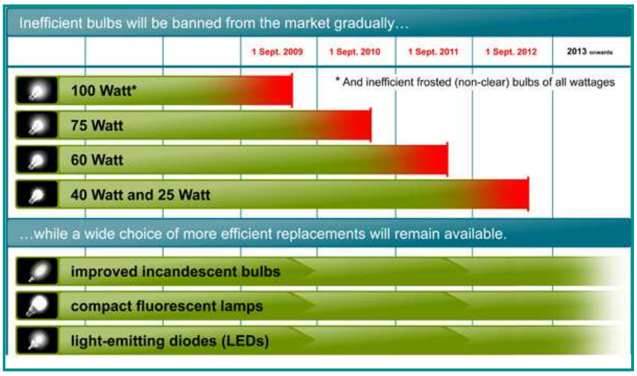



**Figure 2.4-2:** The phase-out process of inefficient light bulbs in Europe.

Due to the lower electricity consumption of the energy efficient alternatives, an average household's total electricity bill will be reduced by up to 15%. This is equal to a net saving of between 25 and 50 € per year, depending on the size of the household and on the number and type of lighting used.

Setting new energy efficiency requirements for light bulbs will save every year over 40 billion kilowatt hours by 2020 – the equivalent of 11 million European household's electricity consumption for the same period. Crucially, it will lead to a reduction of up to 15 million tons of $CO_2$ emissions annually.

After the phase-out of certain types of inefficient light bulbs, consumers in Europe will still have a wide variety of lamps to choose from[38].

*C-class halogen bulbs / improved incandescent bulbs*

Conventional mains voltage halogen lamps do not fulfill the new energy efficiency requirements for household lamps (low-voltage lamps do). But alternative products are already on the market, consumers can choose from two types of halogen lamps with xenon gas filling. When filled with xenon-gas, halogen lamps use about 20 to 25 % less energy for the same light output compared to the best conventional incandescent bulbs.

**Figure 2.4-3:** C-class halogen bulbs.

[38]Changes, bulbs and packaging, available at, http://ec.europa.eu/energy/lumen/overview/whatchanges/index_en.htm

They exist in two versions[39]:

1. Apart from the xenon-gas filling, the socket and the dimensions of the *new generation halogen lamps* are the same as for conventional halogens. They can therefore only be used in luminaires with a special halogen socket. These halogen lamps will remain available after 2016 to be used in luminaires which have this kind of special halogen socket.

2. For improved incandescent bulbs with halogen technology, the improved halogen capsule is placed in glass bulbs shaped like conventional incandescent bulbs with a traditional socket. This makes them one-to-one replacements to conventional incandescent lamps. C-class improved incandescent bulbs are to be further impoved to class B or A from 2016 onwards.

Both versions provide light of equivalent quality to conventional incandescent bulbs, but with normal use last twice as long (2 years). These lamps are fully compatible in size with existing luminaires and dimmable on any dimmer.

*B-class halogen bulbs / improved incandescent bulbs*

A special infrared coating results in further efficiency benefits for filament lamps. An infrared coating applied to the bulb improves the energy efficiency by more than 45% compared to the best conventional incandescent bulbs. However, this is only possible with low voltage lamps. A transformer is in fact needed to make this technology available for mains voltage lamps.

**Figure 2.4-4:** B-class halogen bulbs

The transformer can be a separate unit or a component integrated into the luminaire. It can also be integrated into the bulb itself, which can then replace conventional incandescent bulbs in the same luminaire. As with the C-class lamps both the special socket capsules and the improved incandescent bulbs exist in B-class[40].

[39]C class Halogen light bulbs/improved incandescent bulbs, available at, http://ec.europa.eu/energy/lumen/overview/avariedchoice/chalo/index_en.htm
[40]B class Halogen light bulbs/improved incandescent bulbs, available at, http://ec.europa.eu/energy/lumen/overview/avariedchoice/bhalo/index_en.htm

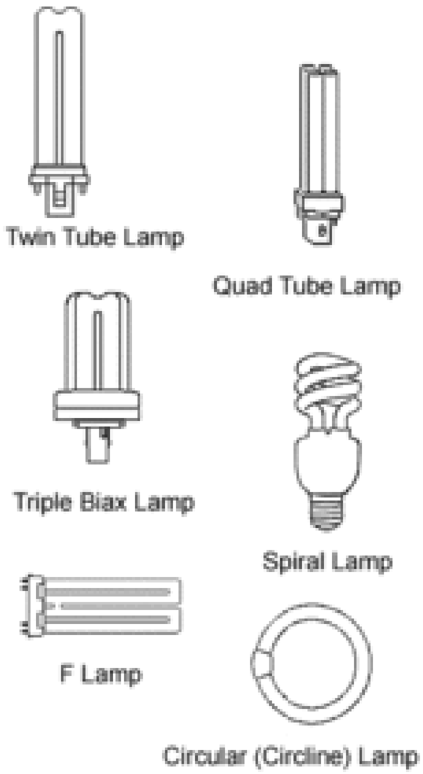
*Compact Fluorescent Lamps (CFLs)*

CFLs are simply miniature versions of full-sized fluorescents. They screw into standard lamp sockets, and give off light that looks similar to the common incandescent bulbs - not like the fluorescent lighting we associate with factories and schools[41].

Compact fluorescent lamps were first commercialized in the 1980's and are known for their long life and high efficiency. A compact fluorescent lamp uses between 65 and 80% less energy for the same light output than conventional incandescent light bulbs.

**CFL Models[42];**

**Twin Tube Lamps:** A CFL that has two parallel tubes are called Twin Tube Lamps. They are designed to fit into lamps, task lights, recessed ceiling lights and wall lights. This type of lamp bulb is also called a "Biax" or "Dulux" lamp.




**Quad Tube Lamps:** Quad Tube Lamps give nearly the same light output as twin-tube CFLs of equivalent wattage. They are only half the length, however. This type of bulb fits better in smaller lamps and similar applications. They are also known as "Double Biax", "PL Clusters" or "PLC" lamps.

**Triple Biax Lamps:** These CFLs generate even more light in a shorter bulb. Because they provide a high amount light output from a bulb that takes up a very small amount of space they are commonly used in fixtures designed for incandescent bulbs, such as table lamps.

**Spiral Lamps:** The shape of a spiral lamp is a continuous tube in a spiral shape. The similarity in shape and light casting qualities to a standard incandescent bulb make this the most popular model of compact fluorescent light bulb.

**F Lamps:** F lamps have two twin tubes, aligned top to bottom instead of side to side like a Quad tube making the shape of the Figure 5: CFL Models bulb resemble an F. This type of CFL is commonly used for task lights and low profile recessed fixtures.

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[41]Compact Fluorescent Bulbs; available at, http://ec.europa.eu/energy/lumen/overview/avariedchoice/fluo/index_en.htm

[42]What are the Different Types of Compact Fluorescent Lights, Jeffrey Orloff; available at, http://saveenergy.about.com/od/efficientlighting/p/CFLModels.htm

**Circular (Circline) Lamps:** Circular lamps were designed for reading lamps and other lamps which use a circular light. There are Figure 3: some individual brands that give the "cool white" light found in a typical fluorescent. Other circlines available, however, have electronic ballasts and give warm light so it is important to make sure you buy the right CFL for what you are lighting

Compact fluorescent lamps sometimes come with an external envelope which hides the gas-filled tubes and makes them look even more similar to incandescent light bulbs. CFLs can last between 6.000 and 15.000 hours, depending on type and use. The lifetime for incandescent light bulbs is only about 1.000 hours. CFLs are known to be a “money saver” because of their high efficiency and lifetime.

**Figure 2.4-6:** CFL light bulb examples

**Advantages of CFL lighting**

- Efficient: CFLs are four times more efficient and last up to 10 times longer than incandescents. A 22 watt CFL has about the same light output as a 100 watt incandescent. CFLs use 50 - 80% less energy than incandescents.
- Less Expensive: Although initially more expensive, you save money in the long run because CFLs use 1/3 the electricity and last up to 10 times as long as incandescents. A single 18 watt CFL used in place of a 75 watt incandescent will save about 570 kWh over its lifetime. At 8 cents per kWh, that equates to a $45 savings.
- Reduces Air Pollution: Replacing a single incandescent bulb with a CFL will keep a half-ton of $CO_2$ out of the atmosphere over the life of the bulb.
- High-Quality Light: Newer CFLs give a warm, inviting light instead of the "cool white" light of older fluorescents. They use rare earth phosphors for excellent color and warmth. New electronically ballasted CFLs don't flicker or hum.
- Versatile: CFLs can be applied nearly anywhere that incandescent lights are used. Energy-efficient CFLs can be used in recessed fixtures, table lamps, track lighting, ceiling fixtures and porchlights. 3-way CFLs are also now available for lamps with 3-way settings. Dimmable CFLs are also available for lights using a dimmer switch.

**Disadvantages of CFLs**

Unfortunately, CFLs have their share of disadvantages and limitations. Most of them stem from the fact that not every bulb is suitable for every job, so it is more a matter of finding the right match. The only real disadvantage as far as I can see is the mercury content.

- While CFLs are supposed to last about 10,000 hours, turning them on and off too frequently can reduce that lifetime substantially. They are unsuitable for places where you would turn on the light only briefly. These bulbs should be used only where they will be left on for a while without being turned on and off frequently.
- While you can buy CFLs for use with dimmer switches, be aware that not all CFLs can be used with them. Check the package before using. A regular CFL not meant to be used with a dimmer switch can burn out quickly. The same applies to using CFLs with timers.
- CFLs when used outdoors need to be covered and protected from the elements. They are also sensitive to temperature, and low temperatures can cause lower light levels. Check the package for suitability for outdoor use.
- CFLs are not suitable for focused or spot lights or where narrow beams of light are required. They are meant only for ambient light.
- Maybe the most alarming thing for environmentally conscious consumers is the presence of mercury in CFLs. Mercury is a toxic metal, and while it doesn't pose any danger when the bulb is being used, it may be released if the bulb is broken, or if disposed incorrectly. These bulbs need to be disposed off very carefully.

*Light Emitting Diodes(LEDs)*

LEDs are solid light bulbs which are extremely energy-efficient. When first developed, LEDs were limited to single-bulb use in applications such as instrument panels, electronics, pen lights and, more recently, strings of indoor and outdoor Christmas lights.

Known mostly as indicator lamps in electronic equipment, LEDs are also increasingly being used for household lighting. LEDs – which stands for light-emitting diode – are a fast emerging technology. Their efficacy as a lighting tool is on par with that of compact fluorescent lamps – and they last even longer[43].

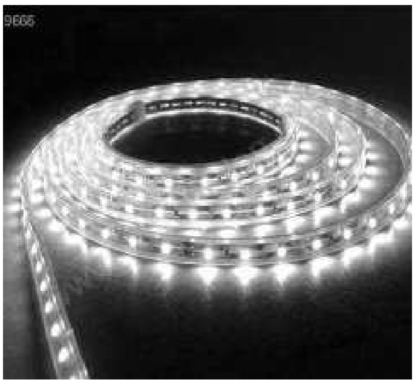


**Figure 2.4-7:** LED rope and linear lights.

[43]LED bulbs; available at, http://ec.europa.eu/energy/lumen/overview/avariedchoice/led/index_en.htm

Solid State Lighting (SSL) uses the emission of semi-conductor diodes to directly produce light, rather than resistance heating of a wire as in incandescent lamps or excitation of a gas as in fluorescent lamps. Electrons and holes are injected into a solid-state semiconductor material. When these recombine, light is emitted at around the wavelength corresponding to the energy bandgap of the material. Once the light is created internally, a high fraction of it must reach the surface and escape rather than be absorbed; this is done either through the shape of the LED or the type of material used. Because these lights can concentrate their emissions in the visible spectrum, they can be very efficient. Different wavelengths can be easily created by using different materials. However, SSL faces the problem that a single LED does not fill the full spectrum and appears colored. Creating a white, general-purpose light causes additional complexity and/or lower efficiency[44].

**Figure 2.4-8:** LED bulbs

LED bulbs for room illumination are new products on the market, but they are already an effective replacement for both clear and non-clear incandescent light bulbs of wattages up to 60. They are likely to become alternatives to the full range of lamps in the near future.

Manufacturers have expanded the application of LEDs by "clustering" the small bulbs. The first clustered bulbs were used for battery powered items such as flashlights and headlamps. Today, LED bulbs are made using as many as 180 bulbs per cluster, and encased in diffuser lenses which spread the light in wider beams. Now available with standard bases which fit common household light fixtures, LEDs are the next generation in home lighting.

A significant feature of LEDs is that the light is directional, as opposed to incandescent bulbs which spread the light more spherically. This is an advantage with recessed lighting or under-cabinet lighting, but it is a disadvantage for table lamps. New LED bulb designs address the directional limitation by using diffuser lenses and reflectors to disperse the light more like an incandescent bulb.

[44]Hadley S. et al,"Emerging Energy Efficient Technologies in Buildings: Technology Characterization on Energy Modeling", May 2004, U.S. Department of Energy

**Figure 2.4-9:** LED spot lights

The high cost of producing LEDs has been a roadblock to widespread use. However, researchers at Purdue University have developed a process for using inexpensive silicon wafers to replace the expensive sapphire-based technology. This promises to bring LEDs into competitive pricing with CFLs and incandescents. LEDs may soon become the standard for most lighting needs.

**Benefits of LED Light Bulbs**

- Long-lasting: LED bulbs last up to 10 times as long as compact fluorescents, and far longer than typical incandescents.
- Durable: since LEDs do not have a filament, they are not damaged under circumstances when a regular incandescent bulb would be broken. Because they are solid, LED bulbs hold up well to jarring and bumping.
- Cool: these bulbs do not cause heat build-up; LEDs produce 3.4 btu's/hour, compared to 85 for incandescent bulbs. Common incandescent bulbs get hot and contribute to heat build-up in a room. LEDs prevent this heat build-up, thereby helping to reduce air conditioning costs in the home.
- Mercury-free: no mercury is used in the manufacturing of LEDs.
- More efficient:LED light bulbs use only 2-17 watts of electricity (1/3rd to 1/30th of Incandescent or CFL). LED bulbs used in fixtures inside the home save electricity, remain cool and save money on replacement costs since LED bulbs last so long. Small LED flashlight bulbs will extend battery life 10 to 15 times longer than with incandescent bulbs.
- Cost-effective: although LEDs are initially expensive, the cost is recouped over time and in battery savings. LED bulb use was first adopted commercially, where maintenance and replacement costs are expensive. But the cost of new LED bulbs has gone down considerably in the last few years. and are continuing to go down. Today, there are many new LED light bulbs for use in the home, and the cost is becoming less of an issue.
- Light for remote areas and portable generators - because of the low power requirement for LEDs, using solar panels becomes more practical and less expensive than running an electric line or using a generator for lighting in remote or off-grid areas. LED light bulbs are also ideal for use with small portable generators which homeowners use for backup power in emergencies.

*Financial Comparison of incandescent, CFL and LED light bulbs*

| | Incandescent | CFL | LED |
|---|---|---|---|
| Light bulb projected lifespan | 1.200 hours | 10.000 hours | 50.000 hours |
| Watts per bulb (equiv. 60 watts) | 60 | 14 | 10 |
| Cost per bulb* | 0,50 € | 3,50 € | 15,00 € |
| KWh of electricity used over 50.000 hours | 3000 | 700 | 500 |
| Cost of electricity (@ 0.13 per KWh) * | 390,00 € | 91,00 € | 65,00 € |
| Bulbs needed for 50k hours of use | 42 | 5 | 1 |
| Equivalent 50k hours bulb expense | 21,00 € | 17,50 € | 15,00 € |
| Total cost for 50k hours | 411,00 € | 108,50 € | 80,00 € |
| Total cost for 25 light bulbs for 50 k hours | 525,00 € | 437,50 € | 375,00 € |
| Savings to household by switching from incandescents | 0,00 € | 7.475,00 € | 8.125,00 € |

* Costs of electricity and bulbs are relevant for Turkey. The results may differ from country to country depending on the prices.

### 2.4.4 Energy efficient lighting technology for commercial buildings

Fortunately, recent technologies have launched a new era of energy-efficient lighting products. Upgrading lighting with today's light sources, fixtures and controls often can cut lighting energy use in half, while maintaining or improving lighting quality. With good design, such lighting improvements typically pay for themselves in energy savings within a few years.

Upgrading lighting offers additional benefits, including reducing the load lighting puts on air conditioning, ventilation and the overall electrical system. Today's efficient lighting comes in a variety of styles and functionalities, offering flexibility for design and business.

Successful lighting design begins with assessing how occupants use the space and their resulting lighting needs. The lighting system should deliver the quantity and quality of light according to those needs.

The quantity of light needed, measured in foot-candles, varies by task. Are occupants walking through a lobby, shopping or performing detailed tasks on small objects? Lighting professionals specify different foot-candle levels in each situation.
Proper lighting quality is essential. The most energy-efficient light sources mounted in the best fixtures will not offer value if lighting quality suffers. Good lighting quality requires an experienced lighting professional who will take steps to maximize daylight, minimize glare, provide appropriate color quality and address other factors. Color quality is critical in most businesses. Lighting experts use two color metrics when evaluating the color from a light source. Both are important to consider:

Color Rendering Index, (CRI) color rendering is the ability of a light source to produce color in objects. The CRI is expressed on a scale from 0-100, where 100 is the best in producing vibrant color in objects. A CRI of 80 or more is considered excellent for most interior lighting applications.

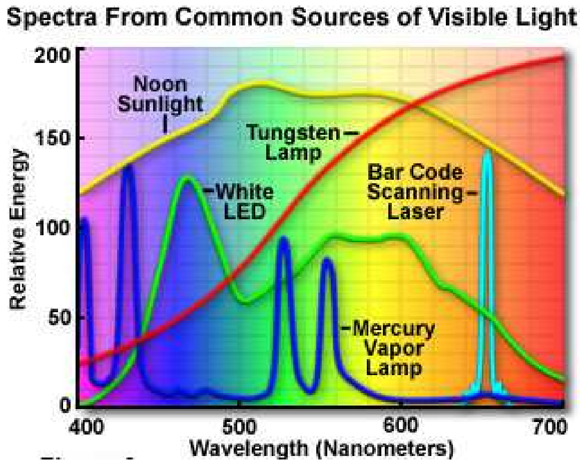



**Figure 2.4-10:** Common Sources of Visible Light.

Correlated Color Temperature, The colour appearance of the light source is represented by the correlated colour temperature (CCT). This is often shown on lamps as colour temperature with a unit of Kelvin (K). The higher the CCT the 'cooler' or blue the light is – 2500 K has a very warm or yellow appearance where as 4000 K is a cool blueish light. 4000 K is common in office areas. A fluorescent tube may have a colour temperature of 3000 K and a CRI of 80. A tube may also be available with a colour temperature of 4000 K and also have a CRI of 80. These tubes will represent the colours in objects equally well, but will appear different in colour.

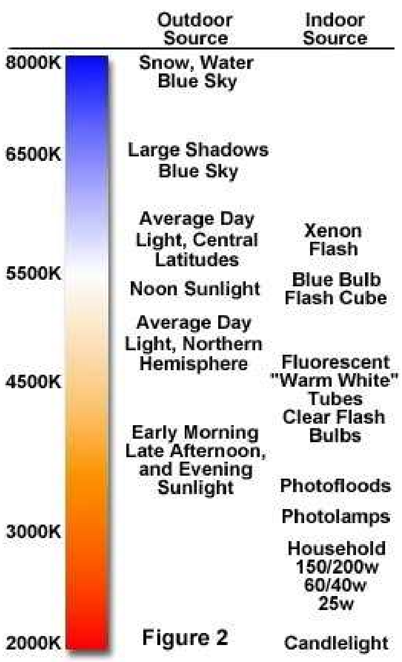



**Figure 2.4-11:** The Electromagnetic spectrum.

**Figure 2.4-12:** An example of good lighting design.

## COMMON TYPES OF LIGHTS

### *General lighting service incandescent lamps*

GLS lamps are no longer available to purchase due to their poor efficiency. These lights have often been used in auditoriums and theatres where dimming is needed. Few sites remain where large quantities of these lamps are installed.

### *Halogen lamps*

Halogen Lamp

Halogen lamps are also an incandescent lamp. Where most incandescent lamps contain a tungsten filament and some gasses (typically argon and/or nitrogen), the halogen lamps also contain iodine. This significantly prolongs lamp life and allows the filament to burn hotter and therefore whiter. Halogen lamps are generally more efficient than standard incandescent lamps.

Halogen Dichroic Lamps

Dichroic halogen lamps have coatings on the inside of the reflector that are able to reflect visible light, but are 'clear' to infra-red (heat) and ultraviolet (UV) light. Therefore the majority of heat and UV light produced is passed through the back of the lamp. Dichroic lamps can cause fires when used in combination with flammable substances or ceiling insulation.

In most cases where dichroic lamps are used, the luminaire does little more than hold the lamp in place. The control and direction of produced light is handled by the lamp and its integrated reflector.

*Fluorescent lamps*

T8 lamp compared with a T5 lamp

Fluorescent lamps come in a variety of forms. Linear lamps and compact lamps are the most common types covered by this report. Fluorescent lamps contain mercury which causes the tube to produce light mostly in the UV region of the spectrum. UV light is not useful for general lighting and so the light is shiftedto the visible spectrum by a combination of coatings. These coatings are seen as white on the inside of the tube and are known as phosphors. These can provide light in a variety of white shades, depending on the blend of phosphors used. The fluorescent tubes are sometimes known as low pressure mercury tubes.

All fluorescent lamps work in the same manner, regardless of their shape.

*High intensity discharge (HID) lamps*

Mercury Vapour lamp

Mercury vapour lamps, sodium vapour lamps and some types of metal halide lamps can be very similar in appearance.

*Mercury vapour lamps*

Sodium Vapour lamp

These are very similar to fluorescent tubes as they use mercury and phosphors. These lamps are not generally used in new buildings as metal halide lamps are more efficient and offer better light quality.

Metal halide lamp

They were commonly used in high bay fittings and old style street lights. They were occasionally used in downlights within large spaces, such as the foyers of tower buildings. These lamps produce a blueish light.

*Sodium vapour lamps*

Sodium vapour lamps are generally used in street lighting and occasionallyin car park lighting. These lamps use sodium instead of mercury and the light they produce is very orange-yellow in colour. Sodium vapour lamps have become less popular with lighting designers over recent years, most likely due to the better light quality of metal halide lamps.

***Metal halide lamps***

These lamps have become quite popular over the last ten years due to advances in technology. They contain a number of different metal halides which produce different wavelengths within the visible spectrum. A good white light is produced by metal halides. These lamps are used in a variety of applications because they are efficient and have long operating lives.

***Induction lamps***

These lamps are similar to fluorescent lamps, except that they do not receive their energy by electrodes creating an arc. The mercury in a typical induction lamp is excited into producing light by the use of a powerful magnetic field. The lamps are operated by electronic control gear.

***Light emitting diodes (LED)***

Electricity is passed through a semiconductor, which produces photons (a basic unit of light). The semiconductor can be made from many different mixes of materials, which means that photons can be produced in a variety of colours. LED can produce more useable white light per unit of energy than metal halide, sodium vapour, fluorescent and halogen light sources.

LED produce a lot of light from a very small source, which helps to control where the light shines. LED can cause a great deal of glare if not managed properly.

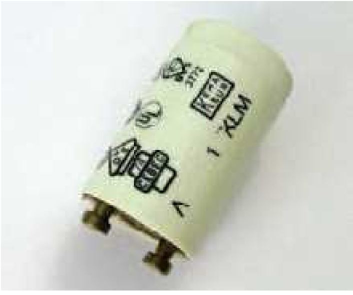
***Ballasts***

Conventional Magnetic

Conventional Starter

Generally, these used to be a copper and iron device, which was quite heavy and relatively inefficient. Conventional ballasts are known by a variety of names, including wound ballasts, magnetic ballasts and copper ballasts. Most conventional ballasts require an external starter to be in circuit.

Electronic ballast systems do not use an external starter. When looking at an installation on-site, if you can see a starter you know that a magnetic ballast is in use.A conventional ballast and starter, when powered from cold, will typically flicker three to four times and then turn on.



An electronic ballast will simply start the lamp. A slight dimness may be detected at first (less than a second) and then the lamp will light up.In the cases where electronic ballasts are used, it is very unlikely that energy use can be substantially reduced at the luminaire.

### 2.4.5 Energy efficient lighting in practice

Integrating all of the possible energy reduction techniques into an overall lighting strategy creates a holistic solution for upgrading projects and is best practice. The following steps should be followed:

1. Assess the natural light available and potential for improvement (e.g. skylights) – introduce natural light into open spaces such as warehouses
2. Link artificial light use to the natural light levels (daylight linking) using sensors and smart control systems to minimize energy use
3. Assess options for zoning, de-lamping, dimming or multilevel switching to reduce energy consumption
4. Identify low activity areas and assess use of occupancy sensors (will be covered in section BEM)
5. Review zoning and increase amount of zones (if appropriate) to allow lights to be turned off when areas are not used
6. Identify lights that could be upgraded with more energy efficient lighting. Control systems often have a major part to play in energy efficient design and the estimate of the savings, and therefore should always be considered.

### 2.4.6 Proposal for implementation – Municipality of Tekirdağ

In order to examine the applicability of energy efficient lighting system in municipal buildings, a case study was prepared. The Additional Services Building of Tekirdağ which built in 2011 was selected to set an example for energy efficient lighting implementation in the municipal buildings. The building was chosen for following reasons:

- The building was recently built. Energy efficient lighting systems such as LED, T5 fluorescent and occupancy detectors etc.were installed.
- Building is visited by many citizens therefore sets a good example for the visitors, employees, raise awareness regarding energy efficiency and low carbon technologies.


**Figure 2.4-13:** Topography of the Additional Services Building of Tekirdağ.

### 2.4.6.1 Current situation of the building

6 storey building is mainly used as an office. Basement floor is archive, where all the documents are kept. Ground floor serves as tax, bill and ticket payment center and it is heavily occupied by citizens during the work hours. Rest of the floors are used as open office occupied by municipal employees such as ICT department, Supporting services etc. Attic is used as refectory and cafeteria.

*Climate data*

Climate of Tekirdağ is similar to Mediterranean climate. Summers are hot and dry, most of the rainfalls are during winter and spring. In inland, winters are colder. Average rainfall is 590 mm and even higher up to 725 mm. Temperature below 0°C more than 30 days; over 30 °C 15 days occur in a year. During the year, temperature changes between -13,5°C and +37,6°C.

**Table 2.4-1**: Basic characteristics of the building.

| Characteristic | Value |
|---|---|
| Type of use | Office |
| Total area [$m^2$] | 875 |
| Total volume [$m^2$] | 2,200 |

**Table 2.4-2**: Usage profile.

| Characteristic | Value |
|---|---|
| Work hours | 8 |
| Days of operation | 5 |
| Months of operation | 12 |
| Heating period | 10/10 to 30/4 |
| Cooling period | 1/6 to 31/8 |
| Average indoors heating temperature [°C] | 22 |
| Average indoors cooling temperature [°C] | 26 |
| Lighting level [lux] | 500 |
| Lighting power per unit area for reference building [W/$m^2$] | 10.8 |
| Lighting power per unit area for the building [W/$m^2$] | 7.15 |

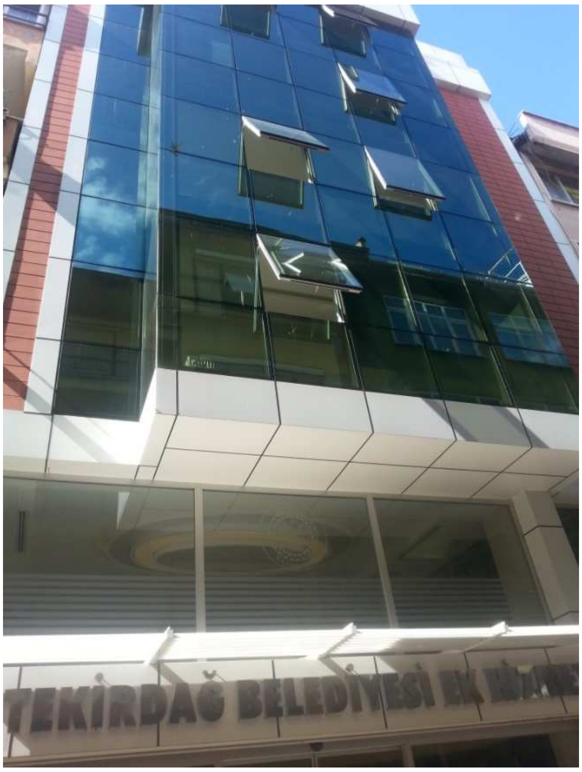



**Figure 2.4-14:**The Additional Services Building of Tekirdağ.

*Mechanical systems*

The air conditioning of the building is carried out by two VRF units with a cooling capacity of 28 kW and 31.5 kW heating for each and a performance coefficient (EER) of 3.2 and (COP) of 3.7 (Figure 2.4-15). The cooling is distributed by interior duct units. There are split air conditioners which provide cooling to server room. Alongside with VRF system, natural gas fired combi- boiler unit produces hot water for both heating and domestic hot water use. A conventional radiator heating system was also installed. (Figure 2.4-15).


**Figure 2.4-15:** VRF unit and radiator distribution system.

*Lighting system*

Building lighting system is well designed using decorative hidden LED system as well as LED spot and T5 fluorescent fixtures. The types of the lights used in the building are 4X14 W T5, 10 W LED Spot, hidden LED rope 14.4 W/m2, 2X18 W T8, 4X18 W T8, and 14 W CFL. Total actual power was estimated to be 7.15 W/m2 which is waybelow national average of 10.8 W/m2 for offices[45]. According to Building Energy Performance Calculation Methodology Annex F, lighting level of office is 500 Lux.

4X14 W T5 Fluorescent light

10 W LED spot

Hidden LED rope

Hidden LED rope

CFL with motion detection

18 W downlight

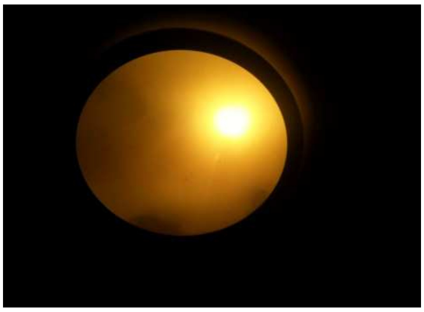


**Figure 2.4-16:** lighting fixture of building

*Summary of energy performance of the building*

Annual energy consumption of the building is shown in the table 3. Due to the lack of electricity consumption data, total energy consumption calculation is limited with natural gas and lighting energy consumption.

[45]ANSI/ASHRAE/IESNA Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings, Atlanta, USA.

**Table 2.4-3**: Final energy consumption [in kWh/m²] – current situation.

| End use | Energy consumption [kWh/m²] |
|---|---|
| Natural gas | 57.0 |
| Lighting | 9.14 |
| RES contribution | 0.0 |
| Total | 66.14 |

The total annual primary energy consumption per fuel type, including the respective $CO_2$ emissions, is presented in Tables 4 and 5.

**Table 2.4-4**: Primary energy consumption – current situation

| End use | Energy consumption [kWh/m²] |
|---|---|
| Natural gas | 63.3 |
| Lighting | 21.0 |
| RES contribution | 0.0 |
| Total | 84.3 |

**Table 2.4-5**: Energy consumption and $CO_2$ emissions per fuel – current situation

| Fuel type | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] |
|---|---|---|
| Electricity (lighting) | 9.14 | 4.8 |
| Natural Gas | 57.0 | 10.7 |
| Total | 66.14 | 15.5 |

### *2.6.4.2 Business as usual scenario analysis*

The aim of the study is to assess applicability of an energy efficient lighting installation in a municipal level. In this case study, actual implementation of lighting system is being analyzed and compared with common lighting installation in buildings.

***BAU scenario***

If common approach was taken in 2011, lighting system of Additional Services Building of Tekirdağ would have been a type of T8 fluorescent. Therefore, to compare actual implementation with common lighting applications, T8 lighting fixtures were chosen as BAU scenario for building.

Total cost of T8 lighting installation and operational costs are taken into account for comparison. The estimated total annual primary energy consumption and energy consumption per fuel type, is presented in Tables 6 and 7.

**Table2.4-6**: Primary energy consumption- BAU.

| | Energy consumption [kWh/m²] | |
|---|---|---|
| | Current building | BAU |
| Natural Gas | 63.3 | 63.3 |
| Lighting | 21.0 | 96.1 |
| RES contribution | 0.0 | 0.0 |
| Total | 84.3 | 96.1 |

**Table 2.4-7**: Energy consumption and $CO_2$ emissions - BAU.

| Fuel type | Current building | | After intervention No1 | |
|---|---|---|---|---|
| | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] |
| Electricity | 9.14 | 4.8 | 14.2 | 7.45 |
| Natural Gas | 57.0 | 10.7 | 57.0 | 10.7 |
| Total | 66.5 | 15.5 | 51.0 | 18.15 |

### 2.6.4.3 Assessment of interventions and conclusions

Analysis clearly shows that current lighting application of municipal building consumes less energy and emits less $CO_2$ emissions. Even better results would have been achieved if LED technology was implemented in all areas of the building.

**Table 2.4-8**: Current situation vs BAU.

| Assessment category | Current Situation | BAU |
|---|---|---|
| Difference of Initial cost [€] | 1,650 | 0 |
| Annual benefit [€/year] | 470 | 0 |
| 20-years benefit (present values) [€] | 5,365 | 0 |
| Net present value [€] | 3,715 | 0 |
| Payback time [years] | 3.5 | 0 |
| Annual electricity savings [kWh/year] | 4,468 | 0 |
| Direct $CO_2$ emissions [kg $CO_2$/m$^2$] | 0.7 | 8 |

# 2.5 Building energy management systems

## 2.5.1 Introduction

An intelligent building requires a sophisticated building automation system to manage a large set of actuators and equipment. Building energy management is a fundamental and important issue regarding building automation[46]. Building Energy Management Systems (BEMS) are currently being developed for application in buildings for energy and environmental management. The main objective of the BEMS is to contribute to the continuous and effective energy management of the building thus achieving significant energy and cost savings. In addition, the performance of a BEMS is directly related to the amount of energy consumed in the buildings and the comfort of the occupants of the building[47]. Therefore, the main goal of a BEMS is twofold; achieving energy efficiency and satisfy the occupants' comfort.

Historically, BEMS were developed from automatic control of HVAC (heating, ventilation, air-condition) systems[48]. The majority of recent developments have followed the advances made in computer technology, telecommunications, information technology, office automation, security and others[49]. The next step in facilitating "green buildings" development is the remote control and real time monitoring of the energy consumption of the building[50], that enable energy end-users to control the operation of the appliances and to optimize functions for the reduction of energy consumption[51].

BEMS are designed to be interoperable and with the ability to be connected to one or more specified building automation and control devices/systems through open data communication network or interfaces performed by standardized methods, special services and permitted responsibilities for system integration[52].

BEMS are a widely accepted and adopted technology for homes, buildings, residential and industrial complexes[3] and are generally applied for the control of active systems, i.e. heating, ventilation, and air-conditioning (HVAC) systems, hot water, lighting, security, fire alarms, sprinklers, pumps and lifts, while also determining their operating times[53,54].

During the last decades, various policies have been put into effect for promoting energy efficient buildings. In this direction, the Directive 2002/91/EC on "Energy Performance of Buildings (EPBD)" was established. The objective of the specific Directive is to promote the improvement of the energy performance of buildings

[46] Yang and Wang, 2013
[47] Yang and Wang, 2012
[48] Figueiredo and Martins, 2010
[49] Avgelis and Papadopoulos, 2009
[50] Meyers et al., 2010
[51] Marinakis et al., 2013a
[52] prEN 15232, 2006
[53] Marinakis et al., 2013b
[54] Siroky et al., 2011

within the European Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness[55]. The recast of EBPD, Directive 2010/31/EU, focuses more on automation, control and monitoring systems and encourages the use of active control systems and intelligent metering systems for energy saving purposes[56].

The European standard EN 15232 on "Energy performance of buildings- Impact of building automation, control and building management" was developed to support the European Directive on EPBD[57]. EN 15232 makes it possible to qualify and quantify the benefits of building automation and control systems, developing a method to define minimum requirements of these systems[58]. Also, four different efficiency classes for buildings (A,B,C and D) were introduced according to building automation and control systems and technical building control systems installed, whereas a function list and assignment to each energy class is described[59].

The Directive 2012/27/EU sets an updated goal of zero-energy or even positive-energy buildings which became a high priority for multi-disciplinary researchers related to building engineering and physics. In detail, the aim and scope of the entitled "20-20-20" Directive is "to ensure the achievement of the Union's 2020 20% headline target on energy efficiency and to pave the way for further energy efficiency improvements beyond that date"[60], in other words aims at a 20% reduction on energy consumption; 20% contribution of renewable energy sources to total energy production; 20% reduction of greenhouse gases in comparison with 1990 levels, before 2020[61].

According to British Security Industry Association, between 60-80% of a typical building's energy consumption can be controlled via building energy management systems. The monitoring and supervision of energy performance data through the application of a BEMS can potentially result in energy savings of 10-40% in commercial buildings, 31% in restaurants, 25% in hotels, 39% in offices, 49% in shopping centers, 18% in hospitals, 34% in schools/universities and 27% in residential buildings[62,63].

The global BEMS market will grow at a CAGR (Compound Annual Growth Rate) of 8.9% during the period 2011–2020 driven mostly by the emergence of Asia–Pacific markets and East European markets[64].

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[55] EC, 2003
[56] Ippolito et al., 2014
[57] CSN, 2007
[58] prEN 15232, 2006
[59] ES, 2007
[60] EC, 2012
[61] EC, 2010
[62] Ahmed et al., 2010
[63] DIN EN, 2007
[64] Reportlinker, 2012

### 2.5.2 The Structure of a Building Energy Management System

The term BEMS includes all products and processes for automatic control (including interlocks), monitoring, optimization, operation, human intervention and management to achieve energy efficient, economical and safe operation of building services. In particular, a building automation system for energy savings and consumption control includes:

- a supervisory system,
- one or more controllers,
- input/output units (relays, dimmer etc.),
- sensors (internal thermometer, motion detector, brightness sensor etc.),
- sockets and switches to control loads.

All components are connected to a network based on a hierarchy and a communication protocol. The main concept of an intelligent environment, controlled by BEMS, is presented in Figure 2.5-1. Occupants interact with different objects and devices, within a space equipped with different sensors and actuators. An automatic controller system implements some sort of intelligence and controls these devices, interpreting the environmental information gathered by sensors, determining what action to take, and commanding the actuators towards taking appropriate action upon the environment. These systems are able to create appropriate environment for occupants without requiring any order from them[65].

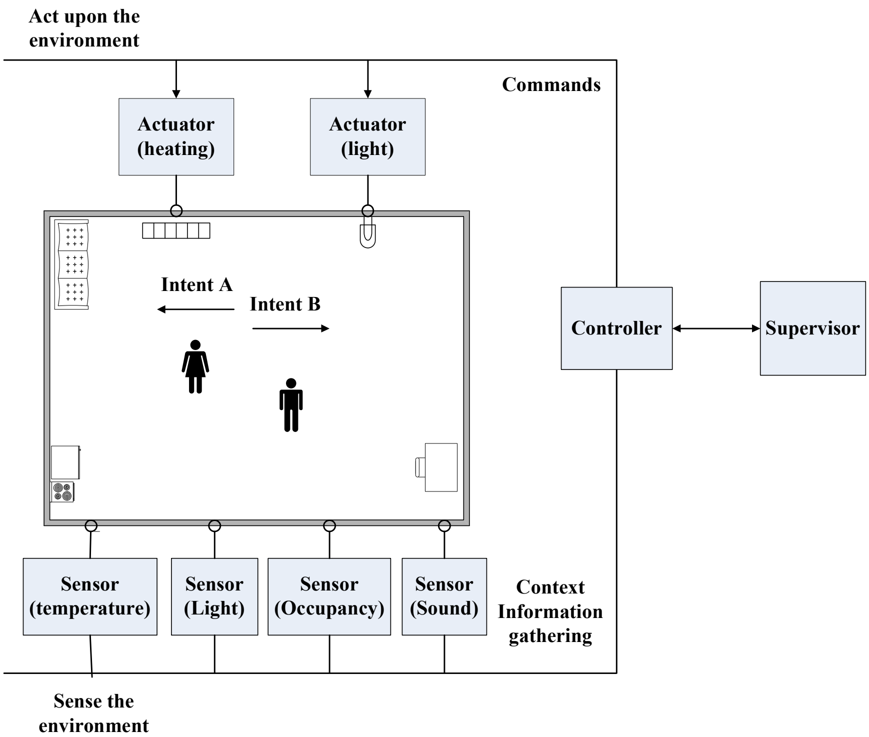



**Figure 2.5-1:** Overview of an intelligent environment. The diagram depicts a smart-home with a BEMS consisting of sensors, actuators, controller and supervisory modules.

[65] Carreira et al., 2013

The hierarchy and topology of BEMS, as presented in Figures 2.5-2 and 2.5-3, comprise three levels of system integration which include:

- Top level: The main goal of the top level devices is the supervision, while energy reports, statistics and graphical representations are also available. The user can monitor in real time the operational status of the devices and the respective energy consumption. Useful recommendations help user to minimize energy consumption by modifying the automation system.
- Middle level: The main goal of the middle level devices is the control of a variety of applications installed in the building. Controllers receive data from sensors and sent commands to actuators.
- Bottom level: The bottom level contains the subsystems such as heating, ventilation and air-conditioning systems, lighting system, hot water system, fire protection system, elevator system, security system and others.

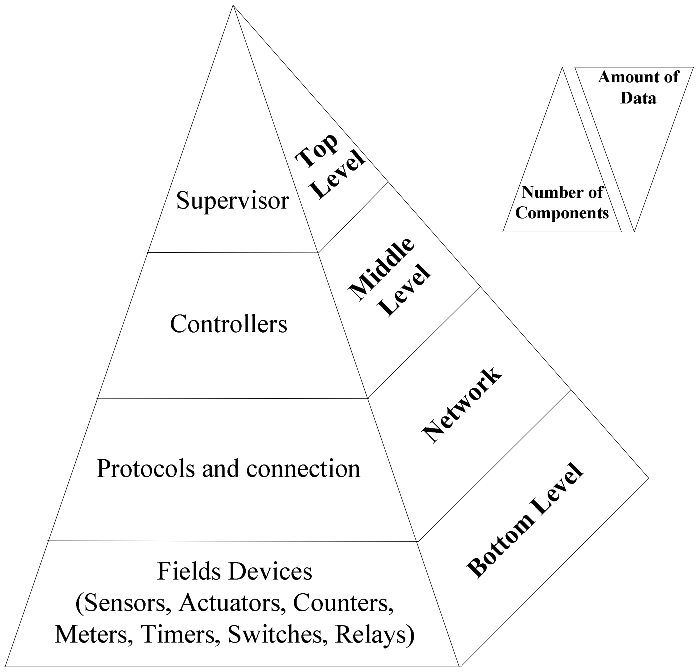



**Figure 2.5-2:** The hierarchy of Building Energy Management Systems.

The higher levels of the pyramid need to handle multiple systems thus requiring higher amount of data whereas lower number of components are included[66].

[66] Marinakis et al., 2013b

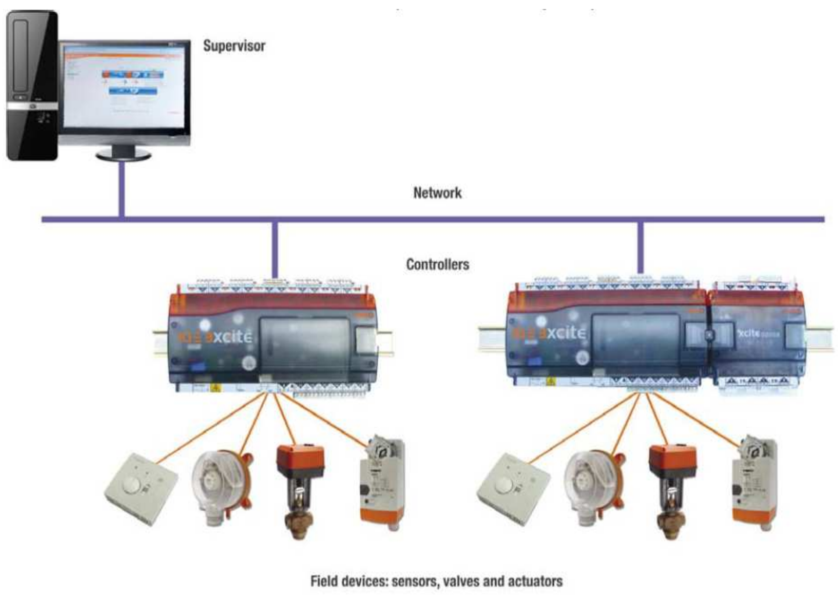



**Figure 2.5-3:** BEMS topology[67].

*2.5.2.1 Top Level*

The supervisory and integrated control processes are mainly implemented by Supervisory Control and Data Acquisition (SCADA) or Kilavi[68] platforms. The supervisory systems are suitable for the management of many dotted devices in large scale buildings. The main goal of a supervisor module is to monitor and control globally the entire distributed systems[69], integrating different types of information coming from the several technologies present in modern buildings- ventilation and temperature control systems, computer network, lighting control systems, etc. The data from building automation systems, including meters, I/O units and sensors are transferred through a controller to a PC. An advanced control structure is composed by two inter-related levels[70]:

- An operational level; usually software (e.g. Excel, Visual Basic, MatLab) which has the ability to provide organized and statistically analyzed data sets regarding energy use in the buildings and their energy efficiency and economic performance. The tool processes data, providing averages, pick-load, statistics and graphs regarding electrical consumption and economic impact. Hence, the energy end-users identify the weak points through real time monitoring and comparisons of energy consumption profiles from different time periods (Figure 2.5-4).

[67] TREND
[68] Oksa et al., 2008
[69] Fiqueiredo and Martins, 2010
[70] Figueiredo and Costa, 2012

**Figure 2.5-4**: Example of a supervisor software interface[71].

At the same time, this management tool has the ability of running alternative optimization scenarios for achieving "intelligent" management of the building's electric loads towards efficient energy and environmental management. After that, the tool sends the command to the controller in order to change the operation of individual units. The philosophy of a supervisory system is presented in Figure 2.5-5.

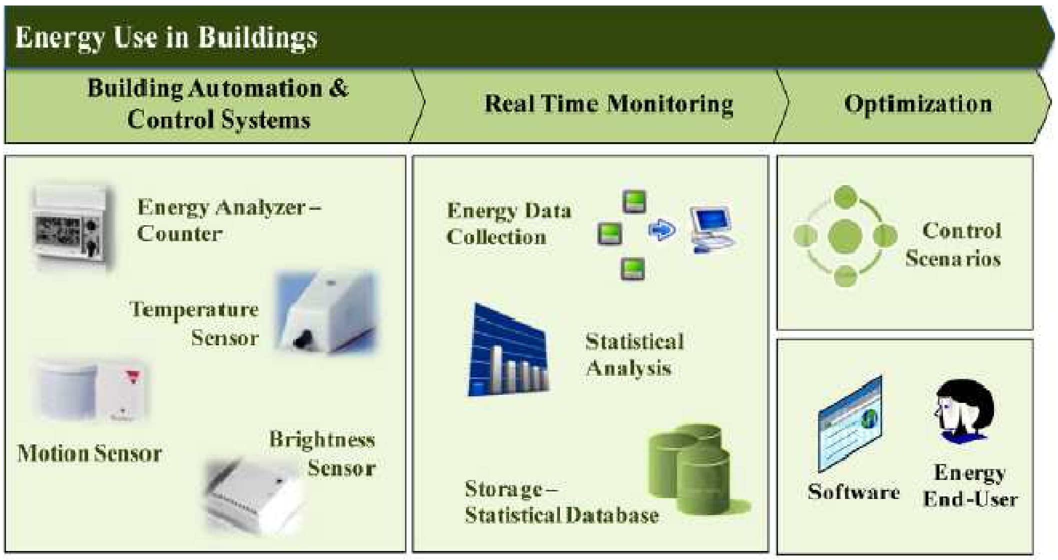



**Figure 2.5-5**: The philosophy of a supervisory system.

- An interactive level; mainly Human Machine Interface (HMI). HMI is the part of the machine that handles the communication between the system and the user. Push Button panels, Membrane Switches, Rubber Keypads and Touch screens are examples of HMI (Figure 2.5-6). The HMI application starts the communication procedure and the supervisory application responds to its requests.

[71] SIELCO, 2007


**Figure 2.5-6:** Examples of interactive devices; a) Push button panel, b) Membrane Switches, c) Rubber Keypads and d) Touch screen.

### *2.5.2.2 Middle Level*

In the specific level, a network of local and master controllers controls a variety of variables. The process is described in Figure 2.5-7, where a sensor produces and sends data to controller. The controller communicates with the supervisory appliance (SCADA or Kilavi platform) and receives information (commands) on how to control actuator in order to achieve energy efficiency and desirable comfort, at the same time.

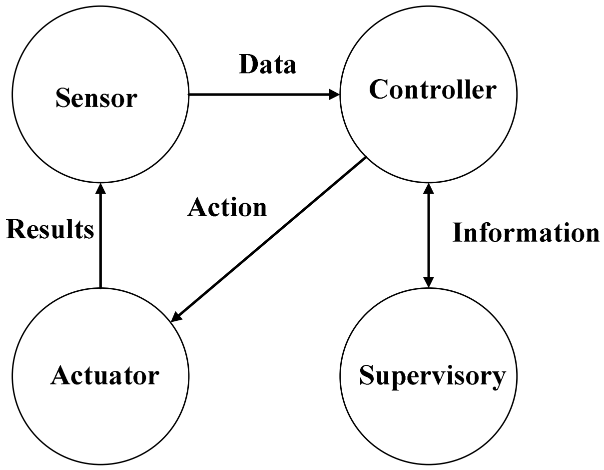



**Figure 2.5-7:** Control process in a Building Energy Management System.

The most commonly used controllers are the Programmable Logic Controllers (PLCs), which are a process control system based on a set of digital and analog inputs and outputs received from the assigned sensors and actuators[72].

[72] Marinakis et al., 2013b

In fact, PLC is a computer that can be programmed to produce desirable outputs by receiving specific inputs. Also, PLCs' operational principles are similar to those of the computers, thus, apart from switching on/off relays, several estimations, measurements and processing of analog and digital signals can be performed.

In brief, a Programmable Logic Controller consists of I/O units, a Central Processor Unit (CPU), a power supply unit and a programming device (Figure 2.5-8). The CPU unit receives input data (sensor, push button etc.), processes them through the installed program and returns output actions (start motor operation, turn on switch etc.). When an input is activated, voltage is developed and the logical value "1" is registered in input memory. In opposite case (low or zero voltage as input), the logical value "0" is registered. Then, CPU runs the installed program and depending on input value, the output value is decided and registered in respective output buffers.


**Figure 2.5-8:** Components of PLC.

An example of PLCs' operation is presented in Figure 2.5-9. When the user turns the switch in position ON, a voltage is developed and the logical value "1" is registered in input memory. The CPU runs the installed program and decides the appropriate output value. The value is registered in the output memory, which sends a relative command to turn the light on.

### *2.5.2.3 Network*

The data exchange takes place both between and within the different levels of BEMS, using numerous systems and communication protocols for home and building automation[73]. Building automation technologies such as Profitbus, BACNET or home automation protocols like X10, European Installation Bus (EIB) and LonWorks or wireless networks such as ZigBee are usually utilized[74]. A general BEMS network is presented in Figure 2.5-10. The specific levels of a BEMS could be connected to each

[73] Wacks, 2002
[74] Kolokotsa et al., 2011

other in three ways or a combination of these ways: a) wired, b) wireless and c) wed-based.

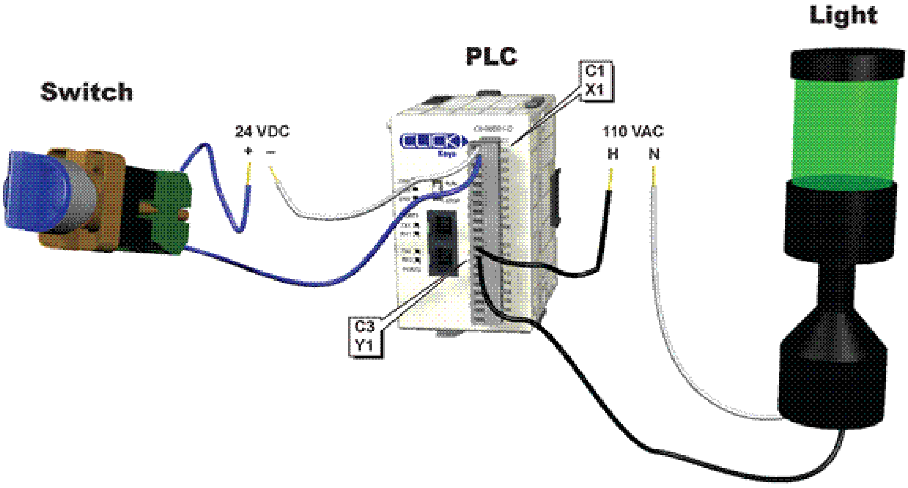



**Figure 2.5-9:** Example of operation of PLC.

Wired

Most building automation networks consist of primary and secondary buses which connect the higher level with lower level devices. For the upper communication level, between supervisory and control modules, Ethernet bus is preferred, because of its great accessibility[75] and its compatibility with other common networks, namely ModBus, BacNet and LonWorks[76]. All the other units of an installation, such as input-output (I/O) units, energy meters and sensors are connected through a pair of wires to the controller, which processes the signals coming from the various bus networks[77]. Examples of physical connectivity between devices are optical fibers, Ethernet, ARCNET, RS-232 and RS-485[29].

Wireless

The wireless communication technology has progressed rapidly over the last decade. In the building sector wireless applications include building automation, indoor environmental monitoring and emerging technologies[78]. The benefits of wireless sensors for buildings include portability, flexibility, fast equipment setup, time synchronization of data collection, negligible occupant disruption during the measurement, and wiring time and cost savings. On the other hand, the major drawback is its high equipment costs[79].

Web - based

The web-based BEMS refers to the highest level functions of a building automation system, such as energy management, maintenance management, overall facility operational management, and is connected to the enterprise resource management system for the entire building or the group of buildings being managed[80].

[75] Neumann, 2007
[76] Figueiredo and Costa, 2012
[77] Marinakis et al., 2013α
[78] Wu and Clements-Croome, 2007
[79] Jeong et al., 2008
[80] Capehart B. and Capehart L., 2007

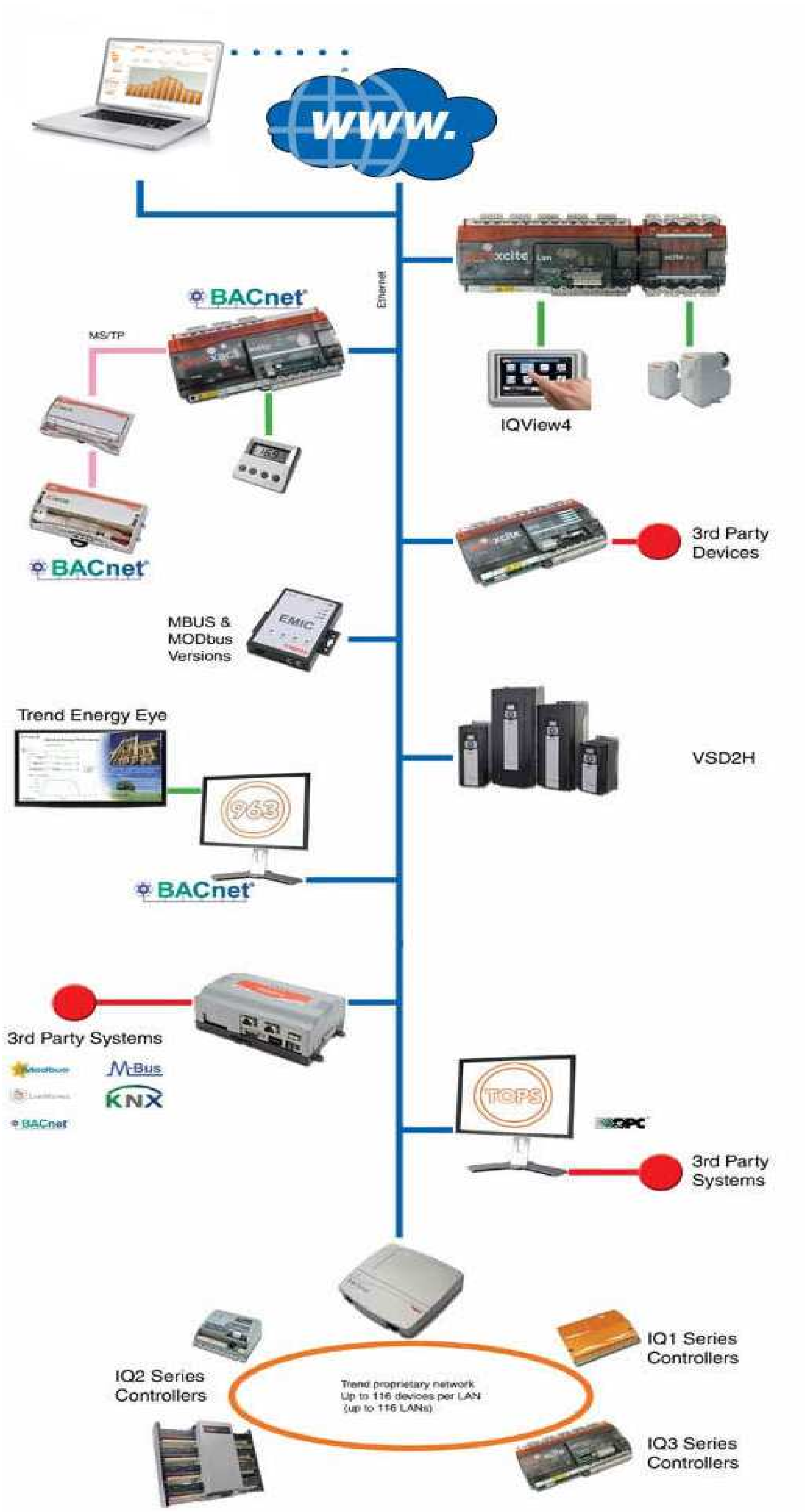



**Figure 2.5-10:** BEMS network[81].

[81] TREND

Protocols and Standards

Many systems and communication protocols have been developed at international level to support the interoperation between BEMS network devices. Specific examples are: BACnet, LonWorks, European Installation Bus (EIB)/ Konnex (KNX), ProfiBus, X-10 international standard for communication among electronic devices, Consumer Electronics Bus (CEBus), Home bus System (HBS) and C-Bus communication protocol for home and building automation[82,83,84,85]. Wireless network protocols such as ZigBee are also available[86]. The main features of the specific protocols are summarized in Table 2.5-1.

**Table 2.5-1:** Protocols used in building automation[87].

| | Application Target | Bus/ Net | Communication Method | Addressing Schemes |
|---|---|---|---|---|
| BACnet | Building Automation | Net | Master-Slave | All |
| ZigBee | Process, discrete control and building automation | Net | Peer-to-peer | Multi-, broadcast |
| Konnex (EIB) | Building Automation, electronics installation | Bus | Peer-to-peer | Multi-, broadcast |
| ProfiBus | Process, discrete control and building automation | Bus | Master-Slave and token pass | Multi-, broadcast |
| LonWorks | Discrete control, building automation | Net | Peer-to-peer | All |
| C-Bus | Lighting Control | Net | Master-Slave | All |

### *2.5.2.4 Bottom Level*

The bottom level of a BEMS includes the field devices for building automation (sensors, actuators and valves). The field devices send or receive data directly to/from controller, in order to control and monitor variables such as temperature, luminosity, air quality etc.

Sensors

Sensors are devices that are used for the detection and measurement of a variable. Sensors constitute a kind of conversion mechanism, which perceives and converts mechanical, magnetic, thermal, optical and chemical changes in electric current and voltage. In this way, physical quantities are understood by an observer and can be processed by electronic devices, such as PLCs. In the following section, an extensive summary of the types of sensors is available.

[82] Wacks, 2002
[83] Ningbo et al., 2004
[84] Evans, 1991
[85] Honda, 1990
[86] Batista et al., 2013
[87] Kolokotsa et al., 2011

- Temperature Sensor. Temperature sensors include thermocouple (T/C), Resistance Temperature Detector (RTD), Thermistor and temperature sensor with chip. Figure 2.5-11 depicts the various types of temperature sensors.

a

b

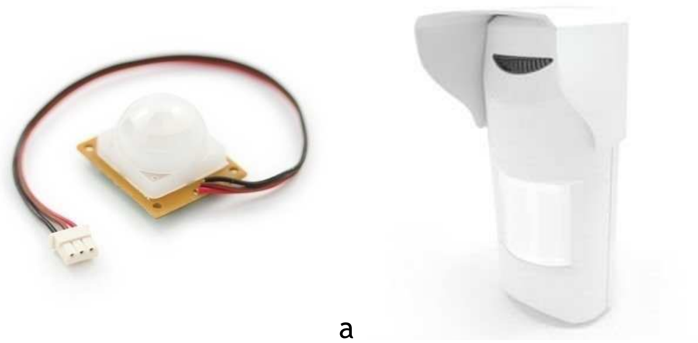
c


d

**Figure 2.5-11:** Various types of temperature sensors. a) Thermocouple, b) RTD, c) Thermistor and d) Chip.

- Motion Sensor or radar. There is a variety of motion sensors, such as PIR technology sensors and double technology radar, or roof radar, outdoor motion radar and secret radar that are connected to and activate other devices such as cameras, lights and alarm system. The most common are the PIR (Passive Infrared) technology sensors, which are widely used in homes, office buildings, hotels etc. These electronic devices have the ability to measure the radiation of infrared light emitted by the objects they focus on. The PIR sensor is a part of an integrated system that is placed in a supervised room. When the sensor detects a change in the amount of infrared radiation within a specified interval, the integrated system changes the output value and the status of a relay[88]. Figure 2.5-12 depicts the two types of motion sensor.

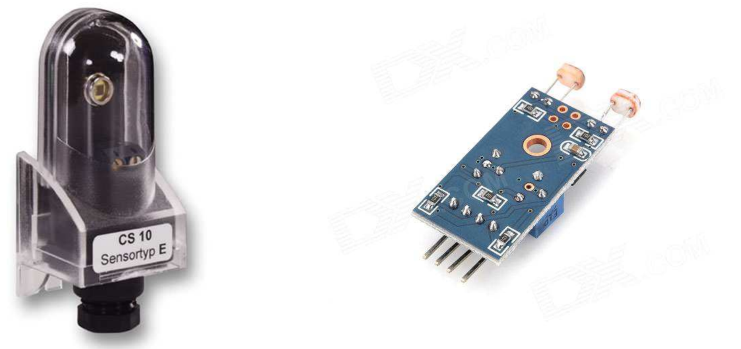
[88] Papazetis, 2012



a b

**Figure 2.5-12:** Various types of motion sensors. a) PIR sensor, b) double technology sensor.

- Luminosity Sensor. A luminosity sensor converts the energy of the light into electric current or voltage. There are two kinds of light detection devices: the photovoltaic or solar cell and the photoconductive cell or photoresistor (Figure 2.5-13).




a b

**Figure 2.5-13:** a) Photovoltaic cell, b) Photoresistor.

- Humidity Sensor. A humidity sensor measures the amount of water in air. Electronic type humidity sensors can be broadly divided into two categories: one employs capacitive sensing principle, while other uses resistive effects. Most capacitive sensors use plastic or polymer as a dielectric material, with a typical dielectric constant ranging from 2 to 15. In absence of moisture, the dielectric constant of the hygroscopic dielectric material and the sensor geometry determine the value of capacitance. Resistive type humidity sensors perceive changes in the resistance value of the sensor element in response to the change in the humidity[89].

[89] Engineers Garage, 2012

a b

**Figure 2.5-14:** Humidity sensors. a) Capacitive and b) Resistive.

- Pressure Sensor. A pressure sensor is a device which perceives pressure and converts it into an analog electric signal whose magnitude depends upon the pressure applied. Pressure measurement can either be relative to a reference value or on an absolute scale. There are three types of pressure sensors[90]:
    - o Absolute Pressure Measurement: Pressure measured relative to perfect vacuum is termed as absolute pressure. Absolute pressure sensors have limited usage because it is impossible to attain a state of perfect vacuum.
    - o Differential Pressure Measurement: In differential pressure measurement, pressures of two distinct positions are compared. Differential pressure measurements find an important application in monitoring filters in various types of purification systems.
    - o Gauge Pressure Measurement: It can be defined as a subtype of differential pressure measurement where we compare pressure at any point to the current atmospheric pressure. Gauge pressure measurement is used in applications like tire pressure or blood pressure measurement.


a b c

**Figure 2.5-15:** The three types of pressure sensors. a) Absolute, b) Differential and c) Gauge Pressure Measurements.

[90] Engineers Garage, 2012

- Sound Sensor. The sound sensor module is a simple microphone, which has the ability to detect pressure differences in the air and transform them into electrical signals. The signal received is so low that a power amplifier and the microphone needed to amplify it. The value of output can be adjusted by a potentiometer.

**Figure 2.5-16:** Sound sensor.

Actuators

Actuators are devices that receive an output message - command from controller and change the status of another device. There are many types of actuators, the most common are mentioned below.

- Actuators for HVAC systems. They are classified into three subcategories:
  - Rotary actuators (Figure 2.5-17a). A rotary actuator has a reversible synchronous motor of permanent magnet type and magnetic overload clutch. The rotary motion of the motor is transmitted to the output shaft via a maintenance free gearing. The lever linkage connected to the output shaft is used, for example, to actuate butterfly control valves or louvers. Rotary actuators are separated in two types: a) rotary damper actuators spring return and b) rotary damper actuators non-spring return.
  - Linear damper actuator (Figure 2.5-17b). A linear actuator consists of the rotary actuator and a linear gear attached to it. Linear actuators are suitable for controlling valves.
  - Fast running damper actuator with or without fail safe function (Figure 2.5-17c). These electric actuators designed for controlling valves used in heating, ventilation and air-conditioning systems. Form-fit or force-locking mechanical connection between the actuator stem and the valve stem.


a b c

**Figure 2.5-17:** Actuators for HVAC systems, a) Rotary, b) Linear and c) Fast running with fail safe function.

- Standard actuator for ventilation (Figure 2.5-18a). The smoke release actuators, as also known, are devices that are installed in windows and open them according the air quality in a specific room. The actuators can be installed on hinged windows, upon which chain motors will be installed and which will enable the stroke length to ensure wide opening of at least $60^0$ deg. from wing size.
- Actuators for air volume controllers (Figure 2.5-18b). In Variable Air Volume systems, the stream of tempered air is supplied by a single air handling unit (AHU) to a network of VAV controls. The air handler unit must be able to respond to the fluctuations in duct pressure caused by the individual VAV dampers constantly opening and closing. To maintain air pressure, a controller senses the air pressure in the ductwork and then adjusts the output of the fans in the AHU to sustain the required duct pressure. Fan output is usually controlled either by changing the fan speed with variable frequency motor controls or fan output with moving inlet guide vans.
- Actuators for fire and smoke protection dampers (Figure 2.5-18c). Their emergency actuating function returns them reliably to the zero position – if the thermal fuses melt, a power failure occurs or the operating voltage is switched off. This closes the fire and smoke protection dampers and thus prevents smoke and flames from spreading through the connected ventilation ducts in an emergency.

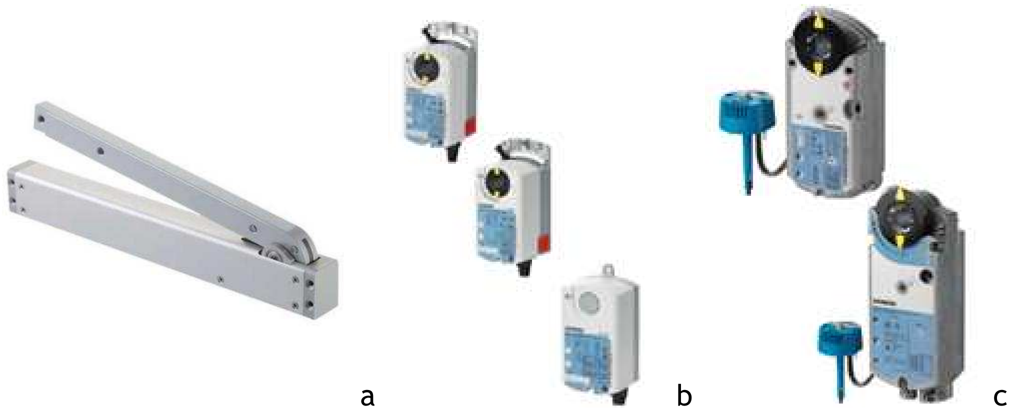



**Figure 2.5-18:** Actuators for a) ventilation, b) air volume controllers and c) fire and smoke protection dampers.

Valves

The valves are devices that regulate the start or termination of a piston and determine the direction of flow of compressed air. The valves are classified in several categories, as follow:

- Stroke valves, which are classified in three subcategories a) flanged (Figure 2.5-19a), b) treated (Figure 2.5-19b) and small (Figure 2.5-19c).

a b c

**Figure 2.5-19:** Stroke Valves, a) Flanged, b) Treated and c) Small.

- Magnetic valves, which are classified in three subcategories a) flanged (Figure 2.5-20a), b) treated (Figure 2.5-20b) and refrigerant (Figure 2.5-20c).

a b c

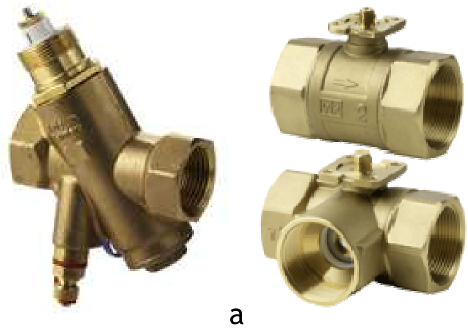
**Figure 2.5-20:** Magnetic Valves, a) Flanged, b) Treated and c) Refrigerant.

- Rotary valves, which are classified in two subcategories a) butterfly (Figure 2.5-21a) and slipper (Figure 2.5-21b).

a b

**Figure 2.5-21:** Rotary valves, a) butterfly and b) slipper.

- Combi Valves (Figure 2.5-22a) and
- Ball Valves (Figure 2.5-22b)



a b

**Figure 2.5-22:** a) Combi Valve and b) Ball Valve.

<u>Thermostats</u>

- <u>Programmable Thermostats</u>: Programmable thermostats offer the ultimate temperature control, combining accessible design and energy saving. They are classified into two categories: a) Digital Thermostats (Figure 2.5-23a) and b) Electronic Thermostats (Figure 2.5-23b), both of them provide a user- friendly operation and LCD screen for interface.
- <u>Electromechanical Thermostats</u>: Electromechanical thermostats have simple manual operation for selection of desired temperature (Figure 2.5-23c).

a b

c

**Figure 2.5-23:** a) Digital, b) Electronic and c) Electromechanical Thermostats.

<u>Switches – Buttons</u>

Switches-buttons are electrical equipment, which consists of a few contacts, and are mechanically coupled to an actuator. Switches are used in order to control devices either fully on or completely off. There are some subcategories of switches that are listed below:

- <u>Switch - Disconnectors</u> (Figure 2.5-24a)
- <u>Motorized Switch – Disconnectors</u> (Figure 2.5-24b)
- <u>Switch Fuses</u> (Figure 2.5-24c)
- <u>Motorized Switch Fuses</u> (Figure 2.5-24d)
- <u>Change - over and transfer switches</u> (Figure 2.5-24e)
- <u>Cam Switches</u> (Figure 2.5-24f)
- <u>Timer Switches</u> (Figure 2.5-24g)

- Thermostatic Switches (Figure 2.5-24h)


**Figure 2.5-24:** Switches, a) Switch- Disconnectors b) Motorized Switch-Disconnectors, c) Switch Fuses, d) Motorized Switch Fuses, e) Change-over and transfer switches, f) Cam Switches, g) Timer Switches and h) Thermostatic Switches.

Meters and counters

- Energy meters (Figure 2.5-25): Energy meters enable optimum measurement of energy consumption, minimum maintenance and long-term stability.


**Figure 2.5-25**: Energy Meters

- Water meters: The water meters are devices for metering cold or hot water. The measurement is implemented through a propeller operation. Mechanical meters indicate the total consumption in a mechanical (gear) while electronic counter on a digital screen (Figure 2.5-26a and 2.5-26b, respectively). Thanks to built-in communication, in some types it becomes possible to collect data via special cabling (M-bus) or CI answer pulse, distance visual (IrDa), or wireless (radio AMR).

a b

**Figure 2.5-26:** a) Mechanical and b) Digital water meters.

- Heat meters (Figure 2.5-27): Heat meters are used to measure the physical flow of energy used for heating.


**Figure 2.5-27:** Heat meter.

### 2.5.3 BEMS in practice

One basic characteristic of the BEMS is that it is capable of providing real-time and extensive data on energy consumption to the facility operator. This information can be used to increase energy efficiency of the overall system. Additionally, the BEMS itself improves energy efficiency by streamlining the operation of the machinery it monitors and controls. Improved energy efficiency leads to increased protection of the environment due to the reduced need for resources. For instance, improved efficiency in the electrical requirement of the building directly results in lower carbon dioxide and $SO_2$ emissions when the electricity is provided by a coal powered facility.

The implementation of BEMS in a building can contribute to social development by making the workplace safer and healthier through the improvement of fire, security and other emergency procedures. The technology can locate potential hazards within the workplace, notify emergency response teams, and inform personnel about the potential danger. Additionally, BEMS can monitor and control the environmental conditions in the buildings. Similar to potential fire or security hazards, BEMS can monitor factors such as air quality and water quality and can react when thresholds are crossed. For instance, the system can increase ventilation when the carbon monoxide levels in a facility increase above a safe limit.

When the BEMS is applied in residential buildings, it informs residents about their energy consumption. Residents can draw upon this information to apply conservation measures. In addition, the BEMS can apply certain comfort settings for the residents.

The implementation of a BEMS provides several benefits however a number of barriers need to be overcome in order to successfully apply it. In Table 2.5-2, a number of advantages and disadvantages regarding BEMS implementation are mentioned.

The installation of a BEMS requires the development of an analytical inventory of energy consumptions and the identification of energy losses. A BEMS should be installed in order to solve a proven problem of high energy consumption in a building, so as the energy costs will be covered by energy savings.

**Table 2.5-2:** Advantages and disadvantages of BEMS implementation.

| Advantages | Disadvantages |
|---|---|
| • Can easily review the performance of controls and conveniently make adjustments.<br>• Can be easily expanded.<br>• Enable energy saving control functions which will reduce energy bills.<br>• Ability to log and archive data for energy management purposes.<br>• Provision of rapid information on plant status.<br>• Automatic generation of alarms to warn personnel regarding equipment failure or condition changes.<br>• Identification of both planned and reactive maintenance requirements.<br>• Close control of environmental conditions, providing more comfort for building occupants. | • The installation of the technology requires training of the installation personnel.<br>• The technology of BEMS is continuously improved; as a result incompatibility between old and new equipment and software can be occurred.<br>• Considerable equipment and installation costs.<br>• Operation and maintenance costs might be higher compared to simpler management systems. However, the BEMS is also capable of reducing overall costs through improved energy efficiency and more efficient use of staff. |

The IPCC[91] concludes that it is yet unclear how much the BEMS technology can reduce energy usage and at what costs. Estimations provided on energy savings differ considerably and therefore more research is needed to determine the financial requirements and costs. For example, IPCC estimates energy savings between 5 % and 40 %[92]. Additionally Roth et al.[93] estimate energy savings up to 20 % in space heating energy consumption and 10 % for lighting and ventilation. Benefits may vary considerably depending on the case study.

### 2.5.4 Proposal for implementation – Municipality of Kavala

In order to examine the applicability of building automation systems in municipal buildings, a case study was developed and is analyzed in the specific section. The Municipal Library of Kavala, was selected as a reference building. The specific building was chosen for the following reasons:

- Many citizens visit the library, thus a potential energy update of the building could act as an exemplar, raising awareness of the visitors and also better communicate the effort of the municipality to follow an efficient energy responsible strategy.
- The specific building presents significant thermal and lighting needs, thus there is a noticeable potential of improvement. Moreover, a complete lack of any automation system was observed.

#### *2.5.4.1 Current situation of the building*

In order to evaluate the interventions proposed for the energy upgrade of the Municipal Library of Kavala , an initial energy audit of the building was performed, based on guidelines of the current Greek legislation and the application of relative software. In this section, an analytic description of the building is provided in terms of prevailing climate data, topography, building use profile, building envelope and electromechanical systems available, in order to estimate its energy footprint/characteristics.

*Climate data and topography*

The climatic data for the region of Kavala are defined by the national guidelines (T.O.T.E.E. 20701-3/2010, "Climate data of Greek Regions"). The climate is generally characterized as Mediterranean with mild winter and dry, hot summer. The prevailing wind direction is south-east. The coldest month is January with an average temperature of 3.9 ˚C, while the hottest month is July with an average temperature of 24.7 ˚C. The average annual temperature is 15.4 ˚C and the average annual humidity is 71%. The average annual rainfall is close to 700mm whereas the number of days with rain is 90 days. The altitude of the area where the building is placed is less than 500m, while the area belongs to the climate zone C (according to degree days).

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[91] IPCC, 2007
[92] IPCC, 2007
[93] Roth et al., 2005

Another important factor affecting the energy performance of the building is shading of the building components by nearby environment. More specifically, the five-storey library is located in densely built urban environment among high buildings (over 4 floors) (Figure 2.5-28). The main façade of the library (Figure 2.5-29) is facing southwest and is not obscured by external obstacles. The sides of the building come into contact with two four-storey residential buildings. The shading profile of the building was estimated with the application of 4M GCAD software, taking into account the solar orbit in the specific region.

**Figure 2.5-28:** Topography of the Municipal Library building.


**Figure 2.5-29:** The main façade of the building.

*Use profile and thermal zones*

The library building is a five storey building with basement and ground floor. For the estimations, it was considered that the total building consist one thermal zone, since the surface of the parts of the buildings that could perceived as different thermal zones (e.g. ground floor) was less than 10% of the total area of the building.

The basic characteristics of the buildings and the desired operating conditions/use profile are summarized in Tables 2.5-3 and 2.5-4 respectively. It should be noted the complete absence of any kind of automation system (classification D) and control management (e.g. with thermostats).

**Table 2.5-3**: Basic characteristics of the building.

| Characteristic | Value |
|---|---|
| Type of use | Library |
| Total area [$m^2$] | 1,496 |
| Total volume [$m^2$] | 5,041 |
| Heat capacity [$kJ/(m^2 \cdot K)$] | 260 |
| Automation systems classification | D (lowest) |
| Air infiltration [$m^3/h$] | 1,428 |
| Natural ventilation coefficient (tertiary sector) | 0 |

**Table 2.5-4:** Use profile.

| Characteristic | Value |
|---|---|
| Visiting hours | 6 |
| Days of operation | 5 |
| Months of operation | 12 |
| Heating period | 15/10 to 30/4 |
| Cooling period | 1/6 to 31/8 |
| Average indoors heating temperature [°C] | 20 |
| Average indoors cooling temperature [°C] | 26 |
| Average indoors relative humidity - winter [%] | 35 |
| Average indoors relative humidity - summer [%] | 50 |
| Required fresh air [$m^3/h/m^2$] | 4.18 |
| Lighting level [lux] | 500 |
| Lighting power per unit area for reference building [$W/m^2$] | 9.1 |
| Annual consumption of hot water [$m^3/m^2$*year] | 0.11 |
| Average desired temperature for hot water [°C] | 50 |
| Average annual temperature of water supply system [°C] | 16.4 |
| Heat emitted by the users per unit area [$W/m^2$] | 17.0 |
| Average coefficient of users presence | 0.18 |
| Heat emitted by appliances per unit area [$W/m^2$] | 0.50 |
| Average coefficient of functioning appliances | 0.18 |

*Building envelope*

The thermal properties of the building envelope were analytically estimated. The U-values of all building components are summarized in Table 2.5-5.

The vertical building components of the envelope (walls and columns) are covered with a light coating whereas the total area occupied is 1450$m^2$. The frames of the building are made of metal and are double glazed with an air gap of 12mm covering a total area of 228$m^2$. The basement which houses the electromechanical installations of the building and also is used as storage space, does not present any heating needs. The insulation of the shell is not continuous and for this reason it is necessary to calculate the existing thermal bridges. The total length of all thermal bridges is 2,113 m and the estimated heat loss is 634.5 W/K.

**Table 2.5-5:** U-values of main building components.

| Building component | U-value [in W/(m²·K)] |
|---|---|
| Walls | 0.387 |
| Beams and columns | 0.479 |
| Roof | 0.397 |
| Floors | 0.033-0.342 |
| Windows | 3.000 |
| Unheated space | 0.241-3.000 |

*Electro-mechanical systems*

*Ventilation system*

The ventilation of the building is carried out mechanically by the central ventilation system (Figure 2.5-30). The overall system flow is 14.4 $m^3/s$, without recirculation.

**Figure 2.5-30:** Ventilation system of the building.

*Elevator*

A hydraulic powered (16kW) elevator is used (Figure 2.5-31) in the specific building. According to national guidelines[94], the specific system was not included in the analysis of the energy performance of the building.

*Heating system*

The heating of the building is performed with the application of a central oil-boiler (400 kW) with an efficiency of 90% (Figure 2.5-32). The insulation of the distribution

[94] T.O.T.E.E. 20701-4/2010

network is insufficient (estimated thermal distribution losses coefficient ≈ 90%). Floor fan coils are used as terminal units with an efficiency of 93%.

**Figure 2.5-31:** Elevator of the building (external).

**Figure 2.5-32:** Heating system of the building (oil boiler, distribution network and fan coils).

*Cooling system*

The air conditioning of the building is carried out by a central air-cooled chiller with a cooling capacity of 286kW and a performance coefficient (EER) of 2.5 (Figure 2.5-33). The cooling system utilizes the same terminal units (fan-coils) with the heating system. The distribution network is also considered in this case as poorly insulated.

**Figure 2.5-33:** Cooling system of the building.

*Lighting system*

The lighting of the building is achieved using conventional fluorescent lamps in the main rooms and incandescent lamps in auxiliary areas (e.g. staircases and toilets). In total, 162 fluorescent type T8-36W lamps, 128 fluorescent type T8-18W, 13 incandescent lamps of 60W and 22 spots of 40W are used. The total actual lighting power was estimated to be 8.8 $W/m^2$. According to relative national guidelines, the required level of lighting for library buildings is 500 lux, while the corresponding installed capacity is taken equal to 9.1 $W/m^2$.

**Figure 2.5-34:** Lighting system of the building.

*Summary of energy performance of the building*

The required heating and cooling loads for the building, including ventilation needs for every season, are given in Table 2.5-6. The corresponding energy consumptions by end use are given in Table 2.5-7.

**Table 2.5-6:** Required heating and cooling loads – current situation.

| Month | Required loads [in kWh/m²] | | |
|---|---|---|---|
| | Heating | Cooling | DHW |
| January | 4.60 | 0.00 | 0.40 |
| February | 3.20 | 0.00 | 0.30 |
| March | 1.60 | 0.00 | 0.40 |
| April | 0.00 | 0.00 | 0.40 |
| May | 0.00 | 0.00 | 0.40 |
| June | 0.00 | 5.10 | 0.40 |
| July | 0.00 | 6.80 | 0.40 |
| August | 0.00 | 6.30 | 0.40 |
| September | 0.00 | 0.00 | 0.40 |
| October | 0.00 | 0.00 | 0.40 |
| November | 1.30 | 0.00 | 0.40 |
| December | 4.30 | 0.00 | 0.40 |
| Total | 15.10 | 18.20 | 4.30 |

**Table 2.5-7:** Final energy consumption by end use [in kWh/m²] - current situation.

| Month | Heating | Cooling | DHW | Lighting | Total |
|---|---|---|---|---|---|
| January | 10.50 | 0.00 | 0.40 | 1.30 | 12.20 |
| February | 7.30 | 0.00 | 0.30 | 1.10 | 8.80 |
| March | 4.00 | 0.00 | 0.40 | 1.30 | 5.60 |
| April | 0.40 | 0.00 | 0.40 | 1.20 | 1.90 |
| May | 0.00 | 0.00 | 0.40 | 1.30 | 1.60 |
| June | 0.00 | 3.40 | 0.40 | 1.20 | 4.90 |
| July | 0.00 | 4.50 | 0.40 | 1.30 | 6.10 |
| August | 0.00 | 4.10 | 0.40 | 1.30 | 5.70 |
| September | 0.00 | 0.00 | 0.40 | 1.20 | 1.60 |
| October | 0.10 | 0.00 | 0.40 | 1.30 | 1.70 |
| November | 3.10 | 0.00 | 0.40 | 1.20 | 4.70 |
| December | 10.00 | 0.00 | 0.40 | 1.30 | 11.60 |
| Total | 35.40 | 12.00 | 4.40 | 14.00 | 66.40 |

The total annual primary energy consumption per end use and energy consumption per fuel type, including the respective $CO_2$ emissions, is presented in Tables 2.5-8 and 2.5-9.

**Table 2.5-8:** Primary energy consumption per end use - current situation.

| End use | Energy consumption [kWh/m²] |
|---|---|
| Heating | 42.5 |
| Cooling | 34.7 |
| DHW | 12.7 |
| Lighting | 42.0 |
| RES contribution | 0.0 |
| Total | 132.6 |

**Table 2.5-9:** Energy consumption and $CO_2$ emissions per fuel - current situation.

| Fuel type | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] |
|---|---|---|
| Electricity | 32.8 | 32.4 |
| Heating oil | 33.7 | 8.9 |
| Total | 66.5 | 41.3 |

### *2.5.4.2 Intervention analysis*

The aim of the specific case study is to assess the applicability of BEMS in a municipal building. The complexity of a BEMS varies from very complicated interventions (including supervisory software and actuators) to more simple ones (installation of sensors). In order to decide the level of BEMS application in this study, specific criteria were set, based on the needs of the municipality, its current situation and the use profile of the building (library). More specifically, it was decided that the interventions to be analyzed should satisfy the following criteria:

- Compliance with existing regulations
- Initial cost <10.000€
- NPV>0
- Implementation time<1 month
- Low level of disturbance during installation

In that aspect, the implementation of a complete BEMS was not examined. Based on the specific criteria, two interventions were qualified for analysis:

- Intervention No1: Installation of timers/thermostats
- Intervention No2: Installation of lighting sensors

*Intervention No1: Installation of timers/thermostats*

In order to better control the indoors temperature of the various areas of the building and thus prevent unnecessary energy waste, the installation of timers/thermostats will be examined. More specifically, it is proposed to install seven (7) modules, two (2) on the ground floor and one (1) in each and every one of the other floors. The estimated total annual primary energy consumption per end use and energy consumption per fuel type, after the installation of the timers/thermostats, is presented in Tables 2.5-10 and 2.5-11.

**Table 2.5-10:** Primary energy consumption per end use – Intervention No1.

| End use | Energy consumption [kWh/m²] | |
|---|---|---|
| | Current building | After intervention No1 |
| Heating | 42.5 | 29.4 |
| Cooling | 34.7 | 23.1 |
| DHW | 12.7 | 12.7 |
| Lighting | 42.0 | 42.0 |
| RES contribution | 0.0 | 0.0 |
| Total | 132.6 | 107.9 |

**Table 2.5-11:** Energy consumption and $CO_2$ emissions per fuel – Intervention No1.

| Fuel type | Current building | | After intervention No1 | |
|---|---|---|---|---|
| | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] |
| Electricity | 32.8 | 32.4 | 28.7 | 28.4 |
| Heating oil | 33.7 | 8.9 | 22.3 | 5.9 |
| Total | 66.5 | 41.3 | 51.0 | 34.3 |

*Intervention No2: Installation of lighting sensors*

In order to better manage the electricity consumed for lighting needs a total of 11 lighting sensors will be installed, two on the ground floor and first four floors (two per floor) and one on the last one. The specific sensors will turn on/off the lights according to the adequacy of day lighting. The estimated total annual primary energy consumption per end use and energy consumption per fuel type, after the installation of the lighting sensors, is presented in Tables 2.5-12 and 2.5-13. In this case, a slight increase in oil consumption is expected, due to reduced contribution of artificial lighting to the heat of the building during the winter months.

**Table 2.5-12:** Primary energy consumption per end use - Intervention No2.

| End use | Energy consumption [kWh/m²] | |
|---|---|---|
| | Current building | After intervention No2 |
| Heating | 42.5 | 43.0 |
| Cooling | 34.7 | 34.5 |
| DHW | 12.7 | 12.7 |
| Lighting | 42.0 | 40.0 |
| RES contribution | 0.0 | 0.0 |
| Total | 132.6 | 130.8 |

**Table 2.5-13:** Energy consumption and $CO_2$ emissions per fuel - Intervention No2.

| Fuel type | Current building | | After intervention No2 | |
|---|---|---|---|---|
| | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] |
| Electricity | 32.8 | 32.4 | 32,0 | 31,6 |
| Heating oil | 33.7 | 8.9 | 34,2 | 9,0 |
| Total | 66.5 | 41.3 | 66,2 | 40,6 |

### *2.5.4.3 Assessment of interventions and conclusions*

Both the installation of timers/thermostats and lighting sensors have a positive impact on reducing the energy consumption of the building. However various factors must be assessed in order to make a final decision regarding the adoption or not of the specific intervention proposals. In the specific chapter a number of economical, social, energy and environmental criteria were assessed using relative indicators, in order to discuss the potential of installing simple automation systems in the municipal library of Kavala. The results are summarized in Table 2.5-14.

As a final statement it could be inferred that the interventions examined (especially the installation of timers/thermostats) have a great potential of energy saving while being cost-effective. Despite the fact that strict limits were set for choosing specific interventions related to building energy management systems, choices are available that may result in significant improvement of the energy performance of the building.

**Table 2.5-14**: Indicators for assessing the proposed interventions.

| Assessment category | Intervention No1 (timers/thermostats) | Intervention No2 (lighting sensors) |
|---|---|---|
| Initial cost [€] | 550 | 1,500 |
| Annual benefit [€/year] | 3,263 | 250 |
| 20-years benefit (present values) [€] | 40,663 | 3,121 |
| Net present value [€] | 40,113 | 1,621 |
| Payback time [years] | 1 | 6 |
| Annual electricity savings [kWh/year] | 13.1 | 1.8 |
| Annual heating oil savings [kWh/year] | 11.6 | 0 |
| Direct $CO_2$ emissions [kg $CO_2/m^2$] | 0.7 | 8 |
| Indirect $CO_2$ emissions [kg $CO_2$-eq × $10^6$] | 0.74 | 0.06 |
| Intervention intensity | Medium | Medium |
| Implementation time [months] | 0.5 | 0.5 |

# 2.6 Frames replacement

## 2.6.1 Introduction

The designs of windows and external doors have a significant impact on the energy consumption of buildings and structures in a period of low and during high ambient temperatures. At low ambient temperatures, some amount of heat power is spent for compensating heat losses through window and door constructions, as well as for heating of the incoming excessive infiltration air through them. In a period of high ambient air temperatures, some amount of the power of conditioning systems is spent on the compensation of heat coming through windows and doors, cooling the excess air infiltration coming through these structures, as well as compensation of the excess heat from solar radiation entering through the translucent structures.

It is possible to evaluate the thermal resistance of the existing door and window designs by means of thermographing the data structures (some designs with large heat losses are presented below).

The temperature fields of window designs with low thermal resistance, poor sealing of casement, defects in translucent structures (inside view) are presented in Figures 2.6-1 and 2.6-2. The temperature fields of window designs with low thermal resistance (outside view) are presented in Figure 2.6-3 and 2.6-4.

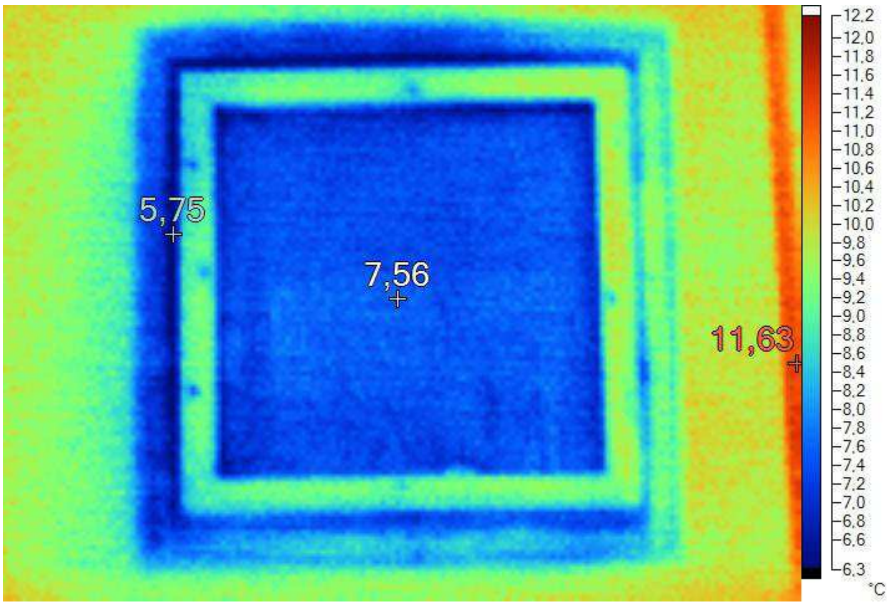



**Figure 2.6-1**: Window design with low thermal resistance and poor sealing of casement (the temperature field inside the room).

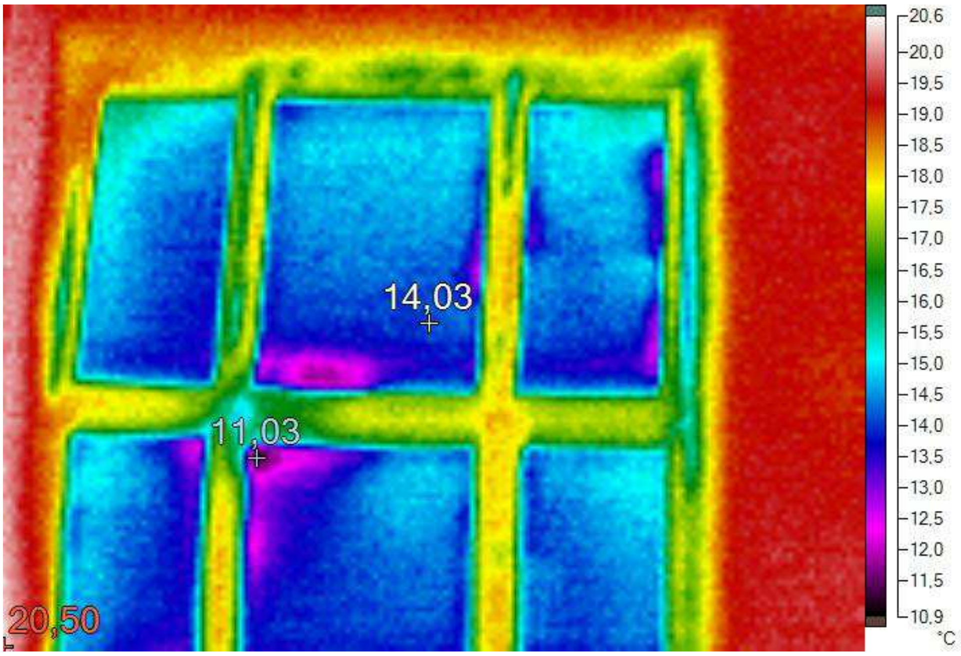



**Figure 2.6-2:** Window design with low thermal resistance and defects in translucent structures (the temperature field inside the room).

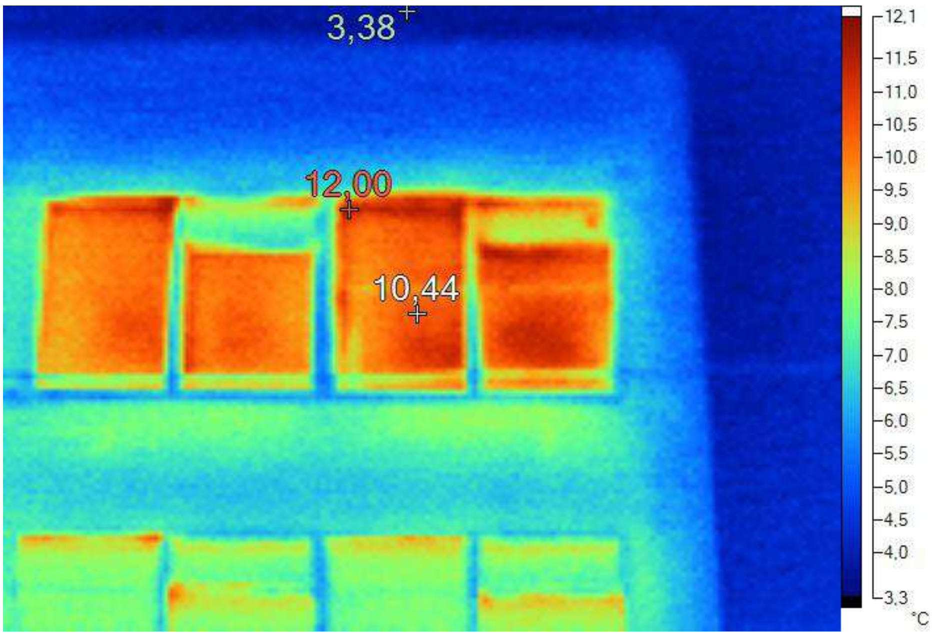



**Figure 2.6-3:** Window design with low thermal resistance (the temperature field outside the building).

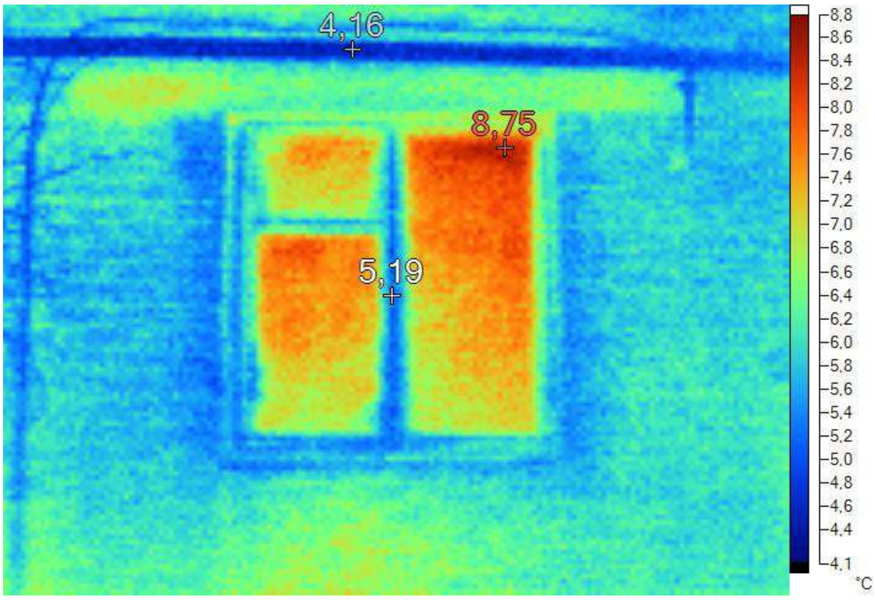



**Figure 2.6-4:** Window design with low thermal resistance (the temperature field outside the building).

The temperature fields of door designs with low thermal resistance (outside) are presented in Figures 2.6-5 and 2.6-6. The temperature field of door design with bad sealing (inside view) is shown in Figure 2.6-7.

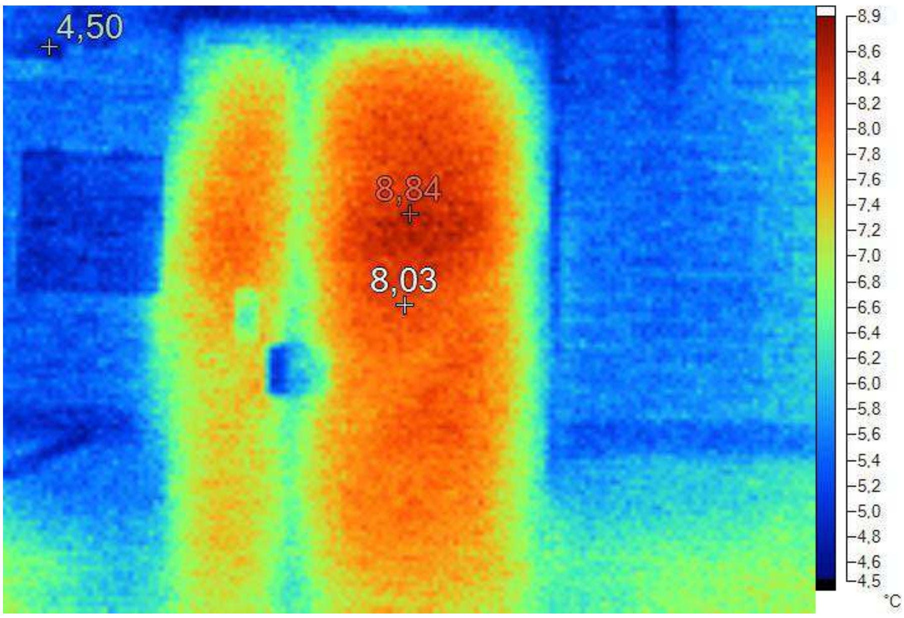



**Figure 2.6-5:** Door design with low thermal resistance (the temperature field outside the building).

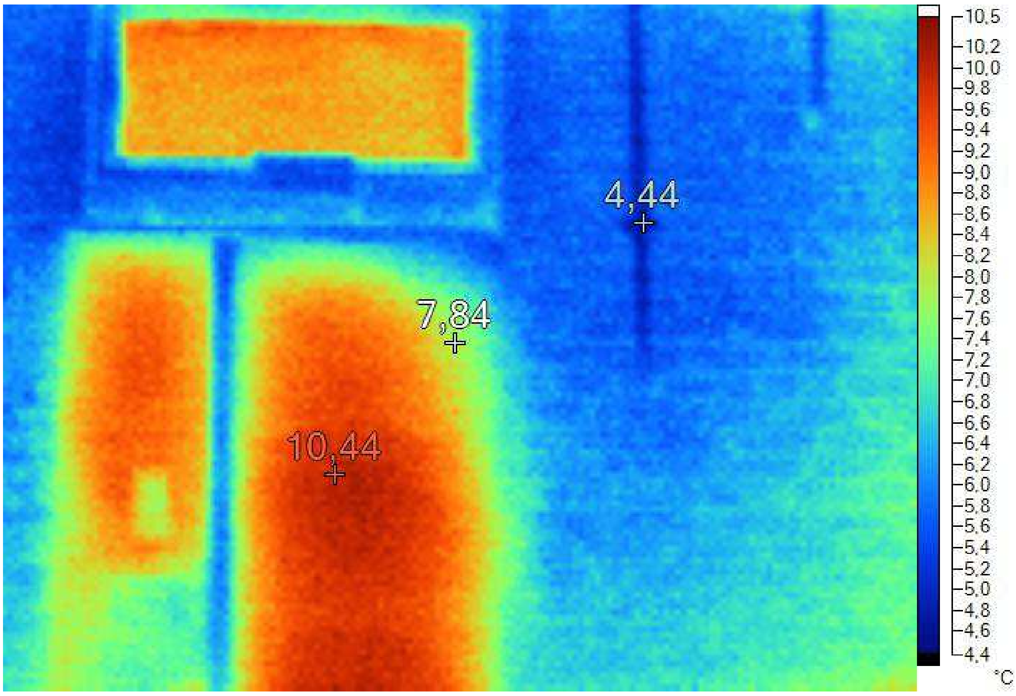



**Figure 2.6-6:** Door design with low thermal resistance (the temperature field outside the building).

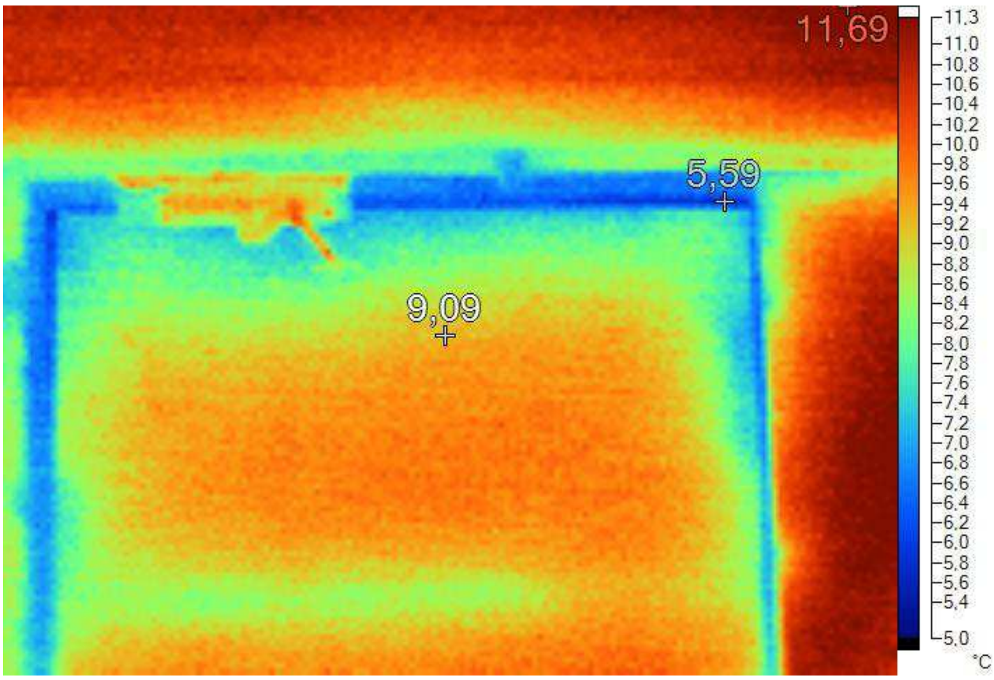



**Figure 2.6-7:** Door design with bad sealing (the temperature field inside the room).

The window is a wall element or a roof structure. It generally consists of the window opening, window unit, assembly seam (nodes of pairing a window unit and a wall or a roof structure), fasteners and various additional elements: windowsills, vent, blinds, esconson, etc.

The main purpose of windows is to provide natural light and ventilation. In addition to its main purpose, window design must provide the following consumer and regulatory requirements:

- protection against heat loss;
- sound and noise insulation;
- protection from excessive solar radiation;
- weather protection (breathability, water resistance, resistance to wind load, snow load resistance, etc.);
- special types of protection (fire-proofing, burglary proofing, shock loading resistance, bullet proofing, explosive resistance, etc.);
- durability, etc.

The door is an element of the wall structure. It generally consists of a door opening, a door unit, assembly seam (nodes of pairing a door unit and a wall structure), fasteners and various additional elements.

The primary purpose of front doors is to enable input (or output) inside a building or structure, as well as for entering the loggias and balconies of buildings (balcony door frames). In addition to its main purpose door designs must provide the following consumer and regulatory requirements:

- protection against heat loss;
- sound and noise insulation;
- providing natural light;
- weather protection (breathability, water resistance, resistance to wind load, etc.);
- special types of protection (fire-proofing, burglary proofing, shock loading resistance, bullet proofing, explosive resistance, etc.);
- durability, etc.

The design of the window unit consists of transparent and opaque parts. Opaque portion includes a number of frame elements – a frame, a sash window, a ventlight, a transom, a casement, etc. One part of the opaque portion is fixed (a frame of a window unit), it is fixed to the wall opening, roof structure or façade construction. Another part of the opaque portion, unless the window does not have a stand sheet construction is mobile (sash window, ventlight, casement, transom).

The opaque part of the window unit is equipped fittings that secure the structural elements together, perform the required operations to move one element relatively to the other, opening – closing of the window to ventilate the room, the regulation of the mutual arrangement of structural elements, etc. To expand consumer properties, a window unit can be additionally equipped with mosquito nets, blinds, lock devices, etc.

The design of the door unit consists of a fixed (a frame of a door unit) and a movable part (a door leaf). The movable part of the structure may be opaque, transparent or partially transparent. A door unit, as well as a window, has necessary accessories for mounting the structure, connections of the elements and perform necessary operations to move one element relatively to the other. Also, a door unit can have additional elements for expanding the range of the consumer properties.

### 2.6.2 Basic frame types and materials

Currently mainly used materials for door and window designs, are the following:
- steel;
- aluminum alloys;
- wood-based products;
- polyvinyl chloride (PVC);
- fiberglass reinforced plastic;
- combinations of the above.

Some designs of PVC profile systems and their actual thermal resistance are shown in Figures 2.6-8, 2.6-9 and 2.6-10[95].

**Figure 2.6-8:** VEKA “Euroline” three-chamber system of 58 mm width dual-seal system, thermal resistance (reinforced)- 0.64 $m^2$*K/W, is used for a multiple glass unit from 4 to 32 mm.[1]

[95]VEKA. Profile systems. Available at: http://veka.ua/products/win/index.html. (Date of access: 08/01/2014).

**Figure 2.6-9:** VEKA «Proline» four-chamber system of 70 mm wide with dual-seal system, thermal resistance (reinforced) – 0.75 m2·K/W, is used for a multiple glass unit from 4 to 42 mm.[96]

**Figure 2.6-10:** VEKA «Alphaline 90» six-chamber system of 90 mm wide with three-contour condensation (seal) system, thermal resistance (reinforced) – 1.04 $m^2$·K/W, is used for a multiple glass unit from 24 to 50 mm.[2]

Some examples of the designs of profile systems manufactured from aluminum and stainless steel are shown in Figure 2.6-11 and 2.6-12.

[96] VEKA. Profile systems. Available at: http://veka.ua/products/win/index.html. (Date of access: 08/01/2014).

**Figure 2.6-11:** The Schüco AWS 75.SI window system of aluminum profile (basic frame 75 mm depth)[97]

**Figure 2.6-12**: The Schüco Janisol HI window system of stainless steel profile (basic frame depth 80 mm)[98]

[97]Schüco. Partners: Products. Schüco Window AWS 75.SI. Available at: http://www.schueco.com/web/uk/partner/fenster_und_tueren/products/windows/aluminium/schueco_aws_basic_depth_from_70mm/schueco_aws_75.si. (Date of access: 08/01/2014).
[98]Schüco. Partners: Products. Janisol HI. Available at: http://www.schueco.com/web/ua/partner/fenster_und_tueren/products/windows/stainless_steel/bautiefe_60mm/janisol_hi#. (Date of access: 08/01/2014).

An example of the combined aluminum wood application is shown in Figure 2.6-13. Aluminum construction provides strength and is used for the exterior, and wood performs the aesthetic function and is used for the interior.

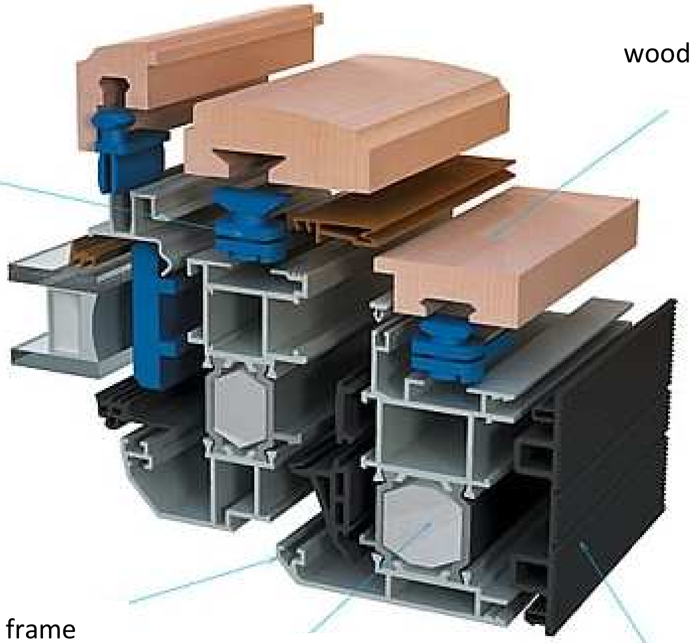



**Figure 2.6-13:** The Starwood® system using two materials: aluminum for the exterior and wood for the interior[99]

The choice of the design and the materials used for windows and exterior doors should take into account:

- the purpose of the facility;
- the size and location of structures;
- functional and customer requirements;
- architectural and aesthetic requirements;
- regulatory requirements to ensure comfort in the premises;
- technical and economic calculations (including taking into account the energy savings);
  - the solvency of the customer.

The advantages of wood-based structures are as follows: low heat and sound conductivity, high frost resistance, high strength at low specific weight, good machinability which allows to create a variety of architectural compositions, maintainability, environmental wood, aesthetic appearance of the surface of natural wood and others. The disadvantages of the wood-based material and designs are: the need to protect the wood from rotting and damage organisms (modern treatment

[99]GEALAN. Window purchasers. Ventilation. GECCO 3. Available at: http://www.gealan.de/en/fensterkaeufer/lueftung/gecco3.php. (Date of access: 08/01/2014).

technologies has achieved high quality and durable protection), hygroscopicity, fire hazards, the need for periodic restoration of protective coatings (especially for old structures, because modern coatings are higher resistance and durable), higher cost in comparison with other designs.
The advantages of PVC-based constructions are: low heat and sound conductivity, resistance to any weather, durable material and color of the product, utilizability of these products, high manufacturability, relatively low cost compared to other designs and constructions, etc. The disadvantages of PVC based constructions include: low maintainability in case of damage, need for reinforcements due to insufficient stiffness, some restrictions to architectural features, etc.

The advantages of fiberglass-based designs are: low heat and sound conductivity, resistance to any weathering, durability, high strength at low specific weight, sufficient rigidity, relatively low cost compared to other designs, etc. The disadvantages of these structures include the following: significant restrictions to architectural solutions, complexity of waste utilization, etc.

The advantages of designs based on aluminum alloy are as follows: high strength at low specific weight, resistance to any weather, durability, the ability to produce large structures, etc. The disadvantages of these structures include high heat and sound conductivity, which leads to the use of special insulating components, higher cost as compared with other designs, electrochemical corrosion under certain conditions, etc.

The advantages of designs based on different grades of steel are as follows: high strength and stiffness, fire safety, resistance to any weather, durability, the ability to produce large structures, etc. The disadvantages of these structures include high heat and sound conductivity which leads to the of use special insulating components, high specific gravity and others.

The application of the different materials allows to mutually compensate for their shortcomings and combine their advantages. On the market there are designs with different combinations of materials: wood and steel, wood and aluminum, wood and plastic, wood-aluminum-plastic, wood-plastic-steel, etc. The combination of materials is selected depending on the required service and consumer properties. The disadvantage of these structures is their relatively higher cost.

Currently on the market of these products there is a wide variety of different types of structures. Architectural and color capabilities that manufacturers provide are also quite diverse. When ordering door and window designs, a buyer has the opportunity to choose: the design and manufacturer of unit, the manufacturer and frame design, the manufacturer and accessories design; a multiple glass unit, inter-glass filling, type of glass coating, additional elements – mosquito nets, window sills, canopies, blinds, lamination or color painting a frame, etc.

Translucent construction must to have the required lighting characteristics. Translucent filling of the window or door design can be performed:

- from separate glass sheets with single (for using in unheated rooms), double or triple glazing;
- with a multiple glass unit;
- using a combination of a glass sheet and a multiple glass unit.

In the frame elements, a glass sheet and a multiple glass unit are installed on gaskets of flexible plastics or silicone sealant.The design of window units can be made:

- with single sashes;
- with paired sashes;
- with separate sashes;
- with separate-paired sashes.

In the door and window designs, as well as for the manufacture of multiple glass units, the following types of glasses for building are used: polished glass, hard-coated energy saving glass or soft-coated energy saving glass, sunproof glass, laminated glass, laminated safety glass, heat strengthened glass, chemically strengthened glass, thermally toughened safety glass, fire resistant glass, etc. Space in a multiple glass unit can be filled with the following:

- dry air;
- inert gas: argon Ar, krypton Kr, or their mixtures (better insulating properties);
- sulfur hexafluoride $SF_6$ (improved sound insulation properties).

Depending on the purpose, glazing types are divided into the following:

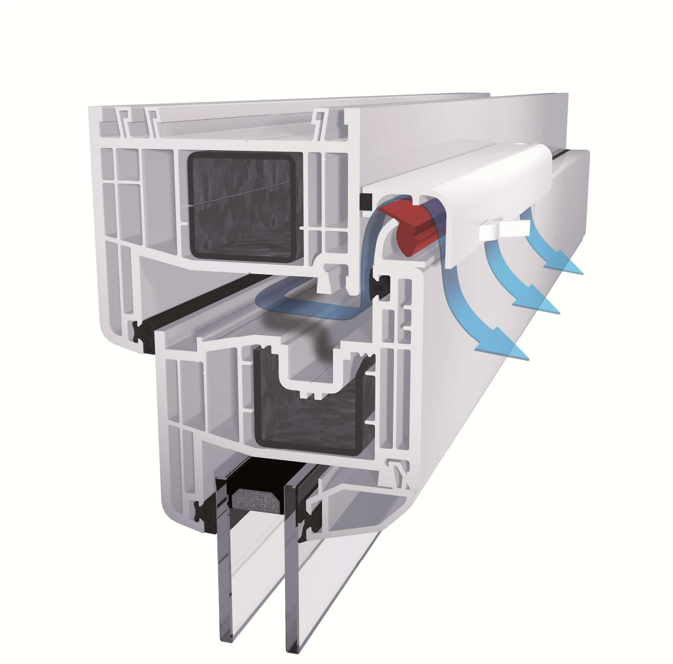
- multiple glass units for general construction purposes;
- multiple glass units for construction purposes with special properties: energy saving, solar control, noise protection, shockproof, etc.

The design of window units must include the feasibility of air exchange, except the cases when air exchange in the room is executed by systems of general exchange forced ventilation, air conditioning or ventilating autonomous devices. To implement ventilation, window blocks may have the following options for the design of air-supply devices:

- casement with turning, folding or swing-out opening;
- sash window;
- transom;
- ventlight;
- ventilation flap;
- interunit ventilation system.

The ventilation system GECCO 3 of GEALAN is an example of the ventilation system design with an air valve, it is shown in the figure 14. GECCO works autonomously – during wind gusts, the ventilation flap automatically shuts the air channel to prevent airdrafts. As soon as the wind dies down, the flap opens again to allow for free passage of air.

a) GECCO 3 closed



b) GECCO 3 open

**Figure 2.6-14:** Automatic ventilation system GECCO 3 of GEALAN[100]

An example of the design of intra-profile self-ventilation system is a window unit using the EXPROF AeroTherma profile of 101 mm width, which is shown in the Figure 2.6-15. In this profile, a special chamber for fresh air passage is provided. In a

[100]GEALAN. Window purchasers. Ventilation. GECCO 3. Available at: http://www.gealan.de/en/fensterkaeufer/lueftung/gecco3.php. (Date of access: 08/01/2014).

window unit there is a system of holes. Four holes in the bottom of the unit connect this chamber with a street, and 18 holes at the top of the unit connect it with inside premises. Air goes a long way within the chamber along the outside perimeter of the window unit and is gradually heated to the temperature above zero.

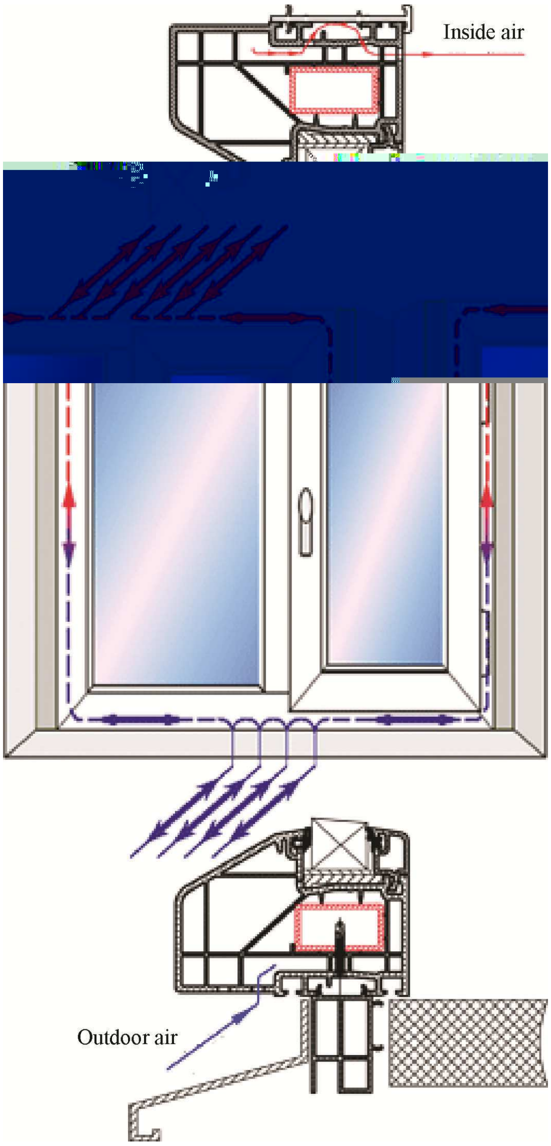



**Figure 2.6-15:** "EksProf" intra-profile self-ventilation system[101]

### 2.6.3 Efficient design and installation of frames

The design and direction of opening casement, sash window, ventlight and transom can be many and varied, manufacturers offer a variety of options. In the structures to ensure the necessary conditions for indoor air regulation, the accessories are used, which provide ventilation slit position, restriction or regulation of the opening of casement, etc.

[101]Exprof. Exprof AeroTherma. Available at: http://www.exprof.ru/files/samoventilatia.pdf. (Date of access: 08/01/2014).

To prevent excess air infiltration in opening structures, there are provided seals. The number and location of the contours in the sealing structure may be as follows:

- one loop seals (for use in unheated areas);
- middle and inner contour seals;
- outer and inner seal contours;
- outer, middle and inner seal contours.

Window and exterior door designs must be durable and weather-resistant to temperature cycling, maximum and minimum temperature conditions, UV, moisture and slightly aggressive chemical medium caused by atmospheric pollution. Components and materials used for the manufacture of window and exterior door designs must also be resistant to long-term climatic impacts. Seals shall be made of weather- and frost- resistant elastic polymeric materials. Liners under glass and windows shall be made and durable plastics. Parts and elements of design, made of metal, wood and products based on them must to have weatherproof protective coating.

The materials used for making window and door designs must be compatible. The mutual impact of different materials shall not reduce the performance characteristics and durability of products. The main components, which include glasses, gaskets, fittings, finishes and coatings, must be tested for durability.

The design of windows and doors shall envisage the replacing of glass, multiple glass units, window fittings, gaskets without violating the integrity of the product.

The design of fittings and hinges, as well as their attachment shall ensure safe and reliable operation of windows and doors. They shall withstand operating loads in any of the specified positions, as well as their transfer from one position to another.

The design of window and door frames must be provide holes for water drainage from the mating cavities of fixed and movable parts, to drain the cavity between the edges of a glasses (or opaque filling) and frame profiles, to compensate for wind pressure and others. The required number of holes, their size and location are determined the operating conditions and product design. The holes should be protected with windproof caps.

Reducing heat losses through window and door structures is achieved by using the materials and components which increase reduced total thermal resistance of the structure.

The main methods of increasing the total thermal resistance for translucent structures of windows and doors consist in applying:

- multiple glazing;
- double multiple glass units;
- inter-glass space filling with inert gas: argon Ar, krypton Kr or their mixtures;
- installation of heat-reflective films;
- application of energy-efficient soft-coating or hard-coating;

- use of two energy-saving coatings in one design;
- installation of the outer shield for extra insulation at night, etc.

Thermotechnical characteristics of the gas used to fill the inter-glasses space and heat transfer coefficients of gas layers of inter-glasses space are shown in Tables 2.6-1 and 2.6-2.

**Table 2.6-1:** Thermotechnical characteristics of gases used to fill the inter-glasses space (at atmospheric pressure and temperature +10 °C)[102]

| Gas | Density, kg/m$^3$ | Thermal conductivity, W/(m·K) | Dynamic viscosity, kg/(m·s) | Thermal capacity, J/(kg·K) |
|---|---|---|---|---|
| Air | 1.232 | 0.02496 | $1.761 \times 10^{-5}$ | 1.008 |
| Argon Ar | 1.699 | 0.01684 | $2.164 \times 10^{-5}$ | 0.519 |
| Krypton Kr | 3.560 | 0.00900 | $2.670 \times 10^{-5}$ | 0.245 |
| Sulfur hexafluoride $SF_6$ | 6.360 | 0.01275 | $1.459 \times 10^{-5}$ | 0.614 |

**Table 2.6-2**: Heat transfer coefficients of gas layers of inter-glasses space[8]

| Gas that fills the space between glass panes | The coefficients of heat transfer gas layer, W/(m$^2$·K), its thickness in mm: | | | |
|---|---|---|---|---|
| | 6 | 9 | 12 | 15 |
| Air | 2.40 | 1.98 | 1.70 | 1.64 |
| Argon Ar | 1.99 | 1.61 | 1.41 | 1.37 |
| Krypton Kr | 1.39 | 1.17 | 1.15 | 1.13 |
| Sulfur hexafluoride $SF_6$ | 2.02 | 1.96 | 1.93 | 1.89 |

The main methods of increasing the total thermal resistance for the frame section of windows and doors consist in applying:

- heat insulating inserts in design;
- multichamber profiles;
- filling chambers of profiles with insulating material;
- increasing the number of sealing contours (for heated premises at least two seal contours are used) and others.

The approximate data on thermal resistance of profiles of various designs for the manufacture of window and door frames are given in Table 2.6-3. Increasing the thermal resistance of opaque filling of exterior doors is achieved by applying a layer of heat insulating material with a high coefficient of thermal resistance inside the structure.

[102]Boryskyna IV, Shvedov NV, Plotnikov A. "Modern svetoprozrachnye konstruktsyy Civil delivered. Directory proektyrovschyka, NYUPTS "MYO", St. Petersburg, 2005.

**Table 2.6-3:** The approximate data on thermal resistance profiles of different designs[103]

| Profile design | Thermal resistance of profile package, $m^2·K/W$ | Heat transfer coefficient of profile package, $W/(m^2·K)$ |
|---|---|---|
| Package of PVC profiles ((frame + casement, including reinforcement) | | |
| 2-chamber system | 0.52 | 1.9 |
| 3-chamber system | 0.59 | 1.7 |
| 5-chamber system | 0.71 | 1.4 |
| Aluminum profile | | |
| "Warm" profile with thermal insert | 0.40 | 2.3 |
| Wood - Pine (thermal conductivity of 0.18 W/(m·K)) | | |
| Thickness 80 mm | 0.44 | 2.3 |
| Thickness 120 mm | 0.67 | 1.5 |
| Wood - Oak (thermal conductivity of 0,23 W/(m·K)) | | |
| Thickness 80 mm | 0.35 | 2.9 |
| Thickness 120 mm | 0.52 | 1.9 |

To reduce solar radiation in translucent structures there are used:

- heat-absorbing glasses;
- low E glasses;
- glasses with reflective coating;
- special components such as sunblinds, solar grills, etc.

Heat-absorbing glass and glass with reflective coating are installed in the outer glass layer. To improve the sound insulation properties of structures there are used:

- multiple glazing;
- increase of the distance between panes;
- installation of glass different thicknesses for multiple glazing;
- installation of panes with different intervals between them for multiple glazing;
- filling the inter-glass space with sulfur hexafluoride SF6;
- laminated glass;
- increase of the number of seal contours.

The minimum requirements for the basic physical characteristics of glass in Ukraine are set out in ДСТУ Б В.2.7-107:2008[104] and are presented in Table 2.6-4. The reference data on the thermophysical characteristics of certain structures without special glass coatings are shown in Table 2.6-5[10]. When choosing the type of translucent structures it is necessary to specify the manufacturer's thermal

[103]Boryskyna IV, Shvedov NV, Plotnikov A. "Modern svetoprozrachnye konstruktsyy Civil delivered. Directory proektyrovschyka, NYUPTS "MYO", St. Petersburg, 2005.
[104]State building codes Ukraine. ДСТУ Б В.2.7-107:2008. Windows glued constructions. Available at: http://dbn.at.ua/load/normativy/dstu/5-1-0-1099. (Date of access: 08/01/2014).

characteristics, as they are significantly dependent on the materials and manufacturing technologies used. The manufacturer must provide the specific data on the product to the consumer.

**Table 2.6-4:** Minimum requirements for the basic physical characteristics of glass in Ukraine[105]

| Purpose of a multiple glass unit | Type of a multiple glass unit | Heat transfer resistance, $m^2 \cdot K/W$, no less | Light transmittance, %, no less | Sound-proofing, dB(A), no less | Dew point, $^0C$, no more |
|---|---|---|---|---|---|
| General construction purposes | Single chamber | 0.32 | 80 | 25 | -45 |
| | Double chamber | 0.45 | 72 | 27 | -45 |
| Sunprotective | Single chamber | 0.32 | - | 25 | -45 |
| | Double chamber | 0.47 | - | 27 | -45 |
| Energy Saving | Single chamber | 0.59 | 75 | 26 | -45 |
| | Double chamber | 0.72 | 65 | 28 | -45 |
| Freezeproofed | Single chamber | 0.59 | 75 | 26 | -55 |
| | Double chamber | 0.72 | 65 | 28 | -55 |
| Soundproofed | Single chamber | 0.32 | 74 | 34 | -45 |
| | Double chamber | 0.47 | 67 | 34 | -45 |

*Note: To characterize the use of sunprotective glass unit, the coefficient of total solar penetration is specified in the design documentation.*

The consumer when choosing the type of design must take into account that the use of some structural components and materials leads to a significant increase in the cost of products but to insignificant improvement in characteristics.

[105] State building codes Ukraine. ДСТУ Б В.2.7-107:2008. Windows glued constructions. Available at: http://dbn.at.ua/load/normativy/dstu/5-1-0-1099. (Date of access: 08/01/2014).

**Table 2.6-5:** Reference data on the thermophysical characteristics of some glass designs[106]

| Glazing designs | Light transmittance in the visible spectrum | The absorption coefficient of light in the visible spectrum | Transmittance of direct solar radiation | The absorption coefficient of direct solar radiation | Coefficient of total solar energy transmittance | Reduced total thermal resistance, $m^2 \cdot K/W$ |
|---|---|---|---|---|---|---|
| 4M1-8-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.28 |
| 4M1-10-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.29 |
| 4M1-12-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.30 |
| 4M1-16-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.32 |
| 4M1-Ar8-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.30 |
| 4M1-Ar10-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.31 |
| 4M1-Ar12-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.32 |
| 4M1-Ar16-4M1 | 0.80 | 0.06 | 0.68 | 0.21 | 0.78 | 0.34 |
| 4M1-6-4M1-6-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.42 |
| 4M1-8-4M1-8-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.45 |
| 4M1-10-4M1-10-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.47 |
| 4M1-12-4M1-12-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.49 |
| 4M1-16-4M1-16-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.52 |
| 4M1-Ar6-4M1-Ar6-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.44 |
| 4M1-Ar8-4M1-Ar8-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.47 |
| 4M1-Ar10-4M1-Ar10-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.49 |
| 4M1-Ar12-4M1-Ar12-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.,52 |
| 4M1-Ar16-4M1-Ar16-4M1 | 0.72 | 0.09 | 0.56 | 0.29 | 0.72 | 0.55 |

Note: Values of the reduced thermal resistance are taken based on the sizes of a glass unit (1.0 x 1.0) m.
Designation: M1 – sheet glass without special types of coating (brand and specifications ДСТУ Б.В.2.7-122-2009); 4 – thickness of the sheet of glass in mm; 6, 8, 10, 12, 16 – width inter of glass gap in mm; Ar – space of a particular glass unit filled with 100% argon.

To meet the needs of producers and consumers in determining the thermal characteristics of windows and doors and keep to choose materials and design, there have been developed different software programs. On the websites of some online vendors consumers can also calculate the properties of such structures online using only materials of the firm. There are some examples of the programs:
– «WINDOW» (PC program determines window product heat transfer as a function of glazing characteristics, gas-fills, and frame properties)[107];

[106] State building codes Ukraine. ДСТУ Б В.2.7-107:2008. Windows glued constructions. Available at: http://dbn.at.ua/load/normativy/dstu/5-1-0-1099. (Date of access: 08/01/2014).
[107]WINDOW. Available at: http://windows.lbl.gov/software/window/window.html. (Date of access: 08/01/2014).

– «THERM» (PC program for analyzing 2-D heat transfer effects through window frames and other building products. It can be used as a stand alone program or as a companion to «WINDOW»)[108];
– «RESFEN» (PC program calculates heating and cooling energy use and associated costs as well as peak heating and cooling demand for specific window products)[109];
– «Pilkington Spectrum» (PC program for modeling various glazing options using products Pilkington allowing you to quickly and efficiently calculate the basic properties of the glass unit)[110], etc.

For reliable, durable, safe and efficient operation of window and door design it is very important to install them in a window or doorway. The requirements for the installation of these structures are set out in the regulations. The installation must be performed in accordance with the design documentation developed for exterior walling of the repaired building and for the particular door or window type design.
When installing, there are fixed the fasteners which transmit the load from the window or door unit to the supporting structure of the building and make an assembly seam between the window or door unit and the load-bearing structures of the building which ensures sealing, thermal, acoustic insulation, etc., extra protective and decorative elements are also installed.

The basic requirements that are applied to the installation of windows and doors are as follows:

- the forces resulting in service windows and doors, shall be transmitted through the fasteners to the supporting structures of buildings;
- the design of mounting assemblies and assembly seam shall be in line with the regulations on operational performance – heat and sound resistance, air and water permeability, etc.;
- the design of assembly seam shall be resistant to weathering conditions and indoor use and durable;
- the design of an assembly seam shall compensate for the change of dimensions and deformation of individual components due to the changes in the temperature and humidity conditions;
- the reliable drainage of water and condensate outside and protection against moisture ingress into the building and its saturation of wall structures shall be provided;
- the inside of the premises must be carried out vapor insulation assembly seam;
- in the design of an assembly seam there shall be no cold bridges that lead to condensation on the interior surfaces, etc.

[108]THERM. Available at: http://windows.lbl.gov/software/therm/therm.html. (Date of access: 08/01/2014).
[109]RESFEN. Available at: http://windows.lbl.gov/software/resfen/resfen.html. (Date of access: 08/01/2014).
[110] Pilkington. Spectrum. Available at: http://www.pilkington.com/Europe/UK+and+Ireland/English/Products/bp/downloads/tools/spectrum/default.htm. (Date of access: 08/01/2014).

An assembly seam usually consists of three layers. The main function of each layer is as follows:

- the outer layer is waterproof and vapor permeable, it shall protect the central layer from the penetration of moisture and moisture vapor and ensure vapour moisture removal;
- the central layer is thermally insulated, it provides regulatory compliance with thermal resistance design;
- inner layer is vapour insulating, it protects the central layer from vapor penetration of moisture from the interior air.

One of the potential versions of mounting a window unit is shown in Figure 2.6-16.

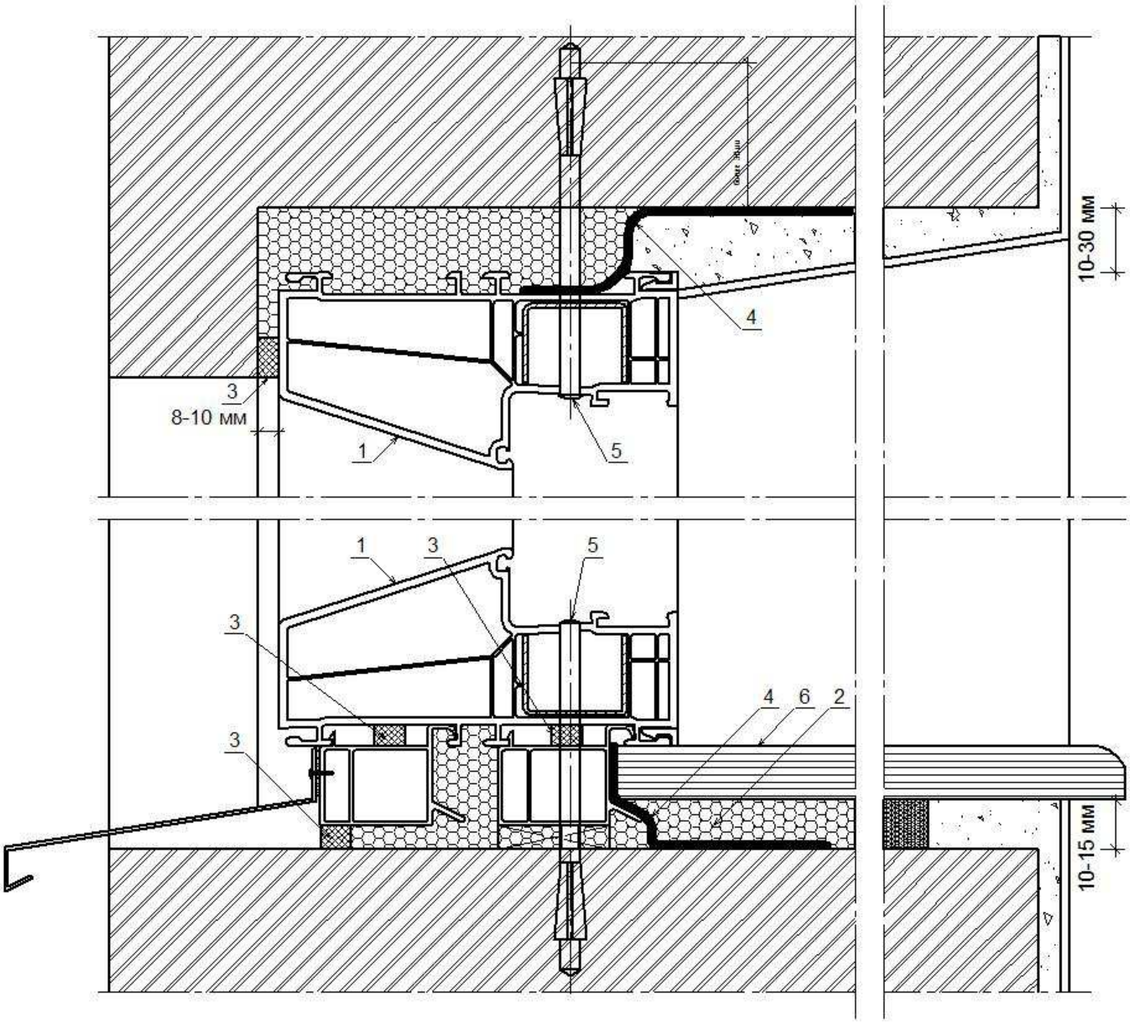



**Figure 2.6-16:** One of the potential designs of mounting a window unit[111]
(1 – window frame; 2 – insulating foam; 3 – precompressed sealing tapes; 4 – vapor insulating tape; 5 – mounting dowel; 6 – windowsill board)

[111] ИНФОРМАЦИОННАЯ СИСТЕМА ПО СТРОИТЕЛЬСТВУ "НОУ-ХАУС.ру". Чертежи в формате autocad. DECEUNINCK. Чертежи в формате AutoCAD (.dwg) – оконные и дверные блоки. Available at: http://www.know-house.ru/st_infotek/adclick.php?bannerid=6603&zoneid=0&source=&dest=http%3A%2F%2Fwww.know-house.ru%2Finfotek%2Finf_dwg%2F07_deceuninck_252_2612.zip. (Date of access: 08/01/2014).

In the structure of the outer layer of the assembly seam must be used materials which weather-resistant in the entire range of climatic conditions, having good adhesion strength to the materials applied in window and door frames and being UV-resistant, if they are not protected from solar radiation. For this layer of the seam there are used special types of films, precompressed sealing tapes, special types of sealants. Waterproofing materials should be laid continuously, without gaps or breaks. Outside this layer can be protected by various kinds of covers.

In the structure of the central layer of the assembly seam there are used: mineral wool, insulating cords of different materials, special polyurethane foams and other materials having high thermal resistance. Filling seam with insulation materials shall be continuous, without breaks and voids.

The design of the inner layer of the assembly seam to perform its function provides for using special types of vapor barrier tapes and films. Vapor barrier materials shall be laid continuously, without gaps or breaks. Over the layer decorative plaster can be put or it can be covered with various cladding parts.

The cost of replacing door and window designs consists of the cost of door and window designs, installation costs of the particular structures and the cost of additional works agreed between the customer and the contractor.

The cost of door and window designs essentially depends on the materials used, architectural features, fittings used for the design, functional and consumer characteristics, etc. Therefore comparative cost of one square meter of various designs is incorrect. Selection shall be based on the prices of real structures for a particular use.

Similarly, the installation cost depends on the design features of the building, the type of door and window designs. The accompanying construction works in the case of replacing door and window structures include the following activities:

- dismantling of old door and window design;
- restoring the places of conjugation of door and window structures with building walls, installing window sills, canopies, etc.;
- restoration of decorative finishing of the exterior part of the building and the interior part of the premises;
- removal of debris and cleaning.

They significantly affect the cost of replacement of window and door structures and shall be carefully considered. The cost of replacing door and window structures also depends on the design and layout of the building, size of window structures, special conditions for the organization of the construction work, etc. In carrying out these works in the existing buildings, builders face a number of difficulties in dismantling large window structures, lifting new structures to the upper floors and removal of construction debris from them, as well as the time constraints of work and requirements to "dust-free" work.

The EU main regulatory document establishes the requirements for windows and exterior door structures is EN 14351-1/A1 2010 «Windows and doors - Product standard, performance characteristics - Part 1: Windows and external pedestrian doorsets without resistance to fire and / or smoke leakage characteristics ». It defines the performance requirements of these products, regardless of the materials used for their manufacture. It also includes a list of references to the standards establishing the requirements to individual components and materials containing the calculation methods, testing, classification structures.

EN 14351-1/A1 2010 standard establishes a list of information and regulated specifications of windows, as well as their distribution into classes depending on the values of the indicators. This data shall be provided by the manufacturer and the choice of the type of product for use under the certain operating conditions is based on them.

The regulations for door and window designs are elaborated in the EU by the European Standardization Committee CEN / TC 33 «Doors, windows, shutters, building hardware and curtain walling». The lists of the current and future regulations for door and window designs are presented on the page of the Committee[112].

The regulations for construction glass in the EU is elaborated by the European Standardization Committee CEN / TC 129 «Glass in building». The lists of the current and future regulations for construction glass are presented on the page of the Committee[113].

Ukrainian regulations are harmonized with EU standards for door and window designs (except of glass products) by the Technical Committee on Standardization TK-313 "Residential Construction". The functions of the Secretariat of the Technical Committee are realized by the State Enterprise " UkrNDIprotsivilsilbud."

The development and harmonization of Ukrainian regulations with EU standards in the field of translucent structures is executed by the Technical Standardization Committee TK-300 "Translucent structures" (Order of the Ministry of Regional Development and Construction of Ukraine of 18.07.2008 No 334[114]). The functions of the Secretariat of the Technical Committee are realized by the Scientific and

[112]European Committee for Standardization. CEN/TC 33 - Published standards. Available at: http://www.cen.eu/CEN/Sectors/TechnicalCommitteesWorkshops/CENTechnicalCommittees/Pages/Standards.aspx?param=6017&title=CEN/TC+33. (Date of access: 08/01/2014).

[113]European Committee for Standardization. CEN/TC 129 - Published standards. Available at: http://www.cen.eu/CEN/Sectors/TechnicalCommitteesWorkshops/CENTechnicalCommittees/Pages/Standards.aspx?param=6111&title=CEN/TC+129. (Date of access: 08/01/2014).

[114]The Technical Committee of Standardization "Translucent design." Order of the Ministry of Regional Development of the establishment TKC-300. Available at: http://ntp-standard.com.ua/tk300/materialu/Nakaz_334.pdf. (Date of access: 08/01/2014).

Technical Enterprise "Standard". The site of this technical committee presents the lists of current and future regulations for translucent designs[115].

### 2.6.4 Proposal for implementation – Municipality of Mykolayiv

The efficiency of substituting windows for modern window designs is considered by the example of Block "A" of the main building of the National University of Shipbuilding named after admiral Makarov (hereinafter NUOS), located in Mykolayiv.
The main building consists of four adjoining Blocks: "A", "B", "C" and "D". There are frame structures and 6 main floors in all the Blocks. At the junction Blocks there are located stairwells. The outer wall structures are mainly made of concrete wall panels. Translucent structures are presented with windows made of steel (Block "A") and wood (Blocks "B", "C" and "D") frames, as well as stained glass windows in the stairwells with steel (Block "A") and aluminum (Block "C") frames. Top view of the main building NUOS is shown in Figure 2.6-17.

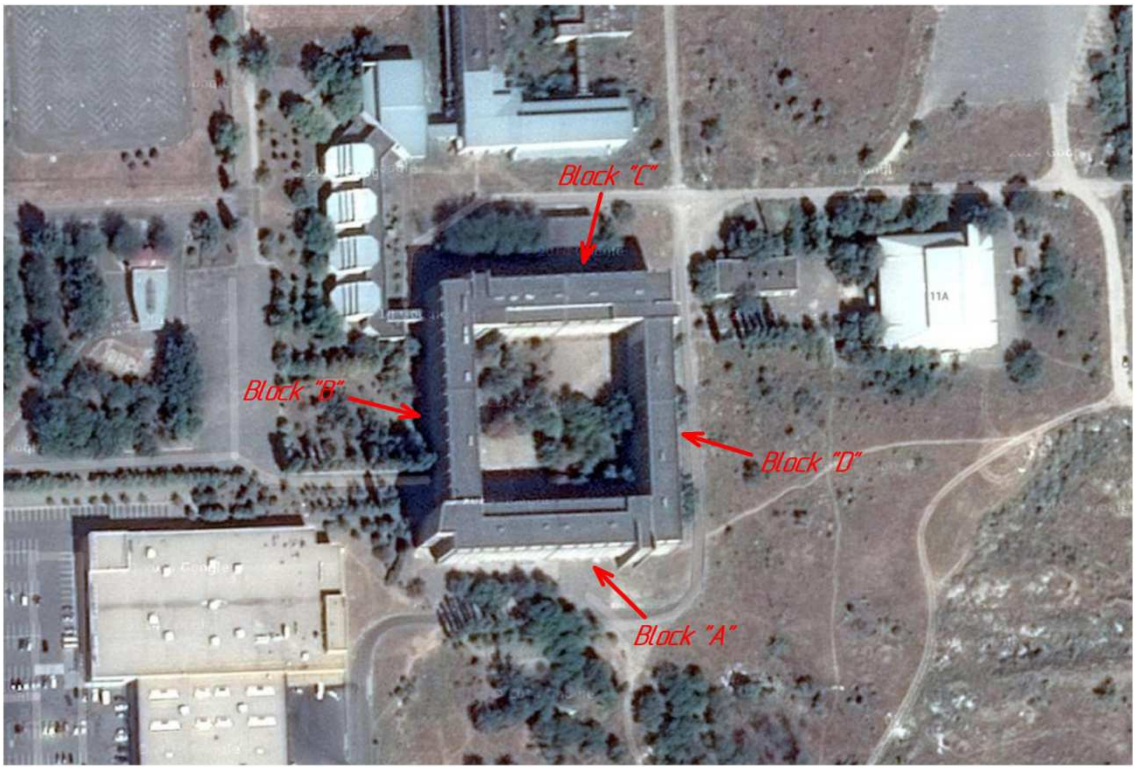



**Figure 2.6-17:** Aerial view of the main building NUOS

The total area of the exterior wall designs, windows and stained glass windows of the NUOS main building are presented in Table 2.6-6.

[115]The Technical Committee of Standardization "Translucent design." Regulations. Available at: http://ntp-standard.com.ua/rozrobleni-nd/#. (Date of access: 08/01/2014).

**Table 2.6-6:** The total area of exterior wall designs, windows and stained glass windows of the NUOS main building, m$^2$.

| Name objects | Wall area | Window area | Area of stained glass stairwell |
|---|---|---|---|
| Block «A» | 2412 | 1641 | 289 |
| Block «B» | 2443 | 1653 | - |
| Block «C» | 2410 | 1607 | 248 |
| Block «D» | 2443 | 1653 | - |
| Total: | 9708 | 6554 | 537 |

The view of the facade of Block "A" is shown in Figure 2.6-18.

**Figure 2.6-18:** The view of the facade of Block "A".

All translucent design projects have double glazing. Window design units in Block "A" are made with separate sashes and with paired sashes in Blocks "B", "C" and "D". In the windows of Block "A" there are used glass window sheet of 6 mm thickness (ГОСТ 111-65), and in the stained glass designs - shopwindow glass of unpolished thickness of 6.5 mm (ГОСТ 7380-68). The distance between the glass axes in Block "A" is 107 mm, in stained glass designs in Block "A" - 500 mm. "A" Block window constructions mainly have the following dimensions: height - 2010 mm, width - 2752 mm.

The types of translucent constructions in Block "A" are shown in Figures 2.6-19, 2.6-20 and 2.6-21.

Block "A" is selected for consideration as its translucent structures have lower values of resistance to heat transfer. The reduced total resistance to heat transfer of the majority of window designs in "A" Block is 0.366 $m^2 \cdot K/W$, stained glass designs – 0.354 $m^2 \cdot K/W$.

**Figure 2.6-19:** The view of window structure in Block "A".

**Figure 2.6-20:** The view of the stained glass design of the right stairwell in Block "A".

**Figure 2.6-21:** The view of the stained glass design of the left stairwell in Block "A"

Some window designs were replaced earlier for structures with three-chamber PVC profiles and multiple glass units – 4M1-16-4M1. The reduced total resistance to heat transfer of the window designs is about 0.36...0.37 $m^2 \cdot K/W$. Their view in Block "A" (PVC profiles) is shown in Figure 2.6-22.

The main disadvantages of translucent structures in Block "A" are the following:

- low resistance to heat transfer does not meet current regulatory requirements;
- corrosion damage of steel elements after 35 years of operation;
- deformation of the elements of window designs;
- damage and destruction of sealing gaskets;
- poor quality of manufacturing and installation of some window designs;
- high cost of the required glass sheet dimensions.

The main consequence of these drawbacks is the high cost of heating. According to July 1, 2013 changes to the ДБН В.2.6-31: 2006 the normative reduced total resistance to heat transfer of translucent structures is increased. Resistance to heat transfer of translucent structures shall not be less than 0.6 $m^2 \cdot K/W$ for the territory where the NUOS main building is located. Thus currently all the existing translucent structures do not meet the current regulatory requirements for the reduced total resistance to heat transfer.

**Figure 2.6-22:** Structures with PVC profiles in Block "A"

Let us consider the possible outcomes of the replacement of window designs from the point of view of energy saving. The normative temperature conditions during the heating season for the NUOS main building are the following:

- duration of the heating period – 161 days;
- the average outdoor temperature during the heating period – +1,1 °C;
- the standard temperature in classrooms – +18 °C, in the lobbies and stairwells – +16 °C.

Air-conditioning in the summer is not performed. All stained glass structures enclose rooms with regulatory indoor air temperature 16 °C. The area of window designs in rooms with regulatory indoor air temperature 16 °C is 88 $m^2$. The remaining 1553 $m^2$ of window designs enclose the space with regulatory indoor air temperature 18 °C.
Taking all requirements and recommendations ДБН В.2.6-31: 2006, let us consider the use of the most simple designs of glass unit of various types, having resistance to heat transfer close to the normative (4K – 4 mm low-emissivity glass with «hard-coating», 4I – 4 mm low-emissivity glass with «soft-coating»):
– 4M1-Ar16-4K – 0.59 $m^2$·K/W;
– 4M1-16-4I – 0.59 $m^2$·K/W;
– 4M1, 4M1-10-10-4K – 0.58 $m^2$·K/W.

The calculated reduced total resistance to heat transfer of window designs of necessary size using PVC profile brands of the most common manufacturers is shown in Table 2.6-7.

**Table 2.6-7:** The reduced total resistance to heat transfer window structures of the required size using different materials, $m^2 \cdot K/W$

| Brand and type of profile | Unit design | | |
|---|---|---|---|
| | 4M1-Ar16-4K | 4M1-16-4I | 4M1-10-4M1-10-4K |
| Veka Euroline (58 mm /3 chambers) | 0.602 | 0.602 | - |
| Veka Proline (70 mm / 5 chambers) | - | - | 0.616 |
| KBE Classic (58 mm / 3 chambers) | 0.617 | 0.617 | 0.608 |
| Rehau Basic-Design (60 mm / 3 chambers) | 0.6 | 0.6 | - |
| Rehau Delight-Design (70 mm / 5 chambers) | - | - | 0.617 |

All of them are listed in Table 2.6-7 complied with ДБН В.2.6-31: 2006 and the reduced total resistance to heat transfer of the same value approximately. Among the considered glass unit designs 4M1-16-4I is the cheapest.

At the moment due to the situation in Ukraine it is not possible to show the actual efficiency of different designs with higher resistance to heat transfer: the imbalance in prices due to inflation and the devaluation of the currency, as well as uncertainty with the cost of natural gas and thermal energy.

The application of designs with profiles made of PVC and with glass units 4M1-16-4I reduces the total heat loss through 1 $m^2$ during the heating period:
- when replacing stained glass designs – 240.1 $MJ/m^2$;
- when replacing windows in the lobby – 220.8 $MJ/m^2$;
- when replacing windows in the classrooms – 250.5 $MJ/m^2$.

Thermal energy saving by replacing all the translucent designs for the whole heating period is as follows:
- when replacing stained glass designs – 69.38 GJ;
- when replacing windows in the lobby – 19.43 GJ;
- when replacing windows in the classrooms – 389.03 GJ.

The total heat saving during the heating season if all windows and stained glass designs are replaced with the normative value of resistance to heat transfer is 477.84 GJ.

The cost of this type of translucent structures including the cost of installation, but excluding finishing work is in the range of 55...80 $ / $m^2$.

On June 1, 2014 in Mykolayiv, the tariff for the thermal energy supplied to budgetary organizations and other consumers (except population) is 23.5 $ / GJ. The value of savings in heating costs by reducing heat loss through 1 $m^2$ of translucent design during the heating season will be the following:

- if replacing stained glass designs – 5.64 $ / $m^2$;
- if replacing windows in the lobby – 5.19 $ / $m^2$;
- if replacing windows in the classrooms – 5.87 $ / $m^2$.

Savings in heating costs by replacing all the translucent structures during the heating period is as follows:

- if replacing stained glass designs – $ 1630;
- if replacing windows in the lobby – $ 457;
- if replacing windows in the classrooms – $ 9142.

The total amount of savings for the heating period will be $ 11,229.

The above calculations show that the simple payback after the replacement of translucent structures is quite high. It should be noted that these calculations do not take into account the additional heat losses due to the increased air infiltration into the old window frames, as well as the additional costs for its liquidation.

## 2.7 Electro/mechanical systems

The main purpose of electro/mechanical systems is to provide thermal comfort and to maintain good indoor air quality (IAQ). These condition is essential for a performant building. The Electromechanical systems are one of the largest energy consumers in buildings, and relatively small improvements in the design or equipment selection can produce large long-term savings in energy expenditures over the life cycle of the system. Electromechanical systems include ventilation, air-conditioning and thermal equipment such as heating boilers.

### 2.7.1 Heating boilers

Heating boilers are used to warm with hot water a district, a building or an apartment.

#### *2.7.1.1 District heating system*

District heating systems produce hot water at a central plant. The hot water is then piped through underground to individual buildings for space heating and domestic hot water. As a result, individual buildings served by a district energy system don't need their own boilers. The district energy system does that work for them, providing valuable benefits including:

- Improved energy efficiency;
- Enhanced environmental protection;
- Fuel flexibility;
- Easy to operate and maintenance;
- Reliability;
- Comfort and convenience for customers;
- Decreased life-cycle costs;
- Decreased building capital costs;
- Improved architectural design flexibility.

When hot water arrives at a customer's building, it is ready to use. It is 100 percent efficient "at the door," compared with 80 percent efficient or less when burning natural gas or fuel oil at a building. In addition, district energy systems can use the "reject heat" that results from burning fuel to produce electricity at a power plant, dramatically increasing the overall efficiency with which useful energy is extracted from the fuel. In this situation, the building must have a heating energy counter and a performing piping distribution system. The building piping system from the basement should be very good insulated to avoid energy loss. In the same time any consumer must have an individual counting of heat energy consumption. Individual counting can be made with:

- individual heating counters - noose heating counter (Figure 2.7-1a);
- heating cost dividers - riser heating counter (Figure 2.7-1b).

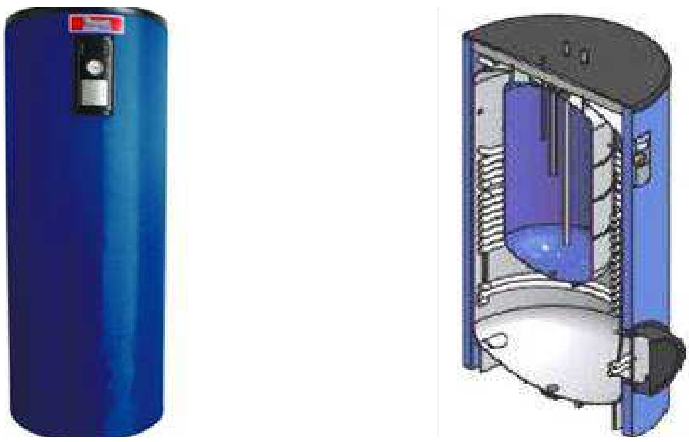
a b

**Figure 2.7-1:** Individual counting device: a - noose heating; b - riser heating

Regarding DHW, individual counting consume is necessary, similar with cold water consumption. For this purpose, water meters for cold and hot water will be mounted.

### *2.7.1.2 Building heating system*

The most common method of heat generation involves the combustion of fossil fuel in a furnace or boiler. For large building with multi-flat apartments, gas boiler is the most indicated heating solution. Gas boiler can have or not the possibility to prepare domestic hot water. Otherwise, a separated gas boiler is mounted. In any situation a buffer (Figure 2.7-2) will be mounted.



a b

**Figure 2.7-2:** Buffer (tank in tank boiler: a – exterior view; b – interior view[116]

Solar energy can be used to improve building heating and domestic hot water systems. This is done by placing solar panels on the roof and interconnect the systems.

For safety and efficiency reasons, two heating boilers are used. Building thermal load is ensured by both boilers, one of them having heating capacity about 60 % of total thermal load, another one having 40 % of total thermal load. In this way, a minimum

[116] http://www.simodorgrup.ro/Pufferetanc-in-tanc--cID69.html

thermal load can be provided in breakdown case, and, if the external temperature is not too low, just one boiler will be in use. An external temperature sensor controls the boilers operating regime. Because heating energy and domestic hot water are used by all building residents, they must be individual counted (the same situation as district heating).

### *2.7.1.3 Individual heating system*

For building apartments is not the best solution but in same circumstances is the only one. For individual heating system, a mural gas boiler with forced circulation is indicated (Figure 2.7-3). This type of boiler provides heating and domestic hot water at the same time.

a b

**Figure 2.7-3:** Mural gas boiler for individual heating. a- with instantaneous DHW; b – with DHW tank[117]

Domestic hot water can be prepared instantly (Figure 2.7-3a) or there is a DHW storage tank (Figure 2.7-3b). The second configuration is most economical concerning energy savings. For large houses and apartments (over 100 m$^2$), a condensing boiler is indicated, because it's very high efficiency. Due to lower working temperature is indicated to be use an oversized radiator or a floor heating system. Another advantage of condensing boiler is the possibility of integration with thermal solar panels (if the collectors can be placed).

A modern solution for individual heating system is gas boiler coupled with an air-to-air heat pump (Figure 2.7-5). The advantage of this system is the possibility to obtain heat water with a heat pump when the outdoor temperature is below -15°C.

[117] http://www.calorserv.ro

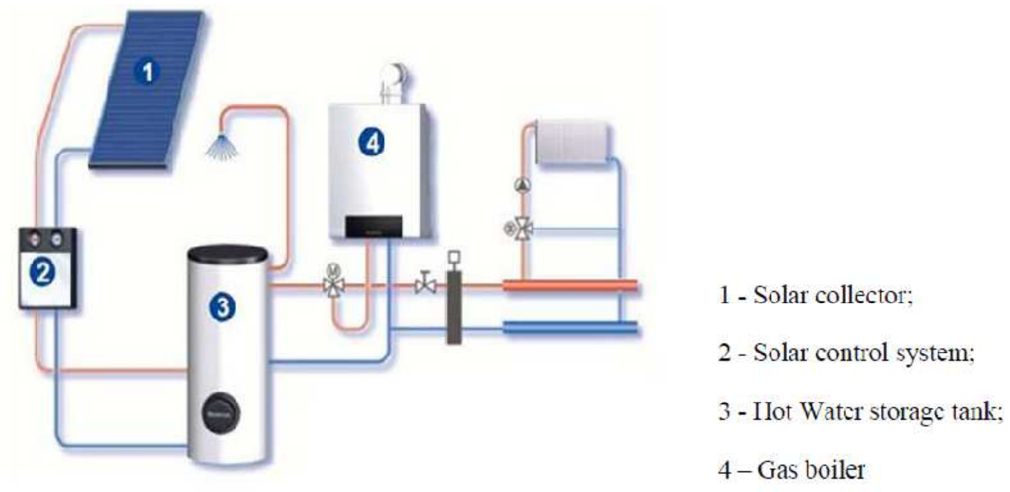



**Figure 2.7-4:** Mural gas boiler with solar collector[118].

**Figure 2.7-5:** Combined air to air heat pump with gas boiler[119]

It can be obtain a large number of heating system by combining traditional heating boiler with RES heat pump.

### 2.7.2 Ventilation system

Ventilation is necessary for maintaining acceptable indoor air quality and can also be used to improve indoor thermal conditions. Good ventilation helps the exchange of air, bringing fresh air from outdoors into the building and exhausting stale indoor air to the exterior. Also ventilation system help reduce the excessive moisture from building.

Ventilation includes air exchange (indoor-outdoor) and circulation inside the building. Despite its benefits, the ventilation system involves significant energy loss during the cold season, causing an energy efficiency decrease. There are three methods for building ventilation:

[118] www.calor.ro
[119] http://www.daikinac.com/

1. Natural ventilation;
2. Hybrid (Mixed Mode) ventilation
3. Mechanical (forced) ventilation.

### *2.7.2.1 Natural ventilation*

Natural ventilation is the process of supplying and removing air from an indoor space without using mechanical systems. It refers to the flow of external air to an indoor space based on pressure or temperature differences. There are two basic types of natural ventilation effects: buoyancy and wind. Buoyancy ventilation is more commonly referred to as temperature-induced or stack ventilation. Wind ventilation supplies air from a positive pressure through openings on the windward side of a building and exhausts air to a negative pressure on the leeward side. The benefits of natural ventilation are:

- Improved Indoor air quality (IAQ);
- Energy savings;
- Reduction of greenhouse gas emissions.

The main disadvantage of natural ventilation is that it depends on the weather conditions (wind speed). Natural ventilation can be achieved by simply opening a window or exterior door or by windows with automated venting device (Figure 2.7-6). In normal position the flap sits open - air can circulate undisturbed. At strong wind flap automatically closes the duct and prevents the apparition of air drafts.

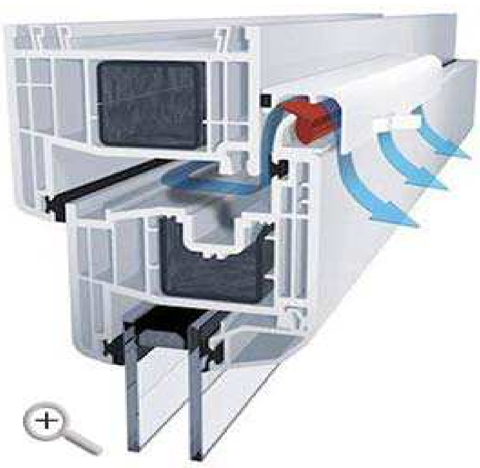


**Figure 2.7-6:** Automated venting device

### *2.7.2.2 Hybrid (Mixed Mode) ventilation*

This type of ventilation is considered when the airflow is due to wind and buoyancy through purposely installed openings in the building envelope supplemented, when necessary, by mechanical systems. The mechanical component of the hybrid system can be a fan for increasing the ventilation rate, and/or a heat exchanger for heating or cooling the outdoor supply air. The fan can be a normal one, or a variable flow fan. The heat exchanger (Figure 2.7-7) ensures an energy recovery up to 78%. As a result, the cooling/heating load can be reduced by up to 20%.

**Figure 2.7-7:** Air to air heat exchanger

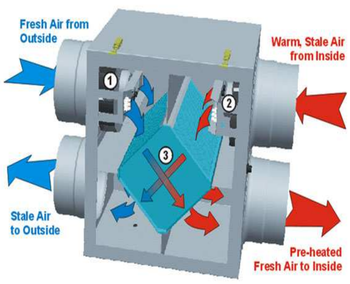
### *2.7.2.3 Mechanical (forced) ventilation*

Mechanical ventilation can be classified in three categories:

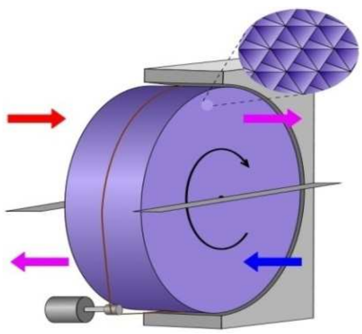
1. Central ventilation plants have one ventilation unit per building and are commonly used in office buildings. The air flow in each room can be controlled e.g. by variable air volume boxes.
2. Semi-central ventilation plants have one ventilation unit per building zone (e.g. level).
3. Decentralize ventilation plants have one ventilation unit per service unit (e.g., apartment). Usually the intake of fresh air and the discharge of exhaust air are decentralized as well. But the intake and discharge can also be central and potentially involve supporting ventilators.

The central and decentralize ventilation are most used ventilation systems in a building. The use of heat recovery units is an important measure for the energy efficiency of buildings and is mandatory in some countries. The following types of heat exchangers are used for waste heat recovery and the typical heat recovery rate (HRR) is pointed out:

- ✓ Cross flow heat exchanger (Figure 2.7-8a): typically ~ 65 % HRR;
- ✓ Counter-flow (countercurrent) heat exchanger: typically ~ 75 % HRR;
- ✓ Circulating heat exchanger (heat recovery wheel, Figure 2.7-8b): approx. 50-80 % HRR, humidity recovery.




a. Cross-flow heat exchanger



b. Heat recovery wheel

**Figure 2.7-8:** Different types of heat exchangers[120]

[120] http://www.iclimate.co.uk/

In Table 2.7-1 a series of advantages and drawback for different types of ventilation are presented.

**Table 2.7-1:** Possible advantages and drawbacks of different ventilation types.

| | Central ventilation | Decentralized ventilation |
|---|---|---|
| Advantages | Simple servicing of filters<br>Silent operation easier to realize | Simple air flow calculation |
| Drawbacks | Technically difficult dimensioning, adjustment and control of air flow per service units | High effort on time for adjustment and servicing of filters |

Decentralized ventilation plants can be an appropriate concept for refurbishment projects. Fans, filters and controlled adjusting flaps are very important for a performing ventilation system.

### 2.7.3 Air conditioning system

By definition, an air conditioning system controls temperature, humidity and air indoor quality in a building. If the temperature control in cold period of the year can be achieved by the water heating system, in the warm period only cooling (or refrigeration) system can control it. Therefore, air-conditioning systems are regarded mainly in terms of comfort parameters control in warm season.

#### *2.7.3.1 Central air conditioning system*

This is the most complex version of an air conditioning system. In technical language, this air conditioning system is named *central air handling system* (Figure 2.7-9).

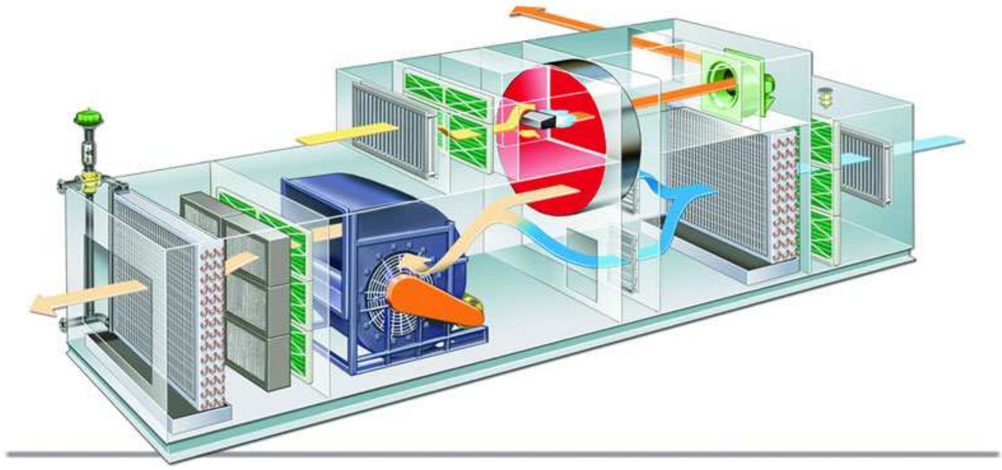


**Figure 2.7-9:** Central air handling system[121]

This combination of complex sets can provide all the air treatment processes: filtration, heating, cooling, adjusting its moisture, mixing fresh air with recirculated air, ventilation. This central air handling is able to provide air with the request

[121] www.thomaseng.com

thermo-physical parameters, which is then sent through a duct system to the area that it serves. The large majority of buildings have not a central air handling system. It is not a solution for a retrofit building, because its installation is very complex and expensive.

### *2.7.3.2 Individual or local air conditioning system*

This type of air conditioners must have incorporated a refrigeration system. There are mechanical activated air conditioners, because there is a compressor electrical activated in refrigeration system structure.

a b

**Figure 2.7-10:** Different types of air conditioners: a – monosplit; b- multisplit[122]

They act directly on indoor air and can operate in heating mode (like an air-to-air heat pump), cooling mode, dehumidification mode and ventilation mode. The working fluid in the refrigeration system is freon. The most used are individual air condition systems (split or multi-split systems) that control de indoor temperature in warm period of the year (Figure 2.7-10). Because they can operate in heating mode until an exterior temperature value (depending of technology) these appliances are very useful in spring and fall period (when the water heating system is not in use).

In heating mode, split air conditioner have a very good coefficient if performance COP (>1). It is indicated to use an interior unit in each room, mounted in windows area (or exterior wall area), because the heat or cold coming from outside is changing the temperature when it enters in the room. If the apartment have more rooms, than a multi-split air conditioners will be used (an exterior unit and an interior unit in each room). The primary energy is electrical energy. An air conditioner must be well dimensioned in conformity with room characteristic, keeping in mind that the power output of the appliance is given for specific exterior and interior temperatures.

[122] www.calorserv.ro

#### *2.7.3.3 Inverter air conditioning systems*

To save energy, inverter type air conditioner must be used. The Inverter technology (DC) is the latest evolution of technology concerning the electro motors of the compressors. An Inverter is used to control the speed of the compressor motor, so as to continuously regulate the temperature. The DC Inverter units have a variable-frequency drive that comprises an adjustable electrical inverter to control the speed of the electromotor, which means the compressor and the cooling / heating output. The drive converts the incoming AC current to DC and then through a modulation in an electrical inverter produces current of desired frequency. A microcontroller can sample each ambient air temperature and adjust accordingly the speed of the compressor. The inverter air conditioning units have increased efficiency in contraction to traditional air conditioners, extended life of their parts and the sharp fluctuations in the load are eliminated. This makes the inverter AC units quieter, with lower operating cost and with less broke downs. The inverter AC units might be more expensive than the constant speed air conditioners, but this is balanced by lower energy bills. The payback time is approximately two years depending on the usage.

A Fixed Speed Unit only has a single speed compressor motor that is either on or off. It works similar to a fan heater that switches off when the desired temperature is reached and on again when the temperature drops to a set level.

Inverter technology uses a variable speed compressor motor similar to a car. It simply slows down and speeds up as needed to hold a selected comfort setting. It provides a more precise room temperature without the temperature fluctuations of fixed speed systems.

Inverter vs Standard air conditioner

Inverter units are approximately 30% more efficient than fixed speed units. Inverter units reach the set room temperature quicker. The speed control of the outdoor unit also means quieter operation, this is important especially at night in residential areas.

#### *2.7.3.4 VRV or VRF air conditioning systems*

In principle, VRV (Variable refrigerant volume) or Variable refrigerant flow (VRF) both work the same and are extremely efficient, reliable, energy saving ways to heat and cool all types of buildings with minimum installation time or disruption.

Modern Air Conditioning Systems can allow independent cooling and heating operation at the same time. This type of system takes heat from areas that require cooling and uses this heat in other areas that require heating, enabling the system to maintain an optimum temperature throughout the building. As a result, a reduction in energy saving of up to 25% compared to conventional systems can be made. By combining VRV air conditioner with a ventilation system, a good air indoor quality is achieved.

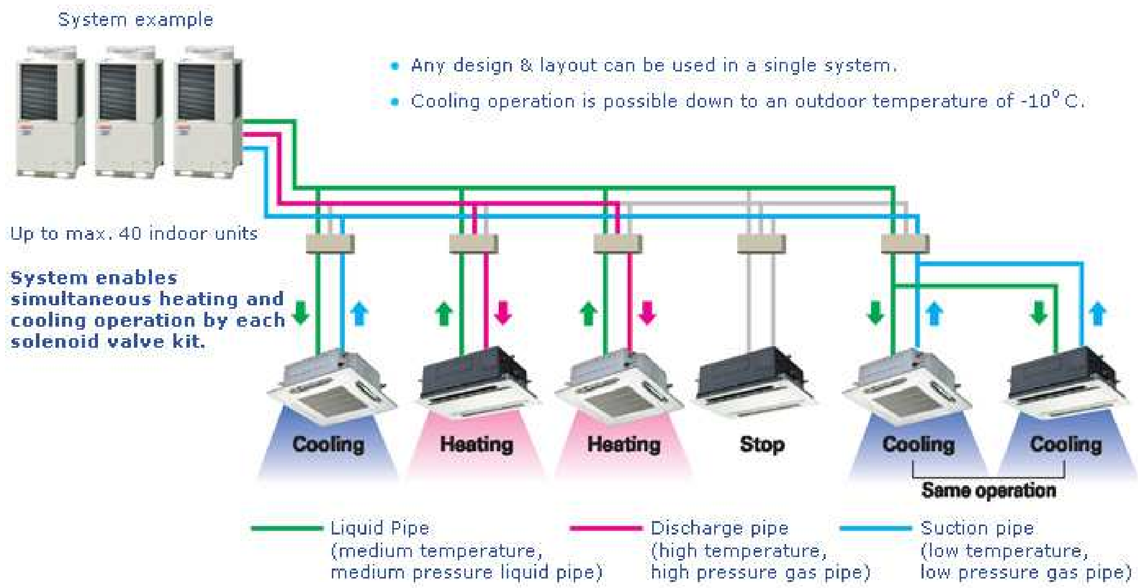



**Figure 2.7-11:** VRV type air conditioner[123]

### *2.7.3.5 Thermally activated air conditioning systems*

In the last decades thermally activated air conditioning systems to ensure the building cooling load are strongly developed. The refrigerating system contains a thermochemical compressor that work using water as fluid. The primary energy is thermal energy which can be a direct fired of a gas fuel, residual thermal energy or solar energy. There are two different refrigerating systems:

- Absorption systems (working pair lithium bromide-water);
- Adsorption systems (working pair silica gel-water).

Thermally activated air conditioning systems offers the following advantages:

- Avoid high electric demand charges;
- Minimal electricity needed during emergency situations;
- Waste heat recovery;
- Cogeneration;
- Trigeneration.

These air conditioners don't act on indoor air directly. They cool water and because of this are also called chilled water systems. The water passes through the tubes of coils that cool air in an air conditioning system, or it can pass through the water heating piping systems. In this case, the radiators are replaced with ventiloconvectors (Figure 2.7-12). This is necessary because, in cooling mode, it is necessary to increase the indoor air velocity to intensify the heat transfer process.

[123] http://www.beairconditioning.co.uk


**Figure 2.7-12:** Ventiloconvector[124]

The development of direct-fired air conditioners can also solve air-conditioning, heating and domestic hot water and electric air conditioning. Advantages:

- Saving up to 86% of electricity compared with a traditional electrical system, thanks to the prevalent use of natural gas;
- Independent and modular, it ensures continuity of service for cooling only as and when needed;
- Thanks to the use of an almost static refrigeration cycle, the performance levels remain unchanged over time and regular refill and disposal of refrigerant is not required.

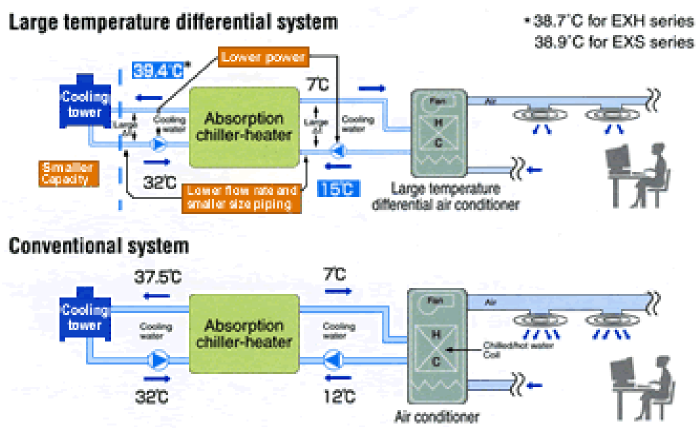



**Figure 2.7-13:** Gas fired absorption chiller[125].

The direct fired air conditioning system can be combined with solar panels, heat recovery component to obtain heating, cooling and DHW. In this category solar activated air conditioning are included, because in hot period a cooling load for the building is necessary in sunshine period.

[124] http://www.climteh.ro/ac_york/
[125] http://www.hitachi-ap.com/

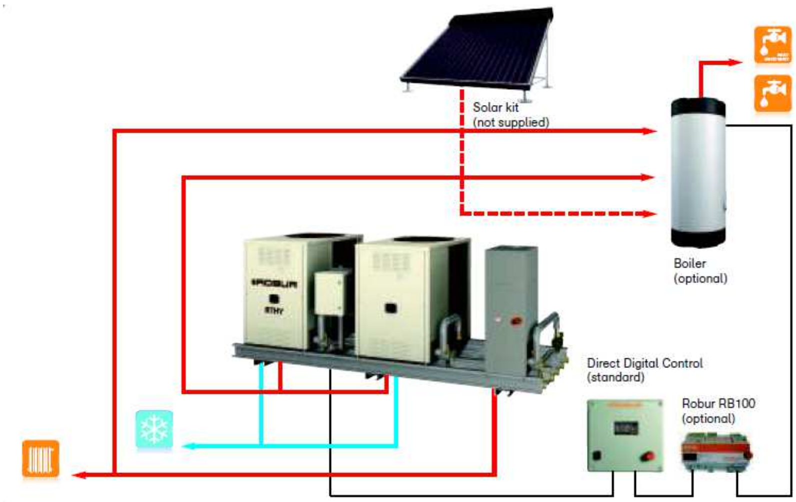



**Figure 2.7-14:** Integrated direct fired chiller for heating, cooling and DHW[126]

Waste heat driven air conditioners

These types of air conditioner are specific for cogeneration and, especially, trigeneration systems. A typical example of trigeneration system with waste heat driven air conditioner is presented in Figure 2.7-15.

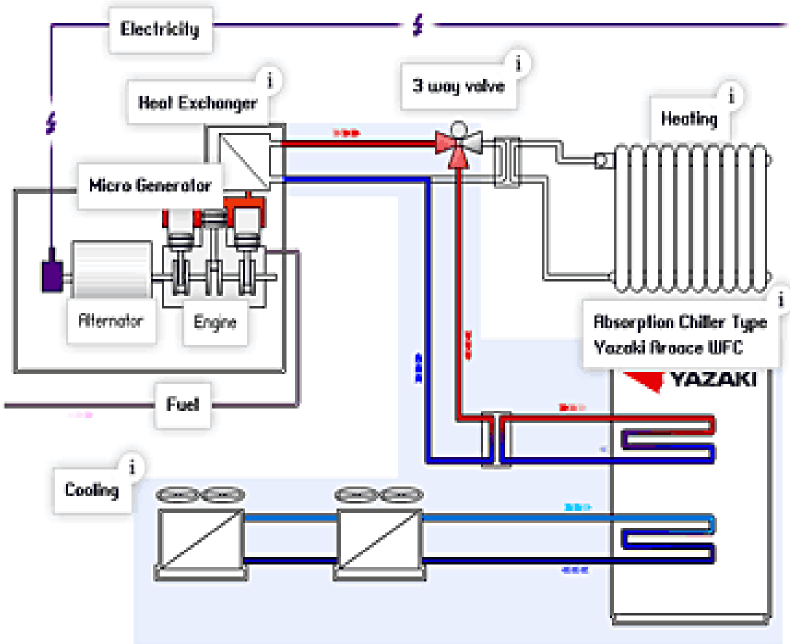



**Figure 2.7-15:** Trigeneration cooling system configuration[127]

In this case, the waste energy is provided by cooling water of a thermal engine. The advantage of this refrigerating system is using heat from the cooling circuit of a thermal engine.

[126] http://www.robur.com/
[127] http://www.yazaki-airconditioning.com.html

<u>Solar energy air conditioners</u>

As paradoxical as it may seem cooling using solar energy is feasible using solar thermal energy. Solar chillers use thermal energy provided by the sun or other backup sources to produce cold and/or dehumidification. There are two main solar cooling processes:

1. Closed cycles, where thermally driven sorption chillers produce chilled water for use in space conditioning equipment;
2. Open cycles, also referred to as desiccant evaporative cooling systems (DEC), which typically use water as the refrigerant and a desiccant as the sorbent for direct treatment of air in a ventilation system.

A new tendency for closed cycles is solar driven adsorption chiller. In this case the working fluid is water and silicagel or zeolites are used like adsorbent. The hot water temperature obtained by solar energy and activate the chiller is (65÷95)°C. This temperature is very easy to obtain even with plate solar panels.

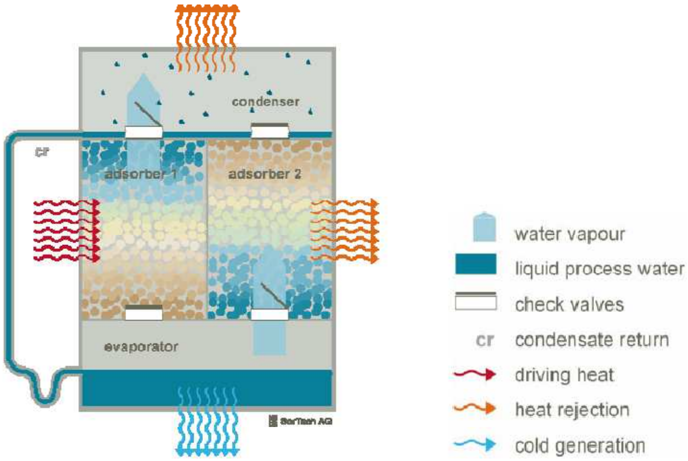



**Figure 2.7-16:** Working process of the adsorption chiller[128]

One of the big advantages of this chiller is that it has no moving pieces, so low probability of failure due to wear. Desiccant systems are used for direct air treatment, using a combination of dehumidification and evaporative cooling. Different solutions are used for each installation, depending on the local conditions.

[128] www.sortech.de

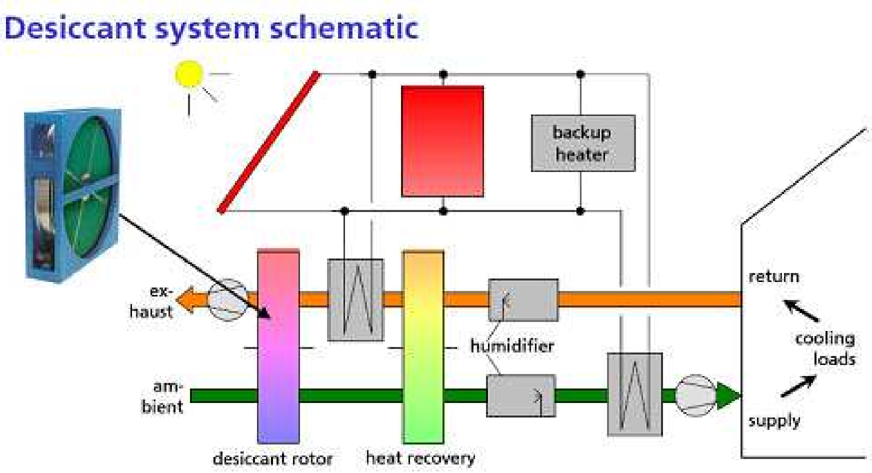



**Figure 2.7-17:** Schematic solar desiccant evaporative cooling systems[129]

Solar powered air conditioning plants installed by them are operational in Germany and other parts of Europe (see Figure 2.7-18).

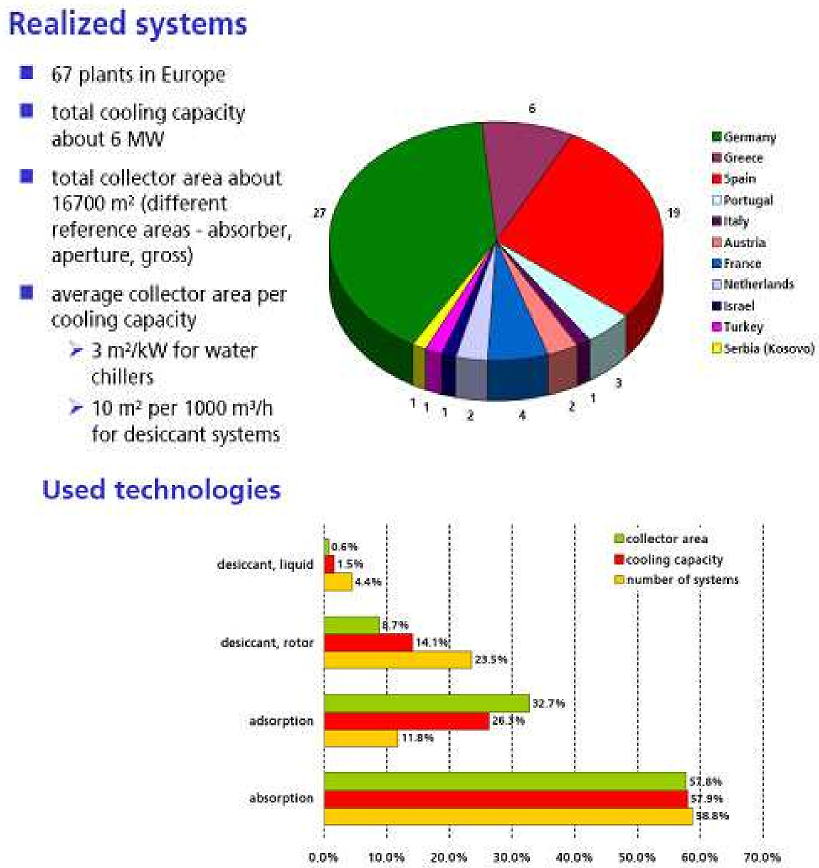



**Figure 2.7-18:** Solar powered air conditioning plants installed and used technologies[14]

Solar cooling has a number of advantages over alternative solutions, e.g.:

- It can help reduce the electricity peak demand associated with conventional cooling, as maximum solar radiation usually occurs when cooling is needed.

[129] http://www.vsmsolar.com/solar_ac.html

Solar thermal cooling can also operate in the evening by using thermal storage;

- When summer is over, solar cooling systems can be used for heating purposes such as domestic hot water preparation or space heating.

### 2.7.4 HVAC technologies using renewable energy sources

European Technology Platform on Renewable Heating and Cooling (known, for short, as the RHC- Platform) brings together stakeholders from all renewable energy sources concerned and related industries including in cross-cutting technologies such as heat pumps, thermal energy storage and district heating to agree a joint strategy for increasing the use of renewable energy sources for heating and cooling. It identifies major technological and non-technological challenges to the uptake of the RH&C systems and assesses the potential of renewable energy sources to contribute to the European and national energy needs and targets.

The "RES" Directive 2009/28/EC on the promotion of the use of energy from renewable sources states in art. 2. The following definitions also apply:
a) "energy from renewable sources" means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;
Of the RES listed, only a few are directly relevant for heating and cooling:

- solar thermal
- biomass
- geothermal
- aerothermal/hydrothermal.

When defining policy mechanisms for solar thermal, ideally they should be based on energy yield (GJ or kWh) rather than on collector surface area installed ($m^2$) even though this is easier to measure. Policy support based on surface area rather than yield disadvantages collectors with a higher performance such as vacuum collectors since these generate more heat/$m^2$ than an equivalent surface area of an alternative design. The more efficient technology would not be compensated for the additional heat produced. Moreover, since the roof surface area available for solar thermal installations is not usually limiting, the area of solar thermal panels installed is less relevant than the production of heat.

Due to the intermittent nature of the solar resource, with an abundant supply in summer when heating needs are generally low and a reduced supply in winter when heating needs are high, solar storage is an important consideration not yet addressed in policy making. In some regions, future policies designed to support solar thermal heat could therefore include a component for seasonal heat storage.

#### *2.7.4.1 Active Solar Water Heating*

Solar energy can be captured for use in a home in several ways. The hot water created by a solar system can be used for domestic hot water or space heating. Hot air solar systems are primarily used for space heating. The fundamental requirement for a solar system is to have a sunny location where the solar collectors can be located. The collectors should have full sun from 9 AM to 3 PM. The collectors should face south at approximately the same angle as our latitude (30 degrees).

Active Solar Domestic Water Heating

There are two basic categories of active solar water heating systems:

- *direct or open loop systems* - the water that will be used as domestic hot water is circulated directly into the collectors from the storage tank (typically a hot water heater which will back up the solar heating). There are two types of direct systems – *draindown* and *recirculating*. In both systems, a controller will activate a pump when the temperature in the collectors is higher than the temperature in the storage tank.
- *indirect systems* (Figure 2.7-19) - systems that use antifreeze fluids need regular inspection (at least every 2 years) of the antifreeze solution to verify its viability. Oil or refrigerant circulating fluids are sealed into the system and will not require maintenance.

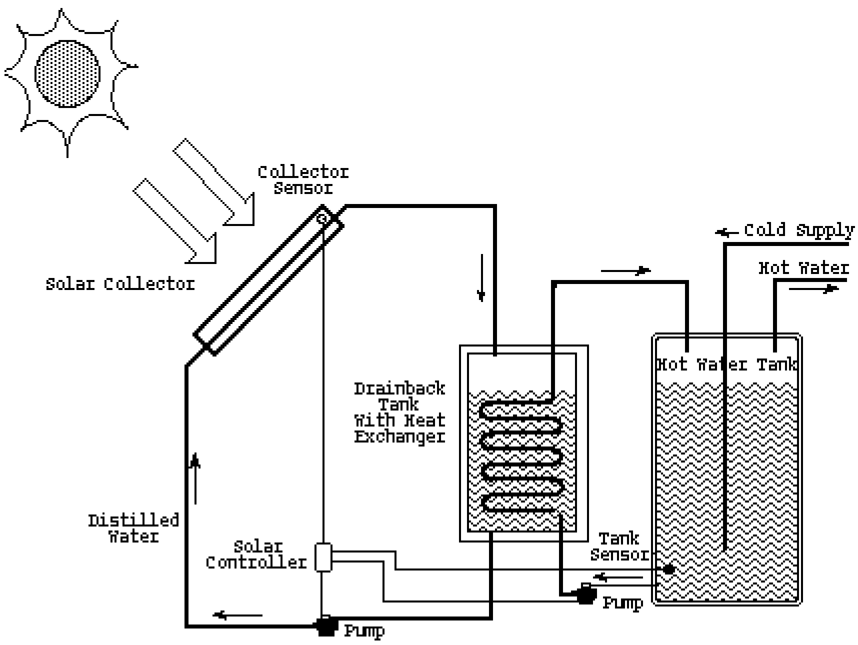



**Figure 2.7-19:** Solar drain back hot water system[130]

An indirect system that exhibits effectiveness, reliability, and low maintenance is the drainback system. The drainback system typically uses distilled water as the collector circulating fluid. The collectors in this system will only have water in them when the pump is operating. This means that in case of power failure as well as each night, there will be no fluids in the collector that could possibly freeze or cool down and delay the startup of the system when the sun is shining.

[130] http://solarheatcool.sustainablesources.com/

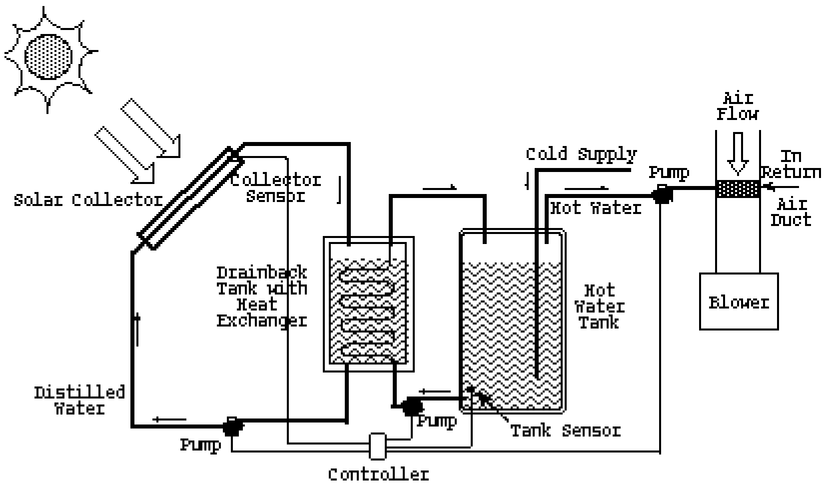



**Figure 2.7-20:** Space Heating System.[131]

This system is very reliable and widely used. It requires that the collectors are mounted higher than the drainback tank/heat exchanger. This may be impossible to do in a situation where the collectors must be mounted on the ground. The fluids that are circulated into the collectors are separated from the heated water that will be used in the home by a double-walled heat exchanger. It may be separate from the storage tank or built into it.

Active Solar Space Heating

The active solar space heating system can use the same operational components as the domestic water heating systems, but ties into a heating distribution system that can use heated fluids as a heat source. The distribution system includes hydronic radiator and floor coil systems, and forced air systems. Solar collectors are also constructed that heat air. The hot air developed in such collectors can be used directly in the home during the daytime or stored in massive materials (rock or water).

#### *2.7.4.2 Biomass heating systems*

On average, biomass accounts for around 95% of the renewable heat produced today. The growth of the biomass heat market has been most successful in countries which have employed a combination of support schemes including indirect incentives for district heating and CHP. For example, Sweden and Denmark have both seen impressive growth in their biomass heat markets on a per capita basis due to employing energy taxes to level the playing field and offered direct subsidies for biomass heat generated in CHP plants connected to district heating grids. As such, these high latitude countries with many residents living in high density, apartment blocks, have successfully developed policy support for the generation of biomass heat on a community scale, rather than targeting small individual households.

[131] http://solarheatcool.sustainablesources.com/

District heating infrastructure has been key in increasing the share of renewable heat in a number of countries.

**Figure 2.7-21:** Biomass boiler[132]

### *2.7.4.3 Geothermal*

Geothermal energy is a relatively untapped domestic energy resource from the heat of the earth and it represents a reliable and nearly inexhaustible energy source, with greatly reduced greenhouse gas emissions.

Most geothermal systems function using a ground-source heat pump. Loop piping is generally run underground either in vertical loops or horizontal loops. The system uses the Earth as a heat source in the winter and a heat sink in the summer. Since the soil below two meters is generally at a constant temperature between 7°C and 21°C degrees in this area, it can be used year round to help cool or heat a home. The system uses a heat pump to transfer the temperature of the fluid running through the underground piping to the air running through your HVAC system. This allows the system to reach fairly high efficiencies (300% to 600%) on the coldest winter nights, compared to 175% to 250% for air-source heat pumps on cool days.

with cabinet without cabinet

**Figure 2.7-22:** Geothermal heat pump[133]

[132]http://www.solusrenewableenergy.co.uk/

[133] http://www.bosch-climate.us/files/

As with any heat pump, geothermal and water-source heat pumps are able to heat, cool, and, if so equipped, supply the house with hot water. Some models of geothermal systems are available with two-speed compressors and variable fans for more comfort and energy savings. Relative to air-source heat pumps, they are quieter, last longer, need little maintenance, and do not depend on the temperature of the outside air.

A dual-source heat pump combines an air-source heat pump with a geothermal heat pump. These appliances combine the best of both systems. Dual-source heat pumps have higher efficiency ratings than air-source units, but are not as efficient as geothermal units. The main advantage of dual-source systems is that they cost much less to install than a single geothermal unit, and work almost as well.

### *2.7.4.4 Aerothermal/ hydrothermal*

Air and water are the most abundant fluids in the environment that does not require special conditions to be used as a heat sources. Therefor a large number of heat pumps use these fluids. There are all possible combination heat pumps:

- Air to air;
- Air to water;
- Water to water;
- Water to air

All these types of heat pumps are suitable to be used for a building or to ensure heating or cooling load. All these four categories of heat pumps can be classified in:

1. Air source heat pumps;
2. Water source heat pumps;

### *2.7.4.5 Air source heat pumps*

An air source heat pump (ASHP) is usually placed outside at the side or back of a property, and takes heat from the air and boosts it to a higher temperature using a heat pump. This heat is then used to heat radiators, underfloor heating systems or even warm air convectors and hot water in your home. The pump needs electricity to run, but the idea is that it uses less electrical energy than the heat it produces. The main advantages of ASHP are:

- Air source heat pumps can generate less $CO_2$ than conventional heating systems;
- They are cheaper than ground source heat pumps and easier to install, particularly for retrofit; although their efficiency can be lower than with ground source heat pumps;
- ASHPs can provide heating and hot water;
- They require very little maintenance.
- They can be used for air conditioning in the summer;
- You need to use electricity to power the pump which circulates the liquid in the outside loop, but for every unit of electricity used by the pump, you get

between two and three units of heat – making this an efficient way to heat a building.

- Cheaper Economy electricity tariffs can be used to lower the cost of electricity to power the heat pump and special heat pump tariffs may be available from some electricity suppliers – alternatively consider solar photovoltaic panels or a wind turbine (if it is installed in a suitable area) for a greener source of electricity.

The main disadvantage of an ASHP has no access to an interseasonal heat store in the ground - it cannot take advantage from the fact that higher temperatures are available from the ground in winter than from ambient air. It is therefore less efficient in winter and suffers from a lower coefficient of performance. It needs to spend energy (and generates noise) on a fan system to blow air across its heat exchangers. It also needs to incorporate a defrost cycle to prevent ice forming on its heat exchangers in cold conditions (when heat is most needed). To improve the ASHP performance in very cold period of the year electrical energy is used, especially for air to water heat pumps.

### *2.7.4.6. Water source heat pumps*

Water Source Heat Pump (WSHP) systems (Figure 2.7-23) are one of the most efficient, environmentally friendly ways to heat and cool buildings because each unit responds specifically to the heating or cooling load of the individual zone it serves. These systems are ideal for office buildings, hotels, health care facilities, schools, condominiums and apartments. The benefits are outstanding - excellent comfort, better efficiency and lower operating costs.

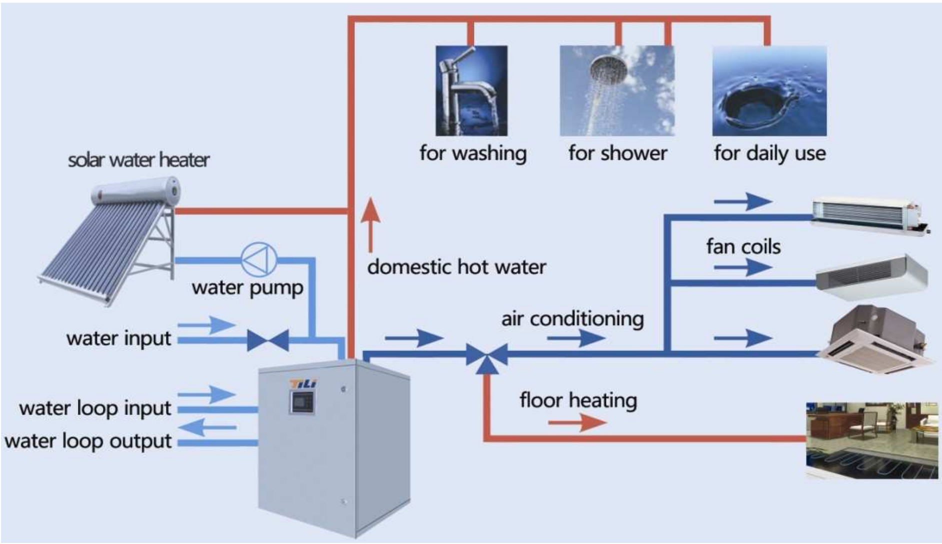



**Figure 2.7-23:** Water source heat pump for heating, cooling and DHW with solar panels[134]

[134]http://gdtili.en.made-in-china.com/

Water source can be a flowing water, a water accumulation (for example a lake), waste water source or underground water.

Advantages of WSHP Systems:

WSHP systems provide good zoning capability, each unit can provide cooling or heating regardless of what the other units are doing, or whether the rest of the building is in occupied mode or not. Small horizontal ceiling units can be relocated easily, or added as needed for changing building or tenant requirements. If a unit fails, the rest of the system remains operational (unless the boiler or cooling tower fails). Electrical energy use for the individual heat pump units can be metered for each tenant to recover at least a portion of heating and cooling costs (does not include the pumping, boiler and cooling tower operating costs). The installed cost of WSHP systems is lower than most competing systems, particularly two and four pipe fan coil systems because of savings in piping, pipe insulation, and control costs.

Disadvantages of WSHP Systems:

The primary disadvantage of WSHP systems is added maintenance. A typical system will have a large number of small heat pump units, all of which require maintenance, and repair or replacement as units fail. A WSHP unit is more complex and has more moving parts than a simple fan coil unit. In addition, the cooling tower is prone to freezing, and requires winterization. Cooling towers themselves are an added and often "strange" maintenance item.

**Conclusion**

Solar thermal, biomass, geothermal, aerothermal, and hydrothermal are on their own often unable to satisfy 100% of energy demand, but they can if are combined. There are a lot of technical solutions to combine RES heating and cooling systems, or using them in combination with a heating boiler or furnace. Any concrete situation must be analyzed to find the best solution. In the same time, it is very important that these systems must be correctly used and a minimum maintenance is necessary any year.

### 2.7.5 Proposal for implementation-Municipality of Galati: Updating the thermal substation of "Costache Negri" National College

In order to examine the applicability of updating of electro-mechanical systems in municipal buildings, a case study was developed and is analyzed. “Costache Negri” National College, Galati, Romania, was selected as a reference building. The reasons for selecting this building are:

- National College "Costache Negri" operates in a heritage building in the city of Galati, Romania, where it has its headquarters since 1900, being included in the National Heritage in 2004. The building was included in a comprehensive program of rehabilitation, which involved the rehabilitation of the heating and domestic heat water systems;

- Although this building is in good conditions concerning thermal efficiency, the heating equipment was very old and an update was required.

### *2.7.5.1 Current situation of the building*

National College "Costache Negri" comprises a group of four independent buildings:

- The main building, which is the headquarter of the college and where all the school activities are carried out. This is a two storey with basement and ground floor building. This building was included in National Heritage;
- A ground floor sports hall, which carries both sporting activities included in the school curriculum and competitions;
- A students accommodation building with basement, ground floors and two storey;
- A thermal substation, which is a ground floor building and serves all three buildings.

*Climate data and topography*

The climate data of Galati city is characterized by a temperate continental climate. It is characterized by 10°C annual isothermal. The coldest month is January, with an average minimum multiannual value of -5°C, and the hottest is July, with an average maximum multiannual value 28°C. The average annual temperature is 10°C and the average annual humidity is 62%. But in cold season the temperature differences are very large (between 0°C and -28°C), so the temperature considered to dimensioning heating system is -18°C (according SR 1907/1-98). Another important climatic factor affecting the energy performance of the building is the wind. The highest frequency in the winter have winds from southeast (22,7%), followed by north-east winds (19,1%) and northern winds (15,5%). The average annual wind speed is 4,5 - 6 m/s.


**Figure 2.7-24:** Topography of the “Costache Negri” National College building.

**Figure 2.7-25:** National College "Costache Negri" headquarter, Galati, Romania.

Figure 2.7-24 presents the topography of the location and Figure 2.7-25 presents the façade of the main building of “Costache Negri” National College.

*Use profile and thermal zones*

The basic characteristics and use profile presented in Tables 2.7-2 and 2.7-3 are referred only to the main building.

**Table 2.7-2:** Basic characteristics of the building.

| Characteristic | Value |
|---|---|
| Type of use | school |
| Total area [$m^2$] | 9,904 |
| Heat capacity [$kJ/(m^2{\cdot}K)$] | 310 |
| Automation heating systems classification | low |
| Air infiltration [$m^3/h$] | 1,428 |
| Natural ventilation coefficient | 0 |

**Table 2.7-3:** Use profile.

| Characteristic | Value |
|---|---|
| Working hours | 12 |
| Days of operation/week | 5 |
| Months of operation | 12 |
| Heating period | 1/10 to 30/5 |
| Cooling period | - |
| Lighting level [lux] | 300 |
| Annual consumption of hot water [$m^3/m^2$*year] | 0.11 |
| Average desired temperature for hot water [°C] | 50 |

*Structural and thermal characteristics of the building*

This building was constructed around 1900. Due to strict functionalist conception existing at that time, the construction has an extended surface area. It was completely rehabilitated in 1985-1987. Because the building was included in National Heritage in 1904, no thermal rehabilitation was carried because the costs.

*Electro-mechanical systems*

The building has no ventilation or cooling system. There are split air conditioners, because in the hottest period of the year (July-August) there are no scholar activities. It has just heating system, using hot water prepared in the thermal substation. According the investment target, only the heating aspects are considered. That because before rehabilitation, despite the energy building profile, the heating system can't ensure the comfort parameters in the building in cold period of the year. The old equipment did not ensure DHW.

*Heating system*

Like most buildings of Galati Municipality, the building is supplied with heat from district heating system via an own thermal substation starting from the secondary heating networks (heating and domestic hot water). This thermal substation is located in a building independence and was designed for heat loads of 5,815 kW ÷ 11,630 kW. Equipping thermal substation was made by two-stage scheme in series with tuber heat exchangers with hot water in two steps, considering the maximum temperature of heating flow pipe 150°C and a temperature difference of 70°C the operation only on heating mode to 180°C in the heating and domestic hot water preparation mode. In fact, in the Galati district heating system, there has never been a higher maximum operating temperature of 105 - 110°C, peak load boilers in CET Galati who had to work with oil, not running ever. For this reason, neither thermal substation automation could not meet the needs for which it was designed, with time being abandoned and even dismantled.

During operation, the devices shell heat exchangers were replaced with plate heat exchangers made of stainless steel. Circulating pumps were old style, low efficiency and high energy consumption. Thermal substation was not equipped with water softener systems and neither magnetization systems of the water that enters the heat exchanger for hot water distribution, to prevent the deposition of salts between stainless steel plates. For this reason, it was necessary to clean plate heat exchangers at relatively short time intervals by removing plates, which led, after a certain number of disassembly, the need for seal replacement. This operation can be done on site by personnel of operation (seals being ordered from the supplier apparatus). Plaques gasket stuck to that are non-removable, it requires replacement to be done in workshop specialized supplier being required by sticking an "annealing" in a special oven, plate gasket adhesion enhancement. This situation requires the use of magnetization systems for cold water treatment before entering the hot water equipment (heat exchangers, filters and meters) and chemical cleaning of heat exchangers, without disassembly, which requires consumption of chemicals suitable for this purpose.

### *2.7.5.2 Intervention analysis*

The thermal rehabilitation refers to the works needed for capital repairs in the thermal substation. Due to scaling on the water, some of the existing equipment must be removed and be replaced with new ones with high performance. In the same time, automation system will be implemented.

Based on the cost of operating expenses and energy consumption criteria, two interventions were analyzed:

Intervention 1: Replacement of the old equipment with new ones and replacement of pipes and their thermal insulation;
Intervention 2: Replacement of electrical circuit and automation system implementation.

*Intervention 1: Replacement of the old equipment with new ones and replacement of pipes and their thermal insulation*

The main components fitted in thermal substation were:

1. Spring and diaphragm valves, hydraulic operated for controlling (limiting) pressure differential between flow and return CET for the motorized valves (Figure 2.7-26).

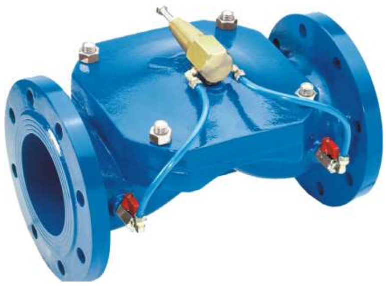


**Figure 2.7-26:**Spring and diaphragm valves.

2. Motorized valves, two and three ways, mounted on the inlet primary agent in plate heat exchangers. Through their shareholders by automation installation, flow control is achieved for primary agent, according to the required temperature in the secondary circuit, which is transmitted by temperature transducers (thermoresistant) to automation device (Figure 2.7-27).

**Figure 2.7-27:** Motorized valves.

**Figure 2.7-28:** Circulation pumps with variable speed.

3. Circulation pumps with variable speed for heating (Figure 2.7-28) and for hot water. Two pumps for each circuit were fitted, one being spare. The pumps are line type ones, with frequency converter.
4. Expansion-water added module. It consists of a tank overflow valves, pumps for water adding, level sensors, electromagnetic valves, pressure sensors, anti-flood protection. Open vessel module is connected to the station of dedurization with cationic filters which feed it with through a solenoid valve controlled by level sensors.

**Figure 2.7-29:** Expansion-water added module.

5. Enclosed expansion vessel with elastic membrane (Figure 2.7-30), which will take only a fraction of water dilation (for a current variation of 10 degrees).The remaining dilated water will be taken from the open vessel from expansion-water added module by an overflow valve and pumped into system when pressure decrease.

**Figure 2.7-30:** Enclosed expansion vessel with elastic membrane[135].

6. Station of dedurization (Figure 2.7-31), which provide the water needed in the first stage of filling the heating system and during operation, supplementing losses due to leaks in the thermal substation, networks end-users. The station is composed of two cationic filters, are generation brine tank for cationic mass, water meter for the treated water flow control and plant automation there for which switch a filter with each other at a certain flow of treated water, ordering and filter regeneration cycle when this is necessary. The station is supplied with cold water from the city network.

**Figure 2.7-31:** Station of dedurization[136].

7. Magnetic water treatment plant from which hot water is prepared in order to avoid deposition of salts in the form of stone, due to warming the water. The magnetic field is produced by an device connected to the electrical grid, the intensity depending on the flow of water and salt content of the water.
8. Thermal energy meters for all heating circuits and domestic hot water circulation coming out of the thermal substation, including DHW recirculating pump, equipped with Mbus communication for remote transmission of the

[135] http://www.ferroli.ro
[136] www.calorserv.ro

parameters: thermal energy consumption, flow, thermal agent volume (Figure 2.7-31).

**Figure 2.7-32:** Thermal energy meters[137].

9. Plate heat exchanger (Figure 2.7-33) for heating, made of stainless steel with removable gaskets, with a thermal loadof2MW.

**Figure 2.7-33:** Plate heat exchanger[138].

10. Plate heat exchanger (Figure 2.7-33) for domestic hot water preparation, made of stainless steel with removable gaskets, with a thermal load of 700 kW.

Another issue that was taken into account was the replacement and insulation of pipes that provide equipment placed in the thermal substation. Thermal insulation of pipelines was made with mineral wool with a protective film of aluminum foil. The estimated total annual primary energy consumption per end use and energy consumption per fuel type, after the equipment replacement, are presented in Tables 2.7-4 and 2.7-5.

137 http://www.maddalena.it
138 http://www.alfalaval.com

**Table 2.7-4**: Primary energy consumption per end use - Intervention No1.

| End use | Energy consumption [kWh/m²] | |
|---|---|---|
| | Current thermal station | After intervention No1 |
| Heating | 112.7 | 106 |
| DHW | 40 | 18 |
| Total | 152.7 | 124 |

**Table 2.7-5:** Energy consumption and $CO_2$ emissions per fuel - Intervention No1.

| Fuel type | Current building | | After intervention No1 | |
|---|---|---|---|---|
| | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] |
| Electricity | 45.9 | 20.4 | 42.6 | 18.9 |
| Heating oil | 112.7 | 27.6 | 98.6 | 24.2 |
| Total | 158.6 | 48 | 141.2 | 43.1 |

*Intervention 2: Replacement of electrical circuit and automation system implementation*

The electrical and automation system installations were completely replaced. To achieve high performance automation systems were needed:

- A programmable automation device powered electronics, Mbus interface that receives all the details on the parameters, processes this information and controls the thermo-mechanical devices(pumps, motorized valves);
- Transducers that receive parameters information and transmit signal and impulses to the automation devices (heat-resistant, pressure switches, thermostats, flow switches, energy meters, the temperature probes).

PLC, visualization and parameterization console provides:

- Temperature control in the heating circuits depending on the outside temperature and operating options by turning the motorized valves fitted to each machine;
- Limiting temperature hot water at 60°C;
- Preparation with priority of the hot water, by reducing thermal heating in periods the maximum consumption of hot water;
- Double pump control by changing periodically active pump with spare pump and switch in emergency mode;
- Maintain a minimum temperature in DHW recirculation system;
- Automatic loading with water of the heating circuit;
- Added pump protection in case of lack of water in heating circuits, hot water tank and filler;
- Connect all emergency signals and parameters of the working fluid in the machine automation.

The estimated total annual primary energy consumption per end use and energy consumption per fuel type, after the electrical circuits and equipment replacement and automation system implementation, are presented in Tables 2.7-6 and 2.7-7.

**Table 2.7-6:** Primary energy consumption per end use - Intervention No2.

| End use | Energy consumption [kWh/m²] | |
|---|---|---|
| | Current building | After intervention No2 |
| Heating | 112.7 | 100 |
| DHW | 40 | 15 |
| Total | 152.7 | 115 |

**Table 2.7-7:** Energy consumption and $CO_2$ emissions per fuel - Intervention No2.

| Fuel type | Current building | | After intervention No2 | |
|---|---|---|---|---|
| | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] | Energy consumption [kWh/m²] | $CO_2$ emissions [kg/year/m²] |
| Electricity | 45.9 | 20.4 | 38.7 | 17.2 |
| Heating oil | 112.7 | 27.6 | 92.3 | 22.6 |
| Total | 158.6 | 41.3 | 131,0 | 39,8 |

### *2.7.5.3 Assessment of interventions and conclusions*

As it is shown in Tables 2.7-4 to 2.7-7, both interventions have a positive impact on reducing the energy consumption of the building. For assessing the proposed interventions, it must take into account a large number relative indicator. In table 8 these indicators are presented. Most important, these interventions ensure DHW and interior temperature in cold period of the year.

**Table 2.7-8**: Indicators for assessing the proposed interventions.

| Assessment category | Intervention No1 (equipment) | Intervention No2 (electrical circuit/ automation) |
|---|---|---|
| Initial cost [€] | 130.000 | 15,500 |
| Annual electricity savings [kWh/year] | 21,209 | 46,274 |
| Annual heating oil savings [kWh/year] | 90,621 | 131,110 |
| Direct $CO_2$ emissions [kg $CO_2/m^2$] | 9,640.5 | 31,492.3 |
| Intervention intensity | High | High |
| Implementation time [months] | 5 | 1 |

The updated thermal substation is presented in Figure 10. The main objectives of thermal rehabilitation of the thermal substation which serves the “Costache Negri” National College headquarter were:

1. Reducing electrical energy consumption by using pumps with variable speed;
2. Reducing heat loss through the insulation in the thermal substation;
3. Reducingheatlossesbytransmissionandheatleakagesthermalsubstation;
4. Reducing costs and operating times of planned and incidental repairs;
5. Increasing energy efficiency of the thermal plant;
6. Decreasing the energy price.

**Figure 2.7-34:**The updated thermal substation

Thermal rehabilitation of the thermal substation was supposed:

- Replacement of plat heat exchangers (one for heating, one for hot water preparation);
- Replacement of the pump for cold water recirculating circuit;
- Replacement of the pump for domestic hot water recirculating circuit;
- Station of dedurization of water;
- Thermal energy meters;
- Thermal insulation of the pipes for hot water circulation;
- The automation of the thermal substation;
- Replacement sanitary installations.

# 3. Comparison and conclusions

The specific study includes a collection of the available retrofitting actions that can be applied to increase the energy efficiency of buildings. Seven (7) generic action-categories were analyzed covering a wide range of interventions available:

a) *Bioclimatic design*: Bioclimatic design (also known as "passive" solutions) offers clever and often simple and inexpensive techniques to reduce the demand for energy inputs during the operation of a building. These solutions are in contrast to the mechanical solutions such as heating, air-conditioning, and mechanical ventilation units. With increased emphasis on environmentally sustainable architecture, there is a reemergence of interest in such "passive" solutions such as building orientation, natural ventilation, passive cooling, daylighting, shading, insulation, building envelope design, cool roofs, and so on.

b) *Renewable energy systems (RES) integration*: The transition to a renewable energy, resource efficient economy is a tremendous chance to boost economic growth and create new jobs while securing environmental protection and mitigating climate change through to 2020. Renewable energy systems that can be integrated in a building include solar photovoltaic RES, solar (thermal) RES, heat pumps, and geothermal heat RES.

c) *Insulation*: Insulation is one of the most effective ways to improve the energy efficiency of a building. Insulation of the building envelope helps keep heat in during the winter and out in summer to improve comfort and save energy. Insulation could add additional benefits such as acoustics and waterproofing. Effective draught proofing, moisture control and ventilation are important at design stage. The appropriate level of insulation intervention will depend on climate, building construction type, and whether auxiliary heating and/or cooling is used. Insulation reduces heat flow and is essential to keep a building warm in winter and cool in summer. A well insulated and well designed building will provide year-round comfort, decreasing energy costs.

d) *Lighting*: Lighting accounts for approximately 5-7% of a household's energy bill providing a great potential for energy and cost savings. Energy efficient bulbs are available for those interested in reducing the energy consumption due to lighting needs. Compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) are the most common types of energy efficient light bulbs available. Changes in the behavior of the occupants can additionally have a great positive impact in energy consumption for lighting.

e) *Buildings energy management systems (BEMS)*: An intelligent building requires a sophisticated building automation system to manage a large set of actuators and equipment. Building energy management is a fundamental and important issue regarding building automation. Building Energy Management Systems (BEMS) are currently being developed for application in buildings for energy and environmental management. The main objective of the BEMS is to contribute to the continuous and effective energy management of the building thus achieving significant energy and cost savings.

f) *Frames replacement*: The design of windows and external doors (frames) have a significant impact on the energy consumption of buildings and structures in a period of low and during high ambient temperatures. At low ambient temperatures, some amount of heat power is spent for compensating heat losses through window and door constructions, as well as for heating of the incoming excessive infiltration air through them. In a period of high ambient air temperatures, some amount of the power of conditioning systems is spent on the compensation of heat coming through windows and doors, cooling the excess air infiltration coming through these structures, as well as compensation of the excess heat from solar radiation entering through the translucent structures.

g) *Electromechanical systems*: The main purpose of electro/mechanical systems is to provide thermal comfort and to maintain good indoor air quality (IAQ). These conditions are essential for an efficient building. The electromechanical systems are one of the largest energy consumers in buildings, and relatively small improvements in the design or equipment selection can produce large long-term savings in energy expenditures over the life cycle of the system. Electromechanical systems include ventilation, air-conditioning and thermal equipment such as heating boilers.

A great focus was given in presenting the best available practices and technologies per category, in order to provide a comprehensive “guidebook” for those interested in increasing the energy efficiency of their building. The knowledge of best available practices/technologies is very important since decision makers can benefit from existing experience and avoid mistakes and waste of time and money. In other words, the specific study can help answering questions such as “what are the available technologies for heating?”, “what are the pros and cons of various types of insulation?”, “are there any examples of implementation and which are the results?”.

In order to examine the potential applicability of the proposed practices, specific proposals for implementation were developed per category, using actual data from the municipalities participating in the BSBEEP project. In Table 3-1 a summary of the key benefits of implementing building energy efficiency best practices is presented.

As a final statement it could be inferred that the practices presented in the specific study, provide a great potential in terms of energy and cost savings. Despite the clear economic and environmental benefits of implementing building energy efficiency best practices, significant obstacles do exist, hampering the wide adoption of energy efficiency retrofitting actions. These obstacles are presented in Table 3-2, including a number of indicative proposals to address them.

**Table 3-1**: Benefits of implementing building energy efficiency best practices/technologies.

| Benefit/advantage | Description |
|---|---|
| Energy savings | • Significant reductions in energy consumption can be achieved if retrofitting actions are chosen carefully according to the special characteristics of the examined building. |
| Cost savings | • Significant cost savings result from reduced energy consumption, especially when life cycle costs are taken into account. |
| Environmental benefits | • Best practices can contribute to the reduction of both direct and indirect GHG emissions, thus contributing to confronting major environmental impacts such as climate change. |
| Higher property value | • Energy efficient buildings have a higher market value due to reduced costs of heating/cooling, maintenance needs etc. |
| Higher living/working standards | • An energy efficient building offers a living and/or working environment which offers an increased quality of life (e.g. better indoor air quality, thermal comfort, etc.) thus increasing the happiness and productivity of the occupants. |
| Increased acceptance and raising awareness | • Occupants and visitors are attracted more by a best practice building. In many cases, best practice buildings act as an exemplar, raising awareness regarding the potential benefits of available best practices. |

**Table 3-2**: Obstacles to implementing building energy efficiency best practices/technologies.

| Obstacle | Description |
|---|---|
| Lack of knowledge | • This obstacle refers to the low public awareness regarding the benefits of implementation. Communication programs, awareness campaigns etc. can really help decision makers to proceed to an intervention. Successful applications must be communicated adequately in order to act as an exemplar of potential benefits (especially in the case of public/municipal buildings). |
| Unclear cost savings | • The actual savings cannot be fully estimated before the action. However, many tools are now available that can help reliably estimate savings using baseline data and relative models. |

| | |
|---|---|
| Long payback times | • Many building owners find the capital cost too high and the payback time too long, to proceed to the implementation (especially when the owner does not benefit from the operating costs – e.g. building occupied by tenant). A life cycle cost analysis would help address the specific problem, especially if it is combined with financial support (e.g. national programs). The long term benefits must be made clear whereas a fair distribution of costs/benefits between owner/tenants is necessary. |
| Special constraints | • In a number of cases, special constraints due to the physical and spatial characteristics of the building (e.g. poor sunlight, historical building etc.) can make some actions more expensive or even impossible to be applied (especially in existing buildings). A best available practice must be chosen while in parallel various considerations are taken into account. |

Selecting a best available practice depends on various parameters (e.g. type and use of the building, spatial characteristics, number of users, prevailing weather conditions, budget available and so forth) and it is usually in the eye of the beholder to select which practice does actually fits to its scope.

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