Editor **Dorota Anna Krawczyk**

SUSTAINABLE BUILDINGS

designing and management of cost-effective and eco-friendly systems

SUSTAINABLE BUILDINGS
DESIGNING AND MANAGEMENT OF COST-EFFECTIVE AND ECO-FRIENDLY SYSTEMS

Editor

Dorota Anna Krawczyk

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Contents

Abbreviations	Description
2D	Two-Dimensional
3D	Three-Dimensional
A	Acoustic
AC	Alternating Current
AEC	Architecture, Engineering, and Construction
AES	Advanced Encryption Standard
AI	Artificial Intelligence
AIVC	Air Infiltration and Ventilation Centre
ALDREN	Alliance for Deep Renovation in Buildings
AM	Air Mass
AMQP	Advanced Message Queuing Protocol
ARM	Advanced RISC Machine
BEP	BIM Execution Plan
BIM	Buildings Information Modelling
BIM	Building Information Modelling
BIOS	Basic Input/Output System
BP	British Petroleum
CBC	Cipher Block Chaining
CCM	Cipher Block Chaining-Message Authentication Code
CDA	Conditional Demand Analysis
CdTe	Cadmium Telluride
CEN	European Committee for Standardization
CIGS	Copper Indium Gallium Selenide
CoAP	Constrained Application Protocol
CPU	Central Processing Unit
CTR	Counter Mode Decription
DC	Direct Current
DCV	Demand-Controlled Ventilation
DDoS	Distributed Denial of Service
DHW	Domestic Hot Water
DN	Diameter Nominal
DNS	Domain Name System
DPA	Discrete Processes Automation
DVR	Digital Video Recorder
EC	European Commission
EIR	Employer’s Information Requirements
EN	European Standards
EPB	Energy Performance of Buildings

Abbreviations	Description
EPBD	Energy Performance of Buildings Directive
EPP	Expanded Polypropylene
EPS	Expanded Polystyrene
EU	European Union
FBI	Federal Bureau of Investigation
FIPS	Federal Information Processing Standards
FTDI	Future Technology Devices International
GDPR	General Data Protection Regulation
GND	Ground
GPIO	General Purpose Input Output
GSM	Global System for Mobile communications
HEPA	High Efficiency Particulate Air
HTTP	Hyper Text Transfer Protocol
HVAC	Heating, Ventilation and Air Conditioning systems
I	Indoor
IAQ	Indoor Air Quality
ICFs	Insulating Concrete Forms
ICT	Information and Communication Technologies
IDE	Integrated Development Environment
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEQ	Indoor Environmental Quality
IoT	Internet of Things
IP	Internet Protocol
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
KNX	Konnex
L	Luminous
LED	Light-emitting Diode
LiFeP	Lithium Iron Phosphate
LPWAN	Low-Power Wide Area Networks
MIPS	Microprocessor without Interlocked Pipeline Stages
MQTT	Message Queuing Telemetry Transport
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NOP	No OPeration
NoSQL	Not Only Structured Query Language
NX	Non-Executable

Abbreviations	Description
OOP	Object-Oriented Programming
OS	Operating System
OSB	Oriented Strand Board
PAH	Polycyclic Aromatic Hydrocarbon
PC	Personal Computer
PE	Polyethylene
PEHD	Polyethylene High-Density
PIR	Polyisocyanurate
PLC	Programmable Logic Controllers
PMV	Predicted Mean Vote
PP	Polypropylene
PPD	Predicted Percentage of Dissatisfed
PUR	Polyurethane
PV	Photovoltaic
PVC	Polyvinyl Chloride
PVT	Photovoltaic Thermal
PwC	Price Waterhouse Coopers
RCE	Remote Code Execution
RFID	Radio Frequency Identification
RGBW	Red, Green, Blue, White
ROM	Read-Only Memory
ROP	Return Oriented Programming
RSA	Rivest, Shamir and Adleman
S/MIME	Secure / Multipurpose Internet Mail Extensions
S2, S3	BIM Project Development Stages
SCADA	Supervisory Control And Data Acquisition
SHGC	Solar Heat Gain Coefficient
SIPs	Structural Insulated Panels
SSH	Secure Shell
SSL	Secure Sockets Layer
STC	Standard Test Conditions
T	Thermal
TAIL	Thermal, Acoustic, Indoor Air, luminous Environment
TCP	Transmission Control Protocol
TPM	Trusted Platform Module
UNE	Spanish National Standard
URL	Uniform Resource Locator
USA	The United States of America

Abbreviations	Description
USB	Universal Serial Bus
UV	Ultraviolet
VIPs	Vacuum Insulation Panels
VOC	Volatile Organic Compound
VPN	Virtual Private Network
WAN	Wide Area Network
WHO	World Health Organization
XPS	Extruded Polystyrene

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Preface

The monograph "Sustainable buildings – designing and management of costeffective and eco-friendly systems" has been developed as the result of scientific cooperation between lecturers and researchers from European universities: Bialystok University of Technology (Poland), the University of Cordoba (Spain), Rezekne Academy of Technologies (Latvia) and Vilnius College of Technologies and Design (Lithuania). The authors' team includes professors with recognized scientific achievements, teachers who cooperate with the industrial sector as well as PhD students starting their career path. The cooperation was possible thanks to joint work in the ADD_ON_SKILLS project (Advanced Digital Design course ON modern buildings developing SKILLS for young engineers, 2020-1-PL01-KA226-HE-095244) carried out within the framework of Erasmus+ programme.

Sustainable buildings should be planned and managed using available, innovative technologies and systems. It is immensely important to implement modern solutions in the early stage of building design.

The first chapter presents possible usage of solar energy through the implementation of active or passive systems. Heating systems and their regulation are described in the second chapter, while chapters three and four are dedicated to the efficency of ventilation and water installation respectively. All those systems should be designed using innovative software and methods like BIM, presented in chapter five. Moreover, after putting the building at users' disposal it becomes crucial to manage it, inluding energy consumption registration and optimalization, that is discussed in the sixth chapter. Chapter seven concentrates on reduction of distribution heat losses.

Undoubtedly, the available technologies, including the Internet of Things, are becoming more and more complex and allow for efficient automation and control of lighting, heating, ventilation, air conditioning, domestic hot water as well as security of home appliances, e.g. ovens or refrigerators. The author of chapter eight explains the terms "Home Automation" and "Internet of Things", that are parts of the Smart Home concept. Finally, chapter nine focuses on issues connected with the life cycle of smart cities and big data protection as well as cybersecurity.

In conclusion, this book highlights the role of designing and manageming cost-effective and eco-friendly systems in making buildings sustainable.

The monograph, published in open access, is targeted at students, scientists, engineers, designers as well as owners or users of buildings who are interested in modern trends in the application of smart solutions.

Dorota Anna Krawczyk, Chief Editor

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1. ACTIVE AND PASSIVE SOLAR BUILDING DESIGN

1.1. Introduction

Fossil fuels – including oil, coal, and natural gas – are still the largest sources of energy in the world. According to International Energy Agency, global electricity demand was set to grow by close to 5% in 2021 and 4% in 2022. As the energy demand is growing every year, it is predicted, that we will run out of fossil fuels by 2060. It is important to find alternative energy sources, as fossil fuels resources are running out. According to BP Statistical Review of World Energy 2021, the world consumption of renewable energy is growing – in 2019 around 11% of global primary energy came from renewable technologies and in 2020 it jumped to nearly 12.55% (Ritchie & Roser, 2021).

Renewable energy, referred to as clean energy, comes from a natural source such as solar, biomass, geothermal, hydro and wind (Fig. 1.1). So, renewable energy could be one of the possible solutions and alternatives to energy from fossil fuels.

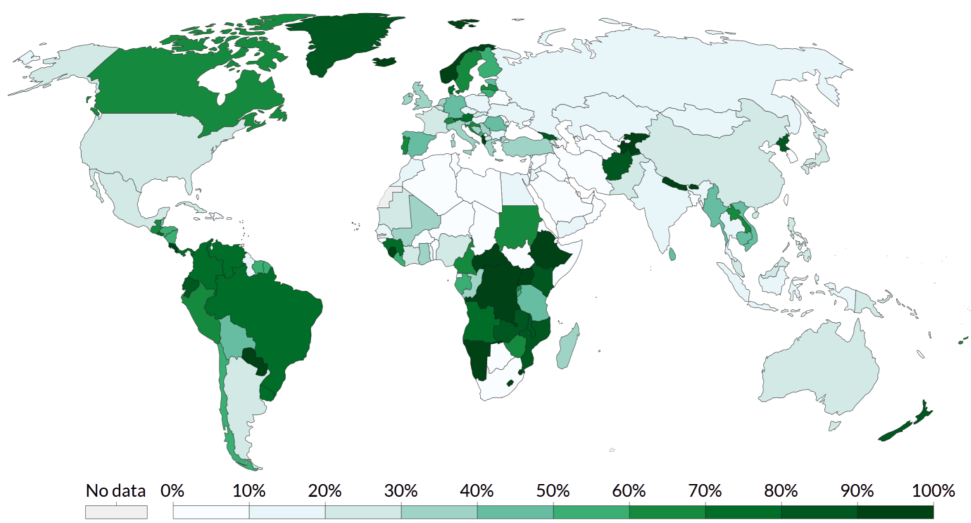

FIG. 1.1. Share of primary energy from renewable sources, 2021 (Source: BP Statistical Review of World Energy, 2021, OurWorldInData.org/energy, CC BY)

Sun is one of the primary energy sources. Solar energy is an essential source of renewable energy. According to NASA the Sun provides approx 1300 watts per square meter every second to the Earth and provides the earth more than 10000 times the energy people currently use. The solar constant at any given location on the Earth's surface depends on the latitude, season, time of day, and sky formation. The Sun has clean and free energy which could be used to light, ventilate, heat, and cool a building.

It is very important to implement methods of energy efficiency in the early stage of building design. Based on needs and options, solar energy in buildings can be used through the implementation of active or passive systems. Both, active and passive solar systems use the same source of energy – solar energy. Despite that, active solar design and passive solar design differs substantially. Some houses have both active and passive systems (Fig. 1.2). The solar design makes home less dependent on traditional energy sources.

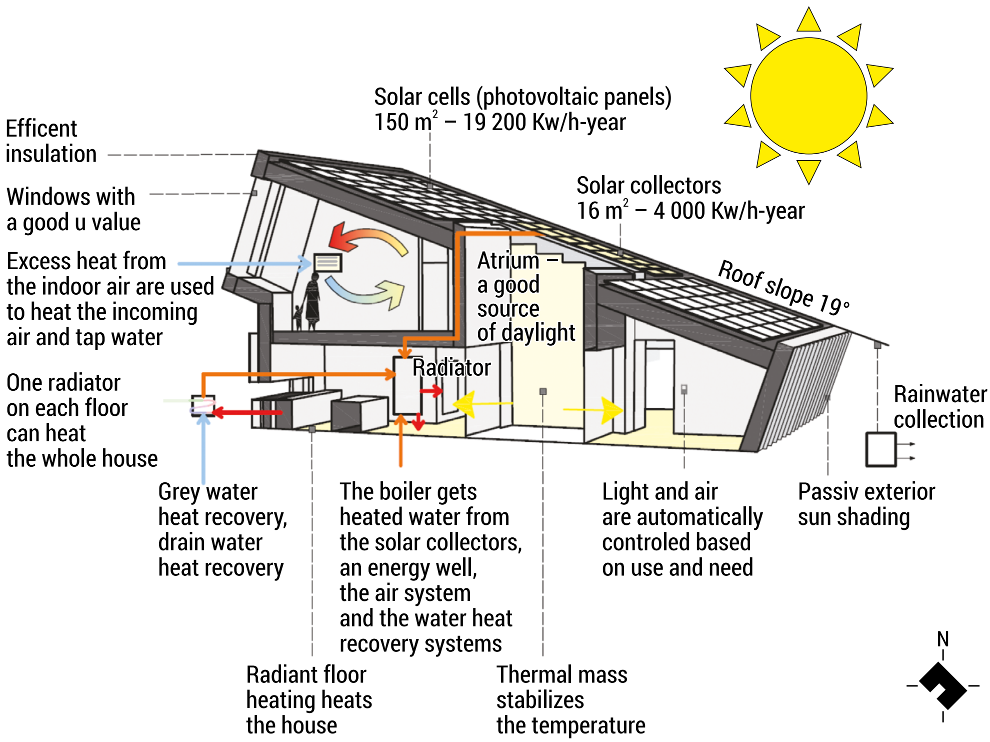

FIG. 1.2. Combined active and passive solar house design (Source: own elaboration)

When we use the term „active", we mean any system that uses special devices, electronic controls, or other intelligent systems. Active solar energy systems typically include photovoltaic panels, collectors, inverters, batteries, charge controllers, and pumps that work together to capture and convert the solar energy into a more usable form, such as hot water or electricity.

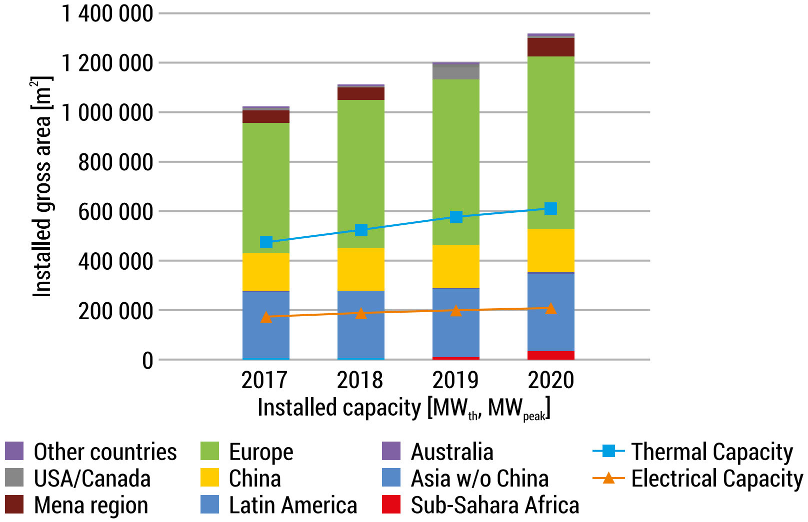

FIG. 1.3. Steady growth on the global PV-Thermal market (Source: own elaboration baced on The International Energy Agency Solar Heating and Cooling programme, 2021)

„PV-Thermal systems – generating both solar heat and solar electricity – becoming more popular in a growing number of countries. The 36 PVT manufacturers reported the highest sales in 2020 in established markets like the Netherlands and France and new markets such as Tibet and Ghana. The global market saw steady growth – 9% on average between 2018 and 2020 (Fig. 1.3) (Weiss & Spörk-Dür, 2021).

Despite the pandemic taking a heavy toll on most national economies in 2020, some large solar thermal markets grew due to increased policy support, like Germany and the Netherlands (Fig. 1.4). In Turkey and Brazil, the demand for solar water heaters increased as homeowners spent more time at home and made improvements around the house (Weiss & Spörk-Dür, 2021).

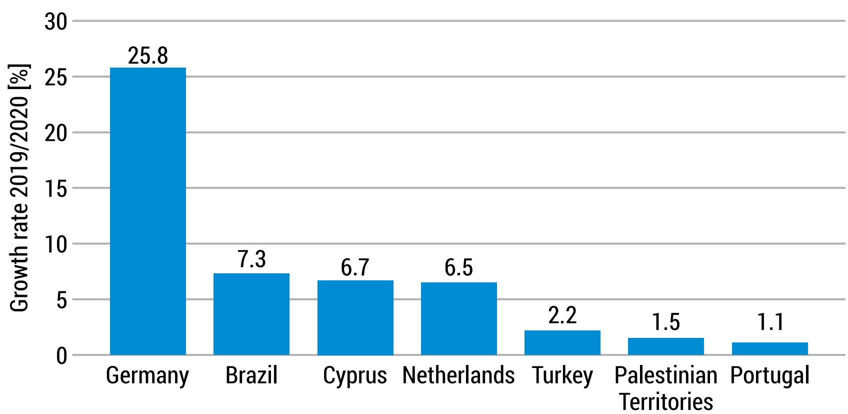

FIG. 1.4. PV system growth rate 2019/2020 (Source: own elaboration baced on The International Energy Agency Solar Heating and Cooling programme, 2021)

When it comes to solar energy, people calculate the cost of solar panels and other equipment, without realizing that solar energy can be used without any equipment at all, as long as the design of the house is properly considered. Even ancient civilizations used passive solar design. Socrates, the Greek philosopher, studied this problem about 2,500 years ago. In Book III, Chapter VIII, of Xenophon's Memorabilia of Socrates, written a few decades after Aeschylus, and in the midst of a Greek wood fuel shortage, the Greek philosopher, Socrates, observed: "Now in houses with a south aspect, the sun's rays penetrate into the porticos in winter, but in the summer, the path of the sun is right over our heads and above the roof, so that there is shade. If then this is the best arrangement, we should build the south side loftier to get the winter sun and the north side lower to keep out the winter winds. To put it shortly, the house in which the owner can find a pleasant retreat at all seasons and can store his belongings safely is presumably at once the pleasantest and the most beautiful." While the Greek house described by Socrates was losing heat as fast as it collected due to convective and radiative losses, the Romans discovered that if portico and south-facing windows were glazed, solar energy would be trapped and the resulting heat could be stored for the night. This simple phenomenon was called the "green house effect." Today, a house that we use the greenhouse effect for heating, we call a "passive solar house."

1.2. Passive Solar Building Design

1.2.1. Concept of Passive Solar Design

Warm in winter – cool in summer. This can be achieved with passive solar building design. A passive solar heating system is an energy system in which the processes of reception, storage, and use of solar energy for heating are carried out naturally in the architectural and structural elements of the building. Passive solar systems do not involve the use of mechanical or electronic devices to convert solar energy. We should pay attention to the need to take into account the possibility of using elements of passive solar systems in the process of designing the building. The implementation of some possible approaches during reconstruction, overhaul, or technical re-equipment can be ineffective with the existing architectural parameters of the building. Passive solar design is a better return than most investments.

A passive solar house must meet three basic requirements:

- Building orientation should be an essential part of building design. The building must act as a solar collector, letting the sun's rays in when heat is needed and keeping them out when it is not.
- The building should be a solar accumulator, retaining heat so that it can be used during cold times when the sun is not shining, as well as keeping it cool during

hot periods. Buildings made of solid materials: stone and concrete are the most effective in this regard.

- A building should be a good heat trap, use heat efficiently and lose it very slowly. This is accomplished primarily by reducing the heat loss of the building through the effective use of insulation, reduction of air infiltration, and windowing.

1.2.2. Basic Types of Passive Solar Design

The shape of the building should be simple as possible to allow maximum solar gain.

According to Nikolić et al. (2018), there are three basic types of passive solar design: direct gain, indirect gain and isolated gain. The purpose of all of them is passive solar space heating.

Direct gain – is the simplest type of solar heating (Fig. 1.5). Sunlight enters the house through the south-facing windows and strikes thermal mass (floor and walls), which absorb and store the solar heat. The walls and floor provide solar collection and thermal storage by absorbing direct, reflected, or reradiated energy. As long as the room temperature remains normal, the storage mass will conduct heat. At night, when outside temperatures drops and the interior space cools, the heat flow reverses, and heat is given up to the interior space until the thermal mass and room reach temperature equilibrium (WEB-5).

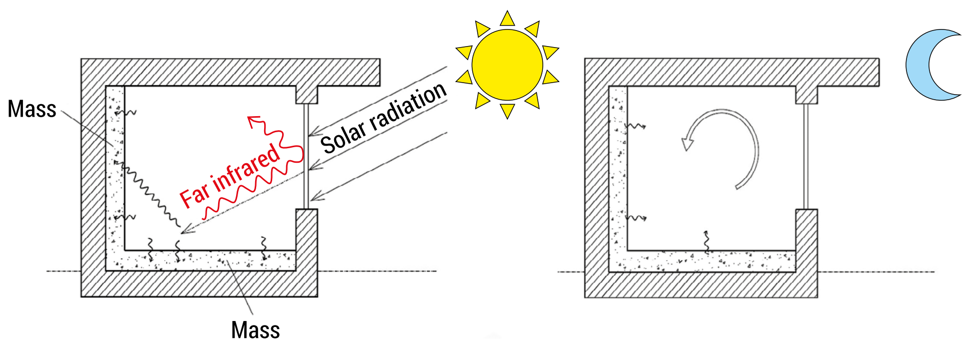

FIG. 1.5. Direct gain solar heating system (Source: own elaboration)

The amount of passive solar energy depends on the area of glazing and the amount of thermal mass. The glazing area determines how much solar heat can be collected, and the amount of thermal mass determines how much of that heat can be stored. It is recommended to have 1m^3 of thermal mass with a high heat-absorbing surface per 1 m^2 of glazing.

Advantages of Direct Gains:

- Low in cost to build, since no special room has to be added.
- Provides direct heating to the living space.

- South-facing windows provide natural daylight and outdoor views (A Design Competition Planbook, 1999).
- Disadvantages of Direct Gains.
- It can overheat if you do not properly balance windows and thermal mass.
- Large areas of south-facing glass cause problems with glare and loss of privacy.
- You can not cover thermal mass by the carpet or block it with furnishings.
- South-facing windows should have summer shading and nighttime insulation in winter. In colder climates, heat will be lost quickly through even the best double or triple glazed windows (A Design Competition Planbook, 1999).

Indirect gain – an indirect gain system uses the basic elements of heat collection and storage in combination with convection. The trombe wall is the most common indirect gain approach (WEB-5).

The Trombe wall is a massive stone structure that is installed on the south side of the building behind the facade glass fence (Fig. 1.6). This wall can be covered with selective absorption foil or painted in black (WEB-10).

Depending on the thickness of the Trombe wall, a longer delay in heat transfer to the room is provided:

- with a wall thickness of 20 cm – the delay occurs for about 5 hours;
- with a wall thickness of 40 cm – the delay occurs by about 10-12 hours.

The optimal thickness of the Trombe wall is 30 cm (WEB-10).

The Trombe wall can be not only concrete but also stone or brick. To improve the heat transfer of the wall, special holes are created at the bottom and top of the wall to ensure natural air convection, and for more efficient heat transfer, fans are installed for forced circulation. The sunlight passes through the glazed window and hit the concrete wall, which is installed at a distance of 100 mm from the glazed window. Ultraviolet rays from the sun hitting the surface of the wall heat it and part of the rays are reflected from the wall in the form of infrared radiation, which does not pass through the glass, thus heating the air as well (WEB-10).

The Trombe wall can be used in the design of two-floor houses, however, in this case, the heat energy will be more distributed to the upper floor, i.e. the lower floor will be cooler, and the upper floor will be warmer. Therefore, when designing a house, in particular, its planning, this feature should be taken into account, and living rooms should be located on the second floor where the residents of the house will spend more time (WEB-10).

Instead of painting the wall in dark colours, you can stick a selective coating that more effectively absorbs the sun's rays (the efficiency reaches 90% compared to 60% for a painted wall). The selective plating is a thin sheet of copper foil on which a layer of chromium and a layer of black copper oxide are applied, which is characterized by a high absorption of sunlight.

Advantages of Indirect Gain System:

- Relatively low cost of the device.
- The design is easy to maintain.
- Durability and reliability of the design (A Design Competition Planbook, 1999).
- Disadvantages of Indirect Gain System:
- The south-facing view and natural daylight are lost.
- Furniture and objects placed against or on the Trombe wall affect its efficiency in heating the living space.
- The Trombe wall heats only the room to which it is connected (A Design Competition Planbook, 1999).

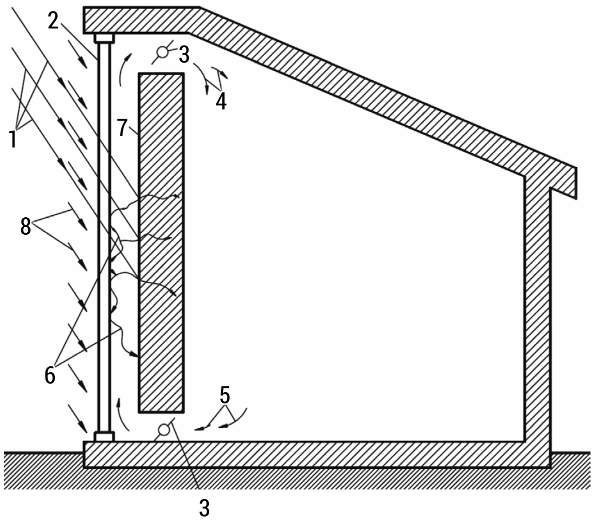

FIG. 1.6. Trombe wall scheme (Source: own elaboration baced on Брызгалин & Соловьев, 2018)

Isolated gain – this system uses convection to take the hot air into living spaces. A sunspace – also known as a solar room or solarium is a versatile approach to passive solar heating. Typically, the sunspace is a separate room on the south side of the house with a large glass area and thermal storage mass. A sunspace can be built as part of a new home or as an addition to an existing one. The air heated in the sunspace spreads through the rest of the rooms by natural convection or through channels with mechanical stimulation and a simple system of sensors. Usually, this is a thermostat that regulates the opening of the valve when the air temperature in the greenhouse reaches the required one. The sunspace can be completely isolated from the house. The heating of buildings with the help of sunspaces is widely used in the reconstruction of residential buildings, even apartment buildings. Sunspaces may often be called and look a lot like "greenhouses." However, a greenhouse is designed to grow plants while a sunspace is designed to provide heat and aesthetics to a home. If the sunspace serves as the primary heating system then it has to be thermally isolated from the living area. This means that the sunspace is closed off from the rest of the house by doors and windows (Fig. 1.7).

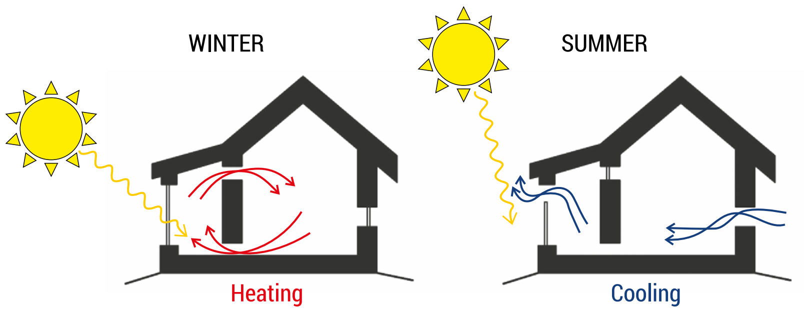

FIG. 1.7. Sunspace (Source: own elaboration)

Advantages of Isolated Gain System:

- It can be physically separated from the living space, so temperature fluctuations within the sunspace do not adversely affect the comfort of the living area.
- Solar thermal panels can be easily incorporated into any architectural style (A Design Competition Planbook, 1999).
- Disadvantages of an Isolated Gain System:
- Heavy furnishings and rugs must be avoided to prevent shading of the thermal storage mass.
- Shading and venting are important to avoid summertime overheating. They may require a forced convection system for best performance (A Design Competition Planbook, 1999).

1.2.3. Passive Solar House Orientation

The sun travels different trajectories in different seasons. It is important to understand the movement of the sun in relation to the design of the house. A properly placed house with passive solar heating and a properly defined area of glazing will have a stable temperature and will not overheat. The essential elements in a passive solar house are south-facing glass, thermal mass, and insulation.

The *ideal* orientation for solar glazing is within 0-5 degrees of true south. This orientation will provide maximum performance. Glazing oriented to within 15° of true south will perform almost as well and orientations up to 30° off – although less effective – will still provide a substantial level of solar contribution (Balcomb et al., 1991).

In the ideal situation the house should be oriented east-west and so have its longest wall facing south (Fig. 1.8). Frequently used rooms should be located on the south side and infrequentely used rooms should be located on the north side. The bedroom should be designed on the east or west.

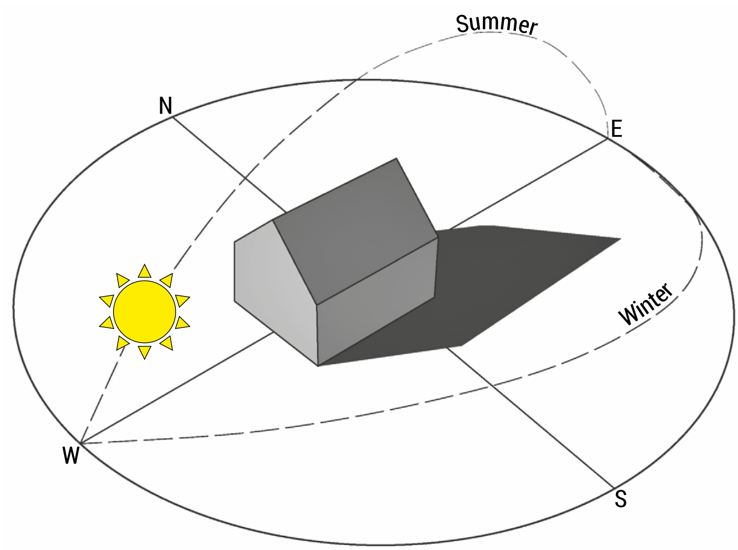

FIG. 1.8. Passive solar house orientation (Source: own elaboration)

Figure 1.9 shows a diagram that shows the ratio of the angle of the axis of the house from the southern orientation and the amount of heat received. The amount of received energy decreases considerably as the house is away from the southern orientation. The north side of the site should be a windbreak of evergreen trees and the hillside. Such a natural windbreak will protect the house from the cold north wind and bad weather. Deciduous trees to the east, south, and west will shade the house in summer, but in winter, dropping their leaves will allow the sun to heat the house.

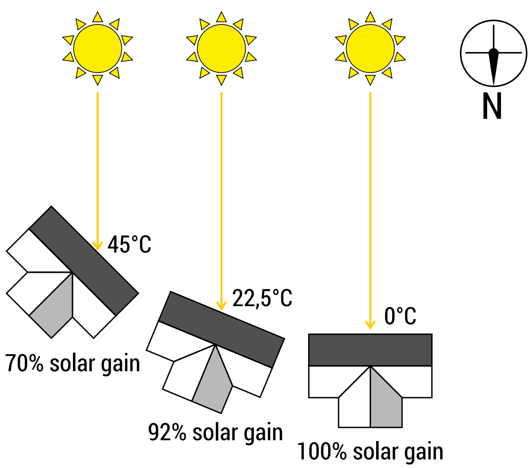

FIG. 1.9. Solar gain is based on the angle (Source: own elaboration)

1.2.4. Passive Solar House Glazing

South-facing solar glass is a key component of any passive solar system. The system must include enough solar glazing for good performance in winter, but not so much that cooling performance in summer will be compromised. The amount of solar glazing must also be carefully related to the amount of thermal mass (Balcomb et al., 1991). Over-glazing would result in overheating during the day and too much heat loss at night. Orienting one's home for passive heat also makes use of natural light.

North windows should be used with care. In general north-facing windows should not be large. Since north windows receive relatively little direct sun in summer, they do not present much of a shading problem. East windows catch the morning sun. Not enough toprovide significant energy, but usually enough to cause potential overheating problems in summer. West windows may be the most problematic and few shading systems will be effective enough to offset the potential for overheating from a large west-facing window (Balcomb et al., 1991).

Passive daylighting strategies promote the quantity and even distribution of daylight throughout a building by collecting natural light and reflecting it into darker areas of the building. Clerestory windows (Fig. 1.10), light shelves, and blinds usually are used for this strategy. Skylights are a bad choice because the light can not be easily controlled. It is difficult to have window coverings.

FIG. 1.10. Passive daylighting (Source: WEB-3)

Low SHGC (Solar heat gain coefficient) glass shoud be used for east and west-facing windows. The lower the SHGC, the less solar heat it transmits and the greater its shading ability. When it comes to an optimal SHGC rating, again one will want to look for a rating of 0,25 or less for efficient energy performance. As many windows as possible should be kept operable for easy natural ventilation in summer.

Passive house windows use either triple glazing (Fig. 1.11) or super-efficient double glazing. The glass and materials used to make the frames must have low thermal conductivity. Specially coated glass is used, and the cavity between the glass is filled with a gas with low conductivity such as argon. One of the most important facets is the window's U-value. The U-value measures how well heat is transferred in or out of a building. The certified Passive House standards state that U-values for windows should be below 0,8 W/(m²K).

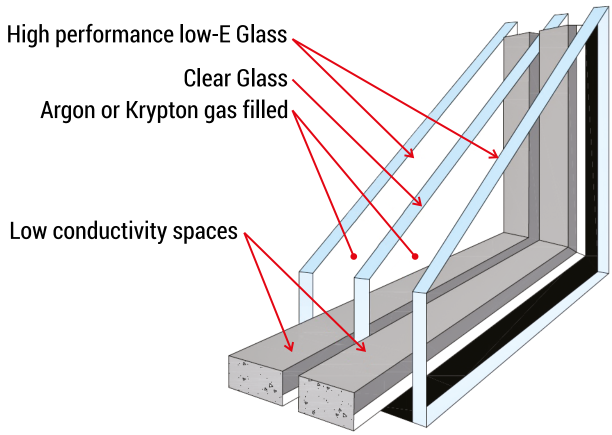

FIG. 1.11. Passive house window structure (Source: own elaboration)

It is recommended to minimize glass on east and west orientations. If one designs the windows on east or west orientations, then plant trees to block sunlight (Fig. 1.12).

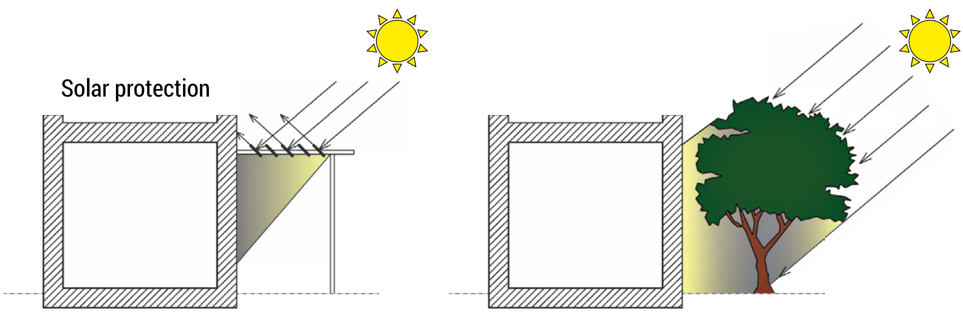

FIG. 1.12. Solar protection (Source: own elaboration)

According to Overen et al. (2021), solar shading is very important architectural element in passive solar house design. It is used to block the high summer sun and allow the low winter sun in. Solar shading could be roof overhangs, trellises, awnings, and external shutters.

1.2.5. Thermal Mass

Thermal storage is the essential element of an effective passive solar strategy, and this is accomplished through thermal mass. All materials have thermal mass of varying capacities. To be effective as a heat storage component in a passive solar building, the material must have adequate heat capacity in order to store enough heat, and it must release the heat at an optimal rate in order to moderate indoor temperature flux. Many metals have high heat capacity, but they are ineffective as passive solar thermal mass because of their high rate of conductance – heat is absorbed and released too fast. On the other hand, wood also has decent heat capacity, but its rate of conductance is too low. By far, the most common form of thermal mass is concrete, masonry, and stone (Russell, 2018).

According to the graph (Fig. 1.13), Thermal Mass absorbs sun heat energy during the day and slowly releases it during the night until the sun will charge it again the next day. It is best when it is on walls or floor and located in direct sunlight. Objects that have thermal mass have inherent qualities for both heating and cooling (Fig. 1.14).

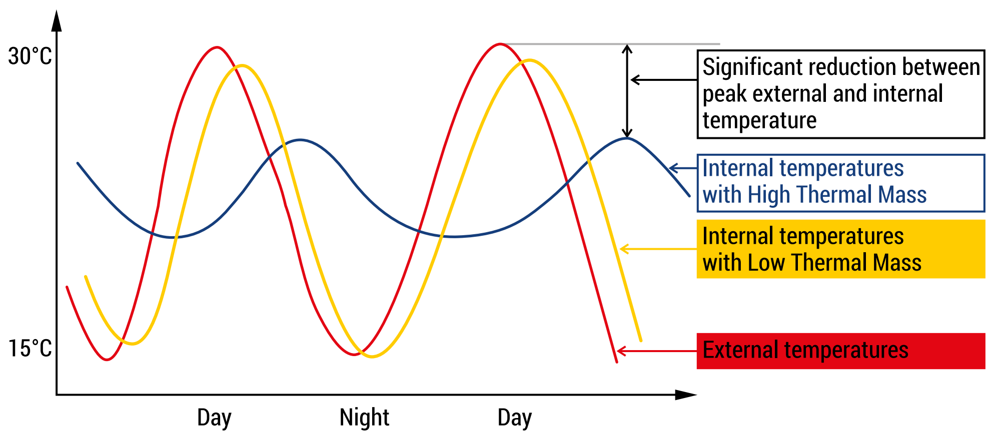

FIG. 1.13. Thermal Mass efficiency graph (Source: WEB-9)

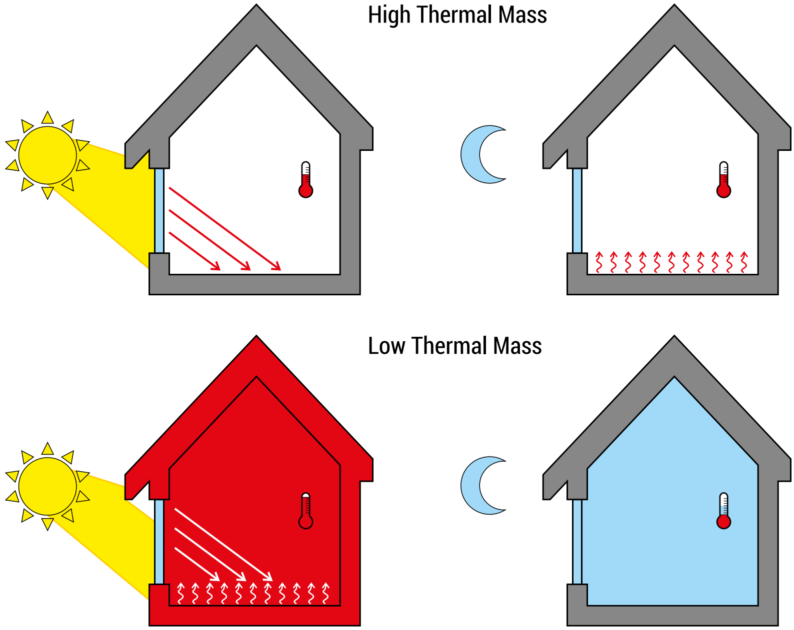

FIG. 1.14. Hight and Low thermal mass (Source: own elaboration)

1.2.6. Insulation

Thermal insulation for Passive Houses must be extremely effective, and so thick walls are built up using 'super insulation' to achieve high R-values. High-grade insulation ensures that the home is well insulated all year round which stops heat gained from the sun from leaking out. The most important surface to insulate is the roof. The roof is the main source of heat loss (about 30%) because hot air rises. Light-colored roofs reflect the high summer heat. White roofing products stay coolest in the sun, reflecting about 60 – 90% of sunlight. A cool roof is designed to reflect more sunlight than a conventional roof, absorbing less solar energy (Fig. 1.15) (WEB-1).

Cool roofs achieve the greatest cooling savings in hot climates but can increase energy costs in colder climates. You may also consider installing a green roof, which refers to the presence of vegetation rather than the color. Green roofs are considerably heavier and more expensive to construct and maintain. Green roofs are cooled primarily by the evaporation of water from plant surfaces rather than by the reflection of sunlight. The soil layer also provides additional insulation as well as thermal mass (WEB-1).

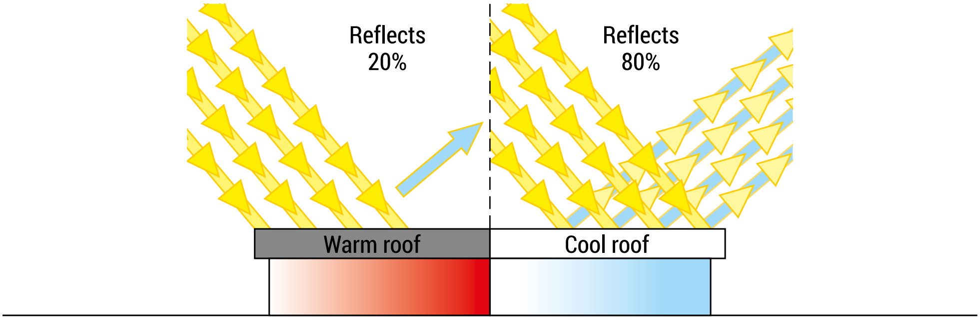

FIG. 1.15. Absorption of solar energy of warm or cool roof (Source: own elaboration)

Not isolated walls are responsible for about 25% of heat loss. The insulation must be consistent, and to be effective it can be done in two ways: either "distributed"; wall acts as insulation throughout its thickness using self-insulating clay brick or wood frame, or "outside"; insulation, preferably a mineral wool covers the wall from the outside to avoid thermal bridging. The floor is responsible for about 7% of heat loss. Windows are responsible for about 13% of heat loss. Doors must be at least made of wood, or incorporate insulation. If the door has a glass surface, make sure it is double glazing.

1.2.7. Ventilation

Natural ventilation is a simple concept. In summer, use convection to bring in the cool night air. In the morninig, the openings are closed and instead of thermal mass admitting heat as it does in wintertime, it will admit its coolness. Cross ventilation is a natural method of cooling. Windows need to be positioned on walls facing the prevailing breeze and on the opposite wall to create a cross ventilation (Fig. 1.16).

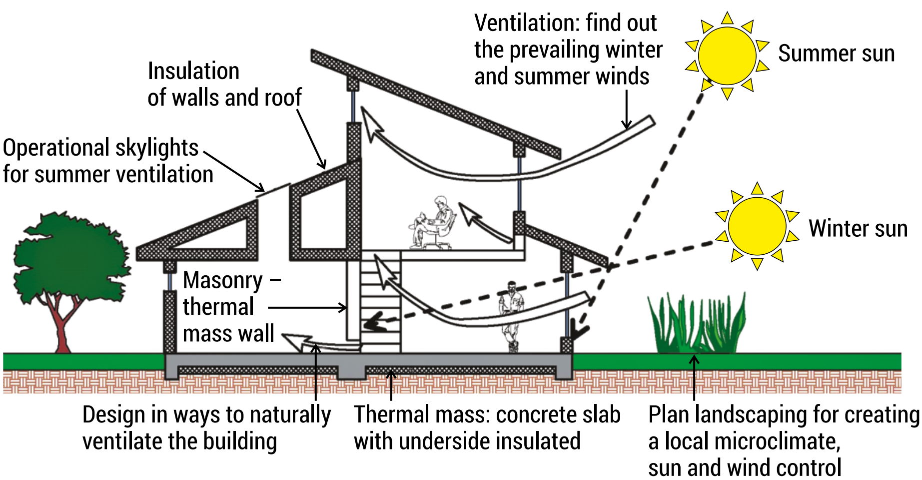

FIG. 1.16. Natural ventilation of a passive house (Source: own elaboration)

1.3. Active Solar Heating Systems

Solar water heaters for heating homes, cottages, and swimming pools allow for getting more hot water. One installation creates 200 liters of heated water daily. A particularly profitable option is the commercial use of solar collectors, in which a full payback is performed after 3 years of active use.

Solar water heaters for home heating are divided into two groups: first, by the method of heating, and second, how the heat source is stored. In the first case, a built-in heat storage tank is used. In the second – the connection is made to the remote storage tank, installed near the collector or inside the building. When selecting a heating solar boiler attention needs to be given to the type of solar thermal energy storage capacity, as the differences in design and equipment affect the features of use and technical properties.

Unlike photovoltaic panels, which use sunlight to generate electricity, solar heaters immediately receive thermal energy, which they transfer to the heat transfer medium (water, antifreeze, etc.).

Typically, collectors are installed on the slopes of the roof, as this saves the area of the site and eliminates access to intruders, animals, and other unwanted elements.

Recommendations:

- South side of the building.
- No visible obstacles blocking the sun‘s rays: trees, nearby houses, etc.
- Location should be convenient for further maintenance and repair of the system.

Before installing and adjusting tube or panel water heaters, determine the optimum angle of installation. In this regard, the following formula is guided:

- In summer – (latitude + (latitude – 22,5 degrees)) ÷ 2;
- In winter – (latitude + (latitude + 22,5 degrees)) ÷ 2.

The angle of inclination will change depending on the season. Therefore, it will be necessary to readjust the solar plant before the start of the winter or summer season. Automated sun tracking, which independently adjusts the tilt angle and position of the solar panel, is gaining in popularity. The construction is set in motion by an electric motor.

With the successful placement of the panel, the stagnation temperature can reach up to 300°. Such a result is not easy to achieve, most often the temperature does not exceed 60-65°, but it is quite an acceptable result for the heating system. Errors made during installation, reduce the efficiency of the solar water heater, the price of which is large enough to treat it with disregard.

They form an entire system consisting of the following elements (Fig. 1.17):

- Collector. A panel that receives thermal energy and transmits it to the heat transfer medium.
- Accumulation tank. Tank in which the heated water is accumulated and the cooled coolant is replaced by the just heated flow.

- Heating circuit. A conventional radiator system or underfloor heating system that realizes the energy of the heating medium. In some types of systems, the heating circuit is not part of the manifold system volume, getting the energy in the storage tank, which in this case is the heat exchanger.

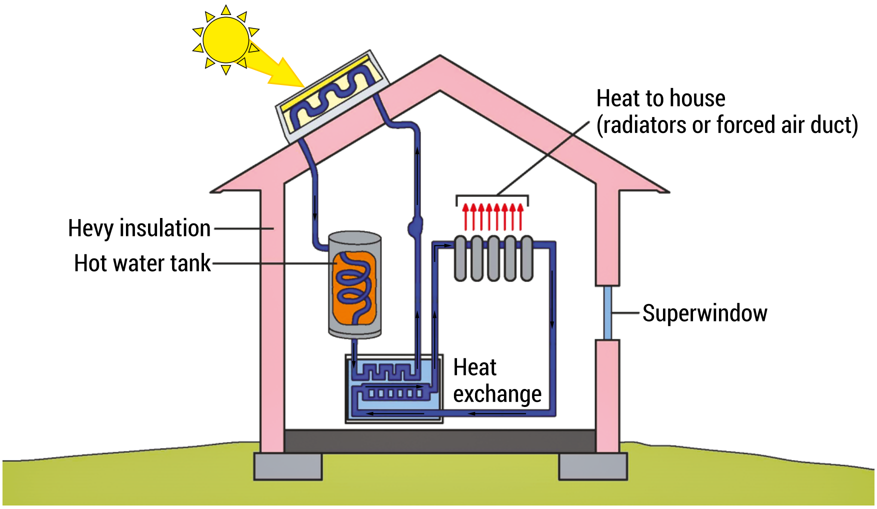

FIG. 1.17. Solar heating system (Source: own elaboration)

Circulating coolant allows receiving heat energy in return for the heat given to the internal atmosphere of the house. According to Jäger et al (2014), there are two types of solar thermal heating systems:

1. ***Passive.*** The operation of the system runs entirely independently, without any additional devices. The energy is received and transmitted directly to the heat transfer medium, which flows by gravity into the storage tank. An example of a passive system is a dark-colored water tank for better heating. Heating water in it occurs without additional assistance, it just needs to put the tank under the sunlight. Circulation is also natural, warm layers rise, giving way to cold layers, which, being heated, in turn give way to cooler layers. The simplicity and lack of maintenance of such plants are attractive, but their operation is highly unstable, and the efficiency is only a fraction of what is physically possible.
2. ***Active.*** An active solar water heating installation can solve all the problems with the circulation mode and get the maximum heat transfer efficiency (Fig. 1.18). Typically, the heating circuit has a closed design for the circulating water or oil. In the normal state, the natural circulation of the oil can not be obtained, but, with the help of a circulating pump, you can get a high degree of heat transfer inherent in oil due to the physical characteristics.

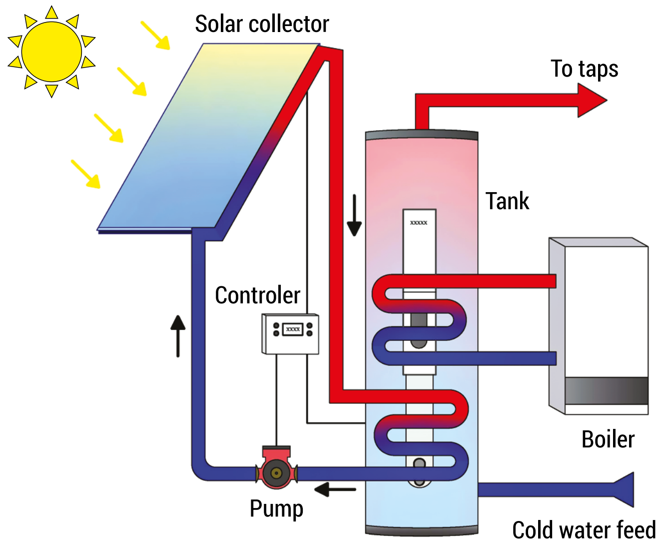

FIG. 1.18. Solar termal system circuit (Source: own elaboration)

Hot water from the sun, obtained in this way, can be directed to one or two--circuit systems, for heating and DHW (Domestic Hot Water) supply. The results obtained from an active installation are much higher, but also the cost of its purchase is much more noticeable. For users who decide to choose solar water heaters for the home, the cost of the set may be too high, so the price of such complexes should be found out in advance.

What kind of collector is installed in the system and how well it fits the external conditions of the region – climate, weather, number, and duration of sunny days – determines how effective the system of water heating from the sun will be.

The solar water heater is usually used as the primary or auxiliary energy source for heating circuit fluid preparation. In addition, the solar water heater can prepare domestic hot water.

There are several varieties of collectors, differing in the principle of absorption or accumulation of heat.

All equipment is divided into two groups:

1. ***Vacuum tube collectors*** – heat accumulation is carried out thanks to special flasks (Fig. 1.19). The principle of tube collectors is as follows: in the tubes, thanks to the highly selective coating and internal device (reminiscent of a thermos flask) air is heated to 280–300°C; the heat is transferred through the plate to the circulating fluid; the coolant enters the separately standing or monoblock storage tank, the water is heated.

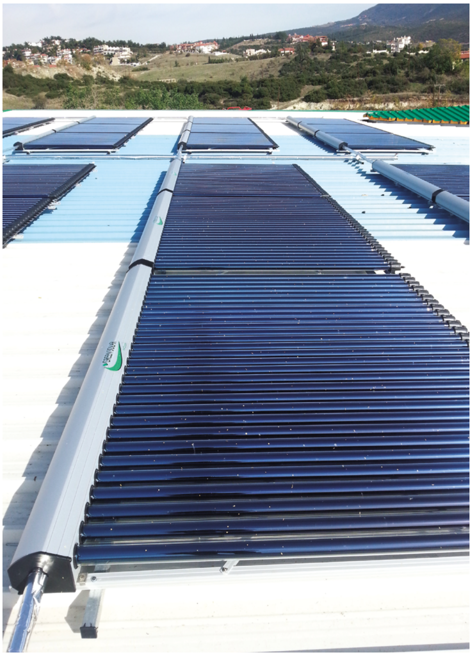

FIG. 1.19. Solar vacuum tube collectors (Source: WEB-7)

2. ***Panel collectors*** – heaters use the greenhouse effect (Fig. 1.20). The sun's rays pass through the transparent surface and hit the absorber, which accumulates heat. The solar water heater is arranged as follows: regular or tempered glass, with various additional functions (anti-vandal, self-cleaning, etc.) housing, made of adonized aluminum; absorber – the role of the heat exchanger is performed by a copper plate placed between two panes of glass. The absorber is the most important part of the solar water heater. The quality of the absorber coating determines the thermal efficiency of the panel collector.

FIG. 1.20. Flat plate solar thermal collectors (Source: WEB-2)

1.4. Solar Photovoltaic System

Direct conversion of the sunlight into electricity using photovoltaic (PV) devices is now considered as a mainstream renewable energy source. According to the international energy agency (IEA) , the world's total renewable-based power capacity is expected to grow by 50% between 2019 and 2024. Interestingly, solar PV accounts for more than 50% of this rise.

1.4.1. Photovoltaic

The heat and light of the sun are directly used in photovoltaic. Photovoltaics (PV) is the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry. The photovoltaic effect is commercially utilized for electricity generation and as photosensors. The power system is controlled using power electronics (WEB-4).

A photovoltaic system employs solar modules, each comprising a number of solar cells, which generate electrical power. PV installations may be ground-mounted, rooftop-mounted, wall-mounted, or floating. The mount may be fixed or use a solar tracker to follow the sun across the sky. The term "photovoltaic" comes from the Greek φῶς (*phōs*) meaning "light", and from "volt", the unit of electromotive force, the volt, which in turn comes from the last name of the Italian physicist Alessandro Volta, inventor of the battery (electrochemical cell). The term "photovoltaic" has been in use in English since 1849 (WEB-4).

George Cove may have invented a photovoltaic panel in 1909, roughly 40 years before Bell Labs did in 1950 (WEB-4).

1.4.2. The Photovoltaic Effect

Silicon solar cells, through the photovoltaic effect, absorb photons and generate flowing electricity. This process varies depending on the type of solar technology, but there are a few steps common across all solar PV cells (Marsh, 2022) (Fig. 1.21).

Step 1: Light is absorbed by the PV cell and knocks the electrons loose.
First, light strikes a photovoltaic cell and the photons are absorbed by the semiconducting material it is made from (usually silicon). This incoming light energy causes electrons in the silicon to be knocked loose, which will eventually become the solar electricity you can use in your home (Marsh, 2022).

Step 2: Electrons begin to flow, creating an electrical current.
There are two layers of silicon used in photovoltaic cells, and each one is specially treated (known as "doping") to create an electric field, meaning one side has a net positive charge and one has a net negative charge. This electric field causes loose electrons to flow in one direction through the solar cell, generating an electrical current (Marsh, 2022).

Step 3: The electrical current is captured and combined with other solar cells.
Once an electrical current is generated by loose electrons, metal plates on the sides of each solar cell collect those electrons and transfer them to wires. At this point, electrons can flow as electricity through the wiring to a solar inverter and then throughout your home (Marsh, 2022).

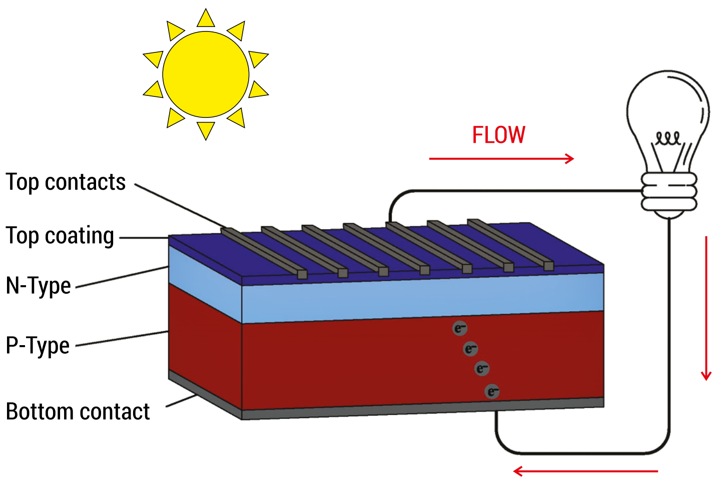

FIG. 1.21. Solar cell structure (Source: own elaboration)

Solar cells are connected to form modules, modules are connected to form panels, and panels are connected to form arrays to increase the overall voltage of a PV system (Goswami et al., 2016). The efficiency of a module is less than the efficiencies of the cells in the module, the efficiency of an array is less than the efficiency of the modules in the array. Most efficient operation is achieved if modules are made of identical cells and if arrays consist of identical modules (Goswami et al., 2016).

1.4.3. PV Cell Technologies

The most common material for solar panel construction is silicon which has semiconducting properties. There are three types of PV cell technologies that dominate in the world market: monocrystalline silicon, polycrystalline silicon, and thin film (Fig. 1.22). Multi-junction cells are less common due to their high cost but are ideal for use in concentrated photovoltaic systems and space applications (Donev et al., 2018).

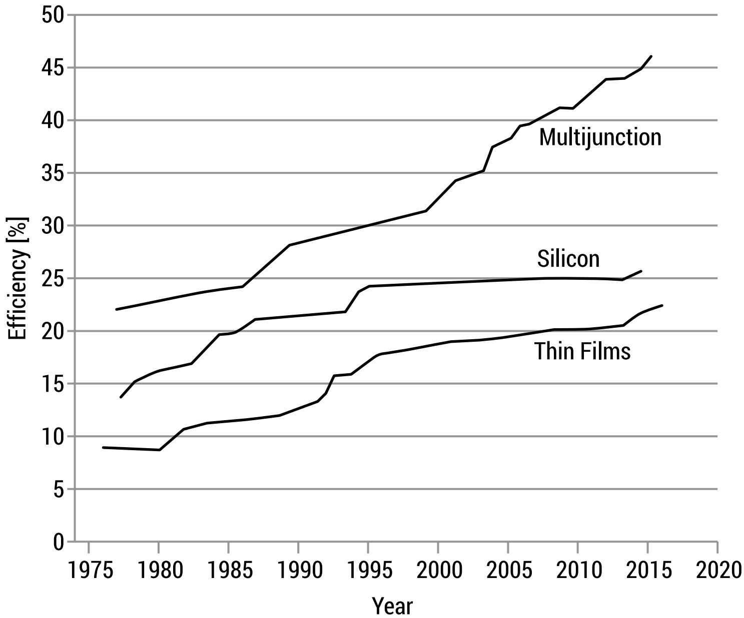

FIG. 1.22. PV cell technologies efficiency (Source: own elaboration baced on IRENA, 2021)

Monocrystalline, polycrystalline and thin-film panels have their advantages and disadvantages and usually, the choice of one or another option depends on the characteristics of the premises and the level of household power needs. Property owners with a large area for a solar power plant can save money by installing less efficient and inexpensive polycrystalline panels. For limited space, the best option would be to install high-performance monocrystalline modules. Thin-film panels are typically installed on the spacious roof of commercial/industrial spaces that cannot support the extra weight of traditional solar equipment.

Monocrystalline solar panels are the most expensive option. The production of such photovoltaic cells involves growing whole silicon crystals. This process, known as the Czochralski method, is quite Energy-intensive and sometimes fails. Damaged blanks can be used for polycrystalline elements.

Polycrystalline solar panels are significantly cheaper. The process of creating photovoltaic cells is much simpler in terms of technology. No need to spend money on processing whole crystals – small fragments are simply melted and pressed into molds. It is cheaper for the producer and the consumer.

Thin Film Solar Panels – how much needs to be payed for thin-film solar panels will depend on the material that was used to produce them. Panels made of CdTe and amorphous silicon will be the cheapest, while the CIGS option will be significantly more expensive.

Multi-junction cells are solar cells with many p-n junctions made from various semiconductor materials. The p-n junction of each material will generate an electrical current in response to different wavelengths of light. The use of multiple semiconductor materials provides absorption over a wider range of wavelengths, increasing the efficiency of the cell's conversion of sunlight into electrical energy.

Visually, the types of solar panels differ as follows:

- Monocrystalline – black cells.
- Polycrystalline – blue cells.
- Thin-film has a different color depending on the semiconductor material used.

1.4.4. Solar Panels Mounting Types

Solar panels need to be directed south so they get more sun throughout the day. According to Stevens Bushongs article „Anatomy Of A Rooftop Solar Mounting System", for installing safe and reliable rooftop systems, these parts and pieces are needed: mounting clamps, racking, mounts, flashings (Bushong, 2014)). Metal racks connect the photovoltaic panels using specialized clips. Metal racks are then attached to mounting points. Mounting points are connected to a rooftop (Fig. 1.23). Weight considerations need to be addressed by an engineer or architect before proceeding with the installation.

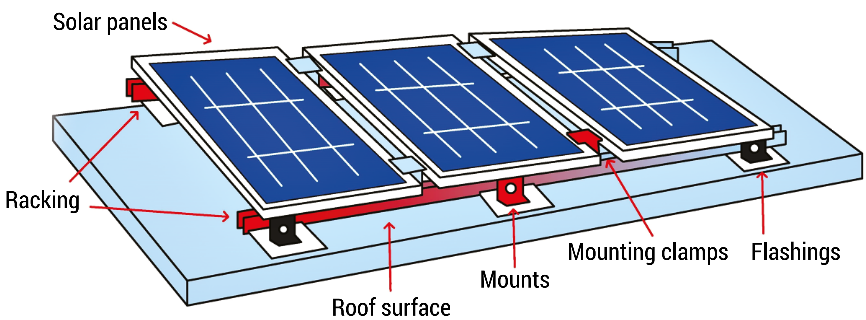

FIG. 1.23. Rooftop solar instalation components (Source: own elaboration)

Ground-mounted systems are simpler to design and install because the weight loading is typically not an issue. The mounting systems remain the same but the racks are connected either to a single post that's connected to a single concrete footer or a rack is constructed that's attached to concrete pads. Pole-mounted systems have the added advantage of being able to be tilted and turned including compatibility with tracking systems (Fig. 1.24).

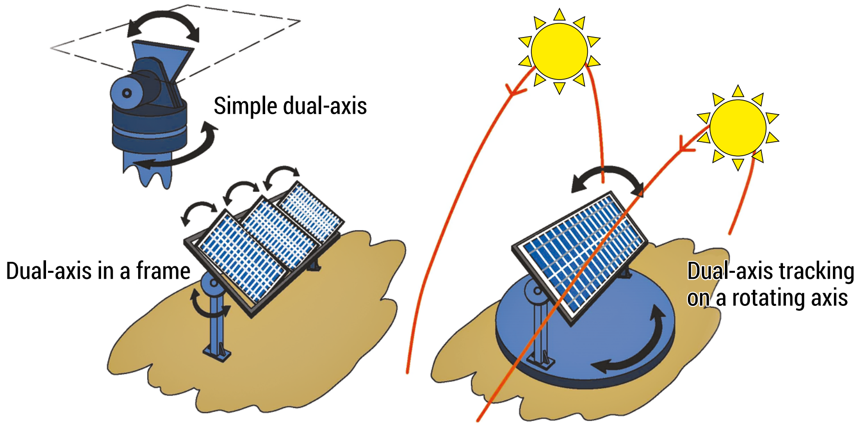

FIG. 1.24. Dual-axis solar panel (Source: own elaboration)

The sun moves across the sky differently depending on the location and the time of year. Solar panel angle is also known as solar panel tilt (Fig. 1.25).

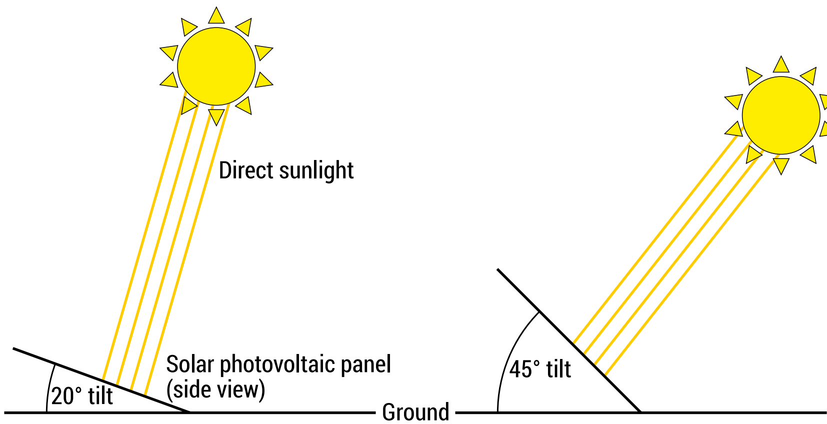

FIG. 1.25. Solar panel tilt angle (Source: own elaboration)

The solar panel angle can affect the amount of solar electricity the panel generates and the result is based on two factors: latitude and the season. The angle of tilt increases with latitude – the further the house is from the equator, the higher the tilt angle should be (Fig. 1.26).

There's a simple angle calculation for fixed-mount solar panels. Subtract 15° from the latitude at the location during summer and add 15° to the latitude during winter. If the latitude is 30°, the optimum tilt angle for the solar panels during winter will be 30 + 15 = 45°. The summer optimum tilt angle will be 30 – 15 = 15°.

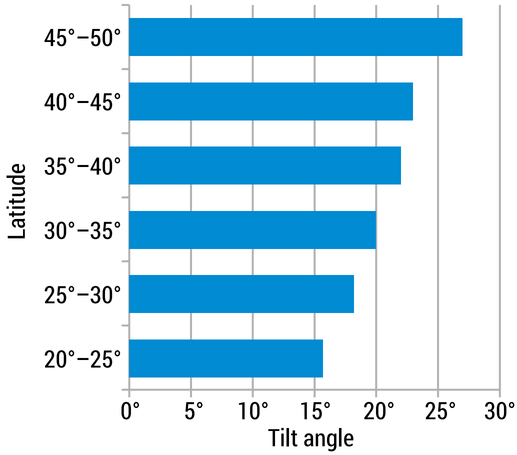

FIG. 1.26. Solar panel tilt angle based on latitude (Source: own elaboration based on Sandh, 2022)

Observing solar panels over a year, there is relatively little difference between the panels installed on a shallow roof and a steep roof. This is because the different pitches will balance themselves out across seasons. Solar panels on a shallow roof capture more sunlight during the summer season, whereas, solar panels on a steep roof will produce more power during the winter. In real situations, you often have to deal with fixed roof angles where there is no option to adjust or tilt the solar systems (Sandhu, 2022).

The inverter is the heart of the connection between the photovoltaic module and the building. The electricity produced from the photovoltaic array is direct curent (DC). Homes and buildings run on alternating current (AC). An inverter is needed to convert the electricity produced by the photovoltaic array so it can be used in the buildings.

There're several types of inverters that are available. Larger inverters can accept and convert photovoltaic electricity from about 10 to 80 modules. It is also possible to have multiple smaller inverters in one large installation serving only 5 to 10 modules per inverter.

A monitoring system is required to both quantify the amount of electricity being produced and monitor the electrical grid connection.

1.4.5. Off-Grid Solar Power System

This type of power system allows complete independence from external power grids. It is a popular choice in places with frequent power cuts and remote areas where access to the grid is difficult. The electricity produced by the solar panel is consumed directly in the home, and any excess electricity is sent to batteries for storage for later use. When sunlight hits the solar panel, the energy is converted into electricity and sent directly to the batteries. This ensures that the batteries are constantly charged the more electricity continues to flow in. When the sun goes down, the house continues to get electricity directly from the batteries, and this continues as long as there is energy in the batteries. It can include more than 4 standard elements: solar panels, solar controller, battery, inverter (Fig. 1.27).

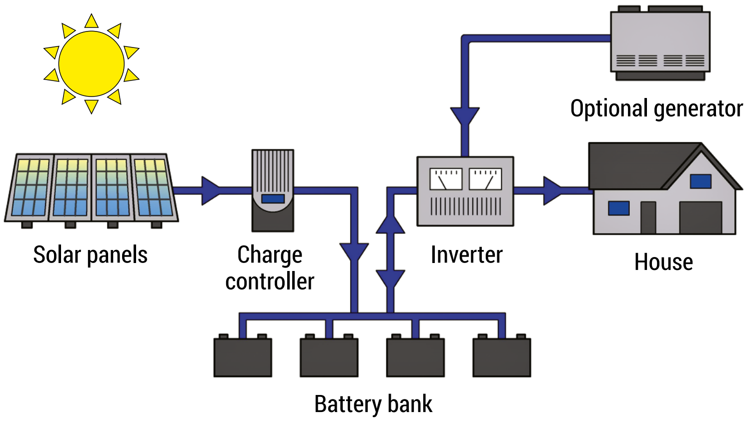

FIG. 1.27. Off-Grid solar system diagram (Source: own elaboration)

Battery plays an important role in energy storage. Batteries are generally installed inside a basement space or storage utility area where there's enough support for the weight of the battery as well as a close connection to the inverter. A charge controller should be installed with a battery system. The charge controller ensures the batteries are not undercharged or overcharged to prevent the risk of failure and or fire.

1.4.6. On-Grid Solar Power System

The on-grid solar power system is the most common type of photovoltaic currently being installed for residential and commercial uses (Fig. 1.28). Such a system is connected to the central electrical network. This gives 2 important possibilities: All excess electricity from the solar panels can be transferred to the grid instead of being dumped by the controllers. If the solar panels cannot cope with the current load, then some electricity can always be taken from the public grid.

Unlike off-grid systems, on-grid systems need a reverse meter that records the given and consumed energy.

On-grid solar power system works without batteries and is used to reduce the payment for grid electricity. The principle of operation is simple: it directs the electricity generated from the sun to the internal grid, and only insufficient electricity is taken from the public grid.

According to Yacoubou (2020), a hybrid solar system combines features of both on and off-grid solar. Solar panels are connected to the grid's power lines and have a backup battery system to store excess power.

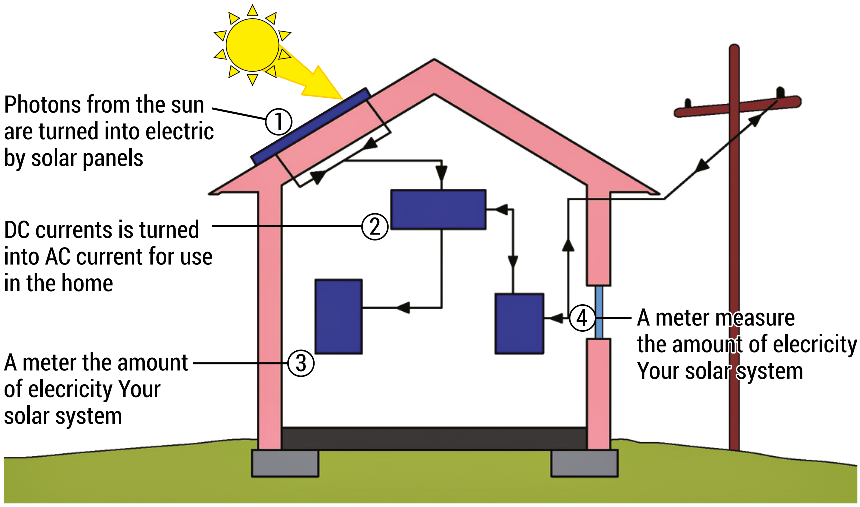

FIG. 1.28. Grid solar power system (Source: own elaboration)

1.4.7. Example of Solar Panel Effiency Rating Calculation

Manufacturer specification sheets typically include common terms. Those terms are always measured under standard test conditions. The standard test conditions (STC) for a PV solar panel:

- 1000 watts per square meter (1 kW/m^2).
- 25°C air temperature.
- 1.5 air mass (AM) (*Standard Test Conditions*).

The five terms:

1. The voltage at maximum power, which is the voltage being put out by the solar panel – V_{mp}.
2. The current at maximum power, which is the current that's being put out under maximum power – I_{mp}.
3. The maximum power is the power of the solar panel which is calculation of the voltage and maximum power, multiplied by the current at maximum power P_{max} or P_{mpp}.
4. The V_{oc}, or open-circuit voltage, which is the maximum voltage that the cell will ever put out – V_{oc}.
5. The I_{sc}, or short circuit current, which is the maximum current the cell will ever put out or the module will ever put out – I_{sc}.

Other information that's usually included in the specification sheets are the modules size, weight and few other electrical guidelines (Table 1.1) (Fig. 1.29).

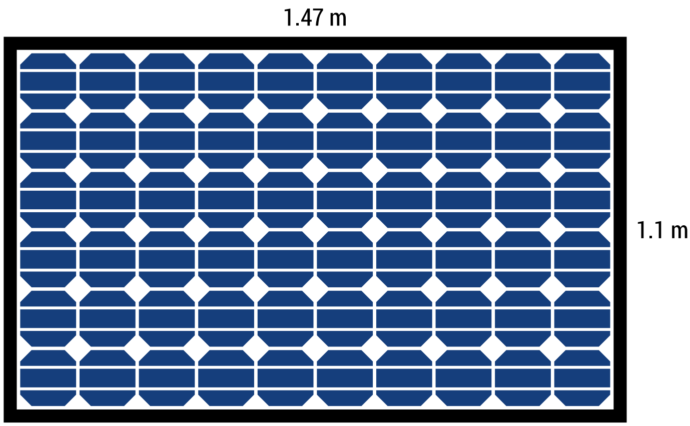

FIG. 1.29. Solar panel (Source: own elaboration)

TABLE 1.1. Example of PV module specification sheet (Source: own elaboration)

MODEL	PV
Maximum power rating (P_{max})	232 [W]
Operating Voltage (V_{mp})	30.1 [V]
Operating Current (I_{mp})	7.7 [A]
Open circuit voltage (V_{oc})	37.1 [V]
Short circuit current (I_{sc})	8.2 [A]
Length	1470 [mm]
Width	1100 [mm]
Temperature coefficient of power	−0,43 [%/K]

General definition of solar panel efficiency:

$$EFFICIENCY\left(solar\ panel\right) = \frac{POWER\quad OUT}{POWER\quad IN}. \tag{1.1}$$

$$P\left(power\right) = V\left(volts\right) \times I\left(amps\right). \tag{1.2}$$

Voltage (V) means how hard the electrical motion is pushing from one side to the other side of the module.

Current (I) show how fast the electricity is moving through the wire.

$$V_{mp} \times I_{mp} = P_{\max}, \qquad 30{,}1 \times 7{,}7 = 232\ \text{W}. \qquad (1.3)$$

Panel area $\qquad 1{,}47 \times 1{,}1 = 1{,}62\ \text{m}^2.$

$$\frac{PANEL \quad POWER}{PANEL \quad AREA} = \frac{POWER}{\text{m}^2} \qquad \frac{232\ \text{W}}{1{,}62\ \text{m}^2} = 143\ \text{W/m}^2. \qquad (1.4)$$

Sunlight input at STC = 1000 W/m²

$$\frac{POWER \quad OUT}{POWER \quad IN} = EFFICIENCY \qquad \frac{143\ \text{W/m}^2}{1000\ \text{W/m}^2} = 0{,}143 \times 100\% = 14{,}3\%. \qquad (1.5)$$

1.4.8. Example of PV Modules Demand Calculation

Photovoltaic power output depends on the sunlight level. In calculation of a solar power system, two parameters must be taken into account. This is the required power consumption and the number of sunny days per year. The true power is only about 80% of what's listed. We need to oversize a system to overcome that external efficiency limit. Solar panels need the direct sunlight of peak sun hours to generate the maximum electricity possible. The location that gets around 4 peak sun hours is considered a good location to produce useful amounts of solar energy. „If the sunlight intensity is measured in kW/m^2, then if the sunlight intensity is integrated from sunrise to sunset over 1 m^2 of surface, the result will be measured in kWh. If the daily kWh/m^2 is divided by the peak sun intensity, which is defined as 1 kW/m^2, the resulting units are hours" (Goswami et al., 2016) (Fig. 1.30).

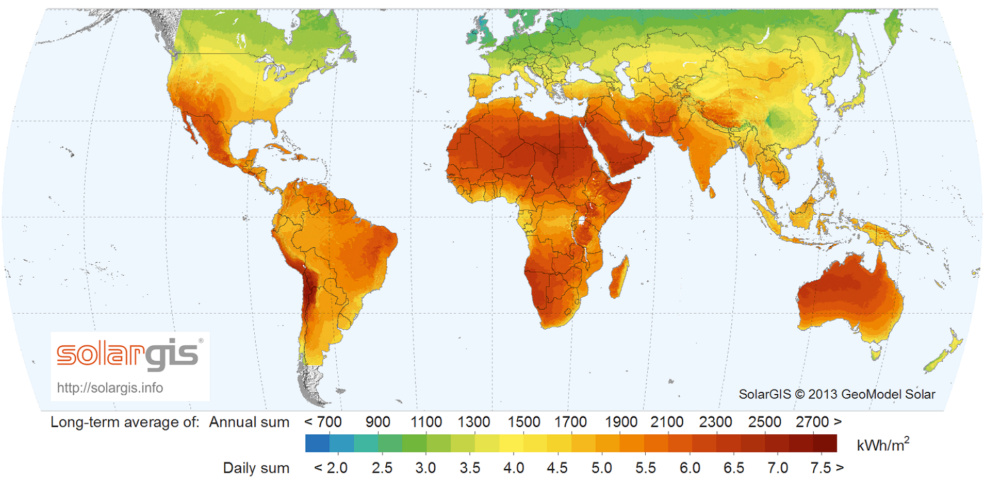

FIG. 1.30. Solar map (Source: WEB-6)

Task. How many PV solar panels are needed to produce 12000 kilowatt hours of electricity from the PV system during the year if your location gets 5,5 peak sun hours per day?

– Annual full sun hours calculation:

$$5{,}5 \quad h/d \cdot 365 \quad d/y = 2008 \quad h/y$$

$$\left(\frac{ENERGY \quad DEMAND}{ANNUAL \quad OF \quad FULL \quad SUN \quad HOURS} \right) \Big/ EFFICIENCY = \text{PV SYSTEM SIZE.} \quad (1.6)$$

– PV system size calculation:

$$\left(\frac{12000 \quad \text{kWh}}{2008 \quad h/y} \right) \Big/ 0{,}8 = 7{,}47 \quad \text{kW.} \quad (1.7)$$

– Quantity of PV solar panels calculation:

$$\textbf{\textit{Solution.}} \ \frac{POWER \quad SYSTEM}{SOLARPANEL \quad POWER} = \ \text{\# of modules} \quad (1.8)$$

In this example, $200W$ is a common size PV solar panel.

$$\text{Then } \frac{7470 \quad \text{W}}{200 \quad \text{W}} = 37{,}4 \text{ panels.} \quad (1.9)$$

We could round up or down, depending on the situation as we can't have a fractional panel.

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2. HVAC SYSTEMS AND THEIR CONTROL EQUIPMENT

2.1. Thermal Comfort

Heating, Ventilation and Air-conditioning (HVAC) systems are used in various types of buildings, such as residential, public, industrial and commercial ones. The main functions of an HVAC system are heating, ventilation and air conditioning, but also cooling, humidifying, dehumidifying, filtering and air distribution. The main task of the HVAC system is to ensure a comfortable life and safe environment for the building users. In recent years, numerous scientific studies have been conducted to assess the impact of the type and operating parameters of the HVAC system on the thermal comfort indicators (Karabay et al., 2013; Sarbu & Sebarchievici, 2015; Olsen et al., 2019).

Thermal comfort primarily means human satisfaction with their thermal environment. There are seven factors that affect thermal comfort (Fig. 2.1).

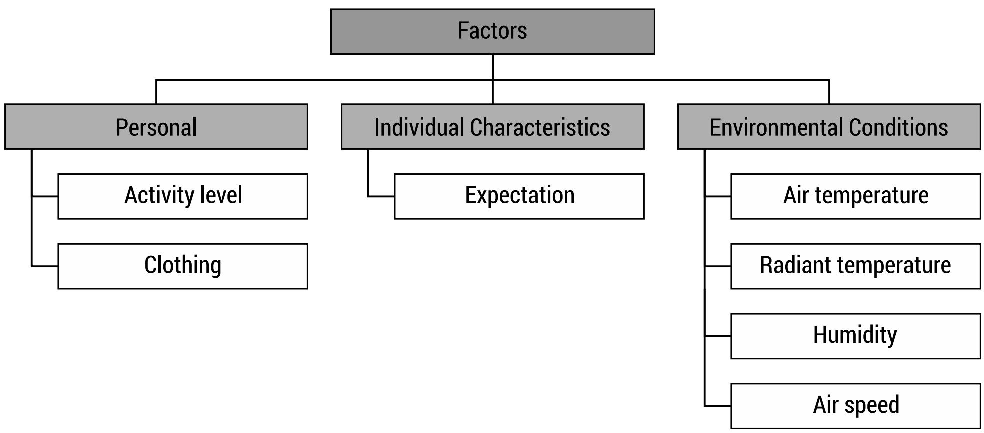

FIG. 2.1. Factors that affect thermal comfort (Source: own elaboration based on McDowall, 2006)

Clothing

The amount of heat transferred by conduction through the garment depends on the size of the garment's surface area, the temperature gradient between the skin and the outer surface of the material, and the value of the thermal conductivity of the materials used. The unit of heat resistance of the garment is clo. 1 clo determines the thermal insulation of clothing required to provide the so-called ~~a~~ standard person with thermal comfort in a room where the air temperature is 21°C, humidity 50%, and the air velocity is 0.01 m/s. In the SI system, 1 clo corresponds to a conduction resistance of 0.155 m^2K/W. Each set of clothing has a specific value of thermal insulation (clo). In standards, e.g. PN-EN ISO 9920:2009, there are tables of insulation properties for individual garments and clothing sets.

Activity level

Metabolism, which changes with the level of activity, is expressed in the following units: met or W/m^2 (1 met = 58.2 W/m^2 of human body surface).

Expectation

Acclimatization is the body's ability to adapt to specific thermal conditions of the environment. It reduces the risk of harmful health effects resulting from being in unfavorable ambient temperature conditions.

Operative temperature

To ensure satisfactory indoor thermal conditions, HVAC operating parameters are usually determined based on recommendations from industry standards. These standards recommend, among other things, optimal temperature ranges for different seasons.

One of the most frequently used and more reliable indicators of thermal comfort – apart from air temperature – is the operating temperature. It is the apparent temperature, perceived directly by humans and is a resultant of the air temperature and the average ambient radiation temperature.

With regard to thermal comfort, the standard PN-EN 16798-1:2019-06 defines the environmental categories (room classes):

I) Rooms with high requirements, recommended for very sensitive people (the disabled, very young children, the elderly).
II) Rooms with a normal level of expectation (new and modernized buildings).
III) Rooms with an acceptable level of expectations (existing buildings).

Table 2.1 shows the values of operating temperature recommended by PN-EN 16798-1:2019-06 in selected categories of rooms.

TABLE 2.1. Examples of recommended operative temperature values according to the standard PN-EN 16798-1:2019-06 (Source: own elaboration)

Category of rooms	Operative temperature [°C]	
	Heating season (for about 1 clo)	Cooling season (for about 0.5 clo)
I	22±1	24.5±1
II	22±2	24.5±1,5
III	22±3	24.5±2,5

Air speed

The air velocity in the room affects the heat transfer process on the surface of the human body. Low air velocity can cause feeling bloated and overheated. The increase in the air speed increases the feeling of coolness. The optimal values of air velocity in the immediate vicinity of the human body depend on the air temperature, thermal insulation of clothing and human physical activity.

Humidity

High humidity makes it difficult for sweat to evaporate from the surface of the body and promotes the growth of bacteria and mold in the room. On the other hand, low humidity in heated rooms can dry out the mucous membranes of the nose and skin, and cause sore throats and headaches. For health reasons, the relative humidity should be in the range of 40–70%.

For the practical assessment of thermal comfort, the indicators PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfed) are used. PMV index predicts the average vote value on the seven-point scale of thermal sensation given in Table 2.2. According to the PN-EN ISO 7730:2006 standard, PMV values from –1 to 1 are the range in which 75% of people are satisfied, and –0.5 to 0.5 is the range in which 90% of people are satisfied.

TABLE 2.2. PMV index (Source: own elaboration)

Value	-3	-2	-1	0	1	2	3
Sensation	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

The analytical relationship between the proportion of the dissatisfied PPD and PMV is shown in the graph (Fig. 2.2). It shows that 90% of people staying in the room assess its environment as comfortable, for the remaining 10% it is either cold (5%) or hot (5%).

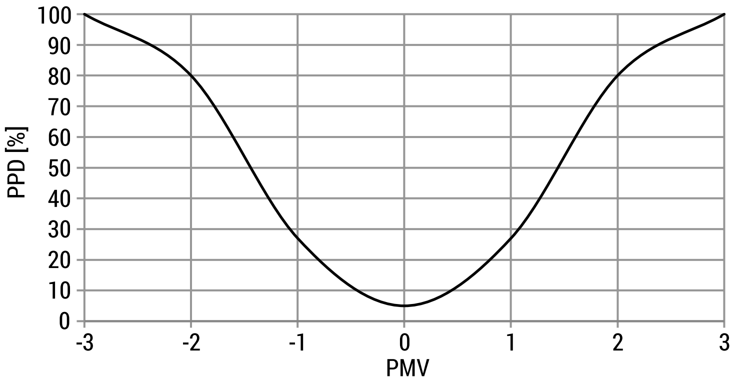

FIG. 2.2. Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV) (Source: own elaboration)

2.2. Classification of HVAC System

The major classification of HVAC systems depends on the location of all the main elements of the system in relation to the users (Bilinskienė et al., 2019):

- local (direct) HVAC systems – in the case of separate handling of a specific zone within the building
- central (indirect) HVAC systems – when servicing the entire building as a whole unit.

Central HVAC systems can be classified depending on the type of the medium (MacDowall, 2006):

- All-air systems – air is the medium that transfers thermal energy. These systems require considerable space for distribution ductwork.
- Air-and-water systems – the system usually consists of a warm water heating system, while cooling and ventilation are based on the medium which is air.
- All-water systems – these systems are used when the air exchange in rooms is ensured by natural ventilation. As a result, other processes (heating / cooling) can be carried out by devices powered by warm or chilled water.

Figure 2.3 shows the main types of local HVAC systems.

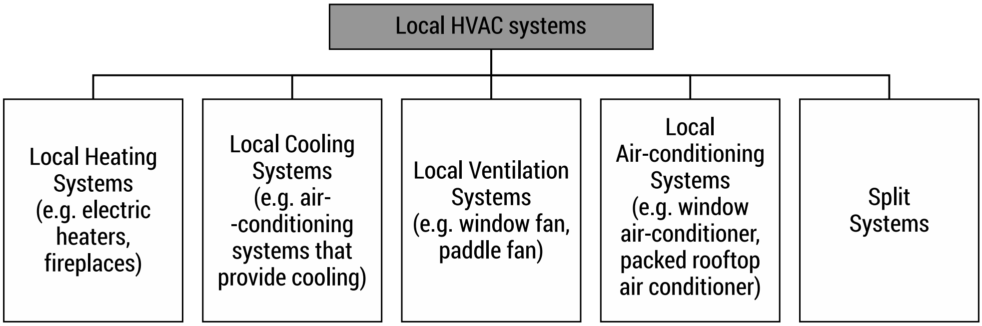

FIG. 2.3. The types of local HVAC systems (Source: own elaboration based on Seyam, 2018)

2.3. Heating/Cooling Systems

One of the primary factors in selecting an HVAC system is the location of the building. In warm climatic zones (eg Spain, Italy) the priority is cooling and air conditioning, in cooler zones (eg Poland, Lithuania, Latvia) – heating and ventilation.

One way of heating / cooling rooms is space heating / cooling systems. It is characterized by the fact that the share of thermal power transferred to the room by radiation is much greater than the thermal power transferred by convection (Koczyk, 2009; Sabiniak et al., 2020). Classification of space heating / cooling systems is shown in Figure 2.4.

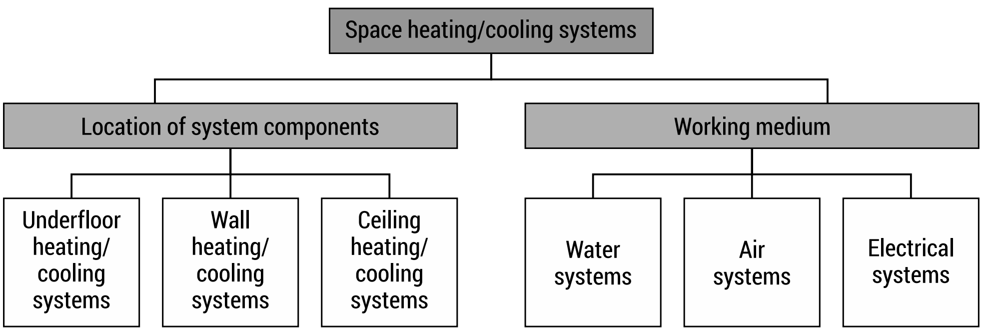

FIG. 2.4. Space heating/cooling systems classification (Source: own elaboration)

Space heating / cooling systems are low temperature systems. The most suitable temperature of the heating medium is approx. 40-45°C (it should not exceed 55°C) (Rabjasz & Dzierzgowski, 1995). Heat for low temperature systems can be produced by renewable energy sources.

Space systems can be used in summer as indoor air cooling installations. The water temperature must be high enough to prevent condensation on the surface of the cooling plate (MCDowall, 2006). To prevent this, the surface temperature of the plate should be at least 1K higher than the dew point temperature in the room. Cooling with Space systems is not very popular also due to the low cooling capacity, approx. 30-50 W/m^2 (Sabiniak et al., 2020).

Due to the increased share of radiation in Space heating systems, it is possible to lower the temperature of the internal air while maintaining the conditions of thermal comfort. Due to the lower air temperature, reduced become the heat losses by penetration through the room partitions and the heat losses related to ventilation. The regulation of space heating systems is difficult due to the high thermal inertia.

Undefloor heating systems ~~is~~ are the most popular type of Space heating systems. They are characterized by a vertical air temperature profile that is favorable for people (higher temperature at the feet level, lower temperature at the head level). For health reasons, there is a limit to the maximum temperature of the floor surface. This affects the maximum thermal efficiency of the radiator, and thus the ability to cover the design heat load of the room. The European standard PN-EN 1264-3:2021-10 limits the floor temperature in the residence zone to a value 9°C higher than the air temperature in the room, and in the edge zone to a value 15°C higher than the air temperature in the room. Therefore the floor surface temperature requirements are as follows:

- for rooms, where people are constantly on the floor (residential and office rooms, kitchens, corridors) – 29°C
- in so-called sanitary rooms (for example, bathrooms and toilets) – 33°C
- in places with increased heat loss – under windows and at external walls (i.e. in the so-called edge zones) – 35°C.

Figure 2.5 shows an underfloor heating system.

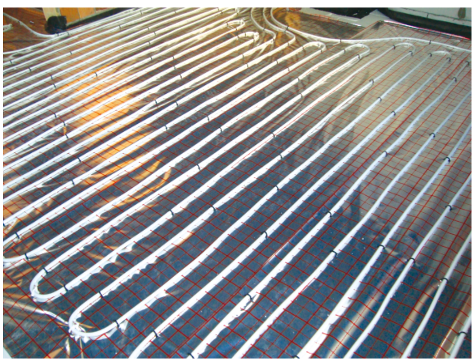

FIG. 2.5. Underfloor heating systems r (Source: photo by T. Teleszewski)

Characteristic parameters of underfloor heating operation are as follows (Mroczek et al., 2008):

- maximum supply temperature – 55°C;
- temperature difference between supply and return – $\Delta t = 5 \div 10$°K;
- loop water velocity – 0.1–0.6 m/s;

- maximum length of the heating circuit from a Ø16 mm pipe – 120 m, and from a Ø20 mm pipe – 150 m;
- the amount of heat transferred to the heated room should not be less than 90% of the heat supplied by the heating pipes;
- the approximate heating power is 80 W/m^2 for a room temperature of 20°C.

The method of dimensioning and execution of Water floor heating / cooling system is discussed in PN-EN 1264.

Water floor heating / cooling system consists of the following components:

- thermal isolation, which prevents the loss of heat to the ground or to rooms under the ceiling with underfloor heating; Depending on the location of the room in the building and adjacent rooms, the thickness of polystyrene insulation may be from 3 to 15 cm (PN-EN ISO 11855-3:2015);
- pipes – most often made of plastic or soft copper. Pipes should be arranged in such a way as to obtain the most even temperature on the floor surface. In the vicinity of places with the highest heat losses, the so-called perimeter zone should be created. It is usually a 1m wide strip along the external walls, in which there is an increased density of pipes (Żukowski, 2009). Examples of basic cable management systems are shown in Figures 2.6, 2.7;
- moisture insulation – in order to avoid the dampness of the thermal insulation in contact with the screed layer, an impermeable anti-moisture layer should be placed on the thermal insulation layer – eg. made of polyethylene or aluminum foil 0.2 mm thick. The foil should be folded out towards the walls. If the floor is on the ground, a layer of anti-moisture insulation should also be placed under the thermal insulation;

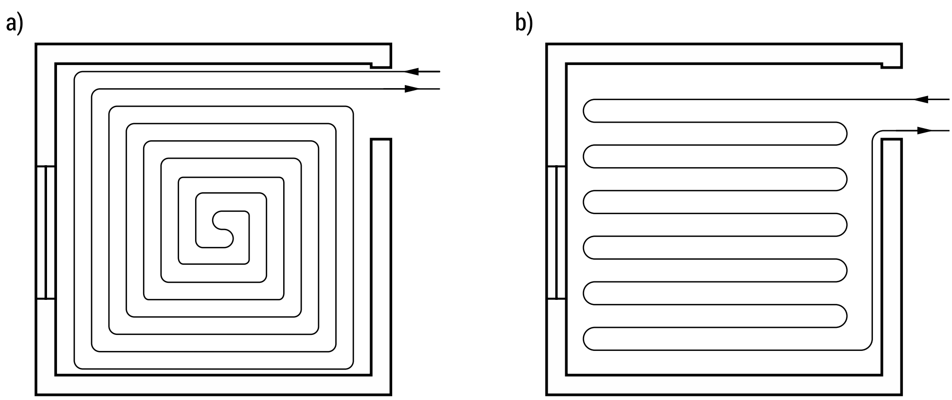

FIG. 2.6. Laying patterns: a) Reverse spiral, b) Meander (Source: own elaboration)

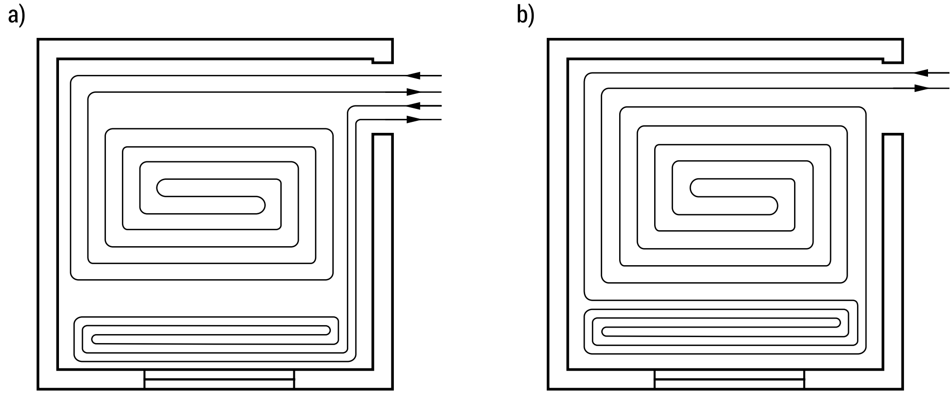

FIG. 2.7. Laying patterns: a) Separate perimeter zone with spiral pattern, b) Intergrated perimeter zone with spiral pattern (Source: own elaboration)

- screed cement with a thickness of 5 to 8 cm, which acts as heat accumulation;
- floor coverings – almost any available material can be used to finish the floor, if the manufacturer allows it to be used for underfloor heating. Table 2.3 shows the thermal resistance of individual types of floor coverings. The maximum allowable thermal resistance for underfloor heating materials is 0.150 (m^2K)/W (Rabjasz & Dzierzgowski, 1995).

TABLE 2.3. Heat conduction resistance of floor coverings (Source: own elaboration based on Mroczek et al., 2008)

Type of material	Material thickness (m)	Heat conduction resistance (m^2K/W)
Ceramic tiles	0.01	0.02
Marble	0.025	0.02
parquet	0.008	0.05
rug	0.005	0.09

There are 7 types of underfloor heating, marked with successive letters from A to G. In Poland, type A underfloor heating is most often used, in which the pipes are embedded in the screed layer (Fig. 2.8).

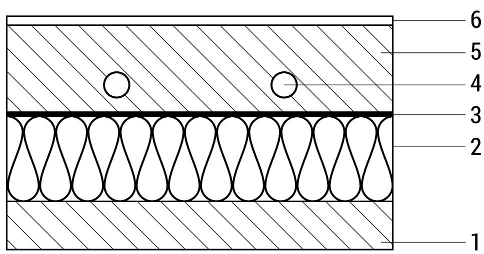

FIG. 2.8. Underfloor heating – elements: 1 – floor construction, 2 – thermal isolation, 3 – moisture insulation, 4 – pipework, 5 – cement screed, 6 – floor coverings (Source: own elaboration)

2.4. Ventilation and Air Conditioning Systems

The task of ventilation is to improve the condition and composition of the air inside the room. The most important parameters of the air that should be kept at a certain level are temperature, humidity, speed and concentration of pollutants.

The classification of ventilation systems can be made on the basis of a number of criteria. Depending on the degree of air treatment, we distinguish (Hendiger et al., 2014):

- ventilation – no regulation of the thermal and humidity parameters of the supplied air;
- ventilation with cooling or heating – the ability to regulate the air temperature,
- ventilation with humidification or dehumidification – the possibility of regulating air humidity;
- air conditioning – the ability to regulate the temperature and humidity as well as purify the air.

Depending on the method of air exchange, we distinguish (Krygier et al., 2000):

- natural ventilation – its operation depends on weather conditions because air exchange is caused by the action of wind, gravity or both. In this system, it is not possible to regulate the amount of air removed from the room;
- mechanical ventilation – air flow occurs thanks to the use of a fan. Thanks to this, the operation of this type of system does not depend on weather conditions.

The division of mechanical ventilation depending on the air movement in relation to the room is as follows (Recknagel et al., 2008):

- exhaust ventilation – the air is removed mechanically, supplied through leaks as a result of negative pressure;
- supply ventilation – the air is supplied in a natural way and the exhaust is mechanically supported;
- supply and exhaust ventilation – supply and removal of air is fully mechanical. This system allows you to adjust the amount of supplied air and its proper treatment.

In air-conditioning systems, the air supplied to the rooms is subjected to processes that ensure the achievement of the appropriate temperature and humidity. The desired air parameters are important for hygienic reasons and for ensuring the well-being of the room users. Due to their construction (the number of rooms serviced), air-conditioning systems are divided into Local Air-conditioning systems (eg. Split Systems, Widow Air conditioner, Rooftop Air conditioner) and Central Air-conditioning systems (Seyam, 2018). Depending on the type of heat / cooling transport medium, we distinguish All-air systems and Air-and-water systems (Fig. 2.9) (Recknagel et al., 2008, Bilinskienė, 2019).

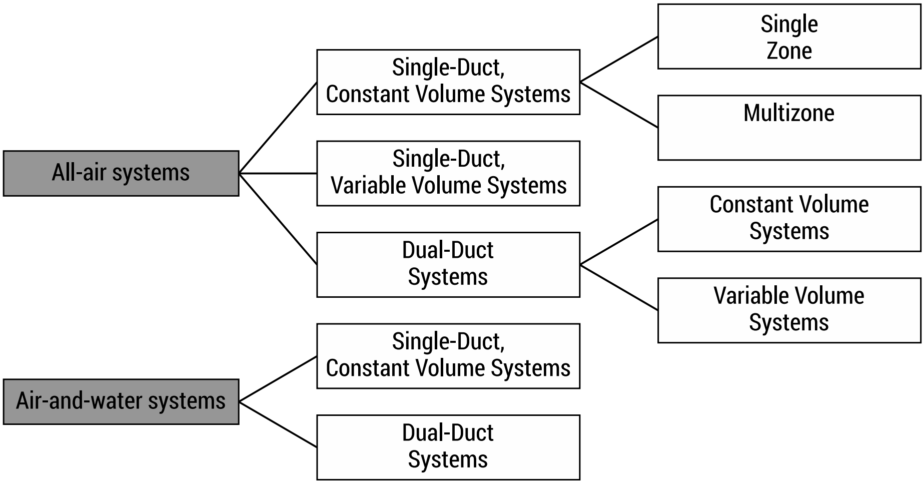

FIG. 2.9. Air-conditioning systems classification (Source: own elaboration)

In order to reduce the consumption of heat / cold for ventilation and air conditioning in modern buildings, systems with heat recovery from the removed air are used. Depending on the type of heat exchanger used, there are three basic methods of heat recovery in ventilation and air conditioning systems (Rosiński, 2012):

- regenerative method – a heat exchanger with a high heat capacity filling mediates the exchange of heat or moisture between the supply and exhaust air;
- recuperative method – an exchanger in which the supply and exhaust air do not touch each other, but are separated by a wall (diaphragm) through which the heat permeates;
- the method with a heat pump – consists in the use of a refrigerant that transfers heat when energy is supplied.

2.5. Control of Heating and Cooling Systems And Example of Equipment Installation

Control of the heating and cooling systems enables to achieve the specified designed indoor temperatures to ensure comfortable microclimate conditions.

There are several control systems (Fig. 2.10) types (Lapinskiene,2011).

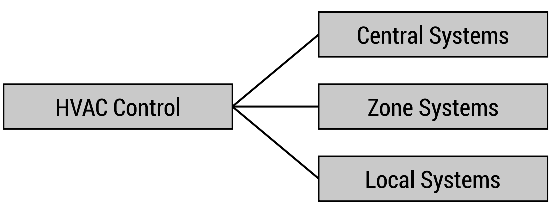

FIG. 2.10. Control systems classification (Source: own elaboration)

The local, zone or central control systems help to keep the balance between supplied or removed heat and the heat losses or gains of a building, thus affecting thermal comfort (EN 12828, 2014).

Of course, the selected control equipment must protect the building systems against frost and moisture damage, in the cases when normal comfort temperature level is not required (EN 12828, 2014).

The energy requirements for heating, cooling and other building engineering systems shall be calculated in order to optimize health, indoor air quality and comfort levels (Directive, 2018). Optimal energy performance under all heating and cooling load conditions must be ensured to provide comfort for the occupants, with the least energy use and operating costs (WEB-1).

2.5.1. The Importance of Balancing Heating and Cooling Systems

The control of building engineering systems should be capable of monitoring, analyzing and adjusting energy use, improving energy efficiency and allowing communication with connected building engineering systems and other appliances (Directive, 2018).

Hydronic imbalances and systems without individual room temperature controls in buildings are the main causes for energy waste, unnecessary costs and the performance gap between expected and actual energy consumption after renovation (WEB-1). Unbalanced heating and cooling systems cause a number of problems for engineering systems users and for technical system maintenance (Danfoss, 2015). This is important for renovation of existing building systems and when designing or installing new heating and cooling systems into the buildings.

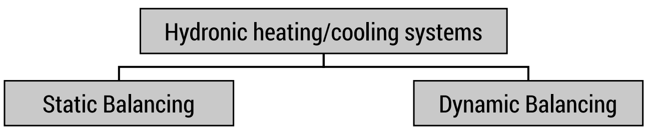

FIG. 2.11. Hydronic balancing (Source: own elaboration based on WEB-1)

Hydronic heating and cooling systems balancing can be divided **into static and dynamic** (Fig. 2.11). Balancing of heating and cooling systems ensures that warmth or coolth is distributed around the system to efficiently meet the building's heating or cooling demand (WEB-1).

2.5.2. The Energy Savings in the Control of Heating and Cooling Systems

The individual, zone or central control and operation of the heating and cooling systems helps users handle these engineering systems while reducing operational costs during system maintenance.

For heating and cooling systems it is recommended to control the average supply and return water temperature based on the outside temperature.

Advanced timing function helps to save energy by setting a lower temperature (e.g., during the night) (Fig. 2.12) to reduce or shut-off the engineering system during scheduled periods of time (e.g. night setback, weekend setback, on/off for extended departures or during holidays) (Danfoss, 2015).

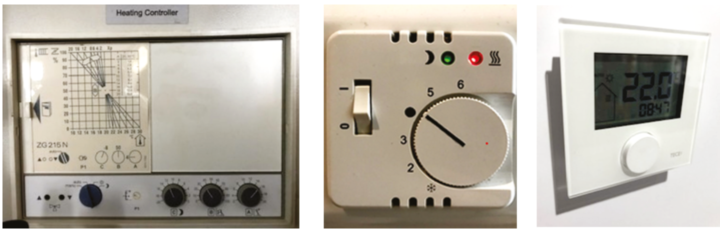

FIG. 2.12. Examples of control equipment (Source: photo by R. Bilinskiene)

Photographs above (Fig. 2.12) present examples of equipment with a timing function for heating and cooling systems control to save energy and balance the system during operation.

The engineering systems users can save energy when they use the system without covering thermostats and heating devices with furniture, decorative grilles or curtains.

2.5.3. Balancing of Heating and Cooling Systems

Hydronic balancing ensures that the right amount of energy is supplied to all rooms in a building, avoiding oversupply.

There are several hydronic systems balancing decisions (Fig. 2.13).

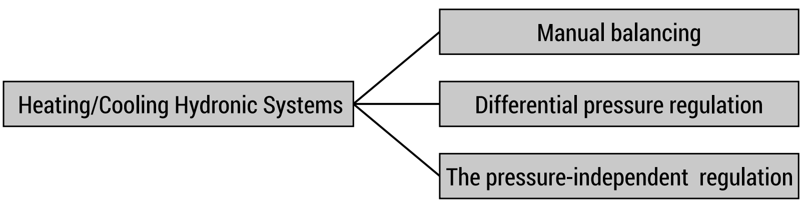

FIG. 2.13. Systems balancing decision (Source: own elaboration based on Danfoss, 2021)

The static or manual balancing of heating and cooling systems is provided by (Fig. 2.14) manual balancing valves (WEB-1).

FIG. 2.14. Manual balancing valves (Source: Danfoss, 2022)

The hot water is distributed evenly in hydronic systems operating at full load when manual balancing is used. However, such decision is not proper for part-load operation of heating and cooling systems, because then the systems might become unbalanced.

FIG. 2.15. Automatic balancing valves for cooling systems (Source: Danfoss, 2022)

The dynamic balancing of heating and cooling systems is provided by automatic balancing valves (Fig. 2.15, 2.16) or pressure-independent control valves which control the pressure across temperature control valves (WEB-1).

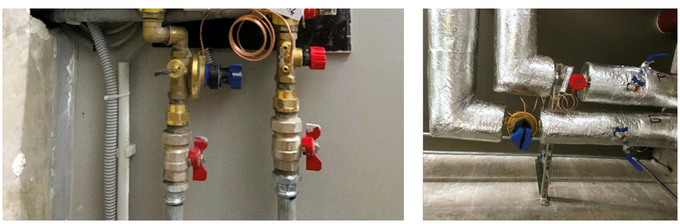

FIG. 2.16. Automatic balancing valves (Source: photo by R. Bilinskiene)

In two-pipe hydronic systems with variable flow, the flow depends on the heat demand. Automatic balancing valves consisting of a balancing valve and a differential pressure regulator (Fig. 2.16) are installed at the bottom of the stands (Danfoss, 2015).

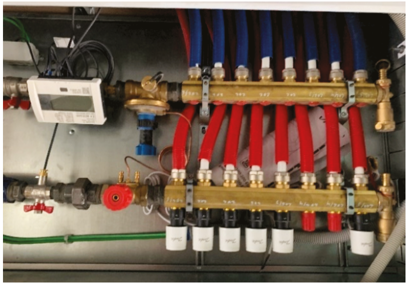

FIG. 2.17. Automatic balancing valves for underfloor heating (Source: Danfoss, 2022)

To reduce the heat consumption and ensure comfortable conditions in the rooms, thermostatic valves are used on radiators and convectors (Fig. 2.18), as well as control equipment for underfloor heating (Fig. 2.17).

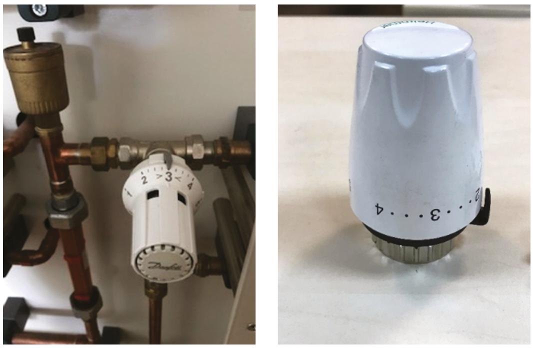

FIG. 2.18. Thermostatic valves (Source: photo by R. Bilinskiene)

Thermostatic valves are installed in the heating systems with radiators. The adjustable valves are usually installed on the radiator supply pipe in the system.

(Fig. 2.19). Thermostatic elements are mounted on installed thermostatic valves (Danfoss, 2015).

FIG. 2.19. Thermostatic valves installation examples (Source: photo by R. Bilinskiene)

It is important to make sure that the chosen equipment has been properly installed according to the manufacturers' instructions. Controlling room temperature helps users save energy in different rooms of the building.

2.5.4. Balancing of Hydronic Systems for Residential and Public Buildings

Hydronic heating and cooling systems could be controlled and balanced in different ways. It's impossible to find one best solution for everyone. When choosing the most effective solution for balancing, it's necessary to take into account the specifics of each system (Danfoss, 2021).

There are various balancing solutions for variable flow systems (Fig. 2.20, 2.25).

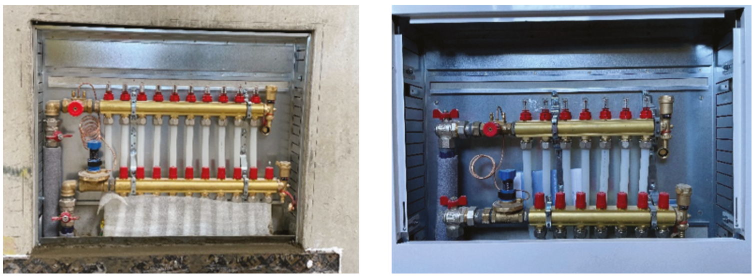

FIG. 2.20. Automatic balancing valves with underfloor system manifold (Source: Danfoss, 2022)

The automatic balancing valves could be used for underfloor systems regulation (Fig. 2.20).

For systems with heating devices, dynamic regulation could be used, an 'H type' connection with a regulation valve inside (Fig. 2.21).

FIG. 2.21. Dynamic H type connection with integrated pressure regulator (Source: Danfoss, 2022)

Small systems with pump heads up to 60kPa can be used without additional balancing on branches or risers. Delta P controller is integrated into the so-called 'H' connection piece. Dynamic 'H' piece ensures dynamic balancing at partial or full load for each radiator. This technology is used for standard radiators for connection from a wall or floor (Danfoss, 2021).

FIG. 2.22. Dynamic regulation valve for heating devices (Source: Danfoss, 2022)

Dynamic regulation valve is used for radiators or convectors regulation.

Two-pipe riser systems are used with side connection radiators. In this case, dynamic radiator valves can be used for small systems with pump heads up to 60kPa. Dynamic radiator valves have integrated delta P controller which ensures dynamic balancing at partial or full load for each radiator.

For both solutions (Fig. 2.21 and Fig. 2.22), dynamic H and dynamic radiator valve, no additional balancing, either manual or automatic, is needed. It is necessary only if the system's pump head exceeds 60kPa. In big systems, automatic delta P controllers can be used on branches or risers (Danfoss, 2021).

Hydronic heating systems distribution collectors could be installed into the staircase or other common areas to ensure access to the equipment.

FIG. 2.23. Automatic balancing valves for distribution regulation (Source: Danfoss, 2022)

In residential building systems, a control solution could be used (Fig. 2.23), that is a distribution manifold with automatic balancing valves.

FIG. 2.24. An example of a system with fan coil regulation (Source: Danfoss, 2022)

Fan coil cooling system with pressure-independent balancing and a control valve in one (Fig. 2.24) The pressure-independent balancing valve ensures the design flow to each unit, and additional balancing on branches and risers are not needed. The integrated control valve has full authority and can be used with all types of actuators (e.g. on/off or modulating control) (Danfoss, 2021).

Hydronic systems with manual~~ly~~ and automatic balancing valves are presented below (Fig. 2.25).

After the system is installed, it is tested and washed. Commissioning must be done for both manual and automatic solutions. Usually, the instrument measures dP on the balancing valve and, depending on the valve DN and setting, it calculates the real flow. The measured real flow, depending on the system design, should have the accuracy of +/- 5….15%compared to the designed flow (Danfoss, 2021).

FIG. 2.25. Systems balancing with automatic and manual balancing valves (Source: Danfoss, 2022)

In well-insulated and 'near-zero energy' buildings, it becomes more important to use the installed heat output in a highly efficient manner (WEB-1).

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3. VENTILATION AND INDOOR AIR QUALITY

3.1. Ventilation in Modern Buildings

3.1.1. Ventilation

Ventilation can be defined as the deliberate supply of a clean outdoor air to a building or space to meet criteria associated with the use of that space. Clean outdoor air is provided to indoor spaces for several reasons including:

- provide oxygen for human breathing,
- dilution or removal of airborne contaminants,
- provide for thermal comfort,
- other reasons such as combustion appliances and for smoke control.

Ventilation dilutes air contaminants, carbon dioxide caused by human breathing exhalation and other air contaminants in occupied spaces. Building's ventilation can be either natural, mechanical or a combination of the two and can be selected according to the building requirements.

3.1.2. Natural Ventilation

Natural ventilation depends on wind and temperature difference to cause air movement between the inside and outside of a building, between enclosures within a building and within enclosures.

Ventilation air is generally delivered through openings of a particular size and distribution in the external facade of a building. Air moves in and out of these openings such as windows, doors, vents, and grilles. Natural forces such as wind, thermal and stack effects move the air. Openable windows and doors can be used in basic natural ventilation systems. Also, natural ventilation systems can be complex and controllable by means of engineered systems.

However, when a building or space cannot meet the building requirements with natural ventilation systems, a mechanical ventilation system is required.

3.1.3. Mechanical Ventilation

Mechanical ventilation depends on fans to cause air movement between the inside and outside of a building, between enclosures within a building and within enclosures. The outdoor air is essentially moved from outside to inside the building using fans in mechanical ventilation systems.

Mechanical ventilation systems are versatile and can be applied to almost any situation or condition to meet building requirements. It provides good control over airflows and an opportunity to filter outdoor and recirculating air streams. Mechanical ventilation can respond to the variable needs of time dependent occupation and can control building and enclosure pressures.

3.1.4. Hybrid and Mixed-Mode Ventilation

Mixed-mode ventilation systems use a combination of the natural and mechanical ventilation approaches but with independent operation and control between the two systems.

Hybrid ventilation systems use both natural and mechanical ventilation, or features of both, in an integrated system. Natural and mechanical ventilation forces can be combined or operated separately, with the operating mode varying depending on the needs of the building and occupants at any given time.

3.1.5. Health Effects and Exposure to Indoor Air Contaminants

People are exposed to different organic (i.e., microorganisms, pollens) and inorganic air contaminants (i.e., fine particles, gases) in the indoor building environment. Different internal and external sources of indoor air contaminants can be considered in the building environment (Fig.3.1).

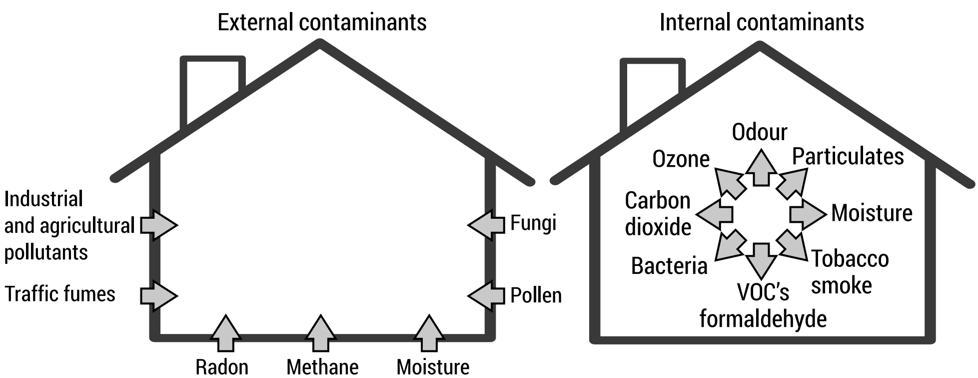

FIG. 3.1. Typical outdoor and indoor sources of contaminants (Source: own elaboration based on AIVC, 1996)

Exposure to indoor air contaminants can cause adverse health effects for occupants (WHO, 2010). Health effects can be acute or chronic and can differ from person to person. To limit the health risk, concentrations of individual substances in the indoor air should be controlled (Table 3.1) and this can be achieved using a variety of strategies including ventilation. Not all potentially dangerous chemicals are known, and many individual chemicals have not had safe exposure standards determined.

TABLE 3.1. Summary of WHO IAQ guideline limits for selected pollutants (Source: WHO, 2010).

Pollutant	Guideline limit	Averaging time	Comment
Benzene	No safe level	Lifetime	Carcinogen
Carbon monoxide	7 mg/m^3 10 mg/m^3 35 mg/m^3 100 mg/m^3	24 h 8 h 60 min 15 min	
Formaldehyde	100 μg/m^3	30 min	
Naphthalene	10 μg/m^3	1 year	
Nitrogen dioxide	40 μg/m^3 200 μg/m^3	1 year 1 hour	
PAH with benzo (α) pirenne as marker	No safe level	Lifetime	Carcinogen
Tetracloroethylene	250 μg/m^3	1 year	
Tricloroethylene	No safe level	Lifetime	Carcinogen

3.1.6. Reducing Indoor Air Contamination

There are several factors that influence the concentration of indoor air contaminants:

- External sources such as the level of air contaminants in the regional outdoor air and the location of outdoor air intake openings relative to local outdoor pollution sources.
- Internal sources such as the generation rate of air contaminants indoors, the level of air recirculation employed in a ventilation system, the level of air cleaning employed, and the level of contaminants generated within a ventilation system.

In the many buildings ventilated by natural means, little can be achieved to avoid the ingress of contaminated air. Therefore, every effort is needed to ensure the quality of outdoor air. Nevertheless, urban pollution, especially from high traffic densities, remains a problem. In these areas, control measures include air filtration, air intakes and fresh air dampers and building air tightness.

Filtration is used primarily to remove particulates from the air. Almost all mechanical supply air intakes incorporate filters to prevent dust from entering the ventilation system. Activated carbon filters can remove gaseous pollutants while high specification (HEPA) filters enable the minutest of particles to be removed.

Air intakes must be located away from pollutant sources. Problems include street level and car parking locations. Also, air quality controlled fresh air dampers can be useful to control peaks occurring during the morning and evening in traffic pollution urban areas.

None of the above control strategies will be effective unless the building is well sealed from the outdoor environment to prevent contaminant ingress through air infiltration.

The preferred order and methods of controlling indoor air contaminants sources are summarized in Table 3.2.

TABLE 3.2. Preferred Methods to control indoor contaminant sources (Source: AIVC, 1996)

Method	Contaminant source
Source control	Emissions from avoidable sources (VOCs and formaldehyde from furnishings, tobacco smoke etc.)
Enclosure and ventilation at source	Pollutants generated by occupant activities (cooking, clothes washing and drying, use of office equipment etc.)
Dilution and displacement ventilation	Emissions from unavoidable sources (primarily metabolic pollution)

Once a contaminant has entered a space, it can only be diluted. Avoidable contaminant sources should therefore be eliminated. This means restricting potentially harmful sources of contaminants such as VOC's and formaldehyde, from furnishings and discouraging tobacco smoking.

Contaminants generated as part of the activity of occupants are usually highly localized. The dominant contaminant in residential buildings is water vapor generated by washing, clothes drying and cooking. Wherever possible source control should be applied, combined with the use of local extractors and cooker hoods to remove these pollutants at source. Similarly localised sources in the workplace should be directly vented to the outside.

General ventilation of a space is needed to dilute and remove residual pollution from unavoidable contaminant sources. Such sources should primarily be odor and CO_2 emissions from building occupants. The necessity to contain metabolic pollution to acceptable levels represents the minimum need for ventilation. A space in which high levels of metabolic products are measured indicates that the ventilation rate is insufficient. Often ventilation is used to dilute avoidable sources of pollutant. Apart from causing unnecessary pollution within such a space, the additional ventilation will result in increased space conditioning load.

3.1.7. Indoor Air Quality (IAQ)

Indoor Air Quality (IAQ) refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. IAQ is a measure of the condition of air in an indoor environment to provide health and comfort of building occupants.

According to the UNE 171330-1:2008 standard, (UNE 171330-1, 2008) Indoor Air Quality is defined as "the environmental conditions of indoor spaces, appropriate to the user and the activity, defined by the levels of chemical and microbiological contamination". IAQ is a part of Indoor Environmental Quality, IEQ, which includes also values of physical factors.

Optimum indoor air quality relies on an integrated approach to the removal and control of contaminants based on source control, filtration, enclosing pollutant sources and ventilating the occupied space (Fig. 3.2).

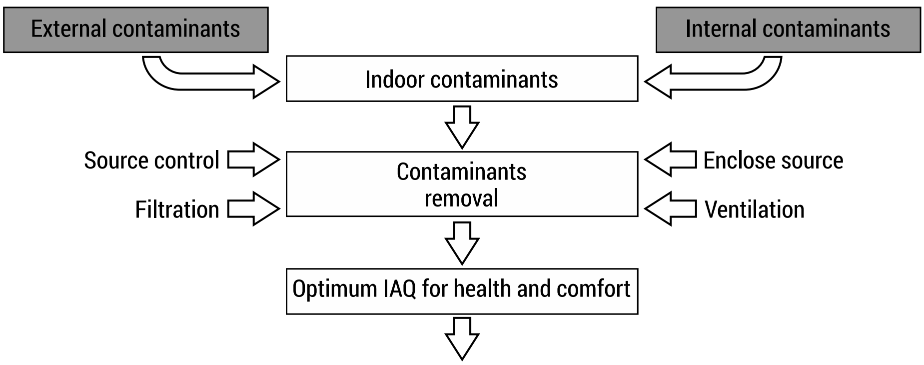

FIG. 3.2. Achieving Optimum Indoor Air Quality (Source: own elaboration based on AIVC, 1996)

Ventilation provides an effective measure to deal with unavoidable contaminants, but source control is the most efficient and, sometimes, the only method suitable for minimizing the effect of avoidable pollutants. Typical unavoidable contaminants are those associated with metabolism (carbon dioxide and odor) and essential occupant activities (e.g., cooking and washing). Avoidable sources include excessive organic emissions from furnishings and fittings, and pollutant emissions from poorly enclosed appliances.

3.2. Ventilation and Indoor Air Quality

The performance of ventilation is dependent on identifying and providing sufficient ventilation for controlling the dominant pollutant. In residential buildings this may be moisture whereas in densely occupied non-residential buildings it may be the occupants.

Provided the dominant contaminant is controlled, all other contaminants should remain below their 'safe' threshold concentration.

3.3. Ventilation Requirements

The ventilation requirements can be fixed depending on several criteria including the contaminant emission rate.

3.3.1. Air Flow Rate Required for Thermal Comfort (Heating And Cooling)

In a mechanically ventilated space, ventilation is also commonly used as part of the heating and cooling distribution system. The amount of ventilation to maintain an internal room air temperature of T_r is given by:

$$\dot{V} = \frac{\dot{Q}_{s,hg}}{\rho\, c_p\left(T_s - T_r\right)} \tag{3.1}$$

where $\dot{V}$ is required warm air ventilation rate (m^3/s), $\dot{Q}_{s,hg}$ is the room sensible heating load (W), ρ is the air density (kg/m^3), c_p is the specific heat capacity of air (1020 J/kg K) and T_s and T_r are the supply and room air temperatures respectively (°C).

A similar calculation approach is applied to cooling and again, the requirement to meet fresh air needs is essential. The flowrate for cooling is thus:

$$\dot{V} = \frac{\dot{Q}_{s,cg}}{\rho\, c_p\left(T_r - T_s\right)} \tag{3.2}$$

where $\dot{V}$ is required warm air ventilation rate (m^3/s), $\dot{Q}_{s,cg}$ is the room sensible cooling load (W), ρ is the air density (kg/m^3), c_p is the specific heat capacity of air (1020 J/kg K) and T_s and T_r are the supply and room air temperatures respectively (°C).

The above equations give an approximate flowrate only. It is assumed that the moisture contents (i.e., mass of water to that of air) of the supply and room air are the same. The room air temperature to be maintained in summer is commonly 22–24°C (offices), while the supply air temperature may be about 15°C. Ideally the same ventilation rate should apply in summer and winter so that the same ventilation system can be used.

3.3.2. Air Flow Rate Between Spaces for Pressurisation

Ventilation is often used to maintain pressure differences between spaces (e.g., in kitchen areas to prevent odors and water vapor from dispersing into other rooms).

Extract ventilation drives the contaminated air through the fan and out of a roof or wall mounted exhaust vent. The resultant under-pressure causes make-up air to come from adjacent spaces. It is important to ensure that the exhaust vent does not contaminate adjacent air supply intakes.

The flowrate to be maintained for pressurization may be obtained by assuming that the sum of the flowrates into and out of a space is equal to zero. Air is lost or gained by leakage from openings around doors, windows, gaps between surface interfaces and via 'leaky' surfaces and to/from a ventilation system via diffusers and grilles.

Pressurized spaces include operating theatres and cleanrooms (as used for the production and testing of integrated circuits), which need to be kept free of contaminants. Calculating flowrates due to pressurization are found using:

$$\sum_{i=1}^{N} \rho_i \dot{V}_i = 0 \tag{3.3}$$

where ρ_i is the air density (kg/m^3), $\dot{V}_i$ is the flowrate via path i (m^3/s) and N is the number of flow paths.

The flowrate $\dot{V}_i$ may be found using:

$$\dot{V}_i = 0.775\, A \sqrt{\Delta P} \tag{3.4}$$

where $\dot{V}_i$ is the leakage rate through openings (m^3/s), A is the leakage area (m^2) and ΔP is the pressure drop across the opening (Pa).

3.3.3. Air flow Rate Required for Removal of Contaminants

In simple mathematical terms the indoor air contaminant concentration of a space can be considered in terms of the relationship:

$$C_i = C_o + \frac{S}{\dot{V}} \tag{3.5}$$

where C_i is the indoor air contaminant concentration (μg/m^3), C_o is the outdoor air contaminant concentration (μg/m^3), S is a measure of contaminant source generation within the space (μg/m^3) and $\dot{V}$ is the outdoor air ventilation rate (m^3/s).

In terms of this relationship the objective of ventilation systems for contaminant control is to maintain C_i as close as possible to C_o. This can be achieved by maximising the outdoor airflow rate $\dot{V}$ and minimizing indoor contaminant generation rate S. The relationship $S/\dot{V}$ is therefore of paramount importance when considering the dilution performance of ventilation systems.

Additional terms would need to be added to this mathematical model to account for infiltration and exfiltration, the action of air cleaning devices, and internal sinks removing contaminants from the air.

Rooms may have one or more pollutant sources/types, different ventilation systems with specific supply and extract locations, given ambient conditions (e.g., temperature, relative humidity, local air speed) and normally it may be difficult to calculate transient and steady-state pollutant concentrations. However, if some simplifying assumptions can be made, then various equations can be used.

For a single room or space, the pollutant concentration for one pollutant source in one room can be found from the following dilution equation:

$$C_{(t)} = C_{(t=0)}\, e^{-\left(\frac{\dot{V}+S}{V}\right)t} + \frac{\dot{V}C_o + S}{\dot{V}+S}\left(1 - e^{-\left(\frac{\dot{V}+S}{V}\right)t}\right) \tag{3.6}$$

where $\dot{V}$ is the flowrate (m^3/s), C_o is the pollutant concentration in the outside air (μg/m^3), S is the pollutant release rate (μg/m^3), V is the room volume (m^3), t is the time (seconds or hours) and $C_{(t=0)}$ is the initial concentration of contaminant (μg/m^3).

The above equation is based on the following assumptions: (1) single pollutant source, (2) constant flowrate, (3) constant external pollutant concentrations, inside and outside pressures, and (4) pollutant and air completely mixed.

If there is no contaminant source (i.e., $S = 0$), then the concentration will decay depending on the ventilation rate, i.e.

$$C_{(t)} = C_{(t=0)}\, e^{-\left(\frac{\dot{V}}{V}\right)t}. \tag{3.7}$$

If the initial concentration of the pollutant is zero, then the concentration is calculated using:

$$C_{(t)} = \frac{\dot{V}C_o + S}{\dot{V}+S}\left(1 - e^{-\left(\frac{\dot{V}+S}{V}\right)t}\right). \tag{3.8}$$

The time constant is the time taken to reach 63% of the steady state value. As the time, t becomes large or greater than four-time constants, the transient term becomes small and the above equation simplifies to the following equation:

$$C_{(t)} = \frac{\dot{V}C_o + S}{\dot{V}+S}. \tag{3.9}$$

The above can be rearranged to give a value for flowrate, i.e.

$$\dot{V} = S\frac{1-C_{(t)}}{C_{(t)}-C_o}. \tag{3.10}$$

This can be simplified to (as $C_{(t)}$ << 1)

$$\dot{V} = \frac{S}{C_{(t)}-C_o}. \tag{3.11}$$

The above formula can be modified to calculate a ventilation supply flowrate if the pollutant emission rate, the required room plus outside air contaminant concentrations and the ventilation system efficiency are known, i.e.:

$$\dot{V} = \frac{S}{\varepsilon_v\left(C_{(t)}-C_o\right)} \tag{3.12}$$

where $\dot{V}$ is the fresh air supply per person (m^3/s), S is the contaminant release rate (m^3/s per person), ε_v is the ventilation system efficiency.

3.4. European Regulation and Standards

A set of internationally harmonized procedures has been developed to assess the overall energy performance of buildings: the set of energy performance of buildings, EPB standards. The EPB standards has been proposed aiming at an international harmonization of the methodology for the assessment of the energy performance of buildings (Fig. 3.3).

The set of EPB standards play a key role to support the Energy Performance of Buildings Directive (EPBD, 2010) of the European Union. EU Member States are encouraged to consider applicable standards, from the list of EPB standards.

The EPBD aims to promote the improvement of the energy performance of buildings within the European Union, considering outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness (Article 1).

The first version of the EPBD was published in 2002 (EPDB, Directive 2002/91/EC). In the interest of clarity, the EPBD was recast in 2010 (EPDB, Directive 2010/31/EU). A revised version of the EPBD was published in 2018 (EPDB, Directive 2018/844/EU). Revised EPBD in 2018: stronger role of the EPB standards, from the amended (2018) text of EPBD Annex 1, point 1:

"*Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1, developed under mandate M/480 given to the European Committee* *for Standardization (CEN). This provision shall not constitute a legal codification of those standards."*

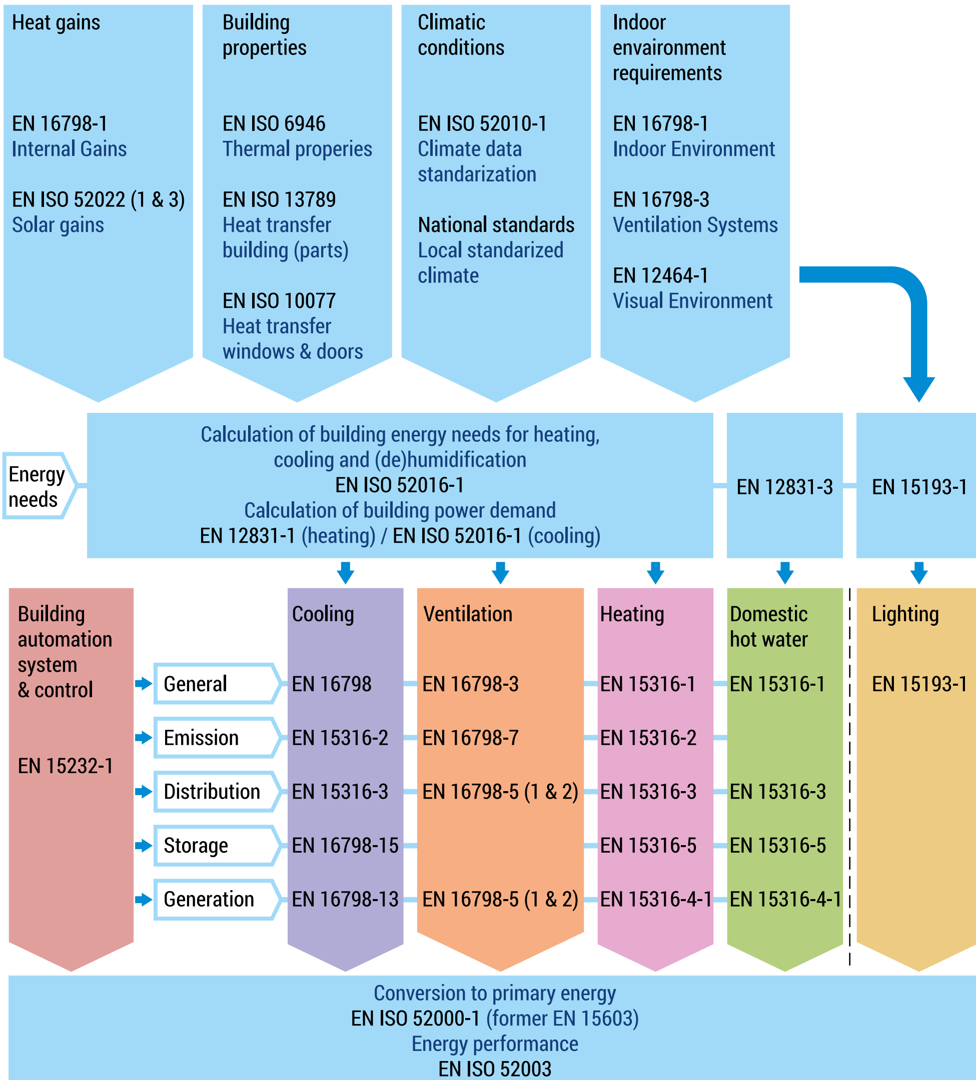

FIG. 3.3. Modular structure of the set of EPB standards (Source: Hogeling, 2016)

Although the new EPBD does not force the Member States to apply the set of EPB standards, the obligation to describe the national calculation methodology following the national annexes of the overarching standards will push the Member States to explain where and why they deviate from these standards. This will lead to an increased recognition and promotion of the set of EPB standards across the Member States and will have a positive impact on the implementation of the Directive.

The set of EPB Standards is used to calculate the energy demand and energy use of a building with its installations. So, it is needed to determine:

- The heat gain: external and internal gains entering the building.
- Building properties: thermal properties of the building envelope and materials of all building elements.
- External climate: the climatic data such as temperatures, humidity, solar data, location/ orientation of the building etc.
- Indoor environment: the indoor environmental requirements (IEQ) like indoor temperatures, humidity, ventilation rate, lighting, and the related assumptions for the user behavior.

The standards regarding technical building system under EPDB such as ventilation system, are shown in Table 3.3.

TABLE 3.3. Technical Building Systems under EPBD (Source: EPDB, 2010)

Sub-Modules	M3 Heating	M4 Coolling	M5 Ventilation	M6 Humidification	M7 Dehumidification
General Needs	EN 15316-1	EN ISO 16798-9	EN 16798-3	EN 16798-3	EN 16798-3
Maximum Load and Power	EN ISO 52016-1 EN 12831-1	EN ISO 52016-1	EN ISO 52016-1	EN ISO 52016-1	
Ways to Express Energy Performance	EN 15316-1	EN ISO 16798-9	EN 16798-3	EN 16798-3	EN 16798-3
Emission & Control	EN 15316-2 EN 15500-1 EN 12098-1 EN 12098-3 EN 12098-5	EN 15316-2 EN 15500-1	EN 16798-7 EN 15500-1	EN 16798-5-1 EN 16798-5-2	EN 16798-5-1 EN 16798-5-2
Distribution & Control	EN 15316-3 EN 12098-1 EN 12098-3 EN 12098-5	EN 15316-3 EN 16798-5-2	EN 16798-5-1		
Storage & Control	EN 15316-5 EN 12098-1 EN 12098-3 EN 12098-5	EN 16798-15			

Sub-Modules	M3 Heating	M4 Coolling	M5 Ventilation	M6 Humidification	M7 Dehumidifi-cation
Generation & Control	EN 12098-1 EN 12098-3 EN 12098-5 EN 15316-4-1 EN 15316-4-2 EN 15316-4-3 EN 15316-4-4 EN 15316-4-5 EN 15316-4-8	EN 16798-13 EN 15316-4-2 EN 15316-4-5	EN 16798-5-1 EN 16798-5-2	EN 16798-5-1 EN 16798-5-2	EN 16798-5-1 EN 16798-5-2
Load Dispatching & Operating Conditions	EN 15316-1	EN ISO 16798-9			
Measured Energy Performance	EN 15378-3				
Inspection	EN 15378-1	EN 16798-17	EN 16798-17	EN 16798-17	EN 16798-17

The general framework and procedures of EPB Standards is set in EN ISO 52000-1 (EN ISO 52000-1, 2017). Indoor environmental input parameters for the design and assessment of energy performance of buildings are regulated in EN 16798-1 (EN 16798-1, 2019) and EN 16798-3 (EN 16798-3, 2017) also used for the performance requirements for ventilation and room-conditioning systems.

Calculation methods for the determination of air flow rates in buildings including infiltration are given in EN 16798-7 (EN 16798-7, 2017). Other calculation methods for energy requirements of ventilation and air conditioning systems, requirements of ventilation systems and control for heating, ventilating and air conditioning applications are given in EN 16798-5-1 (EN 16798-5-1, 2018), EN 16798-5-2 (EN 16798-5-2, 2018) and EN 15500-1 (EN 15500-1, 2017) respectively. Guidelines for inspection of ventilation and air conditioning systems are given in EN 16798-17 (EN 16798-17, 2017).

3.4.1. Indoor Environmental Quality

Indoor environmental quality (IEQ) refers to the quality of a building's environment in relation to the health and wellbeing of those who occupy space within it. IEQ is determined by four main parameters: thermal comfort, indoor air quality, visual comfort, and acoustic comfort, see Figure 3.4.

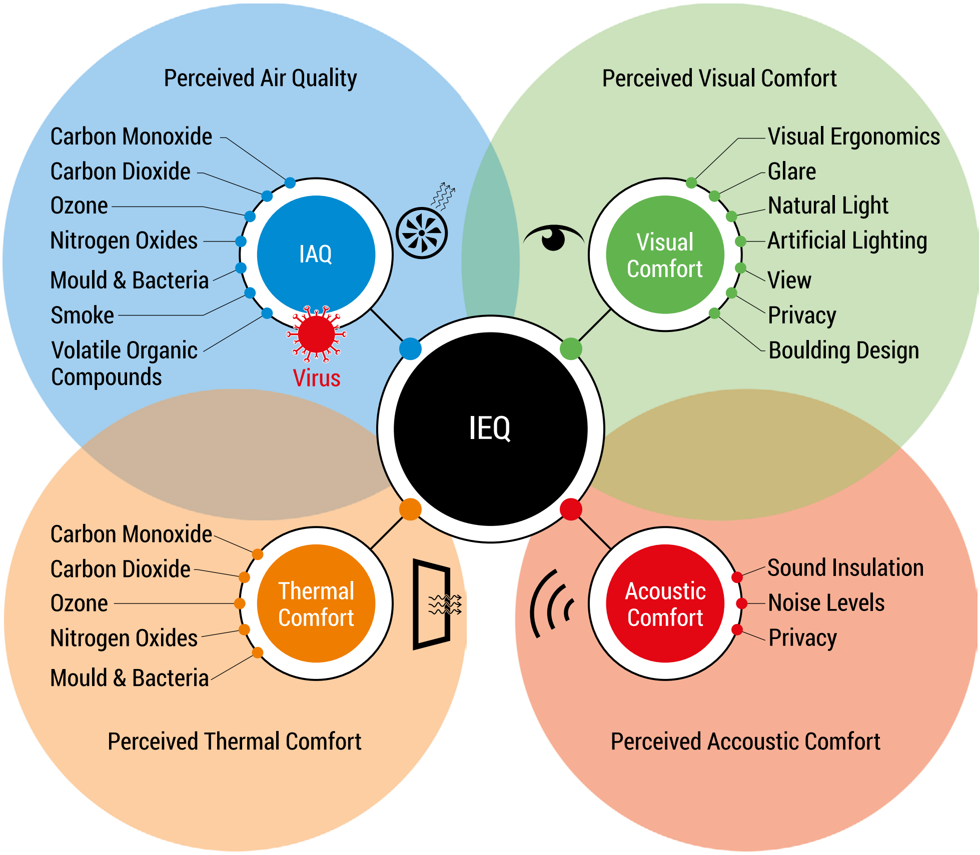

FIG. 3.4. Indoor environmental quality (Source: own elaboration based on AIVC, 1996)

3.5. The European Standard 16798

This document specifies requirements for indoor environmental parameters for thermal environment, indoor air quality, lighting and acoustics and specifies how to establish these parameters for building system design and energy performance calculations.

This European Standard includes design criteria for the local thermal discomfort factors, draught, radiant temperature asymmetry, vertical air temperature differences and floor surface temperature. It is applicable where the criteria for indoor environment are set by human occupancy and where the production or process does not have a major impact on indoor environment.

This European Standard specifies occupancy schedules to be used in standard energy calculations and how different categories of criteria for the indoor environment can be used. The criteria in this European Standard can also be used in national calculation methods. It sets criteria for the indoor environment based on existing standards and reports listed under normative references or in the bibliography. It does not specify design methods but gives input parameters to the design of building envelope, heating, cooling, ventilation, and lighting.

3.5.1. Categories of Indoor Environmental Quality

Categories of indoor environmental quality for design and operation in buildings are given in the European Standard EN16798-1 (EN16798-1, 2019), as shown in Table 3.4.

TABLE 3.4. Categories of indoor environmental quality (Source: EN 16798-1, 2019)

Category	Level of expectation	Contaminant source
IEQ_I	High	Should be selected for occupants with special needs (children, elderly, person with disabilities).
IEQ_{II}	Medium	The normal level used for design and operation
IEQ_{III}	Moderate	Will still provide an acceptable environment. Some risk of reduced performance of the occupants.

Table 3.5 describes some of the aspects and criteria used in EN 16798-1. The criteria are meant to be used in standard energy calculations for offices, schools, dwellings, and other indoor environments that are primarily meant for human occupancy.

TABLE 3.5. Example criteria from EN 16798-1:2019 (Source: Boerstra, 2019)

IEQ aspect	Building/space type	I	CategoryII	III
Temperature range winter	Residential buildings (bedrooms)	21-25[°C]	20-25[°C]	18-25[°C]
	Offices (landscape layout)	21-23[°C]	20-24[°C]	19-25[°C]
	Schools (classrooms)	21-23[°C]	20-24[°C]	19-25[°C]
Temperature range summer	Residential buildings (bedrooms)	23.5-25.5[°C]	23-26[°C]	22-27[°C]
	Offices (landscape layout)	23.5-25.5[°C]	23-26[°C]	22-27[°C]
	Schools (classrooms)	23.5-25.5[°C]	23-26[°C]	22-27[°C]
Maximum CO_2 level (delta CO_2 conc.)	Residential buildings (bedrooms)	380	550	950
	Offices (landscape layout)	550	800	1350
	Schools (classrooms)	550	800	1350
Minimum lighting level Em	Residential buildings (living room)			
	Offices (landscape layout)		500 [lux]	
	Schools (classrooms)		500 [lux]	

IEQ aspect	Building/space type	I	CategoryII	III
Maximum system noise level LAeQ	Residential buildings (bedrooms)	25 [dB]	30 [dB]	35 [dB]

The standard does so not by specifying design methods – leaving manufacturers free to provide their own – but instead it gives parameters that needs to be respected in the design and operation of heating, cooling, ventilation, and lighting systems.

3.5.2. Input Parameters for Ventilation Design in Buildings

Source control, ventilation, or filtration/air cleaning systems are used to control Indoor air quality. Source control is a key strategy for maintaining acceptable indoor air quality. It is assumed that pollutants emissions are constant in each time period.

Three different methods are specified as design parameters for indoor air quality: a method based on perceived air quality, a method based on limit values for substance concentration and a method based on predefined ventilation airflow rates.

A. Method based on perceived air quality

The method based on perceived air quality is used to reduce health risk from a specific air pollutant. The perceived air quality calculation is proposed using the equation:

$$\dot{V}_{tot} = n\,\dot{V}_p + A_R\,\dot{V}_B\,, \tag{3.13}$$

where $\dot{V}_{tot}$ is the total ventilation rate for the breathing zone (l/s), n is the design value for the number of the persons in the room, $\dot{V}_p$ is the ventilation rate for occupancy per person (l/s person), A_R is the floor area (m^2) and $\dot{V}_B$ is the ventilation rate from building (l/s m^2) (Table 3.6).

TABLE 3.6. Ventilation rates defined in EN 16798-1:2019 (Source: EN 16798-1:2019)

		Minimum ventilation rate			
Category	Expected percentage of dissatisfied	Per non-adapted person [l/s person]	For very low-polluted building [l/s m^2]	For low-polluted building [l/s m^2]	For non-low-polluted building [l/s m^2]
		$\dot{V}_p$	$\dot{V}_B$	$\dot{V}_B$	$\dot{V}_B$
I	15	10	0.5	1	2.0
II	20	7	0.35	0.7	1.4
III	30	4	0.2	0.4	0.8
IV	40	2.5	0.15	0.3	0.6

B. Method based on limit values for substance concentration

The method based on limit values for substance concentration aims to reduce or dilute a particular substance. The required ventilation rate for dilution of an air contaminant is defined as:

$$\dot{V} = \frac{S}{\varepsilon_v \left(C_i - C_o\right)} \tag{3.14}$$

where $\dot{V}$ is the ventilation rate required for dilution (m^3/s), S is the generation rate of the substance (μg/s), C_i is the guideline value of the concentration of the substance (μg/m^3), C_o is the concentration of the substance (μg/m^3) in the supply air, ε_v is the ventilation system efficiency. Typical values for ventilation effectiveness as defined in EN 16798-4:2017 (EN 16798-4, 2017) are shown in Table 3.7.

TABLE 3.7. Typical values for ventilation effectiveness as defined in EN 16798-4:2017 (Source: EN 16798-4:2017)

Air difusión	Cold jet Δθ<0K		Hot jet		
	Effective velocity	Ventilation effectiveness	Δθ (supply-indoor)	Low ceiling	High ceiling
Mixing horizontal jet	>1,5 m/s	0.9 – 1.1	<10[°C]	0.8 – 1.0	Not advised
	<0.5 m/s	0.7 – 0.9	>15[°C]	0.4 – 0.8	Not advised
Mixing vertical jet	All diffusers	0.9 – 1.1	<10[°C]	0.6 – 0.8	0.8-1.0
			>15[°C]	0.4 – 0.8	
Displacement ventilation		1.0 – 2.0		0.2 – 0.7	Not advised

If the building has a demand-controlled ventilation system (DCV) the maximum design ventilation rate will correspond to the calculated maximum concentration of contaminant. The ventilation rate can vary between the maximum and minimum ventilation rates specified. Considering a standard CO_2 emission rate of 20 l CO_2/h person the default design CO_2 concentrations above outdoor concentration are given in Table 3.8 for non-adapted persons.

TABLE 3.8. Default design CO_2 concentrations above outdoor concentration assuming a standard CO_2 emission of 20 l CO_2 /(h person) as defined in EN 16798-1:2019 (Source: EN 16798-1:2019)

Category	Corresponding CO_2 concentration above outdoors in ppm for non-adapted persons
I	550 (10)
II	800 (7)
III	1350 (4)
IV	1350 (4)

The above values correspond to the equilibrium concentration when the air flow rate is 10, 7, and 4 l/s per person for category I, II, III and IV respectively and the CO_2 emission is 20 l CO_2 /h person. The default outside concentration average can be assumed 400 ppm.

C. Method based on predefined ventilation airflow rates

Method based on predefined ventilation airflow rates uses a pre-defined minimum ventilation airflow rate estimated to meet needs for perceived air quality and health of occupants. An example is given in Table 3.9 according to EN 16798-1:2019. (EN 16798-1, 2019).

TABLE 3.9. Default design air flow rates for offices and non-adapted persons defined in EN 16798-1:2019 (Source: EN 16798-1:2019)

Category	Design air flow rate for the office building	
	l/(s person)	l/(s m^2)
I	20	2
II	14	1.4
III	8	0.8
IV	5.5	0.55

If the ventilation rates are given by person and by surface area, the higher total ventilation rate should be used as ventilation design rate.

3.5.3. Classification and Certification of the Indoor Environment in Buildings

As shown in Annex G of EN16798-2 2019 (EN 16798-2, 2019), the indoor environment in a building can be classified by:

- Criteria used for energy calculations (new buildings).
- Whole year computer simulations of the indoor environment and energy performance (new and existing buildings).
- Subjective response from occupants (existing buildings).

By dynamic computer simulations it is possible for representative spaces in a building to calculate the space temperatures, ventilation rates and CO_2 concentrations. The distribution between four categories is done by a floor are weighted average for 95% of the building spaces. An example is shown in Figure 3.5.

Quality of indoor environment in % of time of occupancy in four categories				
Percentage	5	7	68	20
Thermal Environment	IV	III	II	I
Percentage	7	7	76	10
Indoor Air Quality	IV	III	II	I

FIG. 3.5. Example of classification by footprint of thermal environment and indoor air/quality/ventilation (Source: EN 16798-2, 2019)

Long term measurement of selected parameters for the indoor environment can be carried out measuring parameters such us temperature, ventilation rate, CO_2 concentrations. These parameters are measured in representative spaces over a whole year or representative time period. The data are analysed and represented in a similar way that shown in Figure 3.5.

3.5.4. Rating of the Indoor Environment in Buildings

There is no widely accepted method for rating the overall level of indoor environmental quality (IEQ), although several different approaches are proposed by standards, guidelines, and certification schemes. To fill this void, a new classification rating scheme called TAIL (Wargocki, 2021) was developed to rate IEQ in offices and hotels undergoing deep energy renovation during their normal use; the scheme is a part of the energy certification method developed by the EU ALDREN project (ALDREN Project 2017-2020). Their quality levels are determined primarily using Standard EN-16798-1 and World Health Organization (WHO, 2010) air quality guidelines and are expressed by colors and Roman numerals to improve communication.

The TAIL scheme standardizes rating of the quality of the thermal (T) environment, acoustic (A) environment, indoor air (I), and luminous (L) environment, and by using these ratings, it provides a rating of the overall level of IEQ. Twelve parameters are rated by measurements, modelling, and observation to provide the input to the overall rating of IEQ. TAIL indicators are describing thermal (T), acoustic (A), indoor air quality (I) and visual-luminous (L) environment parameters (Table 3.10):

- (T) Air temperature defines how the thermal environment affects human thermal comfort.
- Sound pressure level to characterize airborne noise.
- Ventilation rate, relative humidity, CO_2, benzene, formaldehyde, PM2.5, radon, and visible mold. All of them chosen for their availability of IAQ guidelines values and relevant permissible exposure levels.
- (L) Illuminance and daylight factor as lighting is essential for performing work and good room darkening is essential for sleep quality.

TABLE 3.10. ALDREN-TAIL indicators (Source: Wenjuan, 2020)

T Thermal environment	A Acoustic environment	I Indoor air quality	L Luminous environment
Air temperature	Sound pressure level	CO_2 Ventilation rate Air relative humidity Visible mold Benzene Formaldehyde PM2.5 Radon	Daylight factor Illuminance

The measured values at each measuring point during working hours are compared with their defined ranges (Wenjuan, 2020), and their quality levels are determined. The quality level of each parameter defining TAIL are obtained by calculating the interim rating at each of the eight measuring locations:

$$Interim\,rating = \frac{\sum_{1}^{k} R_k O_k}{n}, \tag{3.15}$$

where R is the rank for the specific quality level k ($R = 1$ for green level, $R = 2$ for yellow level, $R = 3$ for orange level and $R = 4$ for red level); O is the number of observed rooms for the specific quality level k; k is the number of quality levels ($k \leq 4$); n is the total number of the rooms where measurements are performed.

The final quality level of each of the four TAIL components at the building level are determined by the worst interim rating for the thermal environment (T), acoustic environment (A), indoor air quality (I), and the luminous environment (L). The overall rating of IEQ is determined by the worst level of the four TAIL components.

Figure 3.6 shows an example of the TAIL level of a building:

- The thermal environment in the building (T) was qualified at the yellow level because the indoor air temperature varied between 20 and 24°C during more than 94% of the working hours in 5 rooms. The thermal environmental quality could be improved to the green level if the indoor temperature had been reduced to 23°C during midday.
- The acoustic environment in the building (A) was qualified at the green level because the sound pressure was lower than 35 dB(A).
- The indoor air quality in the building (I) was qualified at the orange level mainly because CO_2 concentrations in the measured rooms often exceeded 1200 ppm, and there were high concentrations of formaldehyde. The indoor air quality could be improved by increasing the air change rate in highly occupied spaces.
- The luminous environment in the building (L) was qualified at the orange level because the median daylight factors in the selected rooms were between 1.7%

and 3%, and the illuminance levels in the measured rooms were often higher than 500 lux at the desk height. The visual environment could be improved by renovating sun protection systems and reducing artificial lighting.

Since the lowest quality level among TAIL components was orange, the overall quality level of IEQ and the overall rated TAIL level was also orange, which is represented by the Roman III in the middle of the TAIL indicator for this building (Fig. 3.6).

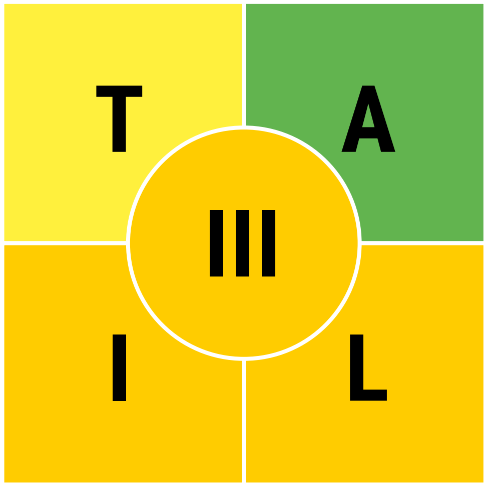

FIG. 3.6. Classification of a buildings using TAIL (Source: Wargocki, 2021)

TAIL creates an incentive to improve IEQ. It allows qualitative and quantitative assessment of non-energy benefits resulting during the process of a deep energy retrofit. The TAIL index focuses on office and hotel buildings to be aligned with the ALDREN procedure, but the intention is to use it in any type of building.

Being measured before the renovation, the TAIL index helps to identify the possible components to be improved on the energy renovation, making the latter even more beneficial for the building and its occupants. In case of measurements done after the energy renovation, the TAIL index 'after' compared to the TAIL index 'before' helps in showing that the renovation has not degraded the IEQ in the building or whether the IEQ improved.

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4. WATER EFFICIENCY IN GREEN BUILDINGS

4.1. The Aim of Water Efficiency on Green Buildings

Increased population, accompanied by other water stressors, is putting stress on the world's water supply. Buildings employ large amounts of potable water, as well as discharge wastewater and contribute to pollutant loadings through stormwater runoff. As our population increases and spreads out, our demand for water also increases and, as a result, our infrastructure spreads. Increased stress on water resources, both in terms of decreasing quantity and quality, has lead to a growing interest in more efficient water uses. Through the implementation of water management strategies, the issues associated with increased water demand may be alleviated.

Similarly, water cannot be infinitely pumped from potable sources to meet community demands. Sustainable solutions that meet current and projected demand as well as preserve natural and human cycles are required.

The building industry significantly impacts the human and natural environments. Buildings account for a substantial portion of electricity consumption, greenhouse gas emissions, material use, waste output, and potable water consumption.

In response to impacts from the building industry, a green building movement has emerged. "Green" building involves the use of two main concepts: sustainability and integrated design (IDB, 2012). These concepts are essential in the planning of a green building and are also necessary when designing any other project. Sustainability requires developers to examine the entire lifetime of the project. The "green" process requires both ideas to combine, leading to savings in water, energy, and costs.

As C. Joustra indicates, savings occur in all sectors when building green (Joustra, 2010). The initial building costs can be no more than those of a conventional structure; but because a green building is more efficient, savings continue throughout the entire lifetime of the structure. In addition to environmental and economic benefits, green buildings also enhance the comfort and health of occupants, by improving air quality, thermal conditions, and the overall work environment.

Green building mentions a building structure that is designed to be environmental-friendly and makes nominal and efficient use of natural resources. Such buildings are resource-efficient and eco-friendly during its entire lifespan starting from its construction to demolition. A Green building design emphasizes on making effectual use of natural resources like water, energy, etc. while reducing several bad effects on the environment and the occupant's health during its use. The 5 main goals of green buildings are:

- site and design efficiency,
- reduced energy usage,
- reduced water consumption,
- environmentally safe construction materials,
- improved air quality.

Considering water efficiency in green buildings, there are several strategies that can be employed to reduce the amount of water consumed at a facility. In general terms, these methods include system optimization (i.e., efficient water systems design, leak detection, and repair), water conservation measures and water reuse/recycling systems.

While not a design specification or technology option, obtaining the participation of building inhabitants in the water conservation program becomes key to achieving water use reduction goals, and is often one of the simplest and most cost-effective strategies to employ (Bourg, 2016). One of the first steps in implementing a water conservation program is to train employees on the use of new water-efficient technologies, as well as maintenance staff on operation and maintenance procedures; technologies that are not properly used or maintained will not achieve their maximum savings potential. For example, double flushing of ultra-low flush toilets may result in more water consumption than older, conventional devices if not used properly.

Some activities can be incorporated into public information and education programs, such as establishing as hot line or other reporting mechanisms to report leaks, place signs on new equipment on how to use, initiate a incentive program; distribute flyers and pamphlets to increase awareness of the facility's water management plan, educate inhabitants on wise water use practices, and develop a display on water management highlighting the practices in use at the facility and its resultant savings and benefits and place in a highly visible area of the building.

The human factor is critical to obtaining the desired results from water conserving strategies, and development of an information and education campaign can help your facility in making the human factor work in favor of water conservation initiatives.

As an example of public information and education programs, Castle Water Limited (Blairgowrie, UK) has developed a guide to provide a first step for businesses wishing to use water wisely and achieve water efficiency use (Castle, 2022).

The Water Management Hierarchy is established as a framework for prioritizing water management and efficiency actions (Fig. 4.1).

Once you have committed yourself to begin saving water, the first step is to understand how water is used in your business, asking questions as "How is water supplied to site?" or "Where is water used in your business (domestic use, process use, inside and outside)?".

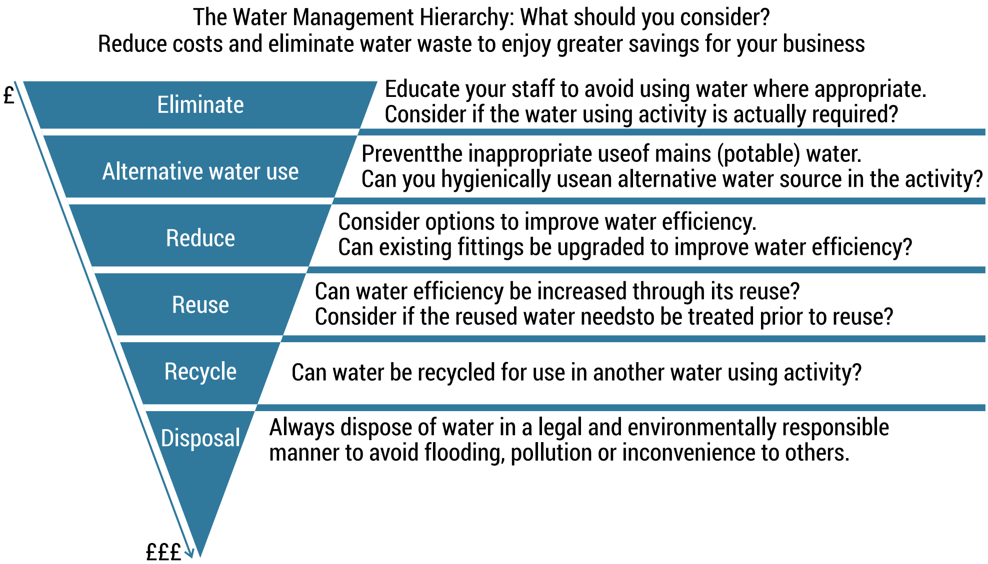


FIG. 4.1. Keep the waste hierarchy in mind when undertaking water savings actions: those which deliver results closer to the top of the hierarchy should be preferred (Source: Castle, 2022)

A simple and effective tool for understanding your water usage is a water balance model (Fig. 4.2), that is to say, numerically accounting for how water enters the site (mains water, other sources), how water is used within the site and how water exits the site (sewer discharge, trade effluent).

Top tip A good water balance model, which accounts for at least 90% of your billed water consumption, will serve as a tool to understand and manage water use.

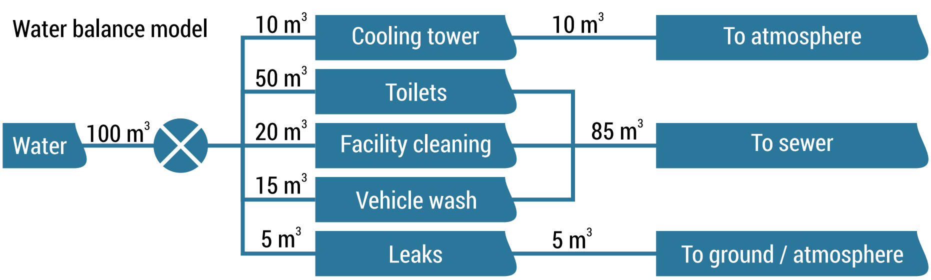


FIG. 4.2. Water balance model will serve as a tool to understand and manage water use (Source: Castle, 2022)

The second step is to set performance indicators like m^3 per employee / site occupant or tonne of product/m^3, and finally, once the water balance has been obtained and a baseline water efficiency established by setting the key performance indicators, the goal is of course to improve performance.

The main objective of this chapter is to stress on the need for water conservation and highlight the several technologies available for implementing water efficiency practices.

A wide range of technologies can be employed to save water and associated energy consumption, to increase the supply of water from an alternative source to conventional natural resources or from water recycling.

Alternative water sources provide a volume of water, taking advantage of non-conventional inputs such as rainwater, wastewater, etc.

They are not really water-saving mechanisms in themselves, as the specific demand of a building does not necessarily decrease. What is sought with them is to reduce the water demand of the general distribution networks and, therefore, to reduce the usage of natural resources.

4.2. Water Saving Systems

In recent years, numerous devices have been developed to save and better manage water demand. This paragraph will introduce some of those technologies for saving water.

A water saving equipment can be classified according to its complexity and the number of elements that make it up, and according to the form of water saving achieved. In this way, we will have water saving devices and water saving systems depending on the complexity of the equipment.

A water-saving device is a simple piece of equipment for a specific application, whereas a water-saving system is a set of elements, not specific, but all assembled in a certain order and functionality, to achieve the desired water-saving effect.

The first ones are intended to reduce the flow rate supplied through the sanitary fixtures, or to reduce the consumption time of the fixtures. Among those that reduce the flow rate are aerators and flow reducers, which will be discussed later. In the group of those that reduce the time of use are domestic hot water recirculation systems.

Systems aimed at reducing the flow rate delivered, the duration of consumption, or even the frequency of usage, include the following:

4.2.1. Tap Aerator

The function of the aerators, or perlizers, is to produce a vein of water that, maintaining the appearance and consistency of a powerful stream, supplies less water than a tap equipped with a standard stream would deliver.

What the aerator does is to mix, right at the tap outlet, the water coming from the supply pipe with air and, thus, generates a “fluffier” stream.

Figure 4.3 shows an aerator and its cross-section, where the air that enters between the aerator and its support is introduced and mixed through the rectangular orifices.

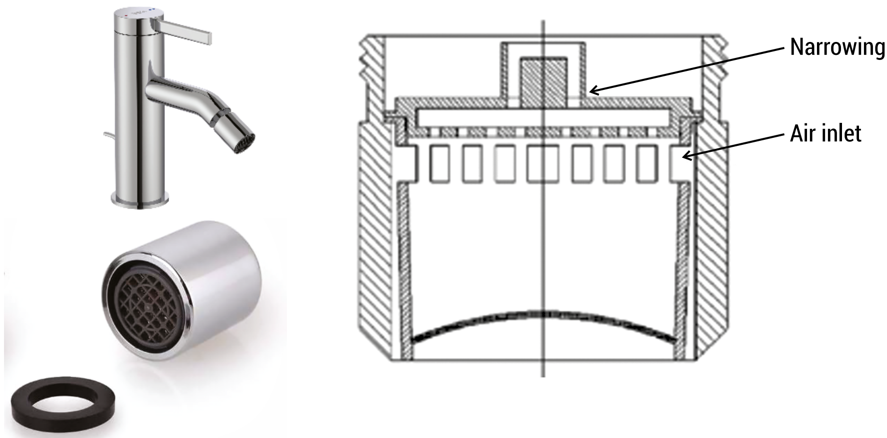


FIG. 4.3. Faucet with aerator and its cross-section (Sources: WEB-1, WEB-2 and López-Patiño, 2015)

There are different types of aerators, and it is very important to select the most suitable one, according to its application. In fact, aerators can be distinguished by the maximum flow rate delivered which, in turn, will be suitable for a type of tap. The lower the maximum flow rate they deliver, the more expensive the aerator becomes, which is why it is interesting to adjust the preselection of the device to the tap on which it will be mounted.

Aerators have the advantage of their great versatility, since they can be placed on any tap, regardless of its design, without changing its appearance, as long as it is a standardized tap.

In addition, it is easily installable by anyone without any plumbing knowledge.

As an example, if a washbasin aerator represents a saving of 54% and the washbasin represents 15% of the total consumption of a home, the absolute saving of the implementation of the aerator is 8% (López-Patiño, 2015).

4.2.2. Flow Reducer for Shower

There are several systems to reduce the flow delivered to the shower, although the device that is going to be developed is the one that is inserted in the connection of the shower hose to its control (Fig. 4.4).

It consists of a pressure reducing valve that decreases the pressure with which the shower head is supplied, in such a way that the flow that it can deliver is also reduced.

The absolute savings in volume depend on the frequency and duration of use of the appliance. A shower reducer that reduces the flow by 55% when the consumption in the showers represents 15% of the total of the house, represents a real saving of 8.25% (López-Patiño, 2015).

FIG. 4.4. Flow reducer for shower (Source: WEB-3)

These devices have the advantage that they can be installed in any type of shower, making them suitable for rehabilitated installations, since the existing taps do not need to be replaced.

However, they have the great disadvantage of being able to be installed with shower heads that are not designed for low pressure and, as a result, the feeling of the jet that is achieved in the shower is very poor, to the point that it looks that there is no flow, as it actually happens.

4.2.3. Shower Head With Flow Reducer

As in the previous case, this system consists of a supply pressure reducing mechanism, but installed inside the shower head. As the supply pressure is reduced, the flow rate is also reduced. The difference with the previous ones is in the fact that the shower head has been designed to work with reduced pressure, so that the user perceives a pleasant sensation of showering.

Therefore, they have the disadvantage that they are not a standard element (Fig. 4.5).

With the same water savings as a reducer, the head is more expensive so, a priori, one cannot be rated better than the other.

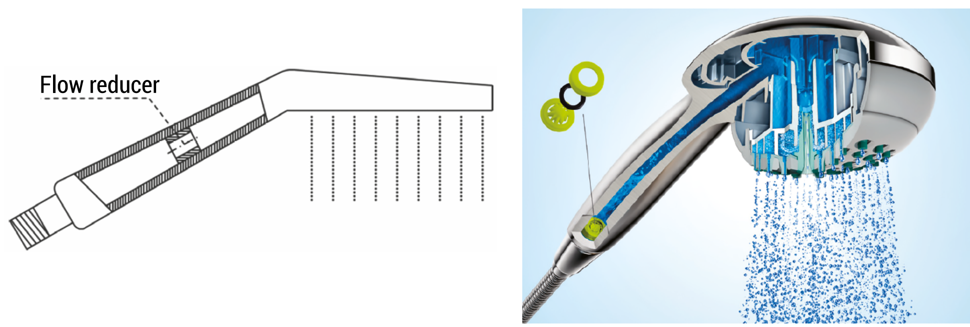


FIG. 4.5. Shower head with flow reducer (Sources: López-Patiño, 2015 and WEB-4)

4.2.4. Low-Consumption Toilet Taps

The toilet faucet is the mechanism for discharging water from the cistern to the toilet bowl for cleaning after each use, so the consumption of the toilet faucet is the volume of water that is released in each flush.

The design of toilets has been continuously improving, in such a way that the volumes required nowadays for cleaning are much less than the 20 liters per flush that were necessary a few years ago. In addition, building regulations have progressively limited the maximum distance between the toilet and the downspout, so the volume required to transport solid waste in the toilet collectors has also been reduced. In addition, discharge taps have been developed that use lower discharge volumes for the single evacuation of liquids, than for the discharge of solids.

New-generation toilets are already equipped with low-consumption cisterns, although two configurations coexist on the market: interruptible flush mechanisms that allow the flush to start when it is pressed and be interrupted at any time by pressing the tap again; while in those with double buttons, the volume of the partial discharge is not fixed in advance as it varies from one discharge to another due to the voluntary action of the user. This second mechanism has two buttons, so it has the advantage of being easily identifiable by the two buttons on the faucet, which makes it especially suitable for public buildings.

As a disadvantage, if the desired cleaning is not carried out with the partial discharge, the user performs a partial discharge again or ends with a complete discharge, preventing water saving.

To avoid this situation, the interruptible flush mechanisms are more suitable, since the user starts the flush and, when he sees that the toilet has been cleaned, he interrupts it.

Figure 4.6 shows different layouts of two-buttons mechanisms.

FIG. 4.6. Two-buttons mechanisms (Source: WEB-1)

4.2.5. Automatic Faucets

The automatic faucets open and close the water outlet without the direct intervention of the user, so the flow supply time in the device can be controlled. In this way, the saving in the volume of water consumed is not produced by the flow supplied, but by the time during which this flow is consumed.

The use of this system is indicated in public buildings, where the user is not directly linked to the payment of water consumption. In a private building, the user himself pays the bill for water consumption, so he is concerned that the taps remain closed after each use.

This system includes are different morphologies: timed taps, whose activation can be mechanical or electronic; and infrared faucets, individual or collective (Fig. 4.7).

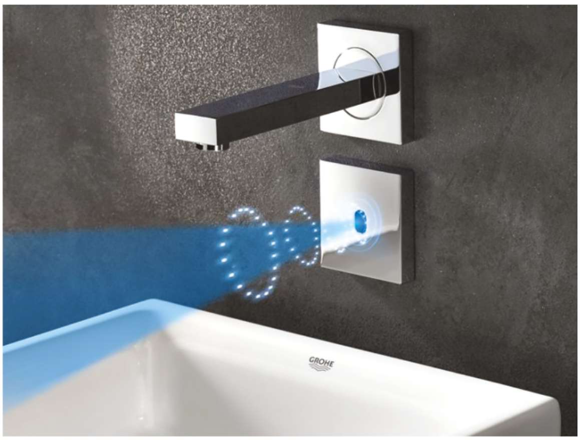


FIG. 4.7. Automatic faucets (Source: WEB-5)

As the reduction of the volume consumed that is achieved is not so much in the reduction of the demand but in reducing the wastage of water, the savings obtained with the individual systems vary a lot depending on the location, awareness, etc. Thus, it is very difficult to assess the savings in a precise manner.

4.2.6. Pressure Reducing Valves

A pressure reducing valve is an automatic valve that maintains sustained pressure at its outlet end as long as the pressure at its inlet end is greater than it (Fig. 4.8).

The way in which the valve reduces pressure is by partially closing it to cause a punctual loss of energy (loss of pressure) inside it. If the pressure at the inlet is higher, it will close more so that the pressure drops more, but if the pressure at the inlet is lower, it will close less and produce less energy loss.

In a detached house, the pressure reducing valve is installed at the entrance of the house, while in residential buildings it is installed at the bypass of each floor.

The pressure reducing valve acts on the entire installation, unlike the flow reducers of the taps that act locally and directly on the point of consumption. Therefore, the implementation of both systems in a home is incompatible.

In general, the placement of individual and localized flow reduction devices is always better than the installation of reducing valves, but these are a cheaper solution.

FIG. 4.8. 40 mm pressure reducing valve (Source: WEB-6)

4.2.7. Single-Lever Taps With Two-Position Opening

It is very common that, in single-lever type faucets, the control action is all or nothing, although they are designed to regulate the flow in any intermediate position .

When the user opens the faucet without control, the opening does not take place at 100%. The control travel in the intermediate opening is 50%, so the flow delivered in this position is usually 50% of the nominal flow of the faucet (Fig. 4.9) (López-Patiño, 2015).

Its use is suitable in installations where there are people with little ability to control their movements, such as the elderly or children populations, with the specific savings percentage achieved being 50% with respect to standard taps.

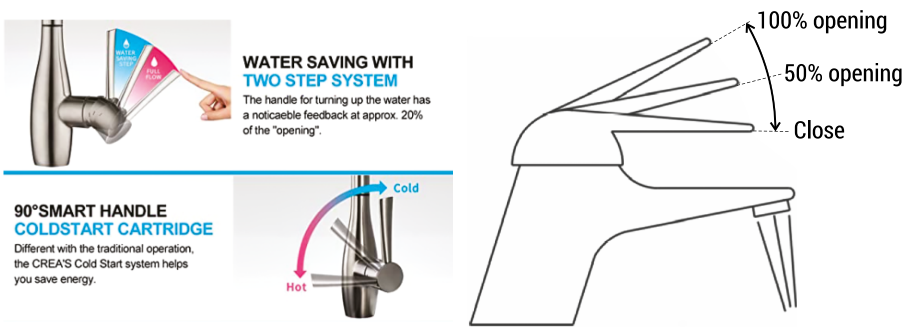


FIG. 4.9. Two-position opening tap (Sources: WEB-5 and López-Patiño, 2015)

4.3. Alternative Sources of Supply

This group includes those systems that, instead of reducing demand, increase the supply of water from an alternative source to conventional natural resources.

This group includes rainwater harvesting systems at a localized level, and condensate collection and utilization systems.

4.3.1. Rainwater Use Systems

The rainwater harvesting systems have become more common as building owners look for ways to manage rainfall runoff and save money.

A retention system uses the rainwater collected on the building for later use in appliances that do not require high quality water (toilets and irrigation). It consists of a set of elements that capture the rainwater that falls on a surface, store it, pump it and distribute to the points of consumption. In general, rainwater is used for irrigating gardens and flushing toilets. In buildings for industrial use, as long as their activity is not food production, it could be used as cleaning water.

Due to its lack of quality, it is important not to crossing the rainwater distribution network and the building's drinking water network. Therefore, the installation will be designed appropriately to avoid it, becoming one of the main conditioning factors of the design. The possibility of using water from the general network due to the lack of rainwater, has to be taken into account along the design.

Buildings that take advantage of rainwater must have a double water supply network: the drinking water network that provides service to all water consumption appliances, including appliances that can use rainwater; and the rainwater distribution network. This makes the system more expensive.

The major components of rainwater harvesting system are briefly explained:

- **The collection elements** are surfaces intended to collect the rainwater that falls on the building and channel it towards the rainpipes that transport the water to the rest of the system (Fig. 4.10). An objective for these elements must be to guarantee that the quality of the water is not altered, so materials that are not very porous and, therefore, not prone to the development of fungi and bacteria, must be chosen. In this sense, galvanized steel is a high-quality material.
- **Primary retention filters,** or grids with a reduced section, to prevent the litter and dirt that is deposited on the catchment surface from being dragged towards the rest of the system. Filters are often made of plastic materials (PVC, PE, PP), galvanized steel or stainless steel (Fig. 4.11 and 4.12).

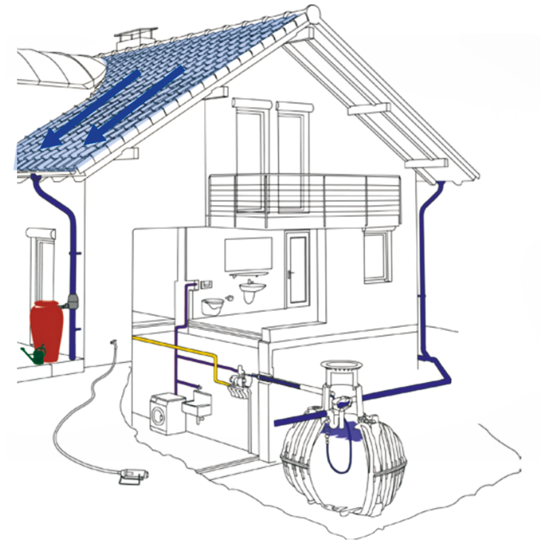


FIG. 4.10. First path of rainwater in the recovery system (Source: WEB-8)

FIG. 4.11. Gutter grilles (Source: WEB-9)

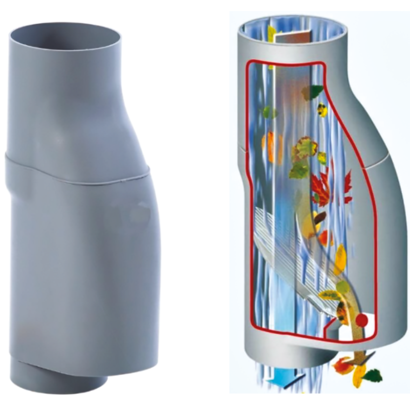


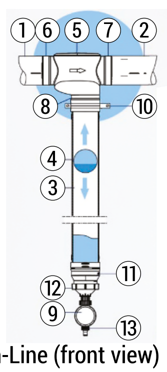
FIG. 4.12. Leaf separator filter for downspout (Source: WEB-8)

- **Pipes** that channel rain between their different parts. The water flow will circulate from the catchment elements to the tank in a free sheet regimen or under pressure, depending on whether the rainwater collection system is atmospheric or under pressure. However, all pipes from the tank will be pressurized. The materials to be used are varied but they must be compatible in quality with the usage that is going to be made of rainwater (as in the collection elements cases).
- **First rainfall separator,** or rainwater diverter, that prevent the contaminant load of an environmental nature that is dragged by rainwater, from reaching the water distribution system. Its function is to direct the first rain that falls, and all the polluting content that it carries, towards the evacuation network and, once the water does not carry a polluting load, divert the flow to the storage tank.

Rainwater diversion systems normally consist of vertical PVC piping several metres in length (Fig. 4.13). These are installed generally along the piping that leads into the top of your tank.

This results in the rainwater flowing into the gutter and down the piping to eventually fall into the vertically installed PVC piping. The rainwater starts filling up this pipe. Inside the pipe is a special ball valve that rises as the pipe fills with water. Once full, the ball value creates a seal at the top preventing the dirty "first flush" of rainwater from escaping. Subsequently, the rainwater flows over the ball down into the rainwater tank as usual.

The rainwater captured into the water diversion system needs to be let out. Otherwise, in future downpours it will not be able to fill up again. Located at the bottom of the vertical PVC piping is normally a slow-release valve.



1 – In-feed from the roof
2 – To the tank
3 – Diverter Chamber
4 – Sealing Ball
5 – First Flush Plus Tee
6 – Chamber Inlet
7 – Chamber Outlet
8 – Ball seat
9 – Advanced Release Valve
10 – Pipe/Wall Brackets
11 – End Coupling
12 – Transparent, Rapid Release Exit Funnel
13 – 25 mm x 20 mm reducing adaptor

FIG. 4.13. Rainwater diverter (Source: WEB-10, WEB-11)

- **Tanks** are the elements that store the filtered water that is collected during rainfall and that will be consumed over time (Fig. 4.14). The first decision to be taken is where the tank will be located and access. If you have a large area with lots of space and easy access to get the tank in, there will be a number of possible options. Where the tank (or tanks) is located will determine its size and shape, and possibly even its colour, in case it needs to blend into the surrounding vegetation or buildings. The ideal size of the rainwater tank will depend on what the water will be used for, the number of people in the household, and also the budget, roof size and rainfall.

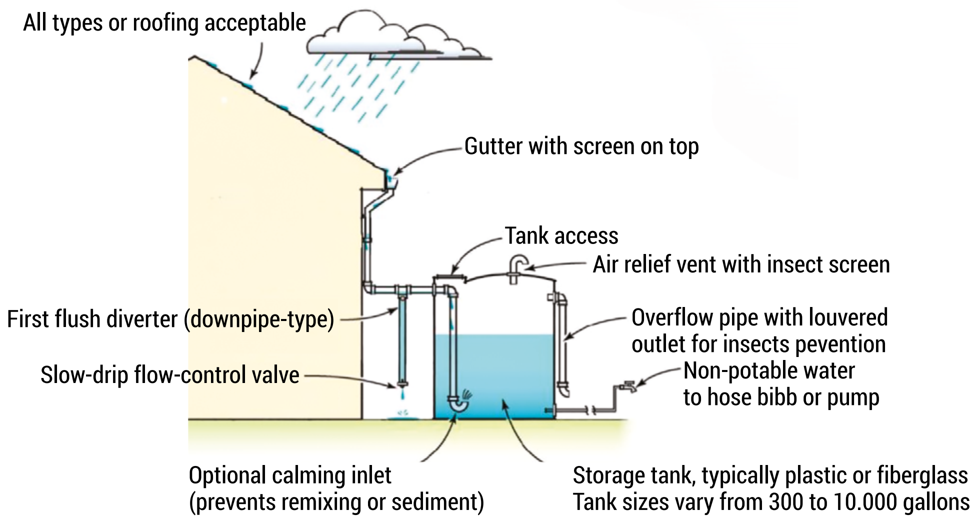


FIG. 4.14. Rainwater tank (Source: Rovira et al., 2020)

There are other factors that need to be considered when looking for a tank. Firstly, the tank will eventually need to be scrapped, and it must be considered what will happen to it at the end of its lifetime.

Stainless steel tanks generally don't corrode to the level that coated steel tanks do, so most scrap metal dealers will actually pay for them. In addition, all of the material in a stainless steel tank can be recycled. Polyethylene tanks pose an interesting problem since, if they have degraded to a point where they can no longer hold water, the plastic has reached a point where it can only be recycled into a limited range of other products, and they will end up in landfill. Fiberglass tanks are generally not recyclable and being a composite material will most likely end up as landfill. In addition, contain quite a lot of polyester resin and small amounts of some rather nasty substances, that will be released as the tanks break down in landfill. Concrete tanks are benign, but they do represent quite a large volume of materials. There are some companies now that can recycle concrete.

The most common rainwater tank materials are polyethylene, metal, and concrete. Polyethylene tanks are a popular choice for above ground tanks because they are durable and most can simply be installed onto a sand base or pavers, or even partly into the ground if needed. They typically come with at least a 10-year guarantee.

The metal tank needs to be installed on a concrete base or reinforced pavers, and they are typically guaranteed for at least 20 years and can be recycled at the end of their lifetime.

Concrete tanks are less common these days but can be a good above or below ground option and they are great for bushfire resilience. They can be prefabricated or constructed onsite.

When building a tank, consider how easily the plumbing for the house can be accessed. If possible, place the tanks on higher ground so that water can gravity feed as much as possible. Tanks do not need to be placed directly next to the house. A system of pipes can be used to take water from tanks further away on the property.

To use rainwater in the house, plumbing connections will need to be made to the pipe network, either at an incoming point or at different points of the house. You will need to get a licensed plumber to make these connections, and backflow prevention devices will need to be used.

The tanks must have connections, as can be seen in Figure 4.15, that allow a correct operation of the tank and its cleaning and maintenance. Depending on the configuration and morphology of the installation, some of these connections could vary in their layout.

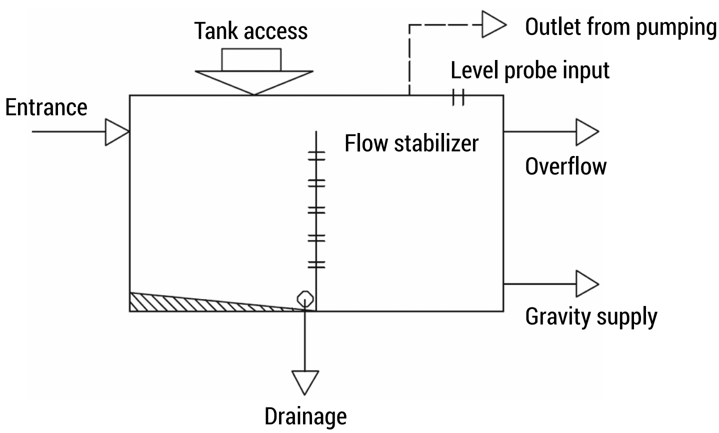


FIG. 4.15. General diagram of a rainwater collection tank (Source: WEB-8)

- **Pumping group** since the available energy is not sufficient to meet the demands. It will consist of one or more pumps and the pressure switches and maneuvering equipment that allow the pump(s) to start and stop automatically according to the levels in the pressurized tank.

Installation scheme

Knowing the different elements that make up the system, it is necessary to organize them so that the system fulfills the purpose for which it was conceived.

Multiple schemes can be configured, so an example of configuration made by the manufacturer GRAF will be shown in Figure 4.16 (WEB-6):

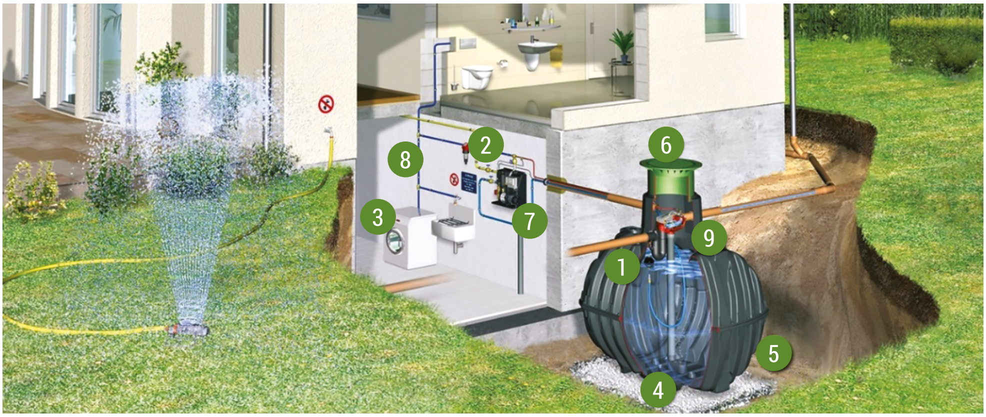


FIG. 4.16. Rainwater system configuration made by the manufacturer GRAF (Source: WEB-8)

1. *Overflow*. Excess water is drained into the sewage system or an infiltration system via the overflow siphon. Particles floating on the surface are also filtered out of the water in the event of overflows. The siphon ensures that no odours from the sewage system enter the tank.
2. *Reversible flow filter.* If using rainwater to flush the toilet and in the washing machine, it would recommend fitting a reversible flow filter (Fig. 4.17.a). This filters out the finest of dirt particles and ensures superior water quality.
3. Rainwater contains no limescale-causing minerals and is therefore ideal for the washing machine. It makes laundry softer and easier to iron. If you wash your laundry with rainwater, you have no need for descaler or softener and will use up to 60 percent less detergent. Health experts confirm that washing laundry with rainwater is totally safe from a hygiene standpoint.
4. Once it has passed through the filter, there are only very small particles of dirt left in the rainwater. Over time these sink to the bottom or float to the surface. The steady inflow prevents the sediment at the bottom of the tank from being stirred up (Fig. 4.17.b).
5. *Tank*. An underground tank forms the very heart of the rainwater harvesting system. Depending on the desired size and installation situation, customers can choose between several tank models. Here the water is stored under optimum conditions.
6. The tank cover seals the rainwater harvesting system at the top edge of the ground. For optimum adjustment to local circumstances, its height can be continually adjusted and it can be tilted. Depending on where it is installed, the cover may be suitable for pedestrian or vehicles. An internal filter is usually installed into the tank cover to clean the rainwater (Fig. 4.17.c).
7. The system control of the rainwater harvesting system ensures constant water pressure in the supply network. It continuously controls the level of water in the tank and adds drinking water to the supply network if the tank level is too low (Fig. 4.17.d). This is essential for the quality of the harvested rainwater.

8. The rainwater reaches the individual consumption or extraction points via the supply network. 50 % of drinking water can therefore be replaced with rainwater at no inconvenience.

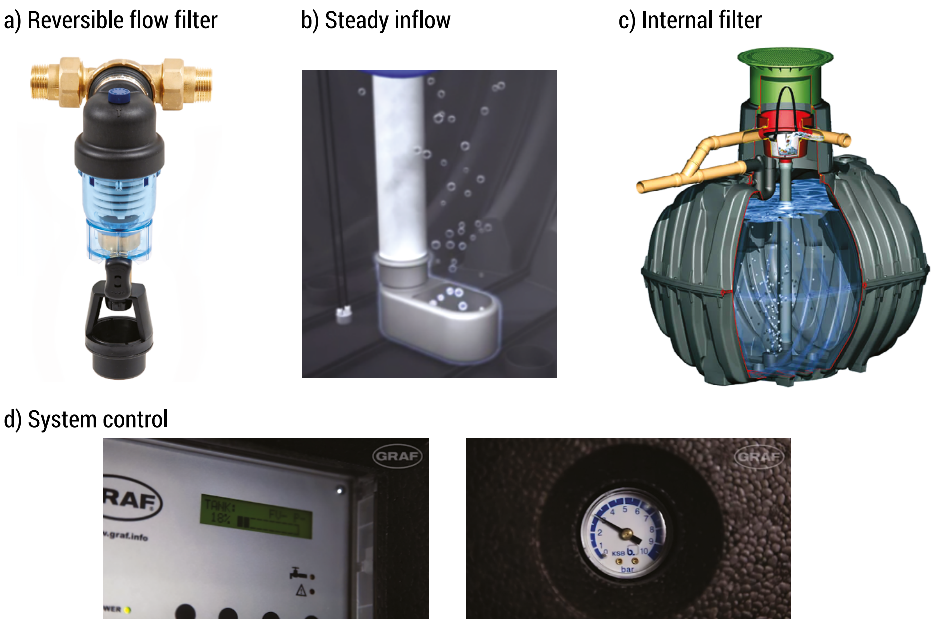


FIG. 4.17. Elements of a collection rainwater system configuration (Source: WEB-8)

4.3.2. Recovery of Condensate in Air Conditioning Systems

Although in chapter 2 the concept of HVAC systems has been extensively developed, in this chapter the heating, ventilation and air-conditioning systems will be briefly treated as another water recovery system in green buildings.

Atmospheric water vapor harvesting is an old technique, where water vapor in the atmosphere is condensed and collected. There are three significant approaches for atmospheric water vapor harvesting (Algarni et al., 2018):

1. Condensate collection on cold surfaces in heating, ventilation and air conditioning units.
2. Absorption of the water vapor by means of desiccants followed by its release in a regeneration process.
3. The generation of convection currents in a tall tower structure to push humid air to a high altitude (cold zone) where condensation takes place. The condensed fresh water, which is directly obtained from the atmosphere, is anticipated to be soft and neutral with very low contents of minerals and metals.

Among the aforementioned techniques to produce potable water via atmospheric water vapor harvesting, the one that extracts air-conditioning condensate through condensate recovery systems has great potential and could be exploited in rather more efficient ways. The heating, ventilation and air-conditioning systems in buildings produce a considerable amount of condensate, especially in hot-humid climates. This one can be regarded as one of the viable options that can contribute to both water sustainability and energy conservation.

The condensate that collects on heating, ventilation and air-conditioning units amounts to a significant volume and could potentially serve as an alternate water source. Moreover, its quality is relatively high as the water is almost mineral free, and has a very low content of total dissolved solids and low conductivity. With regard to water sustainability, collection of condensate from air conditioning systems has tremendous potential because it is an inherent byproduct of heating, ventilation and air-conditioning units. Collecting condensate from commercial heating, ventilation and air-conditioning units would be advantageous because, not only the technique is relatively simple but also the on-site applications that need relatively little treatment offer a potentially quick return on investment. In hot humid climates, the air-conditioning market is expected to grow at a fast pace, and thus, these climates represent promising regions to implement new methods for producing heating, ventilation and air-conditioning condensate.

Figure 4.18 shows the schematic of an heating, ventilation and air-conditioning unit with a condensate recovery systems. Condensate occurs in the cooling coil (evaporator section) of the heating, ventilation and air-conditioning unit, where evaporative cooling drives the heat exchange. The refrigerant is circulated through evaporator coils for the specific purpose of cooling the air forced over it. A condensate drainpipe is provided with a drain pan, which is fixed at the bottom of the cooling coil.

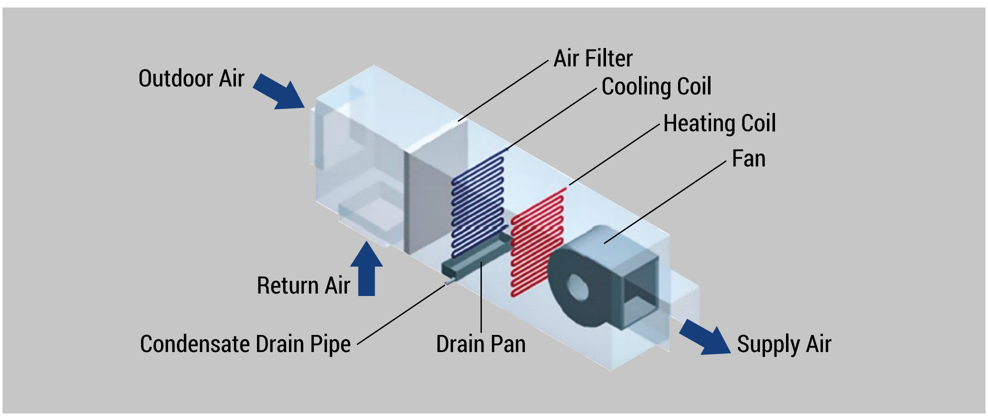


FIG. 4.18. Schematic of a typical heating, ventilation and air-conditioning unit with a condensate recovery system (Source: Glawe et al., 2016)

Source of condensation

When analyzing the possibilities of a condensation water utilization system in air conditioning systems, it is necessary to study the source of said condensation, and the humid air itself. From its analysis, conclusions can be drawn about the amount of condensate that can be extracted, the geographical areas where it is interesting to implement these systems, and the implementation conditions.

Atmospheric moist air contains a small part of water vapor in equilibrium with the rest of its components. The amount of water contained does not depend on the chemical composition of the air, but on environmental conditions, both climatic and geographical, as well as vegetation.

Areas with high vegetation have high contents of water vapour. The air in desert areas, on the other hand, has little water vapor content. Geographical areas close to seas, oceans, and to a lesser extent rivers and lakes, have more humid air than others. The direction of the winds, or the temperature of the air can cause the humidity in the air to vary.

The maximum amount of water that the air can contain is limited by the air pressure and temperature. If any one of those properties varies, so will the maximum amount of water vapor.

The humid air condensate origin is the outside air humidity itself, but also the humidity added because of the people who occupy the building.

Indeed, in air conditioning systems it is common for part of the interior air to be recirculated for energy efficiency reasons. The air increases its humidity because of the occupant metabolic actions. Therefore, when studying the possibilities of the condensation water system use in a building, it is necessary to consider its geographical position, the proximity to environmental sources of humidity, the functional characteristics of the building and its occupation.

Air conditioning systems for the use of condensate

The amount of condensation water that can be obtained from the air conditioning of a building depends on the type of air conditioning system. That is why it is necessary to study the different types of air conditioning systems that exist, assessing their possibilities of taking advantage of condensates, and the operating conditions in which they are produced.

In the so-called all-air refrigeration systems, air, previously conditioned, is transported through air conditioning ducts and drives the premises to be conditioned.

From the point of view of the installation, this system has the advantage that the generation of condensation water is concentrated in a few points, which reduces the necessary piping system. The channeled water is stored in a condensate collection tank that must be located below the position of the machine. This aspect is important because a tank would be needed under the air conditioner. If this is not possible, a condensate pump would have to be installed, which increases the energy consumption of the system and, therefore, the operating costs.

In **conditioning all-water systems**, the heat transfer fluid is cold water, or hot in winter.

From the point of view of the installation, the condensates generation take place at many different points, which makes the piping network more expensive. If, in addition, there is no possibility of the condensate flow flowing by gravity and condensate pumps must be disponible, the installation becomes much more expensive from the point of view of investment and operating cost.

These systems only have air recirculation, so it is not renewed and eventually becomes contaminated.

Mixed air-water or water-air systems are a mixture of the previous two, and arise as a solution to the air quality problems presented by all-water systems.

If clean outside air is supplied, it must be previously conditioned. Hence the mixed systems arise.

The use of condensation water is greater than that obtained with an all-water system, due to the humidity contribution from the outside air flow.

From the installation point of view, there are several condensate collection points that make the piping system more expensive. Condensate circulation is produced by gravity, avoiding the cost of investment and operation of the condensate pump.

The last of the air conditioning systems is the refrigerant system, where the heat transfer fluid is a refrigerant.

From the generation condensation water point of view, in summer mode it is produced inside the building, while in winter mode it is produced outside.

This is a fairly popular system since it is used in numerous homes that have been equipped with air conditioning systems after their construction.

The system does not have air quality renewal, both in summer and winter. The necessary renewal of the air is by opening windows or by using aerators arranged for this purpose.

The humidity of the air inside the building, both in summer and in winter, is produced by its occupants plus the necessary outside air to maintain its quality levels.

Comparing the different systems analyzed, it can be established that the ones that provide the best use are the all-air systems with air treatment units.

4.4. Selection Criteria for Water Saving Systems

Rainwater harvesting systems use the rainwater that falls on the building roof or on the plot on which it is located, to be used in some sanitary devices of the building itself.

These rainwater harvesting systems are conceived to improve the building's consumption efficiency, so it should be more profitable to consume rainwater than drinking water from the general distribution network.

In general, and due to regulatory restrictions, rainwater can be used to supply water to toilets and for irrigation of gardens. In both cases, they are plumbing fixtures or demand points that only use cold water.

Compared to other water saving systems, these systems have very high return on investment periods.

For these and other reasons, it is necessary to optimize the design and dimensioning of the system, adjusting its investment cost as much as possible (López-Patiño, 2015).

Air conditioning systems that cool humid air generate condensation of some moisture contained. Generally, this by-product of the air conditioning process is disposed of through the building's wastewater and/or rainwater drainage network.

However, enough condensation water is generated to be used to partially supply toilets or for irrigation.

The production capacity depends on the flow of treated air, higher for air conditioning systems that work 100% with outside air than for systems with recirculation.

There are buildings in which the water savings obtained from the general dis-tribution network are greater than in others. These buildings are those that have a large volume of air conditioning, are located near the coast, have a relatively small occupation, and have centralized air conditioning equipment.

As G. López-Patiño indicates **to select the most suitable saving system** for a certain building, it is not enough to consider only the quantity of water saving (López-Patiño, 2015). It is necessary to consider the associated energy saving, the socio-environmental impact it produces, the design of the system, and the economic viability of its implementation.

The highest savings values are obtained with alternative source systems. Currently the legislation does not allow the use of reclaimed water for applications in buildings, but in the future, it will be possible to guarantee the suitability of reclaimed water and savings of 100% could be achieved.

With respect to energy saving, which is understood as energy saved as a result of saving water, a negative energy saving values would be produced when a water saving of 100%. This occurs because these types of systems are forced to pressurize the water to be distributed. Besides, domestic hot water must be heated anyway.

The environmental impact could be maximum, regardless of the savings achieved since the social environment of the building will always be positively influenced.

As for the design of the system, the same happens since the equipment functionality and handling can always be improved.

Finally, for the system to be feasible, the lifetime must be greater than the period of return on investment, which could not be achieved in some alternative source type water saving systems.

To conclude, it is necessary to weigh each selection criteria according to the characteristics of the target building, to finally decide which is the most suitable water saving system. For more information, to read Ghimire et al. (2019).

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5. BUILDING INFORMATION MODELLING (BIM) FOR SUSTAINABILITY

5.1. Potential of BIM Throughout the Life Cycle of a Sustainable Project

Building Information Modelling (BIM) is transforming the way building is delivered traditionally. The Construction industry is growing rapidly and the demand for sustainable facilities with the least impact on the environment is increasing. Sustainable development has been divided into water conservation, energy use reduction, sustainable procurement of materials, industrial development, recycling, waste reduction, climate change, transport strategies, and biodiversity (Khan & Ghadg, 2019).

Building Information Modeling is based on the idea of the continuous use of digital building models throughout the entire lifecycle of a built facility, starting from the early conceptual design and detailed design phases, to the construction phase, and the long phase of operation. BIM significantly improves information flow between stakeholders involved at all stages, resulting in an increase in efficiency by reducing the laborious and error-prone manual re-entering of information that dominates conventional paper-based workflows. Thanks to its many advantages, BIM is already practiced in many construction projects throughout the entire world (Borrmann et al., 2018).

One of the most important steps in the planning process is to clearly define the potential value of the BIM in the project and to the project team members by defining the overall goals for the implementation of the BIM. Objectives may be based on project results and include elements such as reducing schedule time, achieving higher performance, improving quality, reducing change costs, or obtaining critical operating data for the facility (Videika & Migilinskas, 2020).

The model-based approach increases efficiency within individual organizations and truly shines during coordinated project delivery. Building Information Modelling (BIM) offers the advantage of time and budget savings for building and infrastructure projects.

Here are the top 11 benefits of BIM by Autodesk (WEB-1):

1. Capture Reality: the wealth of information that's easily accessible about project sites has expanded greatly with better mapping tools and images of Earth. Today, a project starts including aerial imagery and digital elevation, along with laser

scans of existing infrastructure, accurately capturing reality and greatly streamlining project preparations. With BIM, designers benefit from all of that input compiled and shared in a model—in a way that paper isn't able to capture.

2. Waste Not, Want Not: With a shared model, there's less need for rework and duplication of drawings for the different requirements of building disciplines. The model contains more information than a drawing set, allowing each discipline to annotate and connect its intelligence to the project. BIM drawing tools have the advantage of being faster than 2D drawing tools, and each object is connected to a database. The database aids such steps as the number and size of windows for quantity take-offs that are updated automatically as the model evolves. The quick, computerized counting of components alone has been a significant labor and money saver.
3. Maintain Control: the digital-model-based workflow involves aids such as autosave and connections to project history so that users can be certain they've captured their time spent working on the model. The connection to the version history of the model's evolution can help you avoid disastrous disappearances or corruption of files that can make blood boil and impinge productivity.
4. Improve Collaboration: sharing and collaborating with models is easier than with drawing sets, as there are a lot of functions that are possible only through a digital workflow. Much of this added project-management functionality is now being delivered in the cloud, such as Autodesk's BIM 360 solutions. Here, there are tools for different disciplines to share their complex project models and coordinate integration with their peers. Review and mark-up steps ensure that everyone has had input on the evolution of the design and that they are all ready to execute when the concept is finalized and moves forward in construction.
5. Simulate and Visualize: another of the advantages of BIM is the increasing number of simulation tools that allow designers to visualize such things as the sunlight during different seasons or to quantify the calculation of building energy performance. The intelligence of the software to apply rules that are based on physics and best practices provides a complement for engineers and other project team members. The software can do much more of the analysis and modeling to achieve peak performance, condensing knowledge and rules into a service that can run with the click of a button.
6. Resolve Conflict: the BIM toolset helps automate clash detection of elements such as electrical conduits or ductwork that run into a beam. By modeling all of these things first, clashes are discovered early, and costly on-site clashes can be reduced. The model also ensures a perfect fit of elements that are manufactured off-site, allowing these components to be easily bolted into place rather than created on-site.
7. Sequence Your Steps: with a model and an accurate set of sub-models for each phase during construction, the next step is a coordinated sequencing of steps, materials, and crews for a more efficient construction process. Complete with animations, the model facilitates the coordination of steps and processes, delivering a predictable path to the expected outcome.

8. Dive into Detail: the model is a great endpoint for a lot of knowledge transfer, but there's also a need to share a traditional plan, section, and elevation, as well as other reports with your project team. Using automation and customization features, these added sheets can save valuable drafting time.
9. Present Perfectly: with all of the design completed on capture and alteration of existing reality, the model is the ultimate communication tool to convey the project scope, steps, and outcome. The fact that the design is fully 3D also means that there are fewer steps to render impressive views and fly-throughs that can be used to sell commercial space or to gain necessary regulatory approvals.
10. Take it with You: having a model that's tied to a database is an added benefit of BIM, granting you a great deal of intelligence at your fingertips. Combining this capability with a cloud, there are, means that you have access to the model and project details from anywhere, on any device.
11. Reduce Fragmentation. In the days before BIM, getting a truly global view of a project proved difficult—with thousands of unconnected documents in play, sometimes it took years for design teams to see the forest for the trees. By pulling all of a project's documents into a single view, BIM enables teams to collaborate and communicate more effectively.

A building information model can be used for the following purposes (Azhar, 2011):

- Visualization: 3D renderings can be easily generated in-house with little additional effort.
- Fabrication/shop drawings: it is easy to generate shop drawings for various building systems, for example, the sheet metal ductwork shop drawing can be quickly produced once the model is complete.
- Code reviews: fire departments and other officials may use these models for their review of building projects.
- Forensic analysis: a building information model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc.
- Facilities management: facilities management departments can use BIM for renovations, space planning, and maintenance operations.
- Cost estimating: BIM software(s) have built-in cost estimating features. Material quantities are automatically extracted and changed when any changes are made in the model.
- Construction sequencing: a building information model can be effectively used to create material ordering, fabrication, and delivery schedules for all building components.
- Conflict, interference, and collision detection: because BIM models are created, to scale, in 3D space, all major systems can be visually checked for interferences. This process can verify that piping does not intersect with steel beams, ducts, or walls.

Building information modeling facilitates collaboration throughout the entire life cycle of the project. BIM improves communication and information management due to a more efficient exchange and updates of project data. Project participants need to collaborate using BIM-based processes and procedures. However, all members have to put effort into collaboration while utilizing a BIM system from the initial stages. The collaboration of different stakeholders within the project is based on principles that include trust, transparency, efficient communication, open information sharing, risk-taking, equal reward, value-based decision making, and the use of all technological and support capabilities. Finally, BIM offers the potential to produce a high-quality and performing construction project, faster and cheaper, along with reducing errors and the waste of time and cost (Savari et al., 2020).

The sustainability implementations using BIM in the construction sector are creating a healthy built environment and satisfying social, environmental, and economic concerns in a balanced way. The three classical dimensions in which BIM is promoting sustainability are (Khan & Ghadg, 2019):

- **Social sustainability** – Creating healthy and livable communities by providing tools to improve building operations in aspects such as water conservation, energy use reduction, industrial development, recycling, climate change, and waste reduction.
- **Environmental sustainability** – targeted environmentally-conscious decisions throughout the life cycle. Energy consumption, waste management, carbon footprint, etc. – BIM enables users to minimize environmental impact.
- **Economic sustainability** – assuring financial feasibility, reducing waste, and increasing productivity. BIM helps accomplish economic benefits by clash detection at an early stage, better technical decisions, and precise cost forecasting throughout the life cycle of a project.

5.2. BIM in Supporting the Design, Construction, Operation, and Retrofitting Processes of a Sustainable Building

The choice of a building technique, components, and construction material is generally based on criteria such as functionality, technical performance, architectural esthetics, economic costs, durability, and maintenance. Nevertheless, this choice doesn't have to take into account the impact on the environment and human health. Building sustainably ensures that the social, economic, and environmental aspects were taken into account throughout a building's life cycle: from the extraction of raw materials to design, construction, use, maintenance, renovation, and demolition.

BIM technology can be integrated into every point of the project and at any stage of the life cycle (Fig. 5.1).

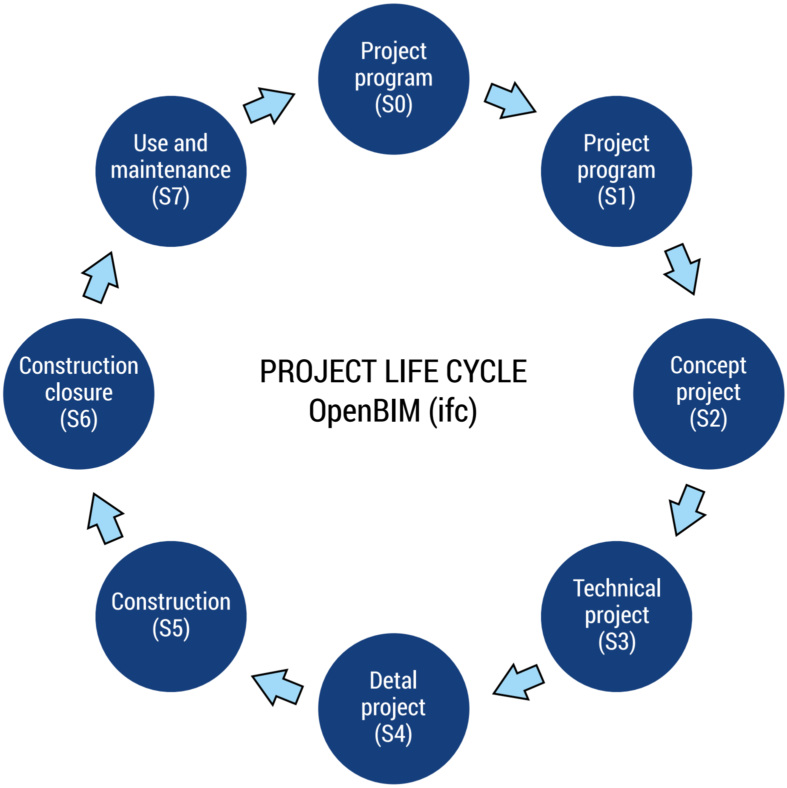

FIG. 5.1. Project life cycle (Source: own elaboration)

The use of BIM in projects also addresses the issue of sustainability.

The most important BIM use cases in the life cycle stages of a building are presented in Table 5.1.

TABLE 5.1. Fragment of stages and BIM Use Case structure (Source: own elaboration based on WEB-2)

BIM project development stages (RIBA approach)	**S0**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
	Feasibility Study	**Project program**	**Concept project**	**Technical project**	**Detail project**	**Construction**	**Construction closure**	**Use and maintenance**
Economic / quantity take-off and cost calculations	S0.1	S1.1	S2.1	S3.1	S4.1	S5.1	S6.1	S7.1
Development of current conditions model		S1.2	S2.2	S3.2	S4.2	S5.2	S6.2	S7.2

BIM project development stages (RIBA approach)	**S0**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
	Feasibility Study	**Project program**	**Concept project**	**Technical project**	**Detail project**	**Construction**	**Construction closure**	**Use and maintenance**
Land plot analysis		S1.4	S2.4	S3.4				
Functional, volumetric, and planning layouts development (S2)		S1.5	S2.5					
Design / Modeling (S3-S4)			S2.7	S3.7	S4.7			
Energy analysis			S2.9	S3.9	S4.9			
Sustainability Assessment			S2.10	S3.10	S4.10			
Structural analysis and design			S2.11	S3.11	S4.11			
Lighting Analysis			S2.12	S3.12	S4.12			
Analysis of engineering systems			S2.13	S3.13	S4.13			
3D coordination				S3.16	S4.16	S5.16		
Health and safety planning					S4.18	S5.18	S6.18	
Building Logistics Planning						S5.21	S6.21	
Technical supervision of construction works						S5.24	S6.24	
Fill-in model (as-built)						S5.25	S6.25	
Planning for building maintenance								S7.27
Analysis of structural (engineering) systems								S7.28
Energy Cost Analysis								S7.29
Asset Management								S7.30
Spatial management and monitoring								S7.31
Sustainability monitoring and analysis								S7.32
Accident Prevention								S7.33

BIM process allows multidisciplinary information to be superimposed with an integrated model, which makes environmental impact evaluation precise and efficient. In applying the BIM methodology, it is important to properly articulate the objectives, requirements, and scope of the building model. Documenting a set of standard procedures in a BIM Execution Plan (BEP) and setting out procedures for coordination in Employer's Information Requirements (EIR) as part of a project's contract documentation is crucial. So too are the BIM Execution Plans authorized by suppliers. During the design and construction process, design team interface managers should assess design decisions and clashes to see if they can resolve them internally, and where this cannot be done, separate models may be combined for review by a design lead (WEB-3).

In the Concept stage of the project (S2), comparable measures and comparable calculations of the cost of the building design must be developed and agreed upon based on which decision can be made regarding the future energy performance class and other important aspects of the building. Initial and intermediate project proposals should be agreed upon with the Customer. At least 2 solutions for the installation of the main structural structures and engineering systems of the assembled building and a comparison of their prices should be provided (WEB-3, 2021). At this stage it is possible to assess which degree and in which sense the type of land use is changed by the construction project. The area is not "consumed", but a usage change of the area takes place. The implementation of compensatory measures can be identified based on the available documents: it is checked if a green roof is planned and if it can be approved as a compensation measure. As well the type, extent, and direction of change of the actual use of the area are recorded and evaluated according to measuring specifications – change from the near-natural toward the built-up. One important design aspect is determined by the integration of technical structure, either outside or inside the building. The integration of the roof in the design of the building and its surroundings shall enhance the development of a three-dimensional urban surrounding. Utilization of this area can reduce CO_2 emissions and can improve the microclimate. Besides the designed integration of the technical structures, the roof can improve the general welfare with suitable areas. Such areas are green roofs, solar-active areas, socio-cultural utilizations such as roof terraces, and historical references to the direct surroundings such as the choice of material and color of the roofing in historical city centers.

In the Technical stage of the project (S3) stage, an intermediate comparison of the modeled main solutions (at least 2 variants) and prices of the modeled main building systems and elements must be envisaged. The variants of the final design solutions and their estimated cost must be agreed upon with the Customer before the completion of the detailing of the S3 stage of the project. The information for the calculations must be taken from the model and linked to the model using an information classification system. (WEB-3, 2021) One of the goals of sustainability at this stage can be to reduce the need for heating to condition the building areas while ensuring high thermal comfort and avoiding structural damage. The following aspects can be assessed of the building envelope in the building model: thermal transmittance coefficients of building components, thermal bridges, air permeability class (window air-tightness), amount of condensation inside the structure, and if necessary solar heat protection.

The BIM model aims to increase the ease of deconstruction, recycling, and dismantling – to avoid waste, in particular by reducing its quantity and hazardousness. Between 40% and 50% of waste in Europe can be assigned to the building sector. The amount of accumulated waste is to be reduced and is to be led into the recycling system. Due to the comparatively long expected useful lifetime, many of the materials that are used today will not accumulate as deconstruction material or potential waste until 50 or 100 years after construction. These materials can serve as important resources for future construction materials. The ability to recapture homogenous deconstruction materials and extract high-grade recycling materials is very important for the evaluation of ease of deconstruction and ease of recycling.

During the process of developing the model for current conditions, the model must include the adjacencies of the structure related to the project, including adjacent buildings, project area, and area for the transport system and engineering communications. It is also necessary to assess the direction, depth, purpose, material, and protection zones of the various other communications which cross the project area.

If the building is being renovated or repaired, a scan of the building should be provided as well.

A scan plan should be produced after the project objectives have been clarified. A scan plan is a set of information that outlines the scope and approach that will be taken to capture the data on-site. Often, a scan plan starts with a detailed analysis of precisely which elements need to be captured. When scanning a new work, most scanners will capture the position of each element that will be geo-referenced. In case of renovation work, scanners will often have the specific objective to gather more information. Identifying the exact scope of elements to be scanned helps the on-site team to prioritize their efforts and mitigate time spent capturing unnecessary elements (Gleason, 2013).

When the project team is preparing a building model for all parts of the project, all systems and elements must be modeled to a sufficient level of detail required to achieve the objectives and implement one or another application for the BIM, to prepare project documentation from the model and to link it to the model.

The project team develops BIM architectural (Fig. 5.2), structural (Fig. 5.3), or other parts of the model (as needed) that can be exported to open format and can be merged, reviewed, analyzed, and used for other BIM purposes.

The model must provide the necessary and harmonized amount of information that is gradually developed throughout the project.

Modeling of natural and artificial lighting is performed in the BIM model. At the same time, the influence of sun glare on workplace comfort must be assessed. Through early and integral daylight and artificial light planning, high quality of illumination can be created with low energy demands for illumination and cooling.

Furthermore, a high degree of daylight use can enhance workplace sustainability and compliance with health requirements and reduce operational costs. Lighting control integrated with daylighting is recognised as an important and useful strategy in energy-efficient building designs and operations. Proper daylighting schemes can help reduce the electrical demand and contribute to achieving environmentally sustainable building development.

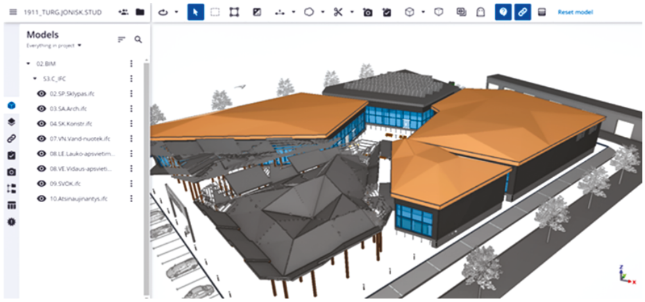

FIG. 5.2. Architectural model of the market building (Source: own elaboration)

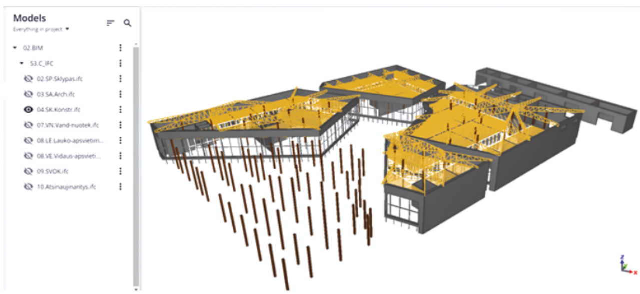

FIG. 5.3. Structural model of the market building (Source: own elaboration)

The visualization of the building helps to assess the integration of the building into the environment (Fig. 5.4) or to evaluate interior solutions (Fig. 5.5).

FIG. 5.4. Visualization of the market building (Source: own elaboration)

FIG. 5.5. Visualization of the market interior (Source: own elaboration)

Dynamic energy demand modeling must be performed when preparing the energy analysis of a building. A comparison of energy efficiency solutions, analysis, and presentation of cost-effectiveness options, and a report for choosing the right option must be provided.

The energy efficiency of buildings pursues as its ultimate goal – the saving of natural resources, the reduction of the carbon footprint, and, ultimately, the preservation of the global balance of our planet. The decisions to be taken in the construction process, such as business decisions, must also correspond to the criteria of business efficiency, i.e. reduction or, at least, compensation of costs. The BIM methodology offers us the tools so that these decisions can be made based on reliable data obtained instantaneously. The reduction of uncertainties is one of the greatest achievements of the BIM methodology. It allows the best possible decisions to be made at the most appropriate moments of the construction process.

Sustainable development is maintained throughout the whole life cycle of the building and should:

- Reduce consumption of resources (save water and energy);
- Reuse of resources during the refurbishment or disposal of existing buildings or use of recyclable resources of new buildings. The wrong environmental management of the site encourages the generation of waste that could have been avoided;
- Eliminate toxic materials and ensure the healthiness of buildings, applying nature protection (climate change mitigation, biodiversity, ecosystem services);
- Emphasize the quality of the buildings, maximizing the durability because generally, it is more sustainable to renovate existing buildings than to demolish and build new;
- Use eco-efficient materials (without processing) and local materials;
- Increase the comfort of life (increase the quality of outdoor areas and indoor air).

The planning and design of high-energy buildings require an efficient process of their assessment, which includes methods for modeling and optimizing building properties.

5.3. Data Required for Simulations of Sustainable Building

Digital models can be used to test combinations of solutions by testing their behavior over the years to select rational solutions.

Energy Models: These building information modeling models deal with all the big questions. The energy model will often be used during the earliest stages of the analysis. The energy model helps to interpret the basic information. Often, only basic geometry will be used to build the models. More realistic and defined specifications come with later energy models. The energy consumption of a building depends significantly on the architectural, structural, and engineering solutions.

Lighting Models: These are all about the presentation because the lighting model handles the visual aspect. They tend to contain many more details than energy models. Geometry and the use of this model will define the properties of the materials. This is the model that helps to figure out exactly what is needed, as well as how everything should fit together. Generally, the finished lighting model is similar to the one that will be presented to clients.

When imported into the energy simulation tool, the model would assume the default values for the location given when creating the digital model. In order to discern that the information related to the selected material used in the model has been completely transmitted over to the energy simulation and analysis tools, new material could be assigned to the 3D model of the building (Fig. 5.6).

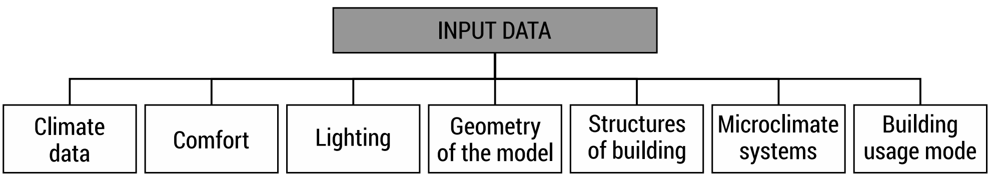

FIG. 5.6. Input data for sustainable building simulations (Source: own elaboration)

Application of building information model during the stages of building development, design, and construction, facilitates transfer of all the information about the building from the architectural models to the building modeling tools, which allow the designer to:

- evaluate alternative solutions,
- make a rational decision according to the chosen functions of the goal,
- reduce the likelihood of ineffective solutions,
- implement the requirements for high-energy efficiency buildings.

The newest feature of building information model is the ability to calculate light levels in space from the sunlight and skylight on a given day and time, e.g. The All-Weather Sky method uses historical weather data to better approximate the sky conditions for the selected day and time.

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6. MANAGEMENT OF POOL RESOURCES AND ENERGY CONSUMPTION IN BUILDIGNS

6.1. Pool Resources

The integration of energy resources in buildings must be analysed from two points of view or perspectives. Firstly, the quantification of needs and the dynamics of these needs must be known, making it possible to establish orders of magnitude, as well as types of technologies for the extraction, storage, and use of energy resources.

Secondly, the availability and viability of each energy resource must be analysed in terms of economic, logistical, or strategic parameters.

6.1.1. New Technologies and Real Integration

There is currently a great diversity of energy generation and accumulation systems aimed at the construction, comfort, and habitability of buildings. New applications and systems that take advantage of different available resources (sun, wind, biomass, hydrogen, geothermal energy, heat transfer, changes of state, etc.) are frequently appearing. A detailed study of their characteristics is the first step towards a correct choice of resources and their appropriate application to the needs of each building. In addition to the technical point of view, the economic viability and availability of resources is not a minor problem and must be carefully considered to avoid problems of unavailability or cost over the useful life of the installations (Fischer, 2016). This availability must include the different energy storage systems that will reduce the energy dependence of each building with the dynamics of markets and availability of resources.

6.1.2. Improved Energy Availability

The transport structures of the different energy resources (oil, gas, electricity, coal) have always been dependent on exoenergy factors that are more related to political structures, strategies, and market interests than to energy viability or optimization. The increase in the use of different renewable resources on a small scale has made it possible to go beyond the limits of the large resource distributors, establishing alternative energy supply procedures with less dependence on exoenergy factors. The cost of these installations, their suitability in each case, obsolescence, technological maturity, and state aid programmes for their implementation are parameters that ultimately determine the success or failure of different energy generation and use systems. It is essential at this point to remember that there is no standard solution in the field of buildings, as criteria of load, location, receivers, availability, time flexibility, building typology, state of conservation, etc. must be considered.

6.2. Load Curves

The first step in any energy analysis to define resources and strategies is to obtain load curves. This concept integrates all the energy demand data of a building, considering both the inputs dedicated to direct consumption and those dedicated to storage for later use. Electricity, Natural Gas, Coal, Water, Steam, Communications, as well as intermediate process elements (Hydrogen, refrigerant gas, thermal solids, etc.) (Ahmad, 2014). To these demand curves must be added the generation curves, both from direct usable energy generation systems and from systems that increase the stored energy resource.

6.2.1. Load Curve Model as Function of Location, Size or Other Requirements

The shape of the load curve depends mainly on whether it is a residential, commercial, industrial load, the day of the week, the season (winter, summer) and climatic factors (mainly temperature).

Analysing the different types of curves for different conditions provides crucial information on the overall load curve of any building over a recurring period of study. This recurrent period usually has a resolution of 8760 values, corresponding to each hour of the study year (Liao, 2015).

Figure 6.1 shows the evolution of the load curve of a mixed-use building (residential and commercial) over a typical day for different weather periods.

To analyse the load curves over a long period, two types of curves are used: the hourly annual demand curve and the ordered annual demand curve (Fig. 6.2). The first is the representation of numerical values at each hour of the year for each of the generators and receivers of the installation or building under analysis. The ordered annual curve is constructed from the sum, for each level of demanded power, of the number of hours in which this power has been equalled or exceeded throughout the year. The area under the annual ordered curve corresponds to the energy demanded.

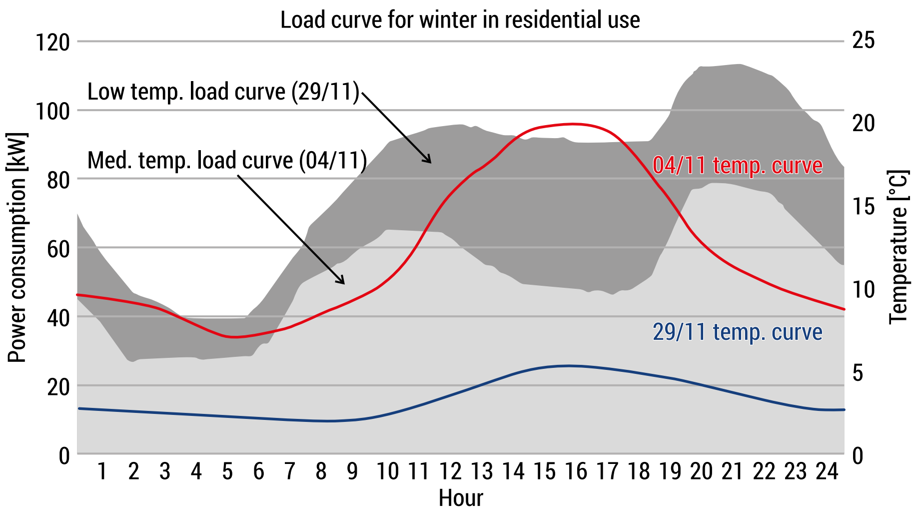


FIG. 6.1. Winter type day load curve (Source: own elaboration)

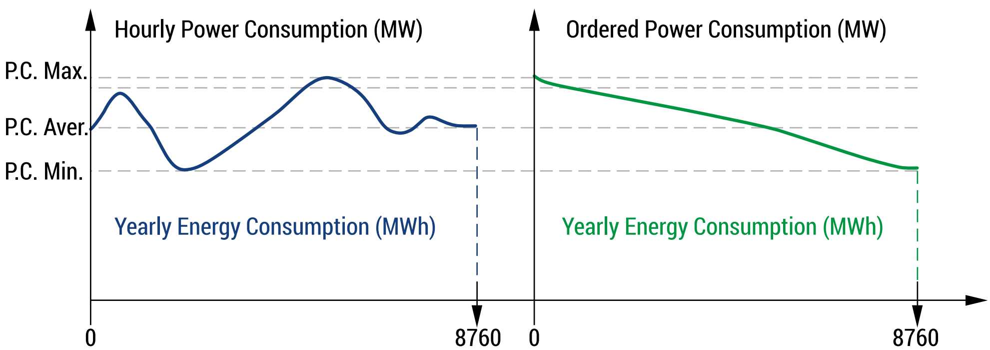


FIG. 6.2. Hourly and orderly load curve (Source: own elaboration)

The following parameters define the characteristics related to energy demand and generation during the period considered.

Yearly energy consumption: energy demanded by the load in the period of one-year Y_{ec} [MWh] is equivalent to the area under the hourly load curve or orderly load curve.

Average Yearly Consumption Power: PC_{aver} [MWh]

$$PC_{aver} = \frac{Y_{ec}}{8760} \tag{6.1}$$

Maximum consumed power: PC_{max} [MWh] is the peak demand that is reached in the period of the year under analysis.

Minimum consumed power: PC_{min} [MWh] is the value of the lowest demand reached in the year under analysis.

Load Factor: *LF*, It is the ratio between the energy demanded, Y_{ec}, and the energy that the load would demand in the considered period *T*, if it were connected to a maximum regime PC_{max}:

$$LF = \frac{Y_{ec}}{PC_{mzx}T} = \frac{PC_{aver}}{PC_{max}} \tag{6.2}$$

6.2.2. Flexible Patterns and Immovable Patterns

In the electricity sector, there are different types of activities, from which the consumption problem can be approached in different ways.

Initially, the main pattern prediction alternatives can be classified into two categories: top-down and bottom-up. This classification arises from the hierarchical position of the information used in relation to the residential sector. Top-down methods use macroeconomic parameters (Gross Domestic Product, Unemployment rate, Population statistics in analysis and projections of their evolution, Growth rates of the availability of electrical receivers, Climatic conditions, Construction, and demolition rates of buildings) to disaggregate the aggregate demand of a building and produce simplified curves of equipment consumption. The evolution of the demands can then be determined by projections. It does not allow the technological evolution of loads connected to the electricity grid to be assessed.

On the other hand, bottom-up methods are based on building-specific information (Area of the rooms, technical properties of equipment and receivers, Individual consumption of some electrical devices. Load usage schedules, Climate characteristics, Internal temperatures, User behaviour) as well as the corresponding usage characteristics of the receivers or loads and extrapolate the information to more general (aggregated) scenarios. These bottom-up methods generate a high level of detail, allow finding specific areas for improvement, consider the effect of customer behaviour and accurately quantify the evolution of demand, allowing to simulate the impact of the discontinuation of some technologies. Bottom-up statistical methods use historical billing information from energy distribution companies together with socio-economic information on buildings to define equipment end-use curves. These methods employ regression techniques and neural networks that correlate electricity consumption with building characteristics. In addition, several regressions can be performed and variables that do not have a significant impact on the final characterization can be progressively eliminated, so that simplified models are obtained.

Within these statistical methods, Conditional Demand Analysis (CDA) is based on the presence of electrical loads or devices in buildings. In this way, a mathematical regression is used to start from the aggregate curve and correlate it with the use of all the indicated receivers. These methods correlate the presence of various electrical devices and their characteristics with other characteristics, such as building areas, demographic factors, number of people, price of electricity, among others.

The classification of top-down and bottom-up methods is shown in Figure 6.3.

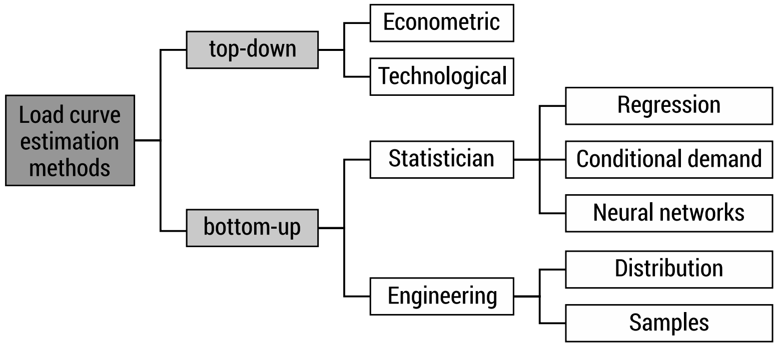


FIG. 6.3. Classification of top-down and bottom-up methods (Source: Altrabalsi, 2014)

Bottom-up engineering methods perform the characterization of end-use curves without using historical consumption information. They rely on the classifications and characteristics of end-use consumptions for modelling. This methodology calculates each end-use energy consumption as a function of the ownership of electrical devices, their use, their classification, and their efficiency. The inputs to this group of methods correspond to data sampled from buildings. The data can be extrapolated if the sampling is representative. For these methods, Smart Metering has made great progress towards effective recognition of electricity consumption patterns and correct forecasting of electricity consumption. It is also of great importance to complement the consumption data obtained from smart meters with external data such as weather conditions or temperature (Kim, 2011). Up to 80% of electricity consumption in buildings can be explained by analysing these variables together.

To correlate the aggregated curve with each end-use, the curve must be disaggregated. The disaggregation of a curve corresponds to separating it into the electricity consumption of each of the electrical devices used in the building under analysis, as shown in Figure 6.4.

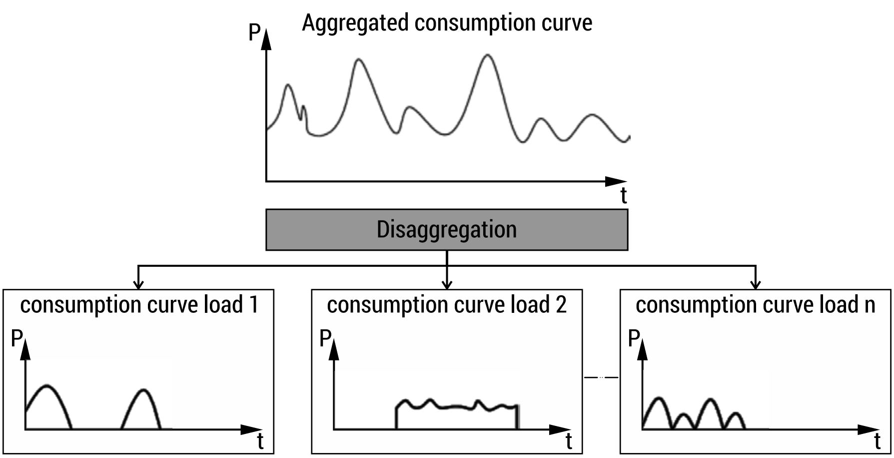


FIG. 6.4. Disaggregation of electricity consumption curves (Source: own elaboration)

The result of the pattern analysis should show a curve as in Figure 6.5 for each variable building scenario (seasonal, weekly, hourly).

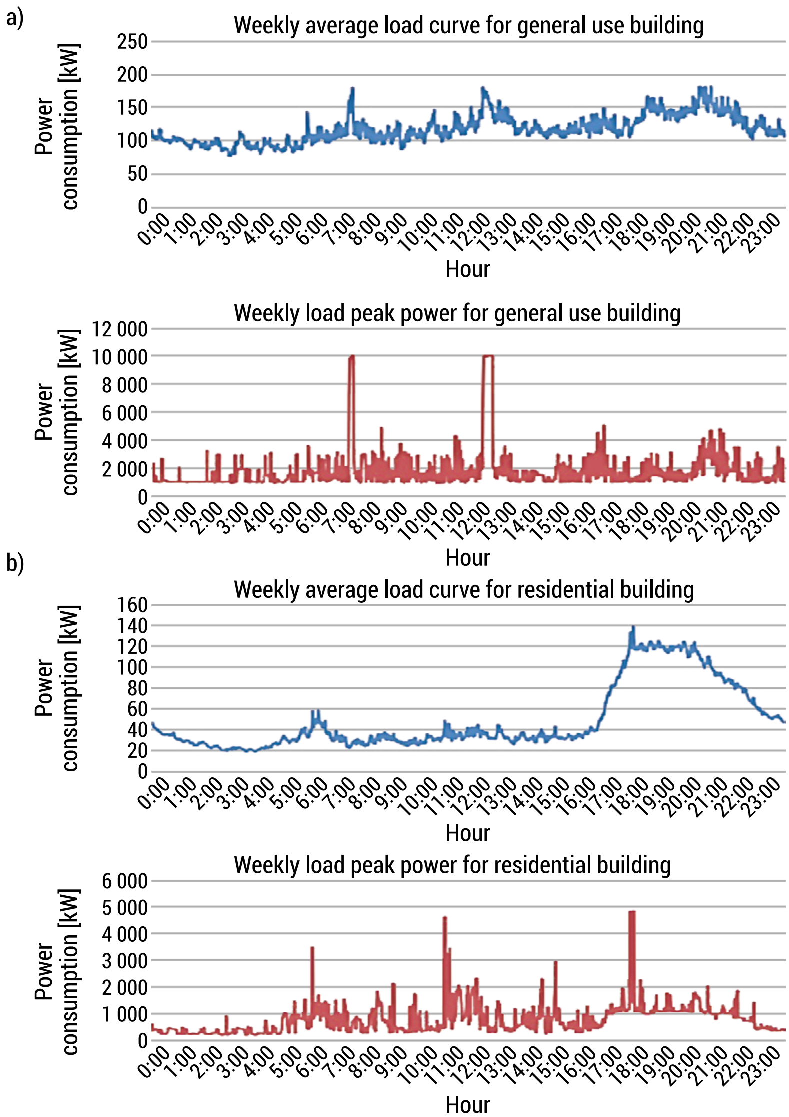


FIG. 6.5. Load Curve and Peak Power for General use buildigs (a) and residential buldings (b) (Source: own elaboration)

This curve, consisting of disaggregated loads shown as a whole, allows easy identification of variable consumption patterns (dependent on the use of the building according to its occupants) and fixed consumption patterns, independent of the flow of users, and responsible for the residual consumption of the building on a continuous basis (Fig. 6.6).

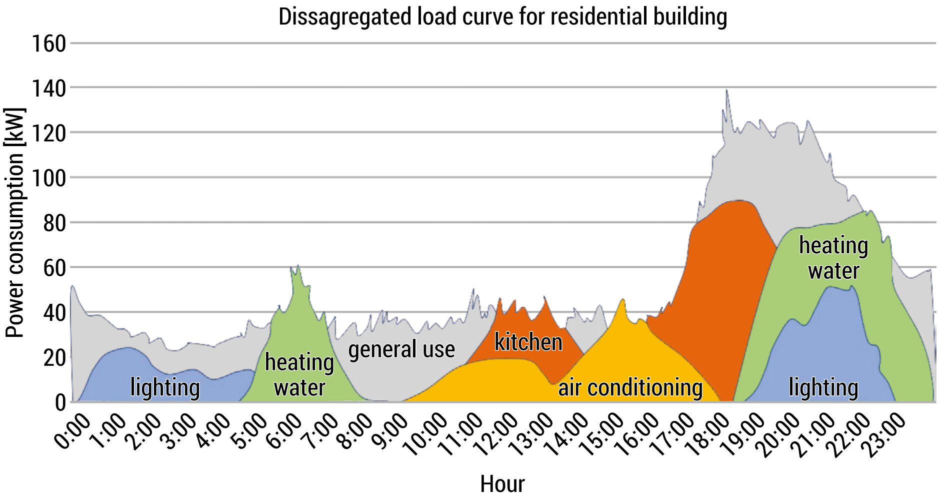


FIG. 6.6. Disaggregated Load Curve for residential buildings (Source: own elaboration)

6.3. Management of Energy Consumption

The load pattern curves analysed in the previous section provide exhaustive information on the periods and destination of the energy consumption of each building throughout the different scenarios that it usually faces. A first analysis of these consumption patterns makes it possible to identify periods of residual consumption (the reduction of which will considerably affect energy savings and efficiency as they are present during most of the time the building is in use). This analysis also makes it possible to identify the periods of maximum consumption to distribute their loads to other periods and stabilise these maximums by means of deferred consumption.

6.3.1. Management of Energy Consumption Using Storing and Self-Consumption With Integration of Renewable Energy

Self-consumption is the consumption by one or several consumers of electrical energy from production facilities close to the consumption facilities and associated with them.

Storing solar electric energy obtained from photovoltaic solar panels (or other renewable and clean energy systems) is the greatest contribution that has been developed to encourage and make solar self-consumption in homes a reality (Nasir, 2019).

This means that any building can be energy self-sufficient without the need for a third party. It also saves a great deal of energy and money. In addition, it is a positive contribution to the environment, as it does not use traditional energy sources (Merino, 2020).

The most used battery storage technology for stationary applications is lithium iron phosphate (LiFeP). The efficiency of a battery is between 80% and 90%. They are found in medium to high consumption solar installations. They can be used in household appliances with higher power, such as ovens and washing machines. Stationary batteries have a useful life of approximately 20 years, have longer charge and discharge cycles, but obviously have a higher economic cost.

Currently, the prices of the energy consumed depend on the contracted tariff and vary from one hour to another. In low energy price scenarios (less than €60/MWh and the difference between the cheapest and most expensive tariffs, corresponding to day and night respectively, close to €40/MWh), the difference between the cheapest and most expensive hours is not large enough to compensate for the cost of purchasing batteries, the current cost of which for stationary systems is around €50-60/MWh.

To assess the economic sense of installing batteries for the purpose proposed and estimate the payback period, it is necessary to analyse these three concepts:

1. The difference in price paid for each MWh consumed, between the most expensive and the cheapest time of the day.
2. The energy consumed.
3. The cost of the batteries.

This price difference between the most expensive and the cheapest time of the day is determined by the contracted tariff.

The next aspect to assess is the energy consumed. We consider the extreme hypothesis that we can buy all the energy we consume at the cheapest time, accumulate it, and consume it from batteries at the most expensive time. This consideration will give us the maximum savings that can be achieved through deferred consumption, which sets the maximums for investment costs.

The third element of the equation – the cost of the batteries – at current domestic battery prices and typical building consumption volumes, the payback may be longer than the lifetime of the battery itself (9-10 years). Furthermore, it should be borne in mind that it is not only the batteries that need to be invested in, but also the installation, the space they occupy and the safety measures.

If the battery is combined with a solar photovoltaic system (Fig. 6.7), the number of years in which the investment is amortised can be reduced to 4 or 5 years. If the PV system is not considered, the payback period is easily extended to nine years as the profit income is significantly lower.

Storage therefore contributes to improving the efficiency of the electricity system. With the entry of storage, we will be able to flatten demand curves, avoiding the peaks that occur at certain times of the day (Fig. 6.8). This will lead to a more efficient use of system resources. In the same way, storage will allow us at certain times of the day to avoid the spillage that would occur in scenarios of high penetration of solar photovoltaic or wind technology, so that the contribution of solar or wind production could be shifted to other times of the day.

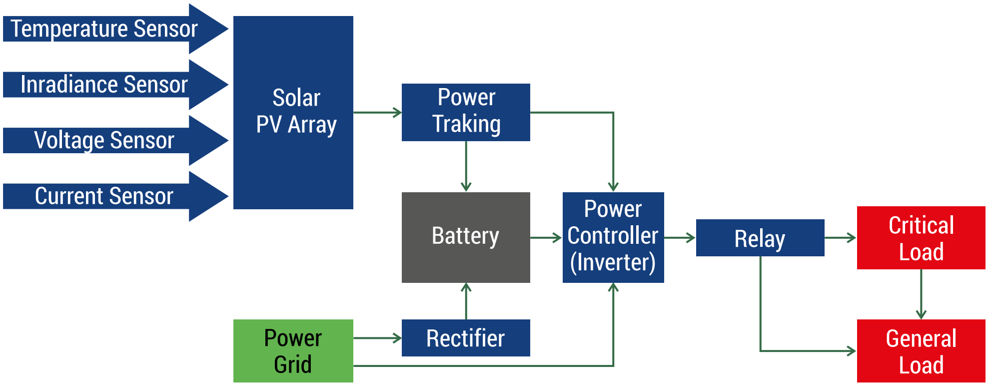
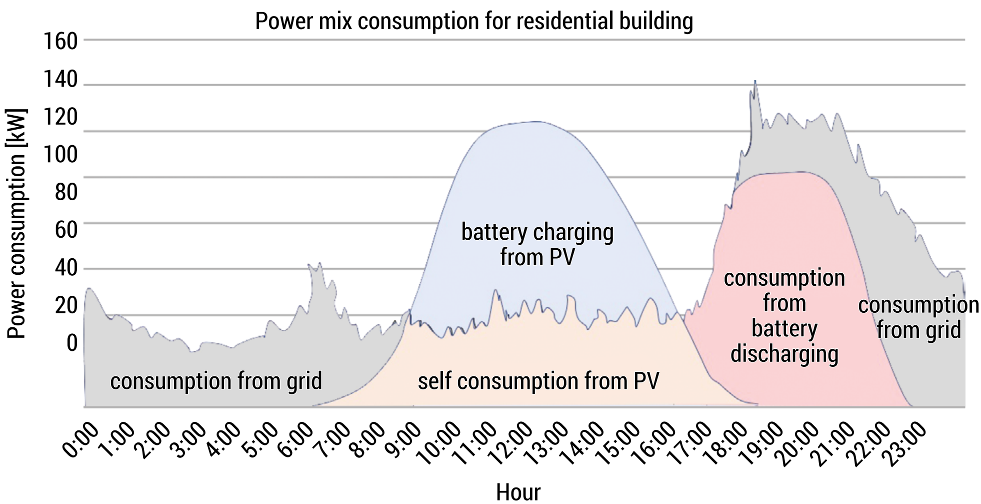


FIG. 6.7. Self-Consumption with storage general scheme (Source: own elaboration)



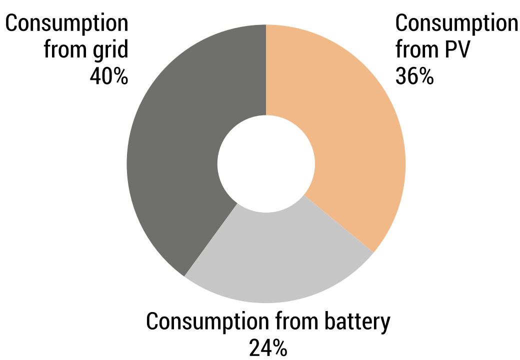


FIG. 6.8. Mix Power consumption (Source: own elaboration)

Only in users with a high peak contracted power and low consumption in terms of energy could the energy storage solution with batteries without self-consumption be of interest.

In conclusion, self-consumption systems using renewable resources without storage require lower initial investments but require longer payback periods.

The inclusion of storage systems increases the initial investment in exchange for reducing the payback period by increasing the efficiency of the self-consumption system, adapting the energy availability to the load curves of the building.

6.4. Optimization of the Energy Consumption

6.4.1. Optimization of the Energy Consumption as Function of the Prize Acquisition

The analysis of consumption patterns, introduction of alternative generation sources and improvement of consumption parameters can be complemented by improving energy procurement by adapting its dynamics to the lowest energy cost periods according to the results of the different markets.

Firstly, load curves should be analysed to identify power peaks and try to reduce the number and frequency of these peaks, reducing the fixed energy cost parameters related to this power availability, which in specific periods may exceed the limits of each contract.

This power reduction involves improving the efficiency of the energy consuming systems (loads) not only in their operation in permanent regime, but also in the previous transient regimes, which appear in the start-up processes or change of load regime. This improvement can be achieved by means of intelligent load regulation and current and power controllers that allow reaching a full load regime through paths of lower power demand in the transient phases.

Consumption habits are a complementary option, whose advantages are the low economic cost and the improvement in self-consumption and energy storage processes, but which, in exchange, are difficult to implement and, above all, to maintain over time. Therefore, efficiency cannot be based on this type of measures as the main point of the energy strategy.

6.4.2. European Regulation, Modalities, Contracts, and Markets

The market structures in each country within the European Union are classified into systems based on fixed or regulated prices, indexed systems or systems based on wholesale markets, two-way market systems and futures market systems. Each country offers, depending on its energy structure, different energy prices and distribution of final energy prices, depending on the final price on the wholesale market, the costs of the transmission networks and the corresponding taxes, as shown in Figure 6.9.

Depending on the power required, the volume of energy consumed and the voltage of the installation, each building may require a different type of energy contract.

Thus, a building with variable consumption and unstable or unpredictable patterns must adapt its consumption to fixed or regulated electricity tariffs, which allow, in any case, to avoid electricity price rises in periods of higher consumption. This damping of price peaks is penalised by a higher average price than would be obtained with other types of more dynamic contracts.

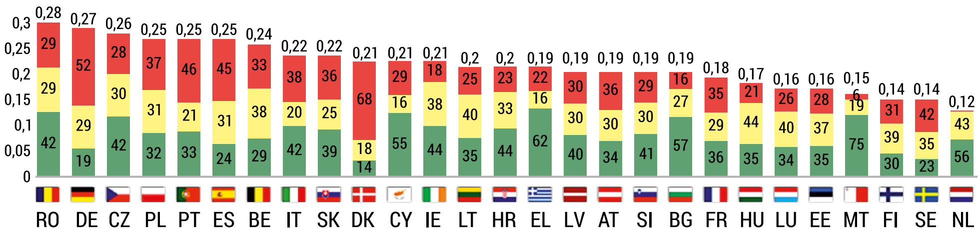


FIG. 6.9. European electricity market prices (Source: WEB-1)

For systems where the volume of energy consumed is considerable, and consumption patterns are known, wholesale electricity markets as well as futures markets offer various options to purchase electricity on an INDEXED basis either at auction results of energy sales in wholesale markets or energy packages in futures markets, which require a commitment to consumption at a pre-agreed date and time. Results are shown in Figure 6.10.

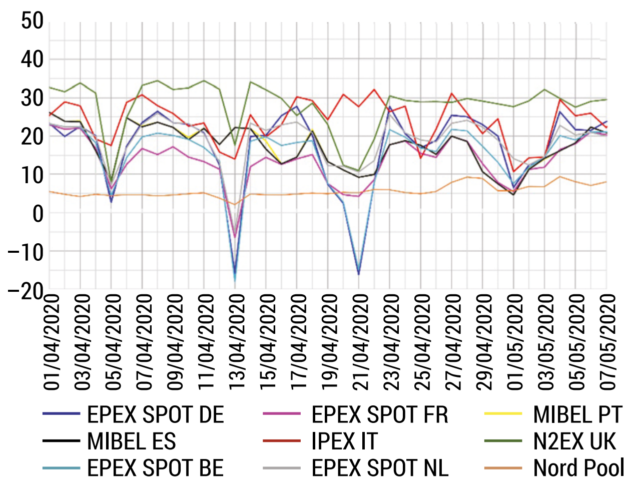


FIG. 6.10. European electricity wholesale market prices (Source: WEB-2)

These variable tariff systems offer considerable savings on bills, although they do not cushion price rises in the electricity market due to contingencies, volatility, or unforeseen causes.

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7. ENERGY-SAVING TECHNIQUES OF HEAT TRANSPORT

7.1. Introduction

Energy-efficient heat transport significantly affects the entire heating system consisting of a heat source, heating network or installation, and heat receivers. In the Directive of the European Parliament and of the Council (EU) of December 11, 2018, heat transfer is mentioned as one of the main elements of the energy chain [WEB-1]: "*Improving energy efficiency throughout the full energy chain, including energy generation, transmission, distribution and end-use, will benefit the environment, improve air quality and public health, reduce greenhouse gas emissions, improve energy security by reducing dependence on energy imports from outside the Union, cut energy costs for households and companies, help alleviate energy poverty, and lead to increased competitiveness, more jobs and increased economic activity throughout the economy, thus improving citizens' quality of life*." In the case of renewable heat sources such as heat pumps or solar collectors, particular attention should be paid to the quality of thermal insulation of pipes, because heat losses from heat transfer can significantly reduce the efficiency of the entire heating system. Research on thermal insulation in heating pipes is described in many publications and most often concerns single pipes (Zhao and Shan, 2019; Danielewicz et al., 2016; Oclon et al., 2019; Babiarz and Zięba, 2012; Bøhm and Kristjansson, 2005) and twin pipes (Oclon et al., 2019; Babiarz and Zięba, 2012; Bøhm and Kristjansson, 2005; Van der Heijde et al., 2017; Khosravi and Arabkoohsar, 2019; Krawczyk and Teleszewski, 2019a). The literature also includes non-standard solutions for multi-pipe thermal insulation and modified insulation shapes for double pipes (Kristjansson and Bøhm, 2006a; Teleszewski and Zukowski, 2019; Krawczyk and Teleszewski, 2019b). The most commonly used materials for thermal insulation of heating pipes are polyurethane foam, polyethylene foam, expanded polypropylene, synthetic rubber and mineral wool. Basic data on materials for thermal insulation of heating cables can be found in the specifications of thermal insulation manufacturers, in reports and publications (Jarfelt and Ramnas, 2006; WEB-2; WEB-3; WEB-4; Bouix et al., 2009; Gally-er, 2001).

7.2. Basic Types of Thermal Insulation Materials Used for Heat Transport

For thermal insulation of heating pipes, porous plastics, polyurethane foam, polyethylene foam, synthetic rubber, expanded polypropylene and fibrous materials (mineral or glass wool) are most often used. Thermal insulation materials can be in the form of pipe laggings (round or eccentric), mats, plates or molds specially made for thermal insulation, fittings (e.g. elbows, tees) or automatic control fittings (e.g. valves, pressure regulators). Coatings are often additionally protected against damage with claddings made of aluminum foil or PVC, which at the same time constitute a barrier for water vapor that can penetrate through the thermal insulation.

Polyurethane foam (Jarfelt and Ramnas, 2006; WEB-2) retains good thermal insulation properties at a temperature of -50°C to +135°C, but is not very resistant to UV radiation. Additionally, polyurethane foam is quite stiff and can absorb moisture, which limits its scope of application. It is produced in soft, hard and super-hard varieties. Very brittle, soft polyurethane foam is used to manufacture fittings for the insulation of domestic hot water pipes and heating installations (Fig. 7.1a-b). Hard polyurethane foam is for producing, among others, thermal insulation for water heaters and heat storage tanks (Fig. 7.1f). Polyurethane foam is often used in pre-insulated ducts (Fig. 7.1c-e).

Thermal insulation made of polyethylene foam (WEB-3) is distinguished by a very high water vapor diffusion coefficient, which makes it almost non-absorbent. In addition, it is resilient and flexible, so it can be freely bent without fear of damage. It can be used to make very thin covers (about 5 mm thick), perfect for thermal insulation of installations led in wall grooves and the floor. Polyethylene foam, intended mainly for heating and sanitary technology, maintains good insulation properties at temperatures from –50°C to +110°C, both in dry and humid environments. However, it may shrink under the influence of high temperature. Polyethylene foam lagging is intended primarily to insulate central heating installations (Fig. 7.2a) and cold and hot utility water (Fig. 7.2b). It is also used in refrigeration.

Thermal insulation in the form of a very flexible foam based on synthetic rubber (elastomer) (WEB-4), resistant to UV radiation and diffusion of water vapor, is mainly used to insulate refrigeration and air-conditioning installations (Fig. 7.3a). Due to its resistance to large temperature fluctuations and changing weather conditions, synthetic rubber is also a good thermal insulation for solar installations (Fig. 7.3b). The temperature range for using synthetic rubber in sanitary technology is from –50°C to + 110°C.

FIG. 7.1. Examples of thermal insulation made of foamed polyurethane: a), b) foamed polyurethane in a PVC housing, c), d), e) polyurethane foam with a casing pipe made of polyethylene of high density (PEHD), f) foamed polyurethane on the heat storage tank (Source: photo by T. Teleszewski)

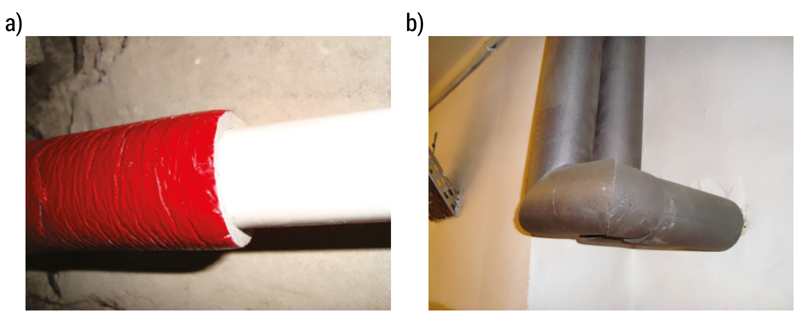

FIG. 7.2. Examples of thermal insulation made of foamed polyethylene: a) polyethylene foamed with an outer coating of polyethylene film, b) foamed polyethylene without an outer coating (Source: photo by T. Teleszewski)

a) b)

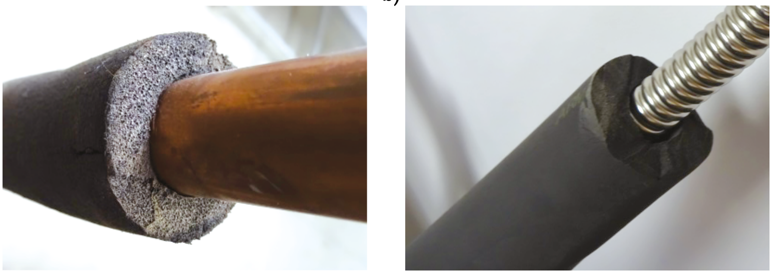

FIG. 7.3. Examples of synthetic rubber thermal insulation: a) synthetic rubber on the heat pump's copper pipe, b) synthetic rubber on corrugated stainless-steel solar collector pipe (Source: photo by T. Teleszewski)

Expanded Polypropylene (EPP) (Bouix et al., 2009) is a foam material that is characterized by high energy absorption, impact resistance, low thermal conductivity, low water absorption, resistance to water and chemicals, and a relatively high strength-to-weight ratio (Bouix et al., 2009). In the heating industry, expanded polypropylene is most often used in the form of housings for circulation pumps and fittings (Fig. 7.4a-b).

a) b)

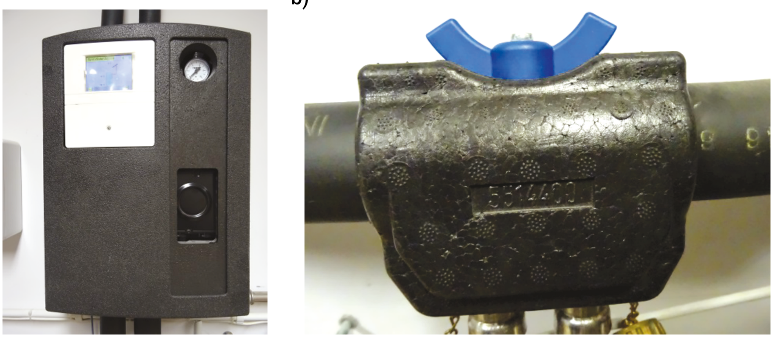

FIG. 7.4. Examples of thermal insulation made of expanded polypropylene (EPP): a) EPP foam casing of the thermal solar pump station, b) expanded polypropylene EPP insulation for the valve of the solar installation (Source: photo by T. Teleszewski)

Mineral and glass wool (Gallyer, 2001) are resistant to high temperatures, up to approx. 1000°C and approx. 700°C, respectively. It should be noted here that the above data applies to the fibers themselves. The binder that connects them to the fibers (both types of wool) can withstand temperatures up to 250°C. The more binder in the wool, the less the wool is resistant to high temperatures. Mineral and glass wool does not absorb moisture, does not shrink under the influence of temperature changes and is very flexible. The loose structure of mineral and glass wool means that it has ~~a~~ low diffusion resistance, i.e. it is vapor-permeable. In the sanitary industry, mineral and glass wool is used for thermal insulation of heat pipes (Fig. 7.5a-d) and ventilation ducts (Fig. 7.5e-f).

a) b) c) d) e) f)

FIG. 7.5. Examples of thermal insulation made of mineral wool: a), b) fireproof thermal insulation of heating pipes made of mineral wool concentric pipes, protected by an outer coating of reinforced aluminum with high resistance to water vapour, c), d) mineral wool in a steel casing, e), f) mineral wool on the ventilation ducts (Source: photo by T. Teleszewski)

7.2.1. Major Errors in Installing Thermal Insulation

The main errors in installing thermal insulation are most often associated with inaccurate assembly. The results of inaccurate assembly are linear and point thermal bridges. Linear thermal bridges (Fig. 7.6a-b) appear usually because of insufficient tightening of the edges of the thermal insulation before it is glued with the assembly tape (Fig. 7.7). Point bridges most often arise as a result of inaccurate installation of thermal insulation at points where the geometry of the conduit changes, i.e. elbows, reductions, extensions, tees and fittings. Figures 7.8a-b show an inaccurate connection of thermal insulation in the elbow of the heating system. Another reason for the formation of thermal bridges is the lack of thermal insulation in the places where the pipelines pass through the walls (Fig. 7.9a-b).

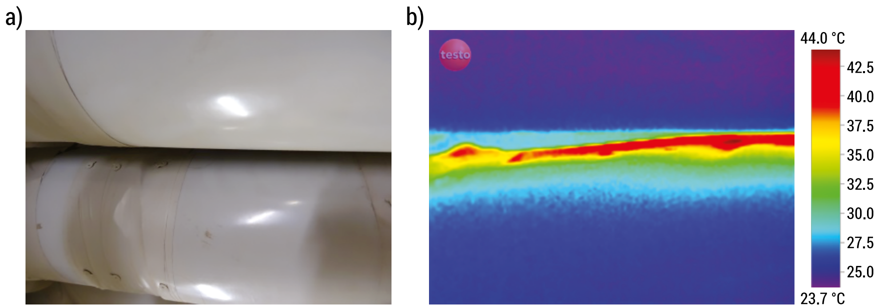

FIG. 7.6. Linear thermal bridge due to inaccurate tightening of the assembly edges: a) view of the heating system pipe, b) thermogram (Source: photo by T. Teleszewski)

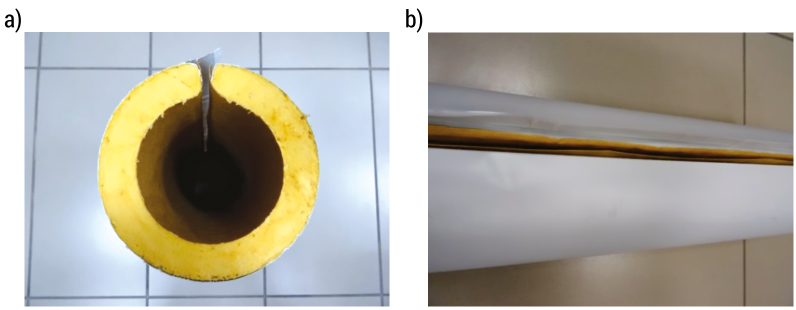

FIG. 7.7. General view of the mounting edge of the thermal insulation (Source: photo by T. Teleszewski)

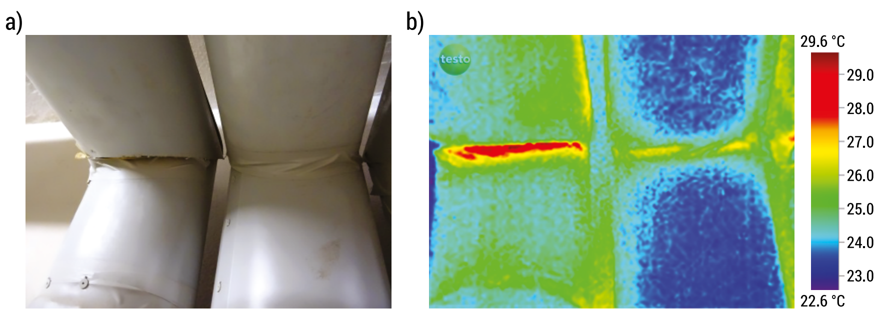

FIG. 7.8. Point thermal bridge on the elbow: a) view of the heating system, b) thermogram (Source: photo by T. Teleszewski)

Significant errors in the installation of thermal insulation are those related to the failure the lack of protection of thermal insulation against biological factors. Figures 7.10a-b show, respectively, examples of damage by birds to the thermal insulation of the solar installation and the heat pump installation on the roof of a building. Figure 7.10c shows the destruction of the thermal insulation of the heating system by rodents.

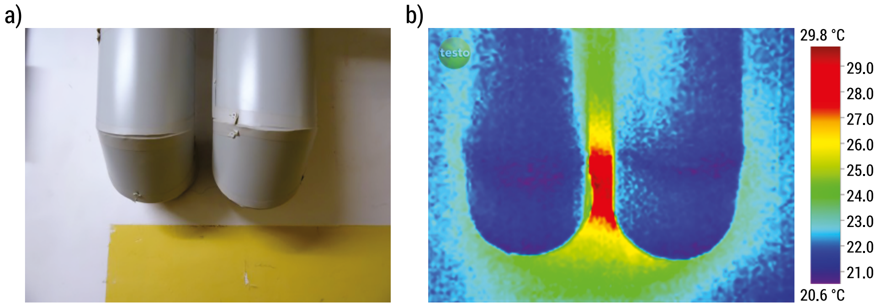

FIG. 7.9. Thermal bridge due to lack of thermal insulation at the point where the pipe passes through the wall: a) view of the heating installation pipe, b) thermogram (Source: photo by T. Teleszewski)

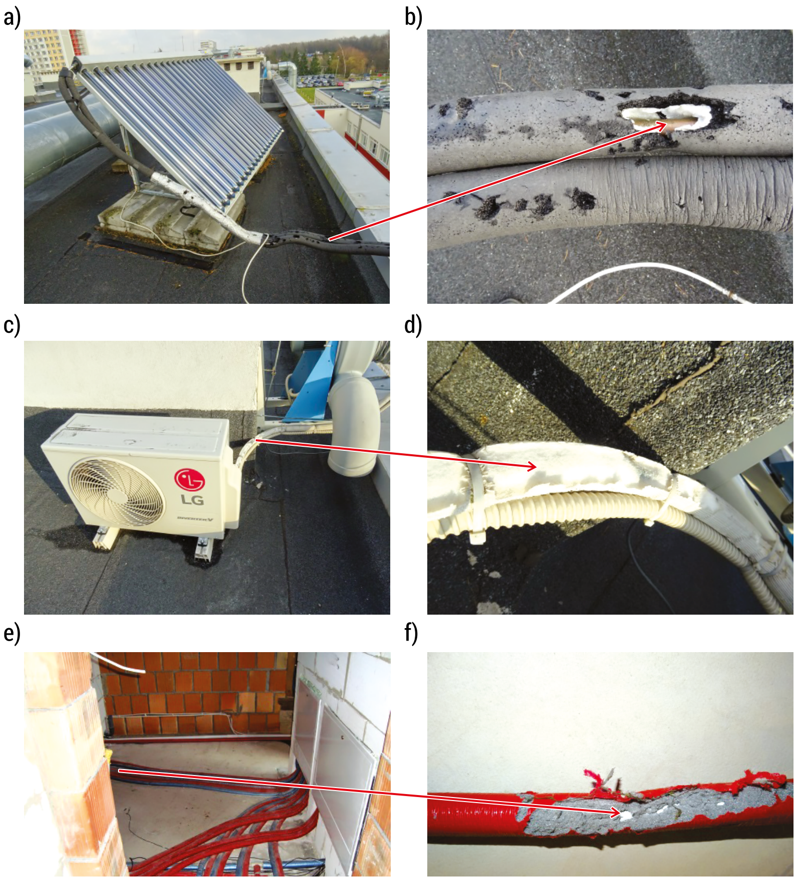

FIG. 7.10. Damage to the thermal insulation to biological factors: a) damage to the thermal insulation of the solar installation caused by birds on the roof of the building, b) damage to the thermal insulation of the heat pump installation on the roof of the building, c) damage to the thermal insulation of the heating system caused by rodents inside the building (Source: photo by T. Teleszewski)

7.3. Ways to Improve the Quality of Thermal Insulation

There are many methods to improve the quality of thermal insulation. The easiest way to reduce heat loss is to use a thermal insulation material with a lower thermal conductivity coefficient or to increase the thickness of the thermal insulation around the heating pipes. The use of materials with a lower thermal conductivity coefficient is usually associated with a higher financial cost of thermal insulation. Heating pipes with increased thermal insulation thickness are usually called "Plus" (Oclon et al., 2019) and are also more expensive than standard thermal insulation. Reduction of heat losses in double ducts can also be achieved by changing the geometry of the thermal insulation shape and by using multi-pipe thermal insulation, which will be discussed in the following sub-sections.

7.3.1. Improving the Quality of Thermal Insulation by Changing the Geometry of Its Shape

Currently, in the transport of heat through pipes, in addition to single pre-insulated pipes, double pre-insulated pipes (so-called twin pipes) are used (Kristjansson and Bøhm, 2006b; Babiarz and Zięba, 2012; Krawczyk and Teleszewski, 2018). Heat losses in double pre-insulated ducts are about 40% (Krawczyk and Teleszewski, 2019b; Kristjansson and Bøhm, 2006b; Babiarz and Zięba, 2012) lower compared to single pre-insulated ducts. In single pre-insulated pipes, round thermal insulations are used, which are characterized by a constant thickness of thermal insulation around the heating pipe, as a result of which these insulations are distinguished by the same heat loss along the insulation perimeter.

In twin pipes, the thickness of the thermal insulation is not the same around the heating pipes (Fig. 7.11a), so the heat flux density is not uniform in the thermal insulation circuit. This situation leads to the formation of areas in the cross-section of the thermal insulation that are not fully used, and there are places where the thermal insulation is too thin (Krawczyk and Teleszewski, 2019b). On the left and right side of the heat pipes placed in the thermal insulation, the heat flux densities are minimal (Krawczyk and Teleszewski, 2019b), while the maximum values are located above the return pipe and under the supply pipe, which is related to the different thickness of the insulation around the supply and return pipes.

Reduction of heat losses in double pre-insulated ducts can be achieved by appropriate modification of the cross-sectional shape of the thermal insulation. The first way to reduce the heat loss of the twin pipe is to change the cross-sectional shape of the thermal insulation so as to obtain a relatively uniform thickness around the supply and return pipes. The second way is to add an additional layer of thermal insulation around the supply pipe in which the heating medium has a higher temperature than the return pipe, thus generating greater heat losses.

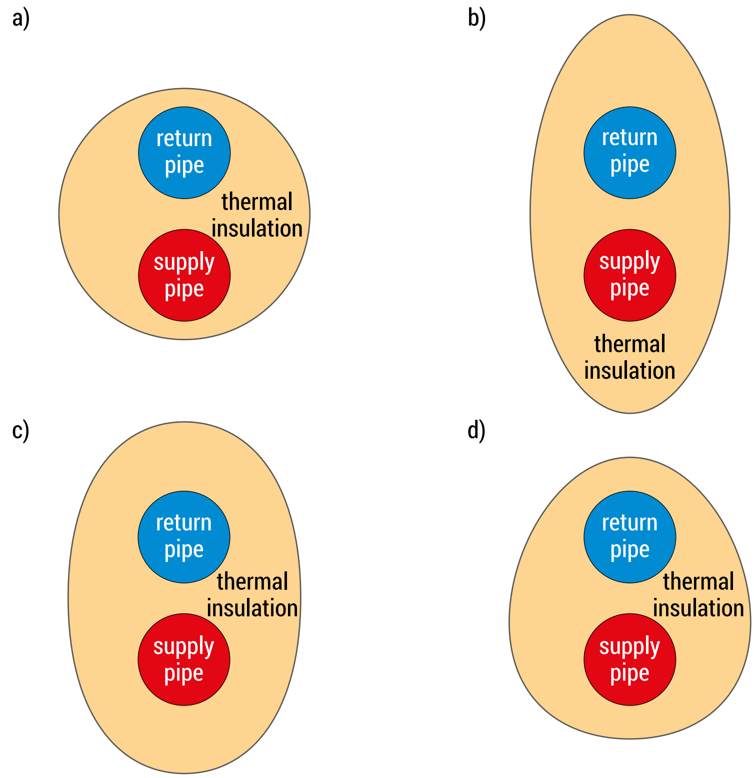

FIG. 7.11. Double pre-insulated pipes: a) standard twin pipe, b) double pipe with elliptical thermal insulation, c) double pipe with oval thermal insulation, d) double pipe with egg thermal insulation (Source: own elaboration)

The implementation of the first method of changing the shape of thermal insulation was described in the works (Krawczyk and Teleszewski, 2019a, Teleszewski and Żukowski, 2019), in which it was proposed to use thermal insulation with an elliptical cross-section shape (Krawczyk and Teleszewski, 2019a) (Fig. 7.11b) or a Cassini oval (Teleszewski and Żukowski, 2019) (Fig. 7.11c), however, in order to implement the second method, the egg shape described in (Krawczyk and Teleszewski, 2019b) (Fig. 7.11d) was adopted. The elliptical, oval and egg shapes of the thermal insulation cross-sections have been selected so that the areas of these shapes are equal to the cross-sectional area of the twin pipe thermal insulation. The use of the elliptical shape and the Cassini oval in the thermal insulation of double pre-insulated pipes increases the thermal insulation field under the supply pipe and above the return pipe, i.e. in those places where the heat flux density is the highest in the standard twin pipe thermal insulation (Krawczyk and Teleszewski, 2019b) as a result of which it is possible to obtain a more homogeneous distribution of the heat flux density and temperature inside the thermal insulation and the heat flux density on the shore. In the case of a double pipe with egg thermal insulation, the supply pipe is surrounded by thicker insulation than the return pipe, which allows to reduce the temperature gradients under the supply pipe and to obtain a relatively homogeneous heat flux density distribution inside the thermal insulation and on the outer edge of the thermal insulation (Krawczyk and Teleszewski, 2019b). The heat losses of a double insulated duct with an elliptical, oval and egg-shaped cross-section of thermal insulation are respectively about 10% (Krawczyk and Teleszewski, 2019a), 11% (Teleszewski and Żukowski, 2019) and 15.5% (Krawczyk and Teleszewski, 2019b) lower than in a twin pipe with round thermal insulation. In the literature (Kristjansson and Bøhm, 2006b), a double pre-insulated duct with egg cross-section was compared with a standard double pre-insulated duct, where the percentage reduction of heat loss when using a duct with egg thermal insulation was about 7.4%.

7.3.2. Improving the Quality of Thermal Insulation by Using Multi-Pipe Thermal Insulation

The significant reduction of heat losses in twin pipes compared to single pre--insulated pipes clearly indicates the great possibility of locating many pipes in a common thermal insulation. The literature (Kristjansson and Bøhm, 2006b) presents the possibilities of using triple pre-insulated pipes, where two supply lines and one return line in a common circular thermal insulation have been adopted. The idea behind the operation of such a triple pipe is that, at the moment of maximum heat demand, the third supply pipe is also put into operation.

Typical double pre-insulated pipes (twin pipes) are characterized by an unused area on the left and right sides of the supply and return pipes, where the heat flux density is small compared to the area under the supply pipe and above the return pipe (Fig. 7.11a). The area with a low value of the heat flux density can be used to place additional heating or domestic hot water pipes with smaller diameters. In the work (Teleszewski et al., 2019), on the basis of the existing heating pipe and domestic hot water pipe, a possible use of a pre-insulated quadruple pipe is presented. It shows a single pre-insulated network consisting of four pipes: a supply and return heating pipes and a domestic hot water pipe with hot water circulation pipe. The hot water and hot water circulation pipes are placed on the left and right side of the twin-pipe. The distances between the pipes are the same as in the standard twin-pipe system. The introduction of additional pipes for thermal insulation of twin pipes allowed to reduce the surface area of thermal insulation in the cross-section by about 21.4% in relation to the existing single heating, domestic hot water and hot water circulation pipes, and by 40.2% in relation to two twin pipes adopted as an alternative solution to single pipes (Teleszewski et al., 2019). The results of heat loss calculations show that the proposed solution of the quadruple ducts allows to reduce heat losses by about 57.1% in relation to the existing heating pipes and hot utility water pipes, and by 12.6% in relation to the two double pre-insulated pipes assumed in the work (Teleszewski et al., 2019).

The work (Teleszewski et al., 2020) proposes a solution of a triple pre-insulated pipe as an alternative to two single heating pipes and one hot water process pipe in meat processing plants in Białystok. In the case of a triple pre-insulated pipe, unit heat losses turned out to be 42% lower compared to single pipes and 24% lower with regard to one twin pipe for heating purposes and one single pre-insulated pipe for hot process water.

7.4. Numerical Methods for Optimization of Thermal Insulation

The basic calculation models used in simulations of heat loss determination can be divided according to the number of dimensions:

- one-dimensional (1D) models are most often used for simple comparative analyzes of single and twin-pipe heating networks. The formulas of one-dimensional methods are most often found in design standards and are used to determine heat losses in single and double ducts. Here it should be emphasized that there are no known 1D solutions for pipes composed of more than two heating pipes. Examples of heat loss calculation results comparing single and twin pipes can be found in the following publications (Oclon et al., 2019; Nowak-Oclon and Oclon, 2020; Sun et al., 2019);
- two-dimensional (2D) models can be used to design new shapes of multi-tube thermal insulation and to compare different solutions of multi-tube insulation with the same boundary conditions, assuming a constant cross-sectional shape of the thermal insulation along the axis of the pipe. Examples of heat loss results determined by two-dimensional models are presented in the following works (Oclon et al., 2019; Zhao and Shan, 2019);
- the three-dimensional (3D) model is most often used in the case of complex boundary conditions or complicated shapes of thermal insulation – the shapes that change along the length of the heat pipe. Examples of simulations using three-dimensional model are presented in the publication (Danielewicz et al., 2016).

One-dimensional models are usually determined using analytical formulas, while 2D models – using numerical methods such as the finite difference method, the finite volume method, the finite element method or the boundary element method, which were used in this publication. In the next section, an example of the boundary element method for determining heat losses will be presented.

7.4.1. The Boundary Element Method

The temperature field in planar steady heat conduction in the cross-section of thermal insulation is described by the Laplace equation for the temperature T (Brebbia et al., 1984):

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \tag{7.1}$$

The components of the heat flux q_x and q_y are defined according to Fourier's law (Brebbia et al., 1984):

$$q_x = -\lambda \frac{\partial T}{\partial x} \tag{7.2}$$

$$q_y = -\lambda \frac{\partial T}{\partial y} \tag{7.3}$$

The boundary problem for the Laplace equation (1) is formulated in the form of the adopted Dirichlet and Neumann boundary condition assuming known temperature values $\tilde{T}(\mathbf{q})$ on the part of the shore L_q ($\mathbf{q} \in L_q$) and known values of the heat flux on the part of the boundary L_T ($q \in L_T$) (Fig. 7.12) (Brebbia et al., 1984):

$$\begin{gathered} -\chi(\mathbf{p})T(\mathbf{p}) + \int_{(L_q)} q(\mathbf{q})K(\mathbf{p},\mathbf{q})dL_q + \int_{(L_T)} T(\mathbf{q})E(\mathbf{p},\mathbf{q})dL_T = \\ = -\int_{(L_T)} \tilde{q}(\mathbf{q})K(\mathbf{p},\mathbf{q})dL_T - \int_{(L_q)} \tilde{T}(\mathbf{q})E(\mathbf{p},\mathbf{q})dL_q \\ \mathbf{p},\mathbf{q} \in L \end{gathered} \tag{7.4}$$

where for a smooth boundary $\chi(\mathbf{p})$ =1/2 and:

$$K(\mathbf{p},\mathbf{q}) = \frac{1}{2\pi\lambda} \ln\left(\frac{1}{r_{\mathbf{pq}}}\right) \tag{7.5}$$

$$\begin{gathered} E(\mathbf{p},\mathbf{q}) = \frac{1}{2\pi} \frac{(x_{\mathbf{p}} - x_{\mathbf{q}})n_x + (y_{\mathbf{p}} - y_{\mathbf{q}})n_y}{r_{\mathbf{pq}}^2} \\ r_{\mathbf{pq}} = \sqrt{(x_{\mathbf{p}} - x_{\mathbf{q}})^2 + (y_{\mathbf{p}} - y_{\mathbf{q}})^2} \end{gathered} \tag{7.6}$$

After determining the unknowns: T(**p**) on the boundary of L_T and q(**p**) on the boundary of L_q, the temperature at any point (**p** ∈ A) of the area (A) is determined from the integral relation:

$$\begin{gathered} T(\mathbf{p}) = \int_{(L)} T(\mathbf{q})E(\mathbf{p},\mathbf{q})\,dL + \int_{(L)} q(\mathbf{q})K(\mathbf{p},\mathbf{q})\,dL \\ (\mathbf{q}) \in (L)\,,\,(\mathbf{p}) \in (\mathrm{A}) \end{gathered} \tag{7.7}$$

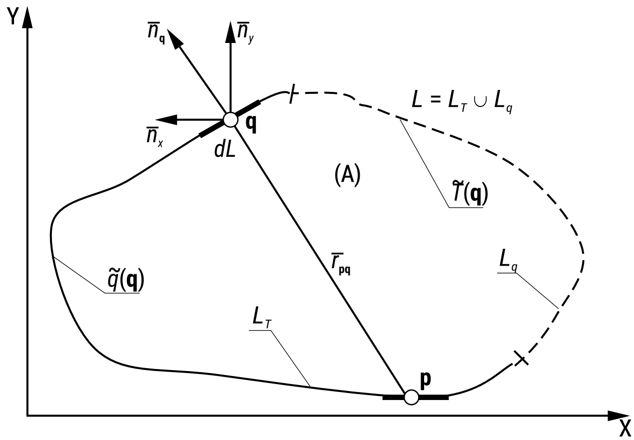

FIG. 7.12. Sketch illustrating two-dimensional boundary problems (Source: own elaboration)

7.4.2. An Example of the Development of Multi-Pipe Thermal Insulation

An example of thermal insulation modification was made on the basis of the existing heating installation located in unheated rooms in the building of the Faculty of Civil Engineering and Environmental Sciences of the Białystok University of Technology. The installation consists of three individual supply pipes with a flow temperature of 70°C and three return pipes with a return temperature of 50°C. The installation length is 40 m. Polyurethane foam with a thermal conductivity coefficient of 0.0265 W/m/K is used as thermal insulation material in the heating pipes. A general view of the pipes located above the ceiling in unheated rooms is shown in Figure 7.13. The steel diameter of the heating pipes is 48.3 mm, while the outer diameter of the thermal insulation is 110 mm. The total cross-sectional area of thermal insulation of the three supply pipes and the three return pipes is 0.04603 m^2.

FIG. 7.13. View of six individual heating pipes in the analyzed example (Source: photo by T. Teleszewski)

Heat losses in single pipes were determined from the known theoretical equation:

$$q = \frac{(T_i - T_{amb})\pi}{\left(\frac{1}{2k}\ln\left(\frac{D_i}{d_i}\right) + \frac{1}{hD_i}\right)} \tag{7.8}$$

where T is the temperature of the heating medium, T_{amb} is the ambient temperature, D is the diameter of the thermal insulation, d is the diameter of the steel wire, k is the thermal conductivity coefficient of thermal insulation, and h = 25 $W/m^2/K$ is the heat transfer coefficient.

The unit heat losses of six individual heating pipes as a function of temperature are shown in Figure 7.14 (the blue dashed line). To determine the heat losses (Fig. 7.15), the range of external temperatures from 0°C to 20°C was assumed.

In order to reduce heat losses, it was proposed to place six heating pipes in a common parallelogram-shaped thermal insulation (Fig. 7.15) with dimensions H = 147.45 mm and L = 237.72 mm , made of the same material as single pipes. The distance between the conductors and the external wall was assumed to be equal to the thickness of a single insulation z = 20 mm (Fig. 7.15). The surface area of the parallelogram-shaped multi-pipe insulation is approximately 28% smaller compared to the thermal insulation area of six single pipes.

For numerical calculations, the boundary of 2600 fixed elements was used. The results of heat losses in common thermal insulation with a parallelogram shape are shown in Figure 7.14 (the solid purple line). Average heat losses in the case of collective thermal insulation turned out to be about 46% lower than in the case of six individual thermal insulations.

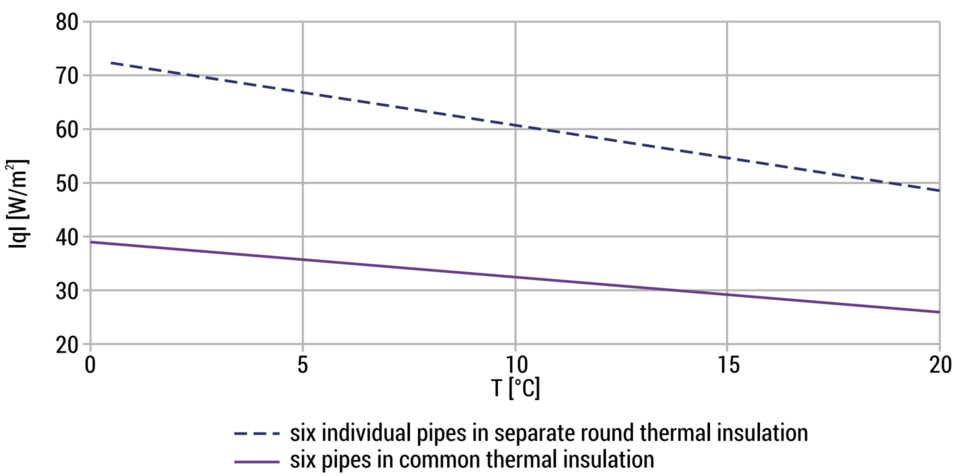

FIG. 7.14. Comparison of the unit heat losses in six individual heating pipes and in a common thermal insulation (Source: own elaboration)

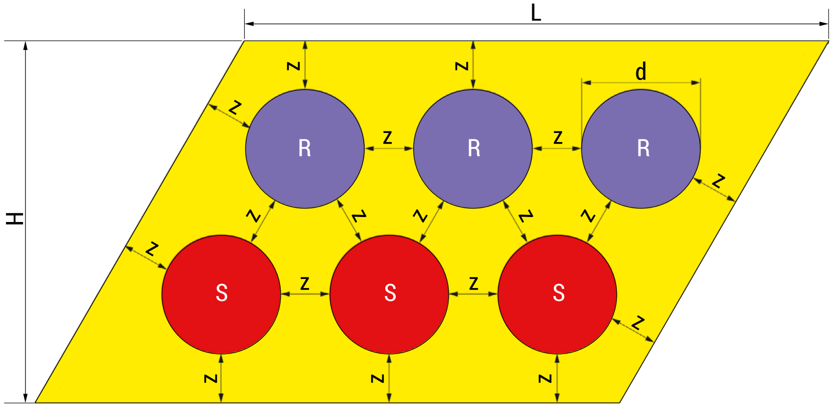

FIG. 7.15. Scheme of common thermal insulation in the form of a parallelogram for six heat pipes (Source: own elaboration)

Figure 7.16 shows an example of the temperature field and heat flow lines for an outdoor temperature of 4°C. In Figure 7.16, one can see unused thermal insulation fields at the sharp corners of the parallelogram, which can also be removed to further reduce the thermal insulation field and thus save some of the thermal insulation material.

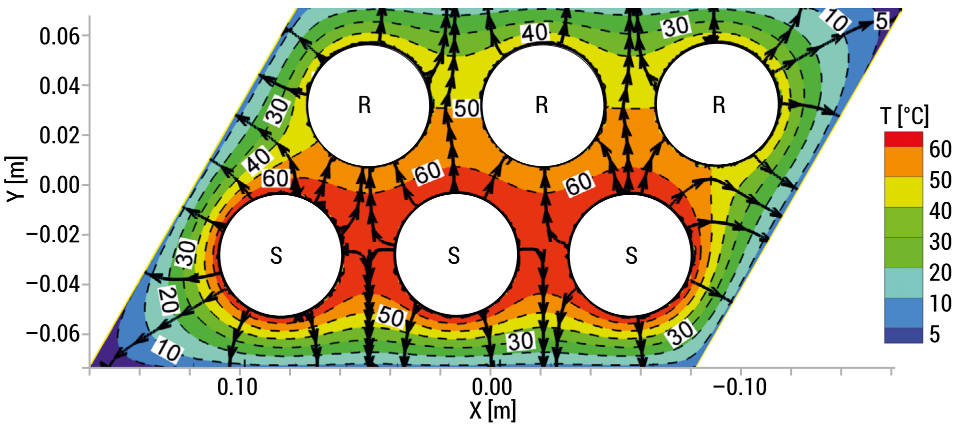

FIG. 7.16. Temperature field and heat flow lines in parallelogram-shaped thermal insulation (Source: own elaboration)

Acknowledgments

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8. IOT TECHNOLOGY IN MODERN BUILDINGS

8.1. Introduction to IoT

8.1.1. History of IoT

The Internet of Things consists of any device with an on/off switch that is connected to the Internet. The Internet of Things (IoT) involves machines communicating information over the internet, and has not been around for very long.

The term "Internet of Things" seems to owe its appearance to Kevin Ashton, who in 1997, working for Proctor and Gamble, for supply chain management has applied radio frequency identification (RFID) technology (Rayes & Salam, 2019). Thanks to this work, in 1999 he was invited to the Massachusetts Institute of Technology, where he and a group of like-minded people organized the research consortium Auto-ID Center. Mr. Ashton stated: „Today computers, and, therefore, the Internet, are almost wholly dependent on human beings for information. Nearly all of the roughly 50 petabytes of data available on the Internet were first captured and created by human beings by typing, pressing a record button, taking a digital picture or scanning a barcode. The problem is, people have limited time, attention, and accuracy. All of which means they are not very good at capturing data about things in the real world. If we had computers that knew everything there was to know about things, using data they gathered without any help from us, we would be able to track and count everything and greatly reduce waste, loss, and cost. We would know when things needed replacing, repairing, or recalling and whether they were fresh, or past their best."

Since then, the Internet of Things has made the transition from simple RFID tags to an ecosystem and an industry, including smart buildings, medicine, energetics, agriculture, transportation and many more (Fig. 8.1).

The Internet of Things will take over virtually every segment in industry, business, healthcare, and consumer products. It is important to understand the implications and why these very different industries will be forced to change their approach to producing goods and providing services. The number of connected IoT devices is growing almost exponentially over the recent years (Fig. 8.2).

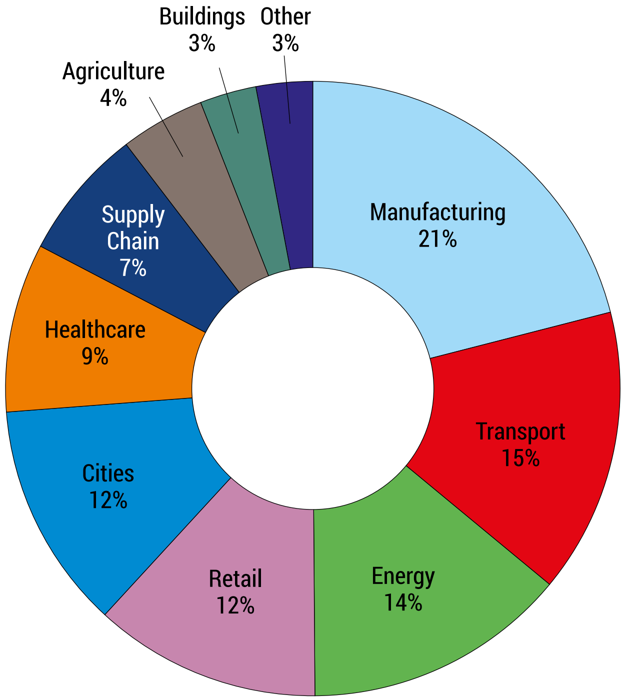


FIG. 8.1. IoT application areas in 2020 (Source: own elaboration based on WEB-1)

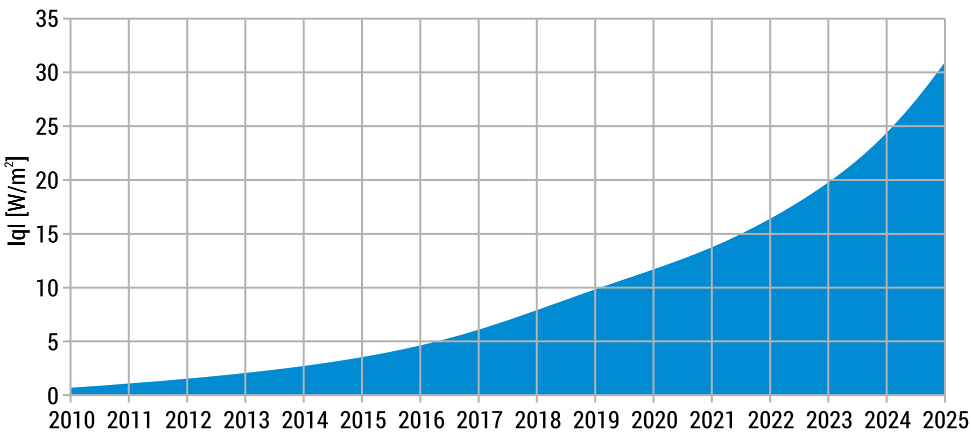


FIG. 8.2. Total number of IoT device connections (Nov 2020 with future estimates, Source: own elaboration based on WEB-2)

Consumer devices were one of the first categories of items connected to the internet. The consumer Internet of Things began with an internet-connected coffee maker at a university in the 1990s. It flourished with the spread of Bluetooth technology in the early 2000s. Now millions of homes are equipped with Nest thermostats, Hue light bulbs, Alexa virtual voice assistant and Roku TV boxes. In addition, people use Fitbit bracelets and other portable devices. The consumer market is usually the first to adopt all new technologies. We can also consider these devices as gadgets. They all come neatly packaged and wrapped, and basically all of them are plug and play. Here are some examples of smart devices for the home: irrigation system, garage doors, locks, lights, thermostats, and security system.

8.1.2. The Structure of IoT

The IoT system starts with the simplest sensors located in the most remote corners of the world and transforms the analog physical exposure to digital signals. The data then travels through wired and wireless signals, various protocols, through natural interference and the imposition of electromagnetic fields, because of which they enter the Internet. From there, data packets are transmitted through various channels to the cloud or to a large data center. The strength of the Internet of Things is that it is not just a single signal from one sensor, but the sum of all signals from hundreds, thousands, perhaps millions of sensors, points, and devices.

These areas are actively using the multitude of devices, software and services offered by the Internet of things. Almost every large technology company invests or has invested in the Internet of things. New markets and technologies have already emerged (and some of them have failed or been resold).

The IoT consists of (Fig. 8.3):

- **sensors**: embedded systems, real-time operating systems, uninterruptible power supplies, microelectromechanical systems (MEMS);
- **communication systems between sensors**: the coverage area of wireless personal networks is from 0 cm to 100 m. For data exchange between sensors, low-speed low-power information channels are used, which are often not based on the IP protocol;
- **local area networks**: usually these are IP-based communication systems, for example, 802.11 Wi-Fi network for fast radio communication, often these are peer-to-peer or star networks;
- **aggregators, routers, gateways**: embedded system vendors, lowest cost components (processors, DRAM, and storage), module vendors, passive component vendors, thin client vendors, cellular and wireless radio vendors, middleware vendors, fog infrastructure developers computing, edge analytics tools, edge device security, certificate management systems;
- **global computer network**: cellular operators, satellite operators, low-power global network operators (Low-Power Wide-Area Network, LPWAN). Internet transport protocols for IoT and network devices (MQTT, CoAP and even HTTP) are commonly used;
- **cloud**: infrastructure as a service provider, platform as a service provider, database developers, streaming and batch processing service providers, data analysis

tools, software as a service provider, data lake providers, software-defined network operators/program-defined perimeters, machine learning services;
- **data analysis**: huge amounts of information are transferred to the cloud. Working with large amounts of data and getting value from it is a task that requires complex event processing, analytics, and machine learning techniques;
- **security**: when bringing all the elements of the architecture together, security issues arise. Security touches every component, from physical sensors to CPUs and digital hardware, radio systems, and the communication protocols themselves. Security, credibility, and integrity must be ensured at each level. There should be no weak links in this chain, as the Internet of Things will become the main target for hacker attacks in the world.

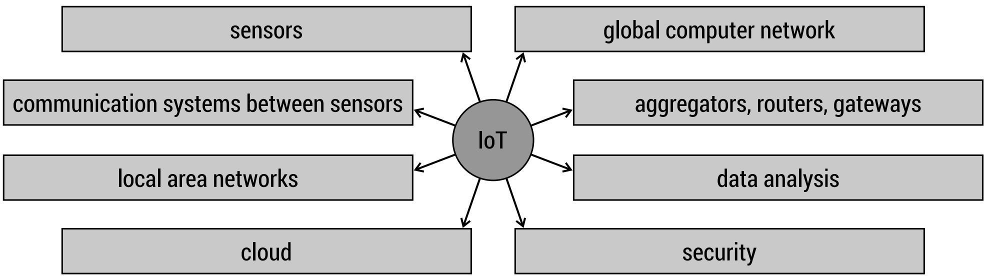


FIG. 8.3. IoT structure (Source: own elaboration)

The IoT architecture, as we have already mentioned, covers many technologies. Each architect must understand what impact the chosen design solution will have on the entire system as a whole and each of its parts separately. The complexity and versatility of the Internet of Things is since this technology is much more complex than traditional technologies: it is distinguished not only by its large scope, but also by a combination of various, often unrelated interrelated types of architecture. The number of possible design solutions is amazing.

For example, at the time of this writing, there are more than 600 IoT platform providers (based on IoT Analytics' latest research) in the world offering cloud storage, SaaS components, IoT management systems, IoT security systems and any kind of data analysis. Add to this a huge number of different protocols for personal, local, and wide area networks, which are constantly changing and adjusting depending on the region.

Selecting the wrong protocol can lead to communication problems and noticeably poor signal quality, which can only be corrected by adding more nodes to the network. The architect must consider the interference in local and global networks: how is data taken from edge devices and transmitted to the Internet? The architect must evaluate the fault tolerance of the system and the cost of possible data loss. Which layer should be responsible for the fault tolerance of the system – the lower layers or the protocol layer? The architect must also choose Internet protocols: MQTT or CoAP and AMQP, and you also need to think about how all this will work if you switch to another cloud service (Perry, 2018).

You also need to decide at what point the data will be processed. At this stage, you can consider fog computing to processing data near the source, which solves the problem of latency and, more importantly, reduces network load and costs when transferring data over global networks and cloud services. Next, we consider all options for analyzing the received data. The wrong analytics tool can clutter up the system with redundant data or force you to use algorithms that require too much computing power to run on edge nodes. And how will requests sent from the cloud to the sensor affect the battery life of the sensor itself?

In addition to all this wide range of options, we must not forget about the security system, as the IoT system we have created becomes the largest target for attacks in the city. As you can see, the choice is huge, and each decision affects the others.

The Internet begins or ends with one event: a simple movement, a change in temperature, or maybe a lever snaps a lock. Unlike many existing IT devices, the Internet of Things is mostly associated with a physical action or event. It gives out a reaction to some factor of the real world. Sometimes a single sensor can generate a huge amount of data, such as an acoustic sensor for preventive maintenance inspections. In other cases, just one bit of data is enough to convey vital information about the patient's health status. Whatever the situation, sensor systems have evolved and, in accordance with Moore's law, have shrunk to sub-nanometer sizes and become substantially cheaper. This is what those who predict that billions of devices will be connected to the Internet of Things are appealing to, and that is why these forecasts will come true.

The Internet of Things would not exist without reliable technologies for transferring data from the most remote and unfavorable areas to the largest data collection centers of Google, Amazon, Microsoft, and IBM. The phrase "internet of things" contains the word "internet", so we must study issues related to networking, data exchange, and even signal theory. The basic pillar of the Internet of Things is not sensors or applications, but the ability to establish a connection. A successful architect understands the intricacies of interfacing a sensor to a WAN and vice versa (WAN to sensor interactions).

To transfer data from sensors to the Internet space, two technologies are needed: a router-gateway and basic Internet protocols that ensure the efficiency of data exchange. The router is especially important in aspects such as security, management, and data routing. Edge routers manage and monitor their respective mesh networks and align and maintain data quality. Data privacy and security are also of great importance. This part explains the role of the router in creating VPNs, VLANs and software-defined wide area networks (Perry, 2018). They can literally contain thousands of nodes served by a single border router, and to some extent, the router serves as an extension for clouds.

The architect must understand what the flow of data is, and in the typical schemes for building cloud services. To learn how to correctly assess how the system will develop and grow, it is necessary to understand all the intricacies and complexities of the architecture of cloud systems. The architect must also understand the impact latency has on the IoT system. Also, not everything needs to be sent to the cloud.

Sending all IoT data is significantly more expensive than processing it at the edge of the network (edge computing) or including an edge router in the area served by the cloud service (fog computing). Data that has been obtained by converting an analog physical stimulus into a digital signal can carry a lot of weight. This is where IoT analytics and rules engines come into play. The degree of complexity of putting an IoT system into operation depends on what solution is being designed. In some situations, everything is quite simple: for example, when you need to install a simple rules engine on an edge router that monitors several sensors that monitors anomalous temperature jumps. Another situation is that a huge amount of structured and unstructured data is transferred in real time to a cloud data lake, which requires high processing speed (for predictive analytics) and long-term forecasting based on high-tech machine learning models, such as a recurrent neural network in a signal analysis package with time correlation.

Many IoT systems will not be limited to the secure space of a home or office. They will be in public places, in very remote areas, in moving vehicles, or even inside person. The Internet of Things is a huge single target for all kinds of hacker attacks. We have witnessed countless mock attacks on IoT devices, well-organized hacks, and even nationwide security breaches.

8.2. Programming IoT Devices

8.2.1. Selecting Hardware and Software Environment with Arduino Example

The best way to learn is to learn by example. In this chapter we will complete some step-by-step examples using ESP8266 Arduino microcontroller, which is one of the most affordable and simple options for education purpose.

The easiest way to work with the ESP8266 is to send text commands through the serial port, because the chip was originally conceived as elementary data transceiver over Wi-Fi. However, this method is unsatisfactory and is not recommended. The better approach is to use the Arduino IDE, which you will have to install on your computer. It will do the job with the ESP8266 is very comfortable, because the Arduino IDE is familiar to everyone, who has ever dealt with Arduino based projects. This method will go throughout this chapter.

We will also need a suitable power source. This is often forgotten, which leads to many problems. If you try, for example, to power the ESP8266 chip from the +3.3V power supply built into an FTDI USB adapter board or an Arduino board, the device simply won't work properly. Therefore, most ESP8266 modules require a power supply that provides at least 300mA of current to operate reliably. Some- boards have a microUSB connector and a built-in power supply, but this does not apply to the boards discussed in this chapter. Therefore, a breadboard power supply that provides 500 mA on the line +3.3 V could be used here (McEwen & Cassimally, 2014).

After all components are properly connected (we will not go into details here but concentrate on programming) we need to install Arduino IDE. The latest version could be found here: https://www.arduino.cc/en/software. After installation of Arduino IDE adding of esp8266 platform is necessary (you can do it in the Settings dialog by installing additional package for this platform).

The next step is to test that the Arduino IDE and ESP8266 are working properly by connecting your module to your home Wi-Fi network. To do this, we will perform the following steps:

Write a program and load it into the module's memory. The program is very simple – we just want to establish a connection to the home Wi-Fi network and display the IP address that our board received in the terminal window. Here is the source code of the program:

```
// import of ESP8266 library
#include <ESP8266WiFi.h>
// your Wi-Fi network parameters
const char* ssid = “your_wifi_name”;
const char* password = “your_wifi_password”;
void setup(void)
{
// serial port initialization
Serial.begin(115200);
// starting Wi-Fi connection
WiFi.begin(ssid, password);
while (WiFi.status() != WL_CONNECTED) {
delay(500);
Serial.printC1.”) ;
}
Serial.println(“”);
Serial.println(“WiFi connected”);
// IP adress out
Serial.println(WiFi.localIP());
}
void loop() {}
```

Do not forget to substitute the name and password of your Wi-Fi access point in the program source code. Save the program with any file name of your choice. Then enter the correct virtual serial port number to which your USB adapter is connected. Now you need to put the board into firmware download mode. To do this, connect the GPIO0 pin to a common wire using the same conductor that was connected earlier. Then reboot the board by disconnecting and reconnecting power.

In the Arduino IDE settings set the speed to 115200 and click the button to upload the firmware to the board. Disconnect the wire between the GPIO0 and GND pins. Reboot the board by disconnecting and reconnecting the power. When the connection is established and the board has obtained an IP address, you will see a message like this:

```
WiFi connected 192.168.1.103
```

This message indicates that your card is connected to a Wi-Fi network.

8.2.2. Programming Fundamentals

Programming is directly related to the algorithm. Initially, an algorithm or sequence of actions is developed that can be performed by an automatic computing device (computer). Usually, this sequence is written (coded) with a certain system of formal notation called an algorithmic (programming) language, the text of the algorithm is called a program, and the process of creating it is called programming.

Programming – development of programs for a computer. Programming involves detailing the problem-solving algorithm and writing it down in the appropriate programming language, selecting and encoding the data structure, and debugging the created program. Programming language – a formal language used to describe computer programs.

8.2.2.1. Short History of Programming

Initially, all algorithms were written using machine language. This approach made the development of algorithms very difficult and very often led to errors that then had to be corrected. Thus, even the development of a simple program was a very complicated and labor-intensive process.

The first step in making it easier for a programmer was to stop using numbers to write commands exactly as they are used on a computer. To this end, the use of mnemonic records instead of numbers was introduced in the development of the program. Identifiers were used to describe some areas of memory, not the coordinates of the corresponding memory cell. These tools helped to create more understandable programs.

Initially, programmers took a mnemonic approach to developing software on paper and then translated it into machine language. However, it soon turns out that the process can be done by the computer itself. As a result, programs called assemblers were developed to translate mnemonic programs into machine language.

The assembler obtained its name because its purpose was to collect machine codes from commands obtained by transforming mnemonic symbols and identifiers. Mnemonic recording systems can now be considered as special programming languages – assembly languages. At one time, the development of assembly languages was a big step forward in the development of programming languages. These languages are called second generation languages (the first generation was machine languages). Despite their advantages over machine languages, assembly languages could not provide a complete programming environment. In addition, the constructions used in these languages were the same as those used for machine languages. The only difference was in the form of syntax. Assembly languages are also machine-dependent, so to run this program on another computer, you had to start (overwrite) it for the appropriate configuration of the registry and command list. The programmer still had to think of machine language concepts that are not necessarily used to create the program.

There are four independent directions in which programming languages have developed:

- procedural,
- declarative,
- functional,
- object-oriented.

The direction of the procedure is the traditional approach to programming. This approach defines the programming process as a sequential command record, in the execution of which the data will be processed to obtain the required result. In this case, the primary ones are the teams. With this approach, it is best to start learning programming, because it is more understandable to a person, but for creating large programs, the direction of the procedure is practically not valid.

In an object-oriented approach (OOP), a data element is considered an active object as opposed to a traditional approach. An object contains not only data, but also operations that can be performed with this data. OOP offers the ability to use objects multiple times, which facilitates program development, as well as object creation libraries that allow programs to be collected as a constructor.

In the declarative direction, the main question is “what is the task”, not what algorithm will be needed. The problem is to find a common algorithm for solving the whole range of tasks. In this case, the programmer must formulate the task precisely, not look for an algorithm. Initially, declarative languages were designed to solve a very narrow range of specific tasks.

The functional approach considers the program development process as construction from “black boxes”, each of which receives input data and outputs output data. Mathematicians call such boxes functions. Functional languages consist of elementary functions based on which a programmer can build the most complex functions. The programming process is the construction of the necessary functions with other simple functions embedded in each other. The advantage of the functional paradigm is the modular approach to programming. In this case, the program is more organized compared to the procedural approach. This is like building a program from building blocks, not from scratch.

8.2.2.2. Variables, Data Types and Arithmetic Operators

A variable is an area of the computer's memory where a value used by a program can be stored. Variable – a character or sequence of characters used to denote a saved value that has its own name and value and can be changed during program execution. All variables must be specified with their data type and name before they can be used in the program. Variables of the same type can be defined in one or separate rows (all examples are given in C++ programming language).

```
int a; //variable definition
int a, b; //definition of 2 variables with same type
```

The variable name must meet certain requirements:

- letters may use letters, numbers, and underscores;
- the name can only start with a letter or an underscore symbol;
- C ++ reserved words may not be used in names.

In C ++, names of variables of any length are allowed, but shorter names are easier to remember and write. It is recommended that variable names reflect their meaning, such as sum or number1, and so on. The C ++ language distinguishes registers, so variables a1 and A1 are not the same. You can define variables in any row of the main function, but you must use these variables. It is also recommended to insert a blank line before defining variables.

An example let us consider a two-number counting program. The text of the program code is as follows:

```
#include<iostream>
#include<conio.h>
using namespace std;
void main()
{
int sk1, sk2, sum;
cout<<"Input first number\n";
cin>>num1;
cout<<"Input second number\n";
cin>>sk2;
sum=sk1+sk2;
cout<<"Sum = "<<sum<<endl;
getch();
}
```

This program allows the user to enter two numbers, then calculates the sum of these numbers and displays the result on the monitor screen.

8.2.2.3. Data Types, Arithmetic Operators, and Flowcharts

The data type of an object is determined during its creation (definition) and denotes the values that can be accepted by the given type of object (integers, logical values, dates, etc.) and the operations that are possible with this type of object. The data type also determines the amount of memory allocated during variable definition.

C ++ supports the following groups of data types:

- base types – are indicated with the help of reserved keywords; the types themselves do not need to be defined;
- user-defined types – structures, indicators, arrays that must be defined before use.

Only base data types will be considered in this collection. In many programming systems, the size of the int data type corresponds to the size of the "machine name". For example, on a 16-bit computer, the int size is 16 bits and 32 bits are 32 bits. The use of different types of data allows you to use computer resources more efficiently, which in turn speeds up program execution.

Many programs perform arithmetic operations. C ++ uses several symbols that are different from those accepted in algebra. Table 8.1 gives the arithmetic operators of the C ++ language.

TABLE 8.1. C++ arithmetic operators (Source: own elaboration based on Deitel, 2018)

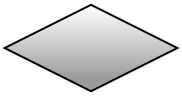
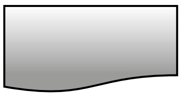
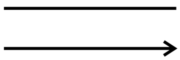
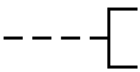
Operation name	Arithmetis operation	Example from algebra	C++ example
Summation	+	F + 7	F+7
Subtraction	–	F – 7	F–7
Multiplication	*	BM	B*M
Division	/	X / Y vai X : Y	X/Y
Residual calculation	%	R mod S	R%S

Arithmetic expressions in C ++ must be written on one line to be executed. Round brackets are used for the same purposes as in mathematics. The operations in parentheses are performed first, followed by the multiplication, division, and balance residual operations, and finally the addition and subtraction (operation priority).

The graphical implementation of algorithms is more compact and more pseudocoded. The algorithm is represented as a sequence of interconnected blocks, where each of the blocks corresponds to one or more operators. This type of graphical representation is called flowcharts. Table 8.2 gives the most widely used flowchart elements description.

Later in this chapter, specific examples of algorithm representation using flowcharts are discussed.

TABLE 8.2. Basic flowchart elements (Source: own elaboration based on Deitel, 2018)

Name	Element graphical representation	Description
Process		Execution of an operation or group of operations that results in a change in value, display format, or data layout.
Decision		Choice of the direction of execution of the algorithm depending on some variable conditions
Defined process		Use of previously developed and separately described algorithms or programs
Input/ Output		Use of previously developed and separately described algorithms or programs
Document		Output data to a printer or other similar device
Connection line		Indication of links between flowchart objects
Connector		Indication of interrupted flow lines (connection of interrupted lines)
Comments		Link between scheme element and explanation
Start/End		Indication of interrupted flow lines (connection of interrupted lines)

8.2.2.4. Control structures

Program operators are usually executed one after the other in the order in which they were written. This is called sequential execution. However, some operators allow you to change this order. These are transfer of control operators. In the 1960s, the unrestricted use of goto operators proved to cause many errors and prolong the program execution process. It was believed that the goto operator, which allowed the programmer to hand over control over a very wide range, was to blame.

```
Again:   //label, where the program will return
...
goto Again;
```

The idea of structuring the program was based on the principle of "Do not use goto". In the 1970s, it was proved that programs could be written without a goth operator at all (Deitel, 2013). The results of this approach have been impressive: the execution time of the program has been reduced as the programs have become more comprehensible and the number of errors has decreased significantly.

It turns out the program can be written using only three control structures:

- sequence structure;
- selection structure;
- repetition structure.

Sequential execution is built into programming languages. Unless otherwise specified (by default), all operators are executed in the order in which they are listed. The program example discussed above are implemented with sequential execution. The flowchart of the two-number counting program is given in Figure 8.4.

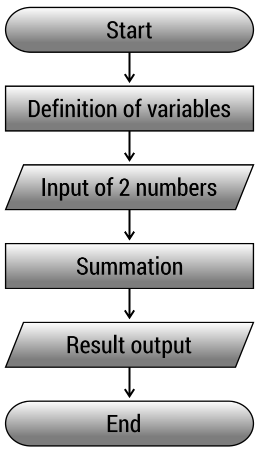


FIG. 8.4. The flowchart of the two-number counting program (Source: own elaboration)

The first control structure is conditional one. A simple if structure performs an equality or relationship test. The type of record is as follows:

```
if (condition) action;
```

If the condition is true, then the action that follows it (one or more operators) will be executed, otherwise the (false) action will not be executed.

An example let us consider a program in which the user must enter two numbers, but the program compares them and outputs the result of the comparison.

```
#include<iostream>
#include<conio.h>
using namespace std;
```

```
void main()
{
int sk1, sk2;
cout<<"Input the first number\n";
cin>>sk1;
cout<<" Input the second number \n";
cin>>sk2;
if (sk1>sk2)
cout<<sk1<<" is greater than "<<sk2;
if (sk1<sk2)
cout<<sk1<<" is less than "<<sk2;
if (sk1==sk2)
cout<<sk1<<" equals to "<<sk2;
getch();
}
```

In this case, the program contains three conditional control operators that consider three comparison cases. The program can output only one comparison result, because in any case only one condition will be true. By placing the semicolon immediately after the condition, the user makes an error in the empty condition test operator (the action that goes immediately after the condition test will be executed in all cases, and the program will output an incorrect result).

The if / else control structure is shown in an example of a quadratic equation solution (code example and a flowchart in Figure 8.5).

```
#include<iostream>
#include<conio.h>
#include<math.h>
using namespace std;
void main()
{
float a, b, c, d, x1, x2;
cout<<"Input coefficient a\n";
cin>>a;
cout<<" Input coefficient b\n";
cin>>b;
cout<<" Input coefficient c\n";
cin>>c;
d=b*b-4*a*c;
if (d>=0)
  {
  x1=(-b+sqrt(d))/(2*a);
```

```
  x2=(-b-sqrt(d))/(2*a);
  cout<<"The solution is "<<x1<<" and "<<x2;
  }
else
  cout<<"No solution";
getch();
}
```

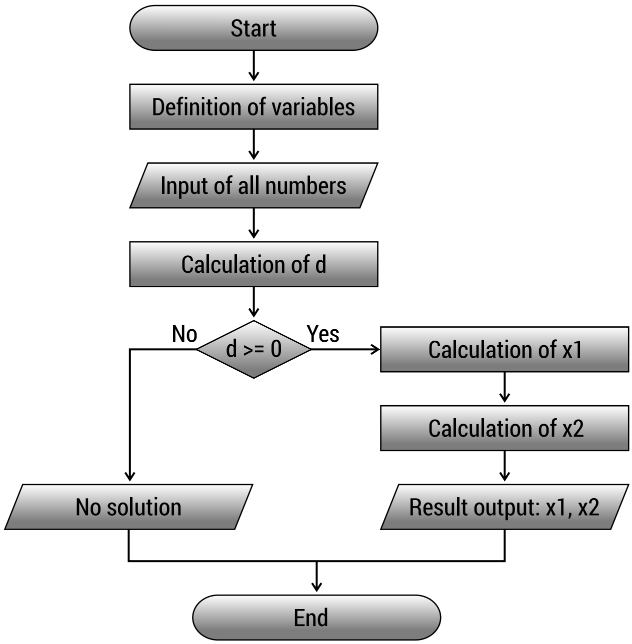


FIG. 8.5. The flowchart of quadratic equation program (Source: own elaboration)

Repetition structures (loops) allow a programmer to define an action that must be performed until a condition is met. Example of a loop while is as following (for simplification the only loop part of a program is given, see Figure 8.6):

```
…
int i=1;
while (i<=4)
 {
 cout<<"****\n";
 i=i+1;
 }
…
```

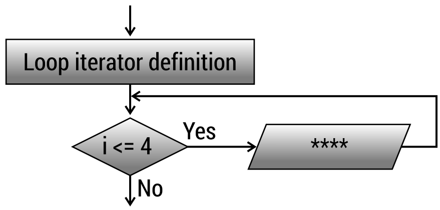


FIG. 8.6. The flowchart of while loop outputting 4 asterisks (Source: own elaboration)

The result of the program will be as follows:

```
****
****
****
****
```

The program shown in the example loops four times. A special variable called a cycle counter can be used for this purpose. In this case, it is a variable i, the initial value of which is 1, but with each subsequent iteration of the cycle, it increases by one (the last program line). The condition in while indicates how many times the loop will run (in this example, until i is equal to 4). As a result, 16 asterisks will be displayed on the monitor screen, four in each line.

The iteration structure for is like the while structure and contains the same elements, the difference being the notation. When this structure begins to execute, a control variable (cycle counter) is defined and assigned a value. The condition for continuing the cycle is then checked and, if true, the operation is executed (iterated). Then increment the counter and check the condition again.

The example above with asterisks for the loop looks like this (the flowchart and result are identical to the while loop):

```
for (int i = 1; i <= 4; i ++)
cout << ”**** \ n”;
```

It should be noted that in the example the operation i <= 4 is used in the cycle conditions. If i <4 is recorded, the cycle will be executed only three times. This is a typical logical error. If the loop counter is defined in the loop header (in parentheses), then this variable must not be used after the end of the loop (syntactic error) because it will not be known to the program. This constraint is called the scope of the variable.

It is possible to use the break and continue operators in cycles. When the operator break is executed in cycles, the cycle exits immediately, but the program continues to execute subsequent operators after the cycle. Typically, the break operator is used to end a loop, but the continue continue skips operators that are immediately after it, and the iteration of the next loop is executed.

Depending on the task, the loops can be placed in each other in unlimited quantities (nested loops).

8.3. Automation Concept and Implementation in Smart Houses

8.3.1. Automation Concept

Home automation or smart house is an extension of building automation and includes the control and automation of lighting, heating, ventilation, air conditioning (HVAC), and security, as well as home appliances such as washer/dryers, ovens or refrigerators that use WiFi for remote monitoring. Modern systems generally consist of switches and sensors connected to a central hub from which the system is controlled with a user interface that is interacted either with a wall-mounted terminal, mobile phone software, tablet computer or a web interface, often via internet cloud services.

The terms “Home Automation” and “Internet of Things” are distinct parts of the Smart Home concept: where a home’s electrical devices are connected to a central system that automates those devices based on user input.

These are electrical devices that are intelligent, courtesy of a connection to the Internet . These devices are capable to assist a user needs. This intelligence comes from device programing, but with time the device can learn and adapt to patterns and interact with its users thanks to artificial intelligence algorithms and methods.

Automated home security systems tend to offer a wider range of features than their predecessors. Systems respond to voice and biometric data, and locks can be upgraded to keypads that are opened with codes or swipe cards. These systems can be turned on or off via remote control, email, or phone, and camera feeds can be sent directly to one’s computer. Audible alarms can be used to alert one of intruders, while silent alarms can be used to alert the authorities.

IoT is going to give the net a more objective way of gathering data, meaning that the conclusions that will be drawn by AI and Machine Learning algorithms are potentially going to be very different from what we expect. It’s also going to mean that the scale and quality of decisions being made by virtual agents in future is going to become better than today.

The smart house is a complex concept which integrates diverse technologies to resolve the new problems in cities and rural area. Fro one side, new technologies enable new applications such as intelligent transportation and smart building management. From the other side, the new applications raise challenges for the current technology. For example, the increasing number of autonomous systems such as self-driving cars and robots need high accurate real-time location information service and context awareness and anomaly detection for decision making. There is also a strong need of better human physical activity information for the purpose of improving security, understanding the human behavior models and health condition monitoring.

Smart homes utilize sensors and controllers to monitor and automatically trigger services to save valuable time in cases of emergency (e.g., fire, intrusion, or gas leak). With the smart building system, services like video monitoring, light control, air-condition control, and power supply control are often managed from the same control center.

The main aspects of a smart buildings IoT technologies are (Sun et al., 2018):

- Safety monitoring and alerting: Examples include noise level monitoring in urban zones and sounding alarms in real-time, electromagnetic field level monitoring by measuring the energy radiated by cell stations and other devices, chemical leakage detection in rivers by detecting leakages and wastes of factories in rivers, air pollution and control of CO2 emission factors, pollution emitted by cars and toxic gases generated in farms, as well as earthquake early detection.
- Smart lighting: here IoT is used to minimize energy consumption, to provide weather adaptive lighting in streetlights, and to automate maintenance.
- Flooding, water leakage, and pollution monitoring: monitoring of safe water levels in rivers, lakes, dams, and reservoirs. Detection of the presence of toxic chemical. Monitoring of tanks, pipes, and pressure variations. Real-time control of leakages and waste in the sea.
- Detection of hazardous gases and radiation levels: Detection of gas levels and leakages in and around industrial buildings and chemical factories. Monitoring of ozone levels during the meat drying process in food factories. Distributed measurement of radiation levels in the surroundings of nuclear power stations to generate leakage alerts.
- Other use cases include detection of garbage levels in containers to optimize the trash collection routes, preemptive monitoring of burning gases and fire conditions to define alert zones, snow level measurement to know in real time the quality of ski tracks and alert avalanche prevention security corps, monitoring vibrations and earth density to detect dangerous patterns in land conditions, and monitoring of vibrations and structural conditions in buildings and bridges.

8.3.2. IoT in Smart Houses

The operation of a smart home system is not as simple as it seems. Before the advent of smart home technology, each installation in a building had only one specific task and had its own automation with separate controllers and remote controls. The boiler heated the house and heated water for domestic needs, the alarm system ensured the safety of residents and their property.

The problem with various controls came at a time when homeowners began to use more modern installations and equipment, such as ventilation and air conditioning, smart lighting, multimedia, blinds and external awnings, automatic watering. Engineers and electronics have joined forces and developed technologies that combine various household appliances into one system and provide uniform control. However, easier control is just one of the many benefits of new technologies in human life.

With this technology under your own roof, you get (Perry, 2018):

- Reducing housing maintenance costs. From an economic point of view, a properly tuned installation effectively reduces electricity and gas consumption. It is estimated that single-family homes save up to 30% of these energy sources. A house that works with motion sensors can always turn off the lights when it detects that no one is in the room. If the windows are open, it makes no sense to use ventilation and heat the premises, and when the owners leave and the window is left open, a notification will come about this, and the heating and ventilation mode will change so that they do not incur unnecessary costs.
- Feeling of safety and comfort. From a security point of view, the most important advantage of the „thinking" technology is its efficient operation, due to the ability to exchange information between all related elements. If events are possible in the building or outside that potentially dangerous for residents, they immediately respond to them by initiating alarm, security, and containment procedures. Ease of use lies in the remote performance of several actions to control and manage for users.
- The pleasure of spending time at home.
- Free expansion of the system and its adaptation to constantly changing conditions and lifestyle requirements (provided that the home is equipped with automation that can be expanded in the future).

The principle of operation of a smart home is to control a computer (advanced controller) that collects, and processes signals received by it from various sensors located inside or outside the house. Electrical cables or radio waves are used to send signals. Sensors (motion, humidity, pressure, light intensity, flooding, smoke, carbon monoxide, sleep gas, etc.) register changes inside and outside and transmit them to the central unit. There are also systems without a central unit, in which each element decides for itself which signals from the detectors are relevant to it. Any change that occurs in one subsystem is immediately considered in another. All subsystems take this into account and respond immediately to the change.

High flexibility is one of the most important performance parameters when choosing a home automation system. Thanks to this, you can reprogram it many times and adapt it to the current needs of residents, expand and add new devices and functions in the future.

Closed systems: offer products (technologies, programs, devices, etc.) from only one manufacturer. When choosing this type of system, users cannot use products from other companies in their work.

Open systems: software, devices, and accessories for them are produced by many programmers and many companies. One popular open system suitable for single-family housing is, for example, the KNX system, formerly known as EIB. All products used in this system are compatible, although they are manufactured by more than 100 companies (Sun et al., 2018).

Systems don't come cheap, so it's best to make sure they're fully tailored to the individual requirements of each family member and the home they live in. Before embarking on a project, it is worth exploring the possibilities of several systems, open and closed. An intelligent installation based on traditional cables can work in the building under construction. On an already built object or after repair, it is easier to set up wireless radio systems. Although the latter, as a rule, are more expensive than regular ones (cable).

How to lay the cables, where to place the sensors and all other necessary components (e.g., drive motors, servo motors, controllers, buttons) must be specified in detail by the project author. It is best if it contains several detailed designs for specific installations – electrical, signaling, multimedia. Before starting the preparation of the project, an in-depth analysis of the needs and requirements of the residents is necessary.

For users of single-family buildings, a mandatory function of intelligent automation is the remote control of heating and electrical systems. They are also usually willing to include systems responsible for the safety of the home and its inhabitants, as well as ventilation and air conditioning.

Temperature and humidity control in a smart building is based on the operation of temperature sensors located in each room, a weather station on the street and humidity sensors. When users leave the house, the system lowers the temperature, closes windows, and manages ventilation and air conditioning more efficiently. After the family returns, the elements begin to work in a different mode, quickly bringing the room to a comfortable temperature and humidity. The devices can be programmed in economy mode for rooms that are rarely used and at night, and rest mode for when traveling.

Lighting: in the premises, the lamps are switched on or off remotely, shine brighter or dimmer thanks to motion sensors and light intensity sensors. Outside (in the garden, on the terrace, at the gate and gate), the lighting points are controlled by twilight sensors. In many smart homes, you set up so-called light scenes from selected lighting points. They are used wherever it is worth creating individual lighting, in the living room, kitchen, corridors, halls. However, the so-called light trails are designed to provide efficient passage through the premises, access to the garage and entrance to the house, or when residents need to go to the toilet at night (dim light or soft LED light is usually used then). In addition, with the help of light it is possible to simulate the presence in the building, this function is directly related to the security function.

Alarm and monitoring: the smart system integrates with building alarms or monitoring. They are indispensable for protection against accidental events caused by fire, gas leakage, etc. The safety of family members and the building can be protected with the help of numerous motion, smoke, gas, water leakage sensors. The panic button, installed next to the owner's bed, triggers a series of events – it sends information to the security service, it can signal or turn on the light in the building. An interesting security feature is access control. Residents use an individual card or key that is recognized in their home. A useful solution is a special button, with which, when leaving the house, you can turn off all electrical appliances that you do not need in our absence (of course, except for the refrigerator, boiler, etc.). With one button, we get 100% confidence that the iron, oven, coffee maker, induction cooker will stop working. The driveway to the entrance and garage gates, video intercom and lighting of the path leading to the house and driveway are the main elements of automation in the field of access control.

Blinds, awnings: in summer, when the sun is too strong, the remote control allows you to facilitate the operation of ventilation or air conditioning by automatically lowering blinds or awnings over terraces and balconies. In winter, lowering the outer blinds further protects the interior from freezing and maintains heating.

Multimedia: a huge number of users include in the intelligent system the so-called multi-room, that is, a multi-zone sound system and a home theater. By integrating a multi-room system with speakers and controllers installed in each room, they can use state-of-the-art audio equipment throughout the building. The sound "wanders" with them from room to room.

Watering: automatic watering starts after the information is sent to the controllers using dusk and soil moisture sensors. A motion sensor near the sprinkler protects garden users from unwanted wetness, while a rain sensor blocks irrigation during prolonged rain.

The septic tank and rainwater tanks: full level sensors in a septic tank, combined with a smart home, keep dirt out of the area. They inform owners (e.g., via SMS) of the need to call the slurry tanker. They are also good in rainwater tanks.

8.3.3. Technological Aspects of Smart Houses

The most popular smart home devices use Wi-Fi, Bluetooth, ZigBee and Z-Wave technologies. Each of the technologies has its pros and cons, and no one forbids using them together, compensating for the shortcomings of each. But different technologies are used for different tasks and different types of smart devices. For example, household appliances (TV, refrigerator, and coffee maker) usually use Wi-Fi or Bluetooth, which are also found in any phone. The reason is that this technique is used even without a full-fledged smart home system. For lighting and climate automation, ZigBee or Z-Wave embedded modules are more suitable, as they are specifically designed to integrate with existing lighting and climate equipment. But for their full-fledged work, a special hub is needed.

Wi-Fi is indispensable in IP cameras, TVs, audio / media players and other video signal transmission equipment. Of course, Wi-Fi can also be used in light switches, sensors, thermostats, but the lack of signal relay and high power consumption do not allow making sensors that work for years on it. Each manufacturer for their Wi-Fi device, whether it's a smart light bulb, a kettle, a refrigerator or a robot vacuum cleaner, releases its own application, and there is no single standard to control all appliances from one application. This does not allow making a Wi-Fi-only smart home truly convenient.

The current version of **Bluetooth** Low Energy 4.2 has low power consumption, thanks to which tiny wireless headphones, speakers and various battery-powered sensors work (Perry, 2018). The problems here are the same as with Wi-Fi: the lack of a common control standard forces each manufacturer to make its own application, which is inconvenient for the user. Mesh technology (mesh network), which is very important for a smart home, appeared only in version 5.0, which is still rarely used anywhere, but perhaps the future of smart homes is in Bluetooth LE 5.

ZigBee was originally developed for use in networks of sensors such as electricity, water, gas meters, temperature sensors. The network topology can be different, including cellular (mesh). This means that any sensor sees all other sensors and can transmit a signal through them, i.e. use relaying, which greatly increases the reliability of transmission. In 2007, a command standard for managing a smart home appeared, the so-called „Home Automation" profile (Perry, 2018). With ZigBee, almost all devices for creating home automation are released: relays, dimmers, lamps, thermostats, locks, sensors. But you will not find household appliances such as refrigerators and TVs with ZigBee. Compared to other smart home protocols, ZigBee devices have the most attractive prices, but the lack of 100% compatibility between devices and hubs from different manufacturers does not allow building a smart home only on ZigBee.

Z-Wave is a wireless protocol developed since 2001 specifically for home automation. Its main advantage is full compatibility between devices from different manufacturers. So the motion sensor from Fibaro can control the Qubino dimmer, and all the automation is based on the RaZberry controller from Z-Wave.Me. At the moment, more than 3,000 different Z-Wave devices are being sold, which cover all the needs of a smart home. This is the most popular protocol for objects ranging from 10 to 500 m^2. Z-Wave, like ZigBee, uses a mesh topology with support for signal relaying and automatic finding of the best route. The main disadvantage is the price. On average, the cost of the device is 60-80 euros, which is about twice as high as that of analogues with ZigBee.

Every year, smart home technologies are gaining more and more fans. The range is growing rapidly, and there really is plenty to choose from, it is not even necessary to order abroad. When you start planning the assembly of a smart home, the question usually arises, what manufacturers are on the market? Whose decision to choose? How is one different from the other?

Xiaomi is one of the most popular smart device manufacturers. Their assortment includes almost all household appliances connected to a smart home, as well as specialized IP cameras, sockets and light bulbs, various sensors (temperature, humidity, CO2) and many other devices. Xiaomi does not use any one wireless technology for its devices but chooses the best one for each type. For example, ZigBee is used to control lighting, sockets, and curtains, and to connect them, you definitely need a hub from Xiaomi with support for this protocol. TVs, vacuum cleaners, and IP cameras are connected via Wi-Fi through a router, because not everyone needs a full-fledged smart home, and almost everyone has Wi-Fi. Temperature, humidity, air quality sensors and locks work via Bluetooth. Such devices can be connected directly to the phone and only view readings, or they can be connected to a Xiaomi hub with Bluetooth support, then it becomes possible to use the sensor in climate control scenarios.

Smart home from Xiaomi is a great solution, because the company offers many good devices for creating a smart home and convenient automation settings. But the Xiaomi hub does not allow you to set up complex automation and use scripts. Only ZigBee devices can be controlled from a phone without the Internet (via a hub), but Wi-Fi lamps and sockets work only via the Internet. ZigBe hubs from other manufacturers allow you to remove these restrictions.

Apple doesn't make smart home devices, but it did create the HomeKit protocol that other manufacturers use to build compatible devices. HomeKit devices work over Bluetooth and Wi-Fi protocols. Locks, thermostats, lighting control modules, RGBW lamps, cameras and many sensors are available with HomeKit support. In addition to devices, there are also gateways that convert commands from ZigBee and Z-Wave devices into HomeKit commands. Xiaomi, Ikea, Philips and many others have such gateways. This expands the range of smart home devices from Apple. So far, Apple's automation capabilities are very modest and do not allow you to create a completely arbitrary scenario. Also HomeKit, for obvious reasons, is not suitable for Android users.

Fibaro is the manufacturer of the most popular Z-Wave devices and home automation centers. All Fibaro devices have many settings and additional features. The equipment line includes opening, motion, leakage, smoke sensors, micro-relay modules, dimmers, etc. The Home Center 2 home automation controller has a pleasant and intuitive user interface and allows you to configure scenarios of any complexity. Because Since the Z-Wave protocol provides for compatibility between devices from different manufacturers, Fibaro can work with any other Z-Wave devices.

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9. BIG DATA AND IOT SECURITY ISSUES

9.1. Big Data Technology

Big Data or big data is structured or unstructured data arrays of large volume. They are processed using special automated tools to be used for statistics, analysis, forecasts, and decision making. The term "big data" was coined by Nature editor Clifford Lynch in a 2008 special issue. He talked about the explosive growth of information in the world. Lynch referred to big data any arrays of heterogeneous data more than 150 GB per day, but there is still no single criterion (Gantz & Reinsel, 2020).

Until 2011, big data analysis was done only within the framework of scientific and statistical research. But by the beginning of 2012, data volumes had grown to enormous proportions, and there was a need for their systematization and practical application.

Since 2014, the world's leading universities have paid attention to Big Data, where they teach applied engineering and IT specialties. Then IT corporations such as Microsoft, IBM, Oracle, EMC, and then Google, Apple, Facebook, and Amazon joined the collection and analysis. Today, big data is used by large companies in all industries, as well as government agencies.

9.1.1. Big Data Basics

To designate an array of information with the prefix "big", it must have the following features:

- **Volume** – data is measured by physical quantity and the space occupied on a digital medium. "Big" refers to arrays over 150 GB per day.
- **Velocity** – information is regularly updated and real-time processing requires intelligent big data technologies.
- **Variety** – information in arrays can have heterogeneous formats, be structured partially, completely, and accumulate unsystematically.

For example, social networks use big data in the form of texts, videos, audio, financial transactions, pictures, and more. In modern systems, two additional factors are considered:

- **Variability** – data streams can have peaks and valleys, seasonality, periodicity. Bursts of unstructured information are difficult to manage and require powerful processing technologies.
- **Value** – information can have different complexity for perception and processing, which makes it difficult for intelligent systems to work. For example, an array of messages from social networks is one level of data, and transactional operations are another.

The task of machines is to determine the degree of importance of incoming information to quickly structure. The principle of operation of big data technology is based on the maximum informing the user about any object or phenomenon. The purpose of this familiarization with the data is to help you weigh the pros and cons to make the right decision. In intelligent machines, a model of the future is built based on an array of information, and then various options are simulated, and the results are monitored.

Modern analytics agencies run millions of these simulations when they test an idea, a hypothesis, or solve a problem. The process is automated.

Big data sources include:

- internet of things and devices connected to it;
- social networks, blogs, and media;
- company data: transactions, orders for goods and services, taxi and car sharing trips, customer profiles;
- device readings: meteorological stations, air and water composition meters, satellite data;
- statistics of cities and states: data on movements, births, and deaths; medical data: tests, diseases, diagnostic images.

The principles of working with data arrays include three main factors (Perry, 2018):

- **System extensibility**. It is usually understood as the horizontal scalability of storage media. That is, the volumes of incoming data have grown – the capacity and number of servers for their storage have increased.
- **Resilience to failure**. It is possible to increase the number of digital media, intelligent machines in proportion to the amount of data indefinitely. But this does not mean that some of the machines will not fail or become obsolete. Therefore, one of the factors for stable work with big data is the fault tolerance of servers.
- **Localization**. Separate arrays of information are stored and processed within one dedicated server to save time, resources, and data transfer costs.

Modern computing systems provide instant access to big data arrays. For their storage, special data centers with the most powerful servers are used.

In addition to traditional, physical servers, they use cloud storage, data lakes (data lakes – storage of a large amount of unstructured data from a single source) and Hadoop, a framework consisting of a set of utilities for developing and executing distributed computing programs. To work with Big Data, advanced methods of integration and management are used, as well as data preparation for analytics.

9.1.2. Big Data and Other Technologies

Blockchain is a decentralized transaction system, where every transaction is verified by every element of the network. Such a system guarantees the immutability and impossibility of data manipulation. Cryptocurrencies and other blockchain technologies are becoming more and more popular. In Japan alone, nearly 50 banks have partnered with Ripple, the open-source blockchain network and third-largest crypto market capitalization in the world. For banks, cooperation will provide instant risk-free transactions at a low cost. Interest in such operations is shown by financial structures in other countries, which means the further development of new technologies in the banking sector.

The popularity of the technology portends an exponential growth in the volume of transactional data recorded in registers. By 2030, the information contained in the blockchain ledger will account for up to 20% of the global Big Data market and generate up to $100 billion in annual revenue (Rayes & Salam, 2019). Storing these "data lakes" with traditional cloud storage providers (AWS or Azure) will cost a fortune. Decentralized data storage providers have entered the market in a timely manner, offering cost savings of up to 90%. Their work facilitates the implementation of the blockchain around the world and guarantees the development of the sphere.

The use of blockchain opens a new level of Big Data analytics. Such information is structured, complete, and secure, as it cannot be faked due to the network architecture. By analyzing it, the algorithms will be able to check every transaction in real time, which will practically destroy fraud in the digital sphere. Instead of analyzing fraud records that have already taken place, banks can instantly identify risky or fraudulent activities and prevent them. Blockchain technology is applicable not only to the financial sector. Immutable records, audit trails and confidence in the origin of data – all this applies to any business area. Already, companies are implementing blockchain in the food trade, and on the other hand, they are studying the prospects of technology in space exploration. Future Big Data and blockchain solutions are expected to radically change the way business is done.

Today, many industries are implementing machine learning to automate business processes and modernize the economic sphere. The concept provides for the training and management of artificial intelligence (AI) using special algorithms. They teach the system based on open data or experience.

Over time, such an application can predict the development of events without explicit human programming and hours spent writing code. For example, using machine learning, you can create an algorithm for the technical analysis of stocks and their estimated prices.

Using regression and predictive analysis, statistical modeling and action analysis, experts create programs that calculate the time of profitable purchases in the stock market. They analyze open data from exchanges and offer the most likely course of events.

When working with Big Data, machine learning performs a similar function: special programs analyze impressive amounts of information without human intervention. All that is required of the operator is to "teach" the algorithm to select useful data that the company needs to optimize processes. This allows analysts to generate reports in a few mouse clicks, freeing up their time and resources for more productive tasks: processing results and finding the most effective strategies.

In a fast-paced world where customer expectations are ever higher and human resources ever more valuable, machine learning and data science play a critical role in a company's growth. Digital technologization of the workflow is vital to maintaining a leading position in a competitive environment.

9.1.3. Big Data Analytics

Thanks to high-performance technologies such as grid computing or in-memory analytics, companies can use any amount of big data for analysis. Sometimes Big Data is first structured, selecting only those that are needed for analysis. Increasingly, big data is used for tasks within advanced analytics, including artificial intelligence.

There are four main methods of Big Data analysis (Perry, 2018):

1. **Descriptive analytics** is the most common. It answers the question "What happened?", analyzes real-time data and historical data. The main goal is to find out the causes and patterns of success or failure in a particular area to use this data for the most effective models. For descriptive analytics, basic mathematical functions are used. A typical example is sociological research or web statistics data that a company receives through Google Analytics.
2. **Predictive analytics** – helps to predict the most likely development of events based on the available data. To do this, use ready-made templates based on any objects or phenomena with a similar set of characteristics. With the help of predictive (or predictive, predictive) analytics, you can, for example, calculate a collapse or price change in the stock market. Or assess the potential borrower's ability to repay a loan.
3. **Prescriptive analytics** is the next level up from predictive. With the help of Big Data and modern technologies, it is possible to identify problem points in a business or any other activity and calculate under what scenario they can be avoided in the future.
4. **Diagnostic analytics** – uses data to analyze the causes of what happened. This helps to detect anomalies and random connections between events and activities.

Data is processed and analyzed using various tools and technologies:

- **Special software**: NoSQL, MapReduce, Hadoop, R;
- **Data mining** – extracting previously unknown data from arrays using a large set of techniques;
- **AI and neural networks** – for building models based on Big Data, including text and image recognition. For example, the lottery operator Stoloto has made big data the basis of its strategy within the Data-driven Organization. Using Big Data and artificial intelligence, the company analyzes customer experience and offers personalized products and services;
- **Analytical data visualization** – Animated models or graphs based on big data.

Developers adhere to two criteria for collecting information: anonymization of data which makes personal information of users inaccessible to some extent and aggregation of data which allows us to operate only with average indicators. To process large amounts of data online, supercomputers are used: their power and computing capabilities are many times greater than conventional ones.

Big data techniques are widely used in many areas like, for example:

- **Public administration**. The study and analysis of big data helps governments make decisions in areas such as health, employment, economic regulation, crime and security, emergency response; Industry. The introduction of Big Data tools helps to increase the transparency of industrial processes and introduce "predictive production", which makes it possible to predict the demand more accurately for products and, accordingly, plan the expenditure of resources.
- **Medicine**. The huge amount of data collected by medical institutions and various electronic devices (fitness bracelets, etc.) opens up fundamentally new opportunities for the healthcare industry. Big data helps to find new medicines, make more accurate diagnoses, select effective treatment, fight pandemics.
- **Retail**. The development of network and electronic commerce is impossible to imagine without solutions based on Big Data – this is how stores personalize assortment and delivery.
- **Internet of things**. Big Data and the Internet of Things are inextricably linked. Industrial and household appliances connected to the Internet of things collect a huge amount of data, based on the analysis of which the operation of these devices is subsequently regulated.
- **Real estate market**. Developers use Big Data technologies to collect and analyze the entire array of information, and then give the user the most interesting options for him. Already now, a future buyer can see the house he likes without a seller;
- **Sport**. With the help of big data, football clubs select the most promising players and develop an effective strategy for each opponent.
- **Agriculture**. An IoT solution from the field of so-called precision farming is when special weather stations that stand in the fields collect data (temperature, humidity) using sensors and send them to the IoT platform using transmitting radio-GSM modules. On it, using big data algorithms, the information collected from

the sensors is processed and a high-precision hourly weather forecast is built. The client sees it in the interface on a computer, tablet or smartphone and can quickly make decisions.

The world leaders in the collection and analysis of big data are the United States and China. So, in the United States, even under Barack Obama, the government launched six federal programs for the development of big data for a total of $200 million. Large corporations are considered the main consumers of Big Data, but their data collection activities are limited in some states – for example, in California.

China has more than 200 laws and regulations regarding the protection of personal information (Rayes & Salam, 2019). Since 2019, all popular smartphone apps have been checked and blocked if they collect user data in violation of the law. As a result, the state collects data through local services, and many of them are inaccessible from the outside.

Since 2018, the European Union has adopted the GDPR – the General Data Protection Regulation. It regulates everything related to the collection, storage, and use of online user data. When the law went into effect a year ago, it was considered the world's toughest system to protect people's online privacy.

There main problems of big data are:

- Big data is heterogeneous and therefore difficult to process for statistical inference. The more parameters required for forecasting; the more errors accumulate in the analysis;
- Working with large amounts of data online requires huge computing power. Such resources are very expensive, and so far, only available to large corporations;
- The storage and processing of Big Data is associated with increased vulnerability to cyber-attacks and all kinds of leaks. A prime example is the Facebook profile scandals;
- The collection of big data is often associated with a privacy issue: not everyone wants their every action to be tracked and transferred to third parties;
- Big data is used not only by corporations, but also by politicians: for example, to influence elections.

9.1.4. Big Data Ethical Considerations

Any technology has both positive and negative features to some extent. On the one hand, research Massachusetts Institute of Technology (MIT) showed that companies using methods of analysis of large data, were able to improve profitability by an average of 5–6% (Betts, 2016).

On the other hand, this young field of computer science gives rise to several ethical problems. These problems need to be identified and addressed, as they may ultimately override the benefits of intelligent systems. Collection, processing, and analysis of client data has now become the way making money, and in some cases a factor that can change an entire industry. Most of this data, directly or indirectly, can be considered personal data and therefore subject to protection. However, this is not enough since data protection laws usually do not cover ethical and moral aspects.

Illustrative is the situation with American company Target. Its specialists have developed an algorithm for offering personalized services by analyzing customer data, including their behavior on the Internet. In 2012 The father of a high school student complained that Target sent his daughter coupons for goods for pregnant women. The company admitted the mistake, but it soon became clear that the girl was indeed pregnant, and the big data algorithm only considered the changes in the behavior of the girl, which was like behavior of pregnant women (Betts, 2016). In this situation, no law was violated, but the public was outraged by such an invasion of privacy.

Also, an example of the use of personal data that is contrary to moral standards can be the work of special services, in particular, FBI. In 2016 it was found that FBI database includes 412 million photos people, among whom many foreign citizens and persons who have never broken the law (Perry, 2018). At the same time, the FBI intentionally hides information about how and to what extent new technologies are used (contrary to the requirements of protecting confidential data). It should be noted that the use of the facial recognition system was effective and helped in the capture of a number of criminals. However, there were some false positives: due to the error of methods analysis of big data, the system called law-abiding citizens criminals.

Based on the mentioned above, some ethical problems and possible ways to solve them can be identified (McEwen & Hakim, 2014):

- **Data collection and use**. People's concern is what will happen to the data after how they were obtained, and what will be the limits of their application. To earn the trust of customers, companies need to indicate all ways of using data in the user agreement, avoiding ambiguous wording.
- **Transfer of data to third parties**. Confidential data must be provided to other companies or individuals without any indication of the identity of its owner. It is also necessary to notify the client about the transfer of his data.
- **Observation**. The use of video analytics or behavioral analytics makes users feel that they are under surveillance. Technology that they feel is intrusive and therefore disadvantages them independence. To solve this problem, the person should be warned about the application of the data analysis algorithm. For example, in places where video analytics cameras are installed. Developers also need to thoroughly test their system to avoid situations like the incident with Target.
- **Prejudice**. Big data should not perpetuate stereotypes such as racism or sexism. For example, the FBI's facial recognition system was the most frequently mistaken when processing photos of African Americans. To avoid such situations, developers need to improve the quality of forecasts, or think about the appropriateness of using the algorithm.

By addressing ethical issues at an earlier stage, steps must be taken to either alleviate the problems or eliminate them. Organizations must implement moral and ethical codes that cover the full life data cycle, including acquisition, preparation, processing, aggregation, sharing, storage, archiving and destruction.

The ethical aspect of big data is dual in nature: on the one hand, technologies (including big data) help in many areas: medicine, finance, education, etc. After a few years, the patient will be invited to see a doctor as soon as symptoms appear. But people will have to live in a world where there will be no place for privacy and where their privacy will be limited.

In a global sense, the problem is how people will use the data they receive. Therefore, the critical importance of modern life starts playing mental and moral level of people. If the society and each its member lacks something in ethical background the negative consequences could spread in all over the world.

9.2. Big Data in Modern Buildings and Smart Cities

According to the United Nations, the world population will grow to 9.7 billion by 2050. Of these, 6.3 billion people will live in cities. For such a high pace of urbanization has two reasons. Firstly, people move from villages or other small settlements to large cities for better living conditions and living standards in general, for better paid jobs, etc. Secondly, people do not move within one country, but on a global scale: migrants from remote poor areas of developing or underdeveloped countries move to large countries, where again the standard of living is higher, better conditions, easier to find work or favorable conditions for visiting residents.

As cities grow, they become more and more difficult to manage.

Many workers are needed to serve each inhabitant, at the same time qualitatively and quickly, so that the standard of living does not fall, but only increases over the years. This need has become one of the reasons for the start of automation of various processes. Starting from fare payment and self-service checkouts in stores, and ending with road map management, management decision support, electronic housing, and communal services – these are examples of the implementation of smart city and smart building projects.

9.2.1. Introduction to Smart Cities

A smart city is a safe, sustainable (green) and efficient urban center of the future with advanced infrastructure of sensors, electronics and networks that drives sustainable economic growth and high quality of life. Many scientists who consider this concept from a scientific point of view emphasize the importance of human capital, modern infrastructure, and information technology.

The British Standard Institution (BSI) describes a smart city as: a combination of different systems (human, physical, information, and others) in the most efficient way to get as a result sustainable, highly intelligent, convenient, and comfortable future for the citizens of the city (McEwen & Hakim, 2014).

Information technology allows city government to interact directly with communities and city infrastructure, and monitor what is happening in the city, how the city is developing, and what ways can improve the quality of life. Using sensors integrated in real time, the accumulated data from urban residents and devices is processed and analyzed. The collected information is the key to solving problems of inefficiency. ICT is used to improve the quality, productivity, and interactivity of city services, reduce costs and resource consumption, improve communication between city dwellers and the state.

From an information technology point of view, a "smart city" is defined as a way to create more intelligent and efficient infrastructure elements: city administration, education and health systems, public order, transport infrastructure, and so on. From this point of view, at the heart of any "smart city" should be information. Information should be accumulated from various sensors installed on buildings and other smart city facilities. Data exchange should keep all the internal processes of the city connected, creating a single ecosystem. The data obtained from sensors must be used in such a way that the living conditions of citizens are stable and comfortable, as well as more economical. For the sustainable development of the city, a model of smart operational management is used.

Because "smart cities" is an innovative and popular topic in the modern world, there are many interpretations of what parts a "smart city" should consist of for its high-quality functioning, as well as how to describe it.

Some researchers studying the infrastructure of smart cities describe it as having the following distinguishing features or features (Perry, 2018):

- increasing attractiveness for investment and just life; creation of new jobs (this paragraph contributes to the implementation of the first paragraph, which indicates that the "smart city" is a complex and constantly improving system);
- an effective social and cultural environment (so that new residents do not feel the same, but retain their individuality); careful attitude to resources (both renewable, such as electricity, and non-renewable, such as water);
- optimization of traffic flows (since, due to the growing population, the pace of life of residents will also increase, therefore, the traffic flow will increase);
- so-called smart buildings, automated commercial services and "engineering infrastructure" (this term refers to the automation of daily events and actions of city residents: ordering a taxi, paying bills, buying groceries, paying transport fares, and so on).

This description of the infrastructure of smart cities clearly explains the essence: make the most of information technology (and constantly update technology, as in the IT field there is a very fast change of devices and methods to more modern ones) in order to provide new people who are increasingly arriving in large cities with a decent standard of living, a workplace and comfortable conditions in material terms for existence (in particular, the ability to automatically perform daily activities). What is included in the concept of "smart city" and what are its components is also an open question. Many scientists divide in their own way, and sometimes each scientist calls the same concept in his own way. After analyzing several such divisions, the following list of smart city components was formulated (Rayes & Salam, 2019):

1. **Smart economy**. The following concepts are used to describe this term: productivity, a clear definition of how private and public spheres are interconnected (and how divided), entrepreneurship development as a way improving the economic condition of the city, observing, and maintaining economic trends in society and the close connection of life with the economy.
2. **Smart people**, which are distinguished by: flexibility and mobility as the basis of a lifestyle, they are highly qualified professionals in in their chosen field, they are ready to learn all their lives, craving for new knowledge and skills, as well as the desire for self-improvement both in work and in personal life. The supremacy of reason and logic over emotions when it comes to making some important and responsible decisions.
3. **Smart living**. High level of social living conditions, health care, high level of medical services, continuous training.
4. **Smart Governance**. Systems that are essential in case of an emergency (fire, ambulance, police, etc.) should be available 24/7 without restrictions to all members of society, support for adoption solutions using digital infrastructure and the latest technologies, the availability of social public services for the provision of services, the control of the level of urbanization (to prevent overpopulation of cities with insufficient resources).
5. **Smart Mobility**. For residents, there should be absolutely no barriers to movement both within their city, country, and between countries. There should be enough resources so that any resident can maintain a high level of automation in their lives. It is important to monitor the safety of residents in various areas.
6. **Smart Environment**. Resource management: special attention to non-renewable resources, but also the control of renewable resources, such as control and reduction of electricity consumption, environmental protection and assistance in its restoration, regulation of air pollution and minimizing them.

The main goal of developing and implementing a smart city system is the need for better city management. To make the implementation of the system of "smart cities" more efficient, scientists use international standards to improve the quality of management.

9.2.2. Life Cycle of Smart Cities

To be able to comprehensively automate an entire city, you need to understand how the system develops, what stages of the life cycle it goes through. To The analyzed

stages of the life cycle of a “smart city” (which are like the stages of the life cycle of a simple city) were assigned the following stages:
1. development,
2. expansion,
3. stagnation,
4. decline.

1. **Stage of development of the city.** The first stage of the life cycle of a city is characterized by a situation where the area of housing, the amount of goods and resources is growing rapidly. At the same time, the number of residents and jobs “does not keep pace” with the development of resources and there is an excess of the latter. Usually at this stage, the emergence of city-forming enterprises occurs, the influx of investors into the city increases, the city becomes attractive for life. If we talk about such indicators as unemployment, it is almost absent, and sometimes completely absent at this stage of the city’s development. It can be noted that this stage is more characterized by a shortage of jobs than unemployment. The urban environment is improving at this stage at a very rapid pace. The very rapid and explosive growth of a smart city in the modern sense means that there will be an increase in the number of housings, public goods, jobs, and so on, together with a sharp increase in urban residents (the population will increase due to the very high rate of urbanization).

   In this context, it would be appropriate to mention one of the components of the “smart city” – “smart economy”, which will primarily adapt to the increase in urban population. “Smart economy” at this stage of the city’s development manifests itself as intensive construction, rapid growth of the city’s economy, making the city attractive for investment. As a result, there is no unemployment, and the comfort of living conditions, transport accessibility and infrastructure, on the contrary, are at the stage of active growth.

   The use of intelligent methods of city management allows you to control the ratio of production volumes, employment of the population and the flow of personnel to the city. A “smart city” is characterized by the existence of a single information system that manages the information flow in the city and controls the main indicators. However, no matter how attractive this phase of the city’s life cycle is, it physically cannot last long and passes into a phase of slowing growth (expansion).
2. **Stage of city expansion.** The next stage, which follows smoothly from the first, can be characterized as the state of the city, when the current number of jobs that can be provided to residents is not enough for everyone who wants to work. Because of this, unemployment arises, resources and vital goods begin to form a deficit. Infrastructure and businesses are no longer improving at the same pace as they were during the first stage of city development – much more slowly. At this phase of the development of the city, the city-forming enterprise usually stops its development (or greatly slows down the pace of development). Investors start

to lose interest in the city, resulting in a lack of funding to maintain public goods. The city is becoming less livable but still attractive to move to due to the availability of jobs, including highly paid. If this phase is maintained without improvement for a long period of time, the city gradually passes into the next stage of the life cycle – stagnation.

3. **Stage of city stagnation**. Stagnation is a stagnation in the economy, production, public life, etc. From the name of this phase, it is clear what happens to the city in this phase. The gap between the number of jobs and those willing to work is widening. The amount of goods, resources and money in the city stops growing, and is also very insufficient for the current number of residents. Since unemployment is increasing and the attractiveness of jobs in unprofitable enterprises does not cause a desire to stay in this city, people begin to plan to move to other places. The state of the urban environment sharply is deteriorating, the attractiveness of the city for moving to it is extremely low. Such a state of the city in a long period without improvement leads to the transition of the city to the final stage of the life cycle.
4. **Stage of decline of the city**. This stage is considered final. It is characterized by the discomfort of the urban environment: housing conditions are poor, the number of resources is insufficient, there are no jobs, the ecological situation adversely affects the lives of people in this place. The unemployment rate reaches such limits that people stop seeing prospects in this city and start migrating, looking for more profitable places to live. Businesses close, go bankrupt, investors don't pay any attention to the city. The state of the infrastructure is at the lowest level. Cities at this stage of development are called "depressed". These are cities that are not able to cope with the situation in which they find themselves and are no longer able to get out of such a strong decline without the help of the state. However, it is unprofitable for the state to invest resources in "depressed" cities because they become centers of social tension not only within themselves, but also seize nearby territories. The state prefers to permanently liquidate such cities.

9.2.3. Biggest Smart Cities

As of 2019, 278 smart city implementation projects have already been implemented in the world. To rank the „smartest cities" in the world, ratings were used from four independent companies from different countries: Forbes, PwC, Juniper Research (international market research agency) and EasyPark (Swedish IT- company).

Singapore is present in all the ratings considered, and in the rating from Juniper Research it ranks first. The core element of a smart city in Singapore is smart traffic. In this city-state intellectual solutions are implemented in both personal and public transport. Examples include smart traffic lights, the main task of which is to minimize traffic jams and congestion, as well as road sensors, which constantly measure traffic density and adjust the entire transport infrastructure to this. Another example of smart traffic can be called „smart parking", which also uses a variety of sensors to register the number of free spaces in a particular parking lot, sending this information in a convenient form to the application. The user on the way can assess the state of the parking lot and change the route, if necessary.

Also, Singapore has already launched unmanned vehicles on its roads, and by 2020 all motorists are required to install a navigation system that tracks the position of the car. The city has developed the concept of „Virtual Singapore": a 3D simulation on which tests can be carried out. For example, plan the evacuation of the city in case of an emergency.

Another important aspect of a smart city is the wise use of resources. The Singapore government is trying to optimize water costs and reduce dependence on Malaysia, from where the city imports fresh water. To do this, blocks of Singapore are equipped with sensors that can track the consumption of electricity, water, and other indicators in real time. One of the blocks, for example, is already equipped with a vacuum waste management system and solar panels to generate electricity. All this not only allows you to save money, but also teaches you to take care of resources. As for healthcare, Singapore is introducing smart technologies in this area. Since 2014, the city has been testing a voluntary monitoring system for the elderly. Special sensors were installed in their apartments and on the doors to track the movement of elderly people. When the system determined that a person was motionless for a long time, she warned relatives and medical specialists about this.

London is in second place in the overall ranking. It has become one of the smart cities thanks to its large data center and high-tech solutions to traffic problems. Since London was among the first cities in Europe to face huge uncontrolled traffic on the roads, the authorities of this city have long begun to fight traffic jams and rebuild the transport infrastructure. A smart parking system (like the one in Singapore) has been in place in London since 2014. In addition, since 2002 there has been a system of payments for road congestion, which has now become completely digital (the driver pays for the right to use a car in a traffic-laden zone on weekdays). Since the metro schemes in London are very confusing, and the distances around the city often must be covered with transfers on public transport, so that residents can more comfortably plan their trip, various applications have been developed that build routes around the city. In particular, the SmartLondon system. Statistical analytical system allows you to identify the most fire hazardous houses. Modeling of each area of the city is made up of 60 criteria, including demographic, geological and historical data. In addition, for 1 sq. km of London accounts for over 300 outdoor video surveillance cameras.

New York. This city was added to the rating because of its advanced security systems: the city is covered by a network of video cameras; sensors are installed on the streets that record sound vibrations from shots and send a signal to the police. There is also a modern fire prevention system. BigBelly smart trash bins are installed in the city center – they are equipped with sensors that tell you when it's time to send a garbage truck for them. Also, smart technologies used for street lighting. The system collects data on the congestion of streets and highways and selects the optimal mode of operation of the lamps.

Barcelona, like the previous cities on the list, uses intelligent parking and traffic systems to monitor congestion. However, this city stands out as "smart" for another very important reason. Barcelona actively uses solar energy. In 2000, the Solar Thermal Decree required all large buildings to produce their own hot water, and in 2006, the city mandated the use of solar water heaters.

In addition, Barcelona stands out for its public transport network. It's one of the cleanest in the world, thanks to its fleet of hybrid buses, as well as the Bicing smart bike initiative, which gives you access to over 400 bike stations through an annual subscription or phone payments.

The city authorities even take out the garbage from the streets "in a smart way." The following system has been introduced in the city: the container is equipped with ultrasonic sensors that give a signal when it is full, this allows significantly save the fuel of garbage trucks and the working hours of city services.

The main "smart" system in Barcelona is Sentilo. 550 sensors – devices for monitoring water supply, light, energy, traffic conditions, noise levels and so on – they collect information about the situation in the city. All data is public and this means that they not only help the authorities to plan development, but also provide a good basis for the development of independent commercial companies.

Copenhagen. The capital of Denmark has taken the top spot in the EasyPark ranking. Copenhagen has the unofficial title of "the most cycling city in Europe", as the cycling infrastructure is very developed here. In Copenhagen, "smart" technologies are used in the field of street lighting and house management. In 2017, a project was launched to equip bicycles with sensors, the main task of which will be to collect and transmit information about the level of road pollution and traffic.

In the same year, the Copenhagen authorities and Hitachi created an "urban data exchange base". Now any individual and legal entity, from an ordinary citizen to the administration of the capital, can place their data here. It looks like the cooperation of social institutions: society, police, administration, and emergency services.

Oslo strives for a progressive and cleaner life. The city authorities monitor the consumption of resources: thus, the city currently uses 65,000 LED lamps, they not only reduce the amount of energy consumed, but also independently regulate the degree of lighting. When it is foggy in the city, such bulbs shine more brightly, when it is light – on the contrary.

In the Norwegian capital, authorities are planning to build an additional 37 miles of bike lanes and ban cars from the city center to get rid of traffic and allow residents to commute comfortably to work. In Oslo, waste is one of the main fuels, and both industrial and standard waste are used. Because the city uses so much waste for fuel, their supply was exhausted in 2013 and the authorities had to import garbage due to frontier. In the future, Oslo aims to reduce fuel emissions by 50%.

9.3. Understanding Security in IoT

Today, there are billions of devices connecting the world to the Internet, and in a short time this number has increased by tens of percent, making the IoT the largest object of attack on the planet. Already, exploits and malware are being developed, deployed, and distributed globally, making life difficult for countless businesses, networks, and individuals.

IoT instances are a separate problem, the security of which was thought of last. Often, systems as simple as sensors are so limited that implementing the industrial-grade protection mechanisms traditional for PCs is too difficult, and sometimes even impossible.

The most important thing about security is to apply it at all levels: from sensors to communication systems, routers, and cloud platforms.

9.3.1. The Main Definitions of Cybersecurity

Here is the list of most popular definitions from cybersecurity area, adopted from (Perry, 2018):

- **Botnets** – hacked and infected devices connected to the internet are controlled to perform joint tasks – usually to send requests in unison to generate huge traffic from different clients. It is also possible to send spam and spyware;
- **brute force** – gaining access to the system or breaking the encryption by trial and error;
- **buffer overflow** exploits a bug or defect in the running software by sending data to a buffer or block of memory that exceeds the allocated space. This allows other information stored in adjacent addresses to be overwritten. An attacker can place malicious code there and execute it by redirecting the current instruction pointer to it. Compiled languages such as C and C++ are especially prone to buffer overflows because they have no internal protections. Most of these errors are due to poorly written code that does not check the bounds of input values;
- **power correlation analysis** is a four-stage attack that allows you to detect secret cryptographic keys stored on the device. First, the dynamic power consumption is analyzed; metrics are recorded for each phase of the normal encryption process. Then the target device is sent for encrypt a few simple text snippets and record energy consumption. Next, small segments of the key (subkeys) are cracked by searching through all possible combinations and calculating the Pearson correlation coefficient between the simulated and real current. At the end, the most successful subkey is collected, which is used is used to obtain the whole key;
- **dictionary brute-force** – hacking the network by systematically entering usernames and passwords from a ready-made dictionary;
- **DDoS attack** – an attempt to disrupt the operation of an Internet service or make it inaccessible by sending it many requests from different (distributed) sources;

- **Fault injection** – This attack consists of sending defective or non-standard data to the device and observing its reaction. For example, if a device starts to perform poorly or shows signs of failure, an attack could reveal a weak point;
- **A man-in-the-middle** attack is a common type of attack that involves placing a device in the middle of a communication flow between two unsuspecting parties. The device monitors, filters and isolates the transmitted information by sending receiving party its modified copy. An attacker can act from the inside, acting as a relay, or simply listen to the data from the outside, leaving it unchanged;
- **NOP-shift** is a sequence of NOP assembler instructions that allows you to „shift" the pointer of the current processor instruction to the area of malicious code. Usually part of a buffer overflow;
- **replay attack** – a network attack with malicious repetition or cyclic reproduction of data by the original sender or an attacker who intercepts, stores, and transmits this data at his own discretion;
- **remote code execution exploit** – allows an attacker to execute arbitrary code. Usually occurs as a buffer overflow over HTTP or other network protocol with the introduction of malicious code;
- **a rootkit** is usually malicious software (although often used to unlock smartphones) that hides the presence of other programs. Rootkits use several highly specialized techniques, such as buffer overflows in kernel components, the hypervisor, and user applications;
- **third-party attack** – extracting information from the victim's system by observing indirect signs of its physical activity; does not imply the search for fresh vulnerabilities or the selection of exploits. Side channel attack includes correlation analysis of power consumption, acoustic analysis, and residual reading. Any data after their removal from memory;
- **spoofing** – an attacker pretends to be another user or replaces a device on the network;
- **Zero-day vulnerabilities** are security holes or bugs in commercial/industrial software that are unknown to developers or manufacturers;
- **Address Space Layout Randomization** is a mechanism for protecting memory and preventing buffer overflow attacks. It makes unpredictable the choice of memory location for loading an executable file, malware, injecting its code after a buffer overflow does not know where it will be loaded, so managing the pointer to the current instruction becomes extremely difficult. ASLR also protects against a library return attack;
- **black hole (or funnel)** – when a DDoS attack is detected, routes are created that direct malicious data from a DNS server or IP address to nowhere. Funnels perform additional analysis to filter out useful data;
- **Data Execution Prevention** – marks areas of memory as executable and non--executable. This prevents an attacker from executing code injected into such areas because of a buffer overflow. The result will be a system error or exception;

- **Deep Packet Inspection** – analyzes each packet (its body and, possibly, header) in the data stream to isolate instructions, viruses, spam and other information filtered by certain criteria;
- **a firewall** is a network security mechanism that allows or blocks the flow of packets between trusted and untrusted zones. Access control lists, or ACLs, can be used to control and manage traffic on specific routes. The firewall can perform stateful filtering and enforce rules based on target ports and traffic state;
- **safe address spaces and non-executable memory** – protects non-executable memory areas that are writable. Protects against NOP shifts;
- **honeypot** – a tool for detecting, redirecting, or reverse-engineering malicious attacks. The honeypot looks like a normal website or network node, but it is isolated and subject to close monitoring. Data and requests entering the device are logged; instruction-based memory access control – a technique for separating data about the returned address inside the stack. Helps protect against ROP attacks and is especially useful in constrained IoT systems intrusion detection system – IDS (English Intrusion Detection System) (network mechanism for detecting network threats through out-of-band analysis of the packet flow) is not tied to the source or destination, therefore it allows you to respond in real time;
- **intrusion prevention system** – blocks network threats using full-fledged linear analysis, statistical methods of detection and filtering by signature;
- **a fake botnet** is a tool that emulates an infected device. Connects to the control server and receives malicious commands that it sends to its botnet;
- **port scanning** – a technique that allows you to find open and available ports on a local network;
- **public key infrastructure** – defines hierarchical mechanisms that guarantee the authenticity of the origin of the public key. The certificate is signed by a certification authority;
- **public key** – generated using the private key and available to external clients. The public key can be used to decrypt hashes;
- **private key** – generated using the public key and never exposed to the public. Stored in a secure location and used to encrypt hashes;
- **the root of trust** – is launched at the very beginning of the device boot and is in an immutable, trusted memory area (such as ROM). If the BIOS or bootloader is available for uncontrolled modification, the root of trust is lost every meaning. RoT is usually the first step in a multi-stage secure boot;
- **secure boot** – a sequence of steps for booting a device. Starts at the root of trust and goes through OS and application startup; each component must be authentically signed. Signatures are verified using the public keys loaded in the previous steps;
- **stack indicators** – protect the stack from overflow and prevent the execution of code placed on the stack;
- **a secure runtime environment** is a secure area of the processor where code and data are protected. Typically, this runtime resides in the core of the main

processor and ensures that secure boot, money transactions, and private key operations are performed at a higher level of security than normal code.

9.3.2. Examples of Cyberattacks

Since the Internet of things consists of hardware networks, protocols, signals, cloud components, frameworks, operating systems, and everything that connects them, all exploits, and attacks on IoT devices can be divided into three main types (Rayes & Salam, 2019):

- Mirai is the most destructive DDoS attack in history, triggered by poor security of IoT devices in remote areas;
- Stuxnet is a government cyberweapon that targets IoT devices in SCADA systems. Caused significant and irreparable damage to Iran's nuclear program;
- Chain Reaction is a research technique for exploiting personal networks. Uses devices like smart light bulbs and does not require an internet connection.

Mirai is the name of a malware that infected Linux-based IoT devices in August 2016. The attack was carried out from a botnet that generated a huge DDoS load. The most notorious victims included Krebs on Security (a popular security blog), Dyn (a very popular and in-demand DNS provider) and Lonestar (a major cellular operator in Liberia). Less significant targets included Italian political websites, Minecraft servers in Brazil, and Russian online auctions. Indirect victims of the DDoS attack on Dyn were its customers, among which were such huge services as PlayStation Network, Amazon, GitHub, Netflix, PayPal, Reddit and Twitter. A total of 600,000 devices were infected and became part of the botnet. The Mirai source code was published on the **hackforums.net** hacker forum. By analyzing it, as well as using tracing and studying log files, the researchers revealed the principle of operation and the chronology of the attack:

- **victim search** – fast asynchronous scanning using TCP SYN packets and checking arbitrary IPV4 addresses. The malware paid special attention to TCP port 23, which belongs to SSH/Telnet, and port 2323. If a suitable port was found, the second stage began. Mirai has a built-in blacklist of addresses to avoid. It contained 3.4 million records belonging to the US Postal Service, Hewlett Packard, GE, and the US Department of Defense. The scanning speed reached 250 bps. For a botnet, this is slow. Attacks like SQL Slammer generated scan queries at 1.5 Mbps. The fact is that IoT devices have much more modest computing capabilities compared to desktop and mobile computers;
- **simple Telnet brute-force** – at this stage, the malware tried to establish a working connection with the victim via Telnet by sending 10 randomly selected login-password pairs from a list of 62 pairs. If successful, the hacked computer connected to the C2 server. Later variants of the Mirai learned how to perform RCE exploits;

- **infection** – the server passed to the potential victim a loader program that was responsible for determining the version of the operating system and installing malware tailored for a specific device. The loader then looked for and terminated any competing processes that were using ports 22 or 23 (including other malware that might be on the device). After that, the bootloader was removed, and the process name was masked to hide its presence. The malware was not stored on persistent storage and disappeared after a reboot. At the end, the bot would go to sleep waiting for further commands.

Mirai's victims included IoT devices such as IP cameras, DVRs, consumer routers, IP telephony, printers, and digital set-top boxes. The malicious binaries supported 32-bit versions of ARM, MIPS, and x86.

Stuxnet is the first documented cyberweapon designed to damage the assets of another country. It was a worm that targeted Siemens Programmable Logic Controllers, or PLCs, based on SCADA. He used a rootkit to change the rotation speed of the motors directly controlled by the PLC. The creators of this virus have done everything to ensure that it attacks only devices with driven frequency-controlled drives, which are connected to Siemens S7-300 PLC modules and rotate at 807 Hz or 1210 Hz, as they are commonly used in pumps and gas centrifuges for uranium enrichment.

The attack began in April or March 2010. The infection process consisted of the following steps:

- **initial infection** – the worm first infected a Windows computer using vulnerabilities found in previous virus attacks. It is believed that this was done via a USB disk connection. At the same time, several zero-day exploits were used at once (unprecedented sophistication). The exploits ran the rootkit in user and kernel mode and then installed a device driver with the correct certificate stolen from Realtek. A kernel-mode driver was needed to hide Stuxnet from various antivirus packages;
- **attack on Windows and distribution** – after installation through a rootkit, the virus began to search the Windows system for files related to the Siemens SCADA controller version WinCC / PCS 7, also known as Step-7. If successful, the worm tried to connect to the C2 server over the Internet using fake URLs to update to the latest version. He then searched the disk for a file called s7otbdx.dll, which was an important communication library for communication between Windows and the PLC. The Step-7 controller included a built-in password database, which was hacked using another zero-sum exploit day. Stuxnet intruded between the WinCC system and s7otbdx.dll, performing a man-in-the-middle attack. First, the virus recorded information about the normal operation of centrifuges;
- **destruction** – when it was decided to coordinate the attack, the virus played back the pre-recorded data and sent it to the SCADA controllers, who were unaware that the system was compromised or was behaving unusually. The damage

was done in two different coordinated attacks based on PLC manipulation, resulting in damage to the entire uranium enrichment complex. Every 27 days, the centrifuge rotors were run for 15 or 50 minutes, causing them to gradually wear out and crack in their shafts. In addition, the enrichment process was disrupted.

The attack on Iran's main uranium enrichment facility at Netanz is believed to have disabled more than a thousand centrifuges. Since then, the Stuxnet code has become public domain and has become a kind of playground for creating derivative exploits (github.com/ microphone/stuxnet).

Chain Reaction is an academic study of a new type of cyberattack that targets personal mesh networks without an internet connection. It also shows how vulnerable remote IoT sensors and control systems can be. The target of the original attack was Philips Hue light bulbs, which can be found in so-called smart homes with support for control via the Internet or mobile applications.

The exploit can scale up to attack entire smart cities – enough just screw in one infected light bulb. Philips Hue light bulbs raise a mesh network based on the Zigbee protocol, which is part of the Zigbee Light Link (ZLL) initiative to ensure interoperability between different lighting methods. ZLL messages are not encrypted or signed, although cryptography is used to protect the keys exchanged when a light bulb is added to a mesh network. As a result, the master key, known to all members of the ZLL consortium, was leaked.

In addition, according to the ZLL standard, the light bulb to be connected must be near the initiator, which prevents it from taking control of the light bulbs of its neighbors. The Zigbee protocol also provides a contactless method for flashing devices, although firmware packages are encrypted and digitally signed. The attack plan that the researchers conducted consisted of four stages:

- crack the encryption and digital signature of the firmware package;
- write and deliver an infected firmware update to a single bulb using cracked encryption and keys;
- the compromised light bulb will join the network using the master key stolen earlier and bypass the proximity-based protection using a zero-day defect found in the widespread Atmel AtMega component;
- after successfully connecting to the Zigbee mesh network, the malicious code will be sent to neighboring light bulbs, which will lead to their rapid infection. The spread of the virus will occur according to the theory of percolation and will cover all lighting fixtures in the city.

To encrypt contactless firmware updates, Zigbee uses AES-CCM. To crack it, the attacker uses correlation and differential power analysis (Correlation Power Analysis [CPA] and Differential Power Analysis [DPA]). This is a sophisticated form of attack that involves placing a light bulb on a special stand and measuring the energy it consumes. Given advanced controls, it is possible to measure the dynamic power consumption of a processor that is executing an instruction or moving data (for example, while an encryption algorithm is running). This is a simple power consumption analysis that leaves little chance of breaking the key. The CPA and DPA methods are more advanced and use statistical correlation. Instead of trying to recognize individual bits, CPA can operate on whole bytes. Power indicators are taken using an oscilloscope and are divided into two sets depending on the intermediate value that is hacked: in the first it is 1, and in the second it is 0. The real value is calculated by subtracting the average from these sets.

Using DPA and CPA, the researchers were able to hack the Philips Hue lighting system:

- the CPA method was used to crack AES-CBC. The attacker had no key, no random number, no initialization vector. Thanks to this approach, a key was obtained, which was then used using the same method to crack a random number;
- the DPA method was used to crack the AES-CTR counter mode and subsequently the encryption algorithm that was used when packaging the firmware. The researchers found 10 sites in which the AES-CTR mode was presumably performed, leaving 10 potential solutions;
- the researchers then focused on breaking Zigbee's proximity-based security to connect to the network. As a result of studying the source code of the bootloader that was used in the Atmel chip, a zero-day vulnerability was found. At the time of sending a scan request to Zigbee, the check for remoteness passes successfully. To get around it, it was enough to start the session with any other message.

This allowed the researchers to connect to the network. A real attack could cause a hacked light bulb to infect its neighbors within a 100-meter radius by giving them malicious code to disable updates so they can't be restored. In effect, the light bulbs would be under the control of an intruder and would have to be destroyed. The researchers were able to create a fully automated attack system and attach it to an unmanned aerial vehicle that systematically circled within range of Philips Hue bulbs on campus and infected each one.

9.3.3. Device and Physical Security

The first level of hardware security is to **establish a root of trust** (RoT). RoT is a hardware-authenticated boot process that ensures that the source of the first executable instruction cannot be changed. This is a key step in the boot process and is involved in the further startup of the system – from the BIOS to the OS and applications. RoT is the basic protection against rootkits. Each stage of the download process authenticates the next stage, thus forming a chain of trust.

The root of trust can be used different launch methods (Perry, 2018):

- loading image and root key from firmware or immutable memory;
- storing the root key in a one-time programmable memory using fuse bits;
- loading code from a protected memory area into a protected storage.

The root of trust must authenticate each subsequent download step. To do this, at each stage, a set of keys with a digital signature is used.

Public and private keys are the key to a secure system. A proper management mechanism is required to protect them. One of the most popular hardware key protection standards is TPM (Trusted Platform Module). Its specification was created by the Trusted Computing Group and is part of ISO and IEC. The current version of TMP 2.0 was released in September 2016. Equipment supplied to the US Department of Defense must support TPM 1.2.

The TPM is a separate hardware component with an RSA key embedded at the manufacturing stage. Typically, TPM is used to store, protect, and manage keys in scenarios such as disk encryption, trust root boot, hardware and software authentication, and password management. The TPM can generate a hash of a verified hardware or software configuration that can help detect third-party tampering at runtime. This technology is also used in creating SHA-1 and SHA-256 hashes, AES block encryption, asymmetric encryption, and random number generation.

The two **main protection mechanisms in the CPU and OS**, which noteworthy are non-executable memory and address space layout randomization. Both are designed to make it harder or to prevent the process of injecting malicious code based on a buffer or stack overflow (Perry, 2018):

- **non-executable memory** is a hardware mechanism by which the operating system makes memory regions non-executable. The goal is to ensure that only areas of memory that contain verified and genuine code can be executed. When malware attempts to inject via a stack overflow, the system will mark the corresponding section as non-executable, because of which the current instruction pointer shift to this section will result in a hardware exception. The marking of non-executable memory is done using the NX bit (via the associative translation buffer). On Intel and ARM platforms, this bit is called XD (English eXecute Disable – turning off the completion) and, accordingly, XN (English eXecute Never – never execute). This technology is supported on most operating systems such as Linux and Windows, as well as on some real-time systems;
- **address space allocation randomization** – ASLR is more of a feature of virtual address space handling in the operating system than a hardware feature, but it is also important to consider. This technology protects against buffer overflows and library return attacks. Such hacking techniques require the attacker to understand the structure of memory and involve the deliberate execution of certain benign code or libraries. This is not an easy task, especially if the address space changes randomly on every boot.

Many IoT devices use persistent storage at the edge or router/gateway. Smart fog nodes also need somewhere to store their data. **Data security** is key to preventing the installation of malware and protecting sensitive information if your device is stolen. Many storage devices, such as flash drives and hard drives, support encryption and security technologies. In addition to encryption, you should also take care of the security of drives being decommissioned. Retrieving content from older storage systems is a relatively simple task. There are additional standards that describe the safe process of deleting data from a drive (whether it be a magnetic platter disk or phase change memory). In addition, the NIST Lab publishes documents on the secure destruction of content, such as the NIST Special Publication 800-88 for Secure Erase".

Penetration resistance and physical security play an important role in the Internet of Things. Many IoT devices are hosted remotely, without any protection. An attacker with direct access to an IoT device can use any tool to compromise the system, as we saw with the Chain Reaction exploit.

An example of a side-channel attack using power analysis has already been presented; hacking can also be done based on time, cache, electromagnetic field radiation and scan chain. The main feature of attacks by third-party channels is that a hacked device, in fact, turns into a test site. This means that it will be monitored in a controlled environment and its activity will be measured in every possible way. In addition, techniques such as DPA use statistical analysis to infer patterns between random input and output. This approach is applicable only if the system exhibits identical behavior with the same input.

Techniques for preventing these attacks are well known and can be licensed and used on a variety of hardware. Countermeasures include the following:

- changing the encryption function to minimize key usage. Using keys valid only for the duration of the current session and based on the hash of the original key;
- for timing attacks: random insertion of functions that do not break the algorithm;
- using random machine instructions to create a large working function that is hard to crack;
- removal of conditional branches that depend on the key;
- for power-based attacks: minimizing leaks and limiting key operations. This will reduce the attacker's working set of metrics;
- interference in power lines. Variation in the execution time of operations or shifting of timers;
- changing the order of independent operations. This reduces the degree of correlation around the calculations in the S-box.

9.3.4. Encryption

Encryption and secrecy are mandatory for IoT devices. They help secure the interaction by protecting the firmware and the authentication process. Encryption can be divided into three main categories (Perry, 2018):

- **symmetric encryption** – the same key is used for encryption and decryption. Symmetric algorithms are RC5, DES, 3DES and AES;
- **public key encryption** – the key used to encrypt data is publicly available. But only the receiving party has the private key to decrypt the message. This type

of encryption is also called asymmetric. Asymmetric cryptography is used to provide data privacy, authentication, and non-repudiation. Public keys are used in well-known Internet protocols for encryption and messaging, such as Elliptic Curve, PGP, RSA, TLS, and S/MIME;

- **cryptographic hashing** – binds data of arbitrary size to a bit string (called a digest). A hash function is created „one-way" from the start. In fact, the only way to recreate the final hash is to try all possible input combinations (the hash function cannot be performed in reverse). Examples of one-way hashes are MD5, SHA1, SHA2, and SHA3. They are commonly used to encrypt digital signatures in firmware images, imitations, and authentication. When encrypting small strings, such as a password, the input may be too short to produce a valid hash; in this case, a salt or a public string is added to the password to increase entropy. Salt is a kind of key derivation function (KDF).

In cryptography, terms such as plain text and ciphertext are used, which denote unencrypted input and, accordingly, encrypted output. The current encryption standard is AES (Advanced Encryption Standard); it replaced the old DES algorithm developed in the 1970s. AES is part of the FIPS specification and the ISO/IEC standard 18033-3 which are used all over the world. AES algorithms are based on fixed length blocks of 128, 192, or 256 bits. Messages that exceed the block length are split into several parts. AES consists of four basic encryption steps.

Block ciphers are algorithms that are based on a symmetric key and process data in sequential blocks. Modern ciphers are based on an article on industrial encryption written by Claude Shannon in 1949. An encryption mode is an algorithm that describes the repeated use of a block cipher to transform large amounts of data consisting of many blocks.

Majority Modern ciphers use an Initialization Vector, or IV, which turns the same input into a different ciphertext each time. The AES algorithm has several modes of operation:

- **Electronic Codebook**, or ECB is the simplest type of AES encryption; it is used in combination with other modes to improve security. The data is divided into blocks, each of which is encrypted separately. Identical blocks produce the same result, making this approach relatively unreliable;
- **Cipher Block Chaining**, or CBC – before encryption, the plain text is XORed with the previous encrypted block;
- **ciphertext feedback**, or CFB- similar to CBC, but forms a stream of ciphers (the output of the previous cipher serves as input for the next one). CFB uses the previous encrypted block to generate input for the current cipher. Because of this dependency, CFB cannot be executed in parallel. Stream ciphers allow block loss in transmission; in this case he will be restored based on subsequent blocks;
- **output feedback chaining**, or OFB mode – this mode is like CFB but allows you to apply error correction codes even before encryption;

- **Counter**, or CTR – turns a block cipher into a stream cipher using an incremental counter that parallelizes the input to each block cipher, which speeds up execution. The input is a combination of a counter and a randomly generated number;
- **Message Authentication Code**, or MAC is used to authenticate a message and confirm that it came from the claimed sender. The recipient then adds a mock insert to the message for later authentication.

AES-CCM uses a double cipher: CBC and CTR. AES-CTR (or counter mode) is used for general decryption of an incoming ciphertext stream that contains an encrypted spoof. AES-CTR decrypts both the simulation inserts and the data itself. At this stage of the algorithm, the so-called expected imitation insertion is formed; the original frame header and the decrypted blocks output from the AES-CTR are marked as input. The data is decrypted, but authentication requires a spoof that is computed in AES-CBC; if it is different from what is expected during the AES-CTR stage, this means that the data may have been changed during transmission.

Asymmetric cryptography is also called public key encryption. Asymmetric keys are generated in pairs (for encryption and decryption); they can be interchangeable – that is, one key can encrypt and decrypt, although this is not a requirement. But usually, a pair of keys is generated – one public and the other private.

The first public-key asymmetric encryption method was described in the **Rivest-Shamir-Adleman (RSA) algorithm**, developed in 1978. It implies that the user must find and publish the product of two large prime numbers and an auxiliary value (public key). The public key allows messages to be encrypted and is available to anyone, but the prime multipliers remain private.

Perhaps the most well-known type of asymmetric key exchange is the **Diffie-Hellman protocol** (named after Whitfield Diffie and Martin Hellman). Typical for asymmetric cryptography is the concept of a one-way function with a Trapdoor Function, which takes a given value A and returns an output B; but in this case, A cannot be obtained from B. The Diffie-Hellman method allows both parties to exchange keys without knowing in advance about the shared key s.

The strength of this key exchange is the generation of a truly random number for each private key. The slightest predictability in the operation of the pseudo-random number generator can lead to breaking the cipher. However, the fundamental disadvantage here is the lack of authentication, which opens up the possibility of a MITM attack.

The third type of encryption technology is hashing functions. They are commonly used to create digital signatures and are considered “one-way” – with no way to reverse. To recreate the original data that passed through the hashing function, one would have to iterate over all possible combinations of input. Key features of the hash function:

- always generates the same hash from the same input; fast in computation, but not instantaneous;
- irreversible;
- cannot generate the original message from the hash;

- the slightest change in input causes significant entropy and completely changes the output;
- two different messages will never have the same hash.

Algorithms of the SHA family are actively used in:

- Git repositories;
- digital signatures of TLS certificates for web browsers (HTTPS);
- authenticate the contents of a file or disk image.

Most hash functions are based on the Merkle-Damgard structure. The example below splits the input into blocks of the same size, each of which goes through a compression function using the compression results of the previous block. An initialization vector is used to select the initial value. Thanks to the compression function, the hash is resistant to collisions.

The SHA-1 algorithm is based on the Merkle-Damgard structure. In general, messages that are fed into the SHA algorithm should be less than 264 bits. They are sequentially processed in 512-bit blocks. The SHA-1 standard has been superseded by more robust versions such as SHA-256 and SHA-3. The possibility of "collisions" was found in SHA-1 hashes; and although for This requires approximately 2^{51} to 2^{57} operations, cracking the hash on a rented graphics adapter will cost only a few thousand dollars. In this regard, it is recommended to switch to other varieties of SHA.

Asymmetric cryptography (with a public key) is the basis of trading and interaction on the Internet. It is ubiquitous in SSL and TLS connections. A typical example is when the transmitted data can be encrypted with the public key (that is, by anyone), but it can be decrypted by the person who owns the private key.

Another use is with digital signatures, where the sender signs binary data with a private key, and the recipient can verify their authenticity if they have the public key. To establish a reliable issuance of public keys, a process called public key infrastructure (English Public Key Infrastructure, or PKI) is used. Authenticity is guaranteed by certifying centers (English Certificate Authorities, or CA), which manage roles and rules, creating distributed digital certificates.

The largest public publishers of TLS certificates are Symantec, Comodo and GoDaddy. Public key certificate formats are described by the X.509 standard. This is the basis for secure communication in the TLS/SSL and HTTPS protocols. X.509 defines attributes such as the encryption algorithm used, expiration dates, and the issuer of the certificate.

Transport Layer Security, TLS, has incorporated all the cryptographic protocols and technologies that we have already discussed. Initially, the level of secure sockets (eng. Secure Sockets Layer, or SSL) was introduced in 1990, but after 9 years it was replaced by TLS technology. TLS 1.2 includes the SHA-256 hash generator, which was added in place of SHA-1 to improve security.

The encryption process in TLS is as follows:

1. the client opens a connection to a server that supports TLS (port 443 for HTTPS);

2. the client provides a list of ciphers it supports;
3. the service selects the cipher and encryption function and notifies the client;
4. the server transmits to the client a digital certificate issued by a certification authority and containing a public key;
5. the client confirms the authenticity of the certificate;
6. One of two methods is used to generate the session key:
   - a random number is sent to the server, previously encrypted using its public key. The server and client then create a session key based on it, which is used throughout the interaction;
   - The session key for encryption and decryption is generated using the Diffie-Hellman protocol. The resulting key is used until the connection is closed.
7. the interaction goes into an encrypted channel.

9.3.5. Blockchain and Cryptocurrency in IoT

Blockchain is a public, digital, decentralized registry (ledger) or a chain of cryptocurrency transactions. The first cryptocurrency blockchain is Bitcoin, but in addition to it, there are more than 700 new currencies on the market. The strength of this technology lies in the absence of a single entity that controls the state of transactions. It also provides system redundancy, forcing each member to keep a copy of the registry.

Assuming that the participants in the system are not inclined to trust each other, their interaction should be based on consensus. This raises the question: why transfer data or currency on a blockchain if we have already solved the problems of authentication and security with asymmetric cryptography and key exchange? The fact is that the transfer of funds and valuable information requires something more.

Imagine that we have two devices (let's call them Bob and Alice). According to information theory, when Bob sends a message or piece of data to Alice, he keeps a copy of the transmitted information. When exchanging money or contracts, the data must leave the source and appear at the destination. They must exist in a single copy.

Authentication and encryption provide interoperability, but we a new tool is needed to transfer ownership. Secure blockchain-based cryptocurrencies are of great importance for the Internet of Things (Perry, 2018):

- **direct cash payments between devices** – the Internet of things should be ready to support devices that exchange services for currency;
- **supply chain management** – the immutability and security of the blockchain can come in handy in logistics, inventory, and movement of goods, making paper accounting unnecessary. All containers, movements, locations, and states can be tracked, verified, and certified. Attempts to change, delete, or change accounting information become impossible;
- **solar energy** – think of solar energy as a service. In this case, solar panels are installed on the roof of a residential building, which can not only generate electricity

for residents, but also supply it to the public grid (for example, in exchange for so-called carbon credits).

The part of Bitcoin that belongs to the cryptocurrency is not a blockchain as such. Bitcoin is an artificial currency, which has no value and is not backed by anything (unlike gold). It cannot be felt; it exists only within the network. And finally, the number of „coins" Bitcoin is not controlled by a central bank or government. It is a completely decentralized technology.

Like other blockchains, it is based on public key cryptography, a large and distributed peer-to-peer network, and a protocol that defines the structure of Bitcoin. In 2008, Satoshi Nakamoto (pseudonym) published a white paper in a cryptography mailing list entitled "Bitcoin: A Digital Peer-to-Peer Cash System." In 2009, the first Bitcoin network was launched, in which Satoshi generated the first block (Betts, 2016).

The concept of blockchain implies the existence of a block, which represents the current fragment of the ledger. A computer connected to a blockchain network is called a node. Each node participates in the authentication and transmission of transactions; to do this, he gets a copy of the registry and, in essence, becomes its administrator.

Distributed networks based on peer-to-peer topologies are ideal for Bitcoin. Metcalfe's law applies to the Bitcoin network since its size determines the value of the currency. The network keeps a chain of records (registry). The question arises: who would want to volunteer their computing resources to monitor a journal?

The answer is a mining-based reward system. First, a request is made, which is broadcast over a peer-to-peer (P2P) network of computers (nodes). This network is responsible for authenticating its users, during which the transaction itself is also verified. Then transactions are merged into a new block of data in a distributed ledger. Once filled, the block is added to the existing blockchain and is no longer subject to change.

Here is a qualitative analysis of the blockchain in general and the operation of Bitcoin in particular (Perry, 2018). It is important to understand these fundamental principles, which are based on all the security features that we covered earlier in this chapter:

- **digitally signed transaction** – Alice wants to give Bob 1 Bitcoin. The first thing to do is to announce it publicly. To do this, Alice writes the message „Alice will give Bob 1 Bitcoin" and confirms it with a digital signature based on her private key. Anyone with the public key can verify the authenticity of the message. However, Alice can repeat her message and thus counterfeit the money;
- **unique identification** – to solve the counterfeiting problem, Bitcoin creates a unique serial number, just like the US Treasury does on its banknotes. To do this, instead of a number that is assigned in a centralized way, a hash is used. This hash is automatically generated during the transaction and allows it to be identified. Another big problem is double spending. Even if the transaction is signed and has a unique hash, Alice can try to transfer the same bitcoin to other participants. Bob will validate the transaction initiated by Alice and everything will

fit. But if Alice performs the same transaction, only in relation to Charlie, she, in essence, will wrap the system around her finger. The Bitcoin network is very large, but the possibility of theft of funds in it, although insignificant, is still present. To protect against double spending, Bitcoin users accepting payments via the blockchain, awaiting confirmation. Over time, more and more confirmations appear, which increases the chance of successfully passing the test;

- **authentication by other nodes** – To avoid double spending on the blockchain, the recipients of the transaction (Bob and Charlie) transmit the payment information to the network and ask other participants to verify its authenticity. Such verification is not free of charge; proof of work – the problem of double spending is still not fully resolved. Alice can take control of the network with her own servers and claim that all her transactions are genuine.
- To eliminate this possibility once and for all, the **concept of proof-of-work** was added to Bitcoin. It has two aspects. First, verifying the authenticity of a transaction must be computationally intensive. It should be something more complex than matching keys, usernames, transaction IDs, and other trivial authentication attributes. Second, users should be rewarded for helping to confirm other participants' money transactions (see next step); to force users verifying transactions to do some work, a randomly generated number is added to the transaction headers. Bitcoin hashes this number, along with the header message, using the secure SHA-256 algorithm. This hash is called the target hash; it is less than 256 bits in size, and its content is constantly changing. The smaller this value, the more resources are spent searching for the original message. Because each hash essentially generates a completely random number, users must compute multiple SHA-256 values. On average, each value takes approximately 10 minutes.
- **Bitcoin Mining Incentives** – To encourage building a peer-to-peer network to verify other people's transactions, users are rewarded for their work. There are two ways. The first is through Bitcoin mining, which benefits participants who verify blocks with transactions. The second way is to pay a commission for the transaction. The miner gets the commission which helps to verify the authenticity of the block. Initially, the commission was equal to zero, but with the growth of the popularity of Bitcoin, it also began to grow. On average, a successful transaction is rewarded with $35 (in the form of BTC). If the block is processed in an accelerated mode, the commission can be raised. Thus, even after calculating all the hashes in the current generation of Bitcoin, users will have an incentive to support transactions;
- **Block chaining security**, the order in which transactions are executed, is also of great importance for the integrity of Bitcoin. If funds are transferred from Alice to Bob and then from Bob to Charlie, these events must be recorded in the ledger in that order. To do this, transactions in the blockchain are linked. Each new block that enters the network contains a pointer to the last block in the chain that was verified. In Bitcoin, a transaction is not valid until it is added to the longest chain, and until at least five other blocks are confirmed after it. This solves the asynchrony problem if Alice tries to pass the same funds to Bob and Charlie.

Recently, a new **cryptocurrency IOTA** has appeared, designed specifically for the Internet of things. Its architecture is based on a Directed Acyclic Graph (DAG), and the chain of trust is formed by the IoT devices themselves (Betts, 2016). Bitcoin provides a commission for each transaction.

There are no fees in IOTA. This makes it possible to conduct microtransactions, which is very important in the context of the Internet. of things. For example, multiple clients can subscribe to sensor readings via MQTT. Overall, this service has some value, but each individual transaction is so insignificant that the fees charged on the Bitcoin network would be higher than the cost of the data itself. The IOTA architecture has the following features:

- control over funds is not centralized;
- on the blockchain, users can form large groups to increase the number of blocks they can generate and the corresponding reward. This can lead to a concentration of influence and harm the network;
- no need for expensive equipment. Cryptocurrency mining on the Bitcoin network requires powerful processors that can handle complex calculations;
- micro- and nanotransactions at the level of individual IoT devices; reliable protection against hacking by simple enumeration, even if quantum computers are used; through IOTA, you can transfer not only currency, but also data. At the same time, there is full support for authentication and protection against substitution;
- in the IOTA network, the content of a transaction can be anything, so on its basis it is possible to build a national voting system that is protected from third-party interference;
- the role of a service can be performed by any device with a compact chip. IOTA allows you to rent anything: a drill, a personal router, a microwave oven, or a bicycle – all it takes is a small chip or microcontroller.

The DAG graph in IOTA is called a tangle and is used to store transactions in the form of a distributed ledger. Transactions are used by nodes (IoT devices) and make up a DAG tangle. If transactions A and B are not directly connected by a directed edge, but it is possible to pass from A to B a route no less than the distance between these two points, A is considered to indirectly confirm B. There is also the concept of a primary transaction. Since a tangle cannot be started by mining graph edges and there are no incentives or fees, each node must hold all the tokens; the primary event sends them to the founders' addresses.

This is the static set of all tokens new, which will never be replenished again. Each new transaction must confirm (or reject) the previous two; this process forms a straight edge in the graph and is called direct confirmation. To make a transaction, it is necessary to perform "work" on behalf of the tangle. The job is to find a random number (nonce) that matches the hash of the fragment of the confirmed transaction.

Thus, using IOTA, the network becomes more distributed and secure. Transactions can be confirmed many times. With the increase in their number, the confidence in their eligibility grows. When attempting to approve an unauthorized transaction, a node runs the risk of rejecting its own transaction and being kicked out of the tangle.

9.3.6. Improving IoT Security

On the Internet of Things, security must be considered from the very beginning, and not after the fact, after design or commissioning is completed – at these stages it will be too late. In addition, the approach to security should be comprehensive and cover all aspects: from hardware provisioning to the cloud. This section looks at a simple IoT project with security that permeates all its layers, from the sensor to the cloud infrastructure. We'll try to deploy it with different precautions to make it harder for potential attackers.

If you focus on any one aspect of the Internet of Things, the resulting security chain will have weak links. Security must permeate all levels of the system: from the sensor to the cloud. This is an integrated approach. Each component in the control and data chain must have checklist of security settings and potential threats.

Below is a list of time-tested recommendations and ideas related to security (Perry, 2018):

- Use the latest versions of operating systems and libraries with all necessary patches.
- Use hardware that supports security features such as secure runtimes, TPMs, and non-executable address spaces.
- Obfuscation of code in the hope that an attacker cannot unravel it is a relatively hopeless undertaking.
- Sign, encrypt and secure your firmware and software images – especially those available on the company's website.
- Choose the initial password randomly.
- Use root of trust and secure boot to ensure that your customers' devices are running genuine software.
- Remove passwords from the firmware code.
- All IP ports should be closed by default; use address space allocation randomization, stack indicators and safe memory segments that are supported in modern operating systems.
- Use automatic updates. Give manufacturers a mechanism to fix bugs and vulnerabilities in production systems. To do this, the software architecture must be modular.
- Plan decommissioning ahead of time. IoT devices can work for a long time and productively, but someday they will have to be disposed of. This includes safely removing and destroying all read-only memory (flash) modules in the device.
- Offer your customers and users rewards for found bugs – especially those that can lead to zero-day vulnerabilities.
- Subscribe to active threat alerts sent by US-CERT to stay up to date on the latest exploits and cyberattacks; building a project around simple (and insecure)

protocols like MQTT or HTTP might be tempting, but you should ship your devices with TLS or DTLS-based authentication enabled.

- Encrypt data from the sensor to the cloud.
- Use anti-debug fuse bits. Detonate them during production for safe debugging before release.

With well-known viruses such as Mirai and Stuxnet specifically targeting IoT devices, IoT system specialists must be concerned about the security of their architectures from the outset. The Internet of Things is an ideal environment for executing all sorts of attacks. Usually, systems of this type have less mature protection compared to PCs. IoT devices represent the largest attack surface on the planet, and the remoteness of some of them allows attackers to gain physical access to equipment unthinkable in a secure office environment. These threats require serious attention, as their consequences can affect individual devices, cities, or even entire countries.

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