Editor
Dorota Anna Krawczyk

BUILDINGS 2020+

Constructions, materials and installations

Bialystok - Cordoba - Vilnius 2019

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CONTENTS

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PREFACE

This book was developed by a group of teachers and scientists from Bialystok University of Technology (Poland), the University of Cordoba (Spain) and Vilnius College of Technologies and Design (Lithuania) working within the VIPSKILLS project (Virtual and Intensive Course Developing Practical Skills of Future Engineers) Erasmus+ 2016-1-PL01-KA203-026152.

The continual development of technologies, changing requirements in law regarding standard of new buildings' constructions reshapes European cities. The book explores relations between architecture, environmental and civil engineering. Collaboration in a process of buildings' design and construction is extremely important for further proper operation and thermal comfort of users, as well as achieving low energy consumption and good indoor air quality.

Continuous improvements in buildings have been for the most part imposed by the European Parliament and the Council of Europe that obligated member countries to achieve low energy standards (Directive 2002/91/EC on the energy performance of buildings and its Recast). In this book Authors presented development of architecture, showing a variety of public and residential buildings located in different parts of EU. Typical materials used in modern low-energy buildings have been shown, and some environmental-friendly ones that are still underused have been mentioned. Types and elements of HVAC systems have been described. Moreover main issues related to methodology of energy certification of buildings have been presented, including differences in requirements and documents in Poland, Spain and Lithuania. Besides existed constructions and a way they could be modernized to achieve a lower energy consumption were considered.

Bialystok, September 2018 *Dorota Anna Krawczyk, Editor*

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1. MODERN ARCHITECTURE – PUBLIC BUILDINGS

1.1. Introduction

Vitruvius, who lived in the 1st century BC, thought that architecture was based on three principles: durability (*Firmitas*), utility (*Utilitas*) and beauty (*Venustas*) (Witruwiusz, 1952). The ancients created their world based on these principles. The contemporary people rediscovered them again only in 1415, when the Florentine humanist Poggia discovered in the library of St. Gallen Monastery in Switzerland the Vitruvian multi-volume treatise entitled "De Architectura" (Witruwiusz, 1952). European architecture was based on a balance between construction, function and form. In the twentieth century the triad was smashed. Le Corbusier, a French architect, urban planner, painter and sculptor – the leading representative of modernism, in his architectural treatises and activities raised the importance of the aesthetics of the building. In his opinion architecture is a play of elementary solids in light (Pevsner, 1980; Giedion, 1968). Extremely different views were voiced by rationalists in the middle of the last century. According to Ergon Eiermann, architecture is the result of a process of reasoning, which has nothing to do with art and arises as a result of economic, construction and functional conditions. The modern neo-modernizers, among them Livo Vachini, Luigi Snozzi, Aurelio Galfetti and Dariusz Kozłowski, think that architecture is a uselessness that arises when we cross the border of banal utility (Basista, 2006; Basista, 2016). By interpreting these views, it must be stated that a building must be useful. Its purpose must be rational. It must be durable and safe for the people in it. At the same time, it must work. Technological solutions are essential. Their standard should be dependent on the purpose of the building, and the technical solutions should enable this building to be ecological (Gyurkovich, 2010; Fabiański & Purchla, 2012). Thus, Vitruvian durability and utility are objective, obvious and necessary, and beauty is a superior value.

Here comes the question, "what is beauty?". And what buildings are beautiful today? Answers to them, in the era of deconstruction, are not clear. The views of modern philosophers have allowed for parallel functioning of many currents, in case of fine arts a lot of stylistics, and even more, have allowed them to freely mix and create unknown hybrids (Basista, 2006; Gyurkovich, 2010; Kosiński, 2011). We can describe and interpret periods defined in the history of art which existed in the past. We have tools and knowledge to do this. We are surprised by clashing with modern constructions. We see buildings and we cannot name them. Their position, body, shape, proportions, details and used materials are bewildering. Today, more than ever, they depend on design tools. The emergence of modern architecture without computer would be impossible. The attempt to describe it is a very difficult task. Therefore, the authors in their study decided to reach out to the elements of a building and to chapter the world of structures which were built contemporarily, by work their location in space, building elements and sometimes their intended use.

1.2. Foundations

Buildings have been permanently linked to the ground since ancient times. Stable basis gave them not only physical support, but also shaped their position. Strong support gave them optical stability, which made them monumental. From the earliest times, pyramids and ziggurats have been treated as a peculiar foundation. Shapes of these buildings evidently result from construction conditions. The weight is transferred to the ground. In ancient Greece the stylobate had already a slightly different role. Superimposed stairs elevated the building up, making it tower over to the surroundings. Medieval buildings were based on strong socles, which in the period of Renaissance (modern) were replaced by massive rusticating. Modern buildings of the industrial revolution era were also permanently linked to the ground, and their statics gave a sense of stability. Also, secessionist and expressive buildings of the early twentieth century, in spite of their waving walls and roofs, we perceive as stable, statically embedded in the ground.

Ideas for such a building, existing in its surroundings, changed in the period of constructivism and modernism. Architects wanted the buildings to break away from the ground. They wanted to design structures raised on columns whose centers of gravity would disturb the balance of solids. By creating the principles of modern architecture, Le Corbusier even advocated the raising of buildings using the so-called *pylons.*

Today, we can observe a number of ideas related to shaping the "foundation of a building" – creating its connection to the ground (Fig. 1.1A-B). They cling to the ground. The Madrid Planetarium rises over the park (Fig. 1.2A) (Garcia Cassas, 2014). This facility perfectly implements Modernist dreams. People move on platforms above the area, which is completely covered by green. Modern realizations are trying to break away from the ground. Former architects' dreams come true today thanks to modern technologies. Cantilevers appear in many buildings (Fig. 1.2B) (Herve, 2010).

Fig. 1.1. Buildings which are stably based on monumental foundations constructed from stairs. A) Grande Arche (La Défense, Paris, France), B) Bibliothèque Nationale de France – Site François-Mitterrand (Paris, France) (Source: photos by M. Kłopotowski)

Fig. 1.2. Buildings that look like suspended in space. A) Madrid Planetario Building erected on pillars (Madrid, Spain), B) MAXXI Museo nazionale delle arti del XXI secolo (Rome, Italy), C) Palau de les Arts Reina Sofía (Valencia, Spain), D) EYE Film Museum (Amsterdam, the Netherlands) (Source: photos by M. Kłopotowski)

They cover the usable parts of the building or are purely decorative elements. At present, they take on different shapes, from round to polyhedral. Their connection to the ground appears to be at points only (Fig. 1.2C-D). These buildings are powerful structural cantilevers. Today we can also observe buildings located in a completely new space – on the walls and roofs of already existing buildings (Fig. 1.3A-B). The classic foundation does not exist, it is redundant for such structures of the 21st century.

A

B

Fig. 1.3. Buildings "constructed" on existing facilities. A) Les Docks – Cité de la Mode et du Design (Paris,France), B) Kunsthaus Graz (Graz, Austria) (Source: photos by M. Kłopotowski)

1.3. Walls

The basic building partition is the wall. From the dawn of history, its function has been to divide the interior space and together with the roof shape the place of human refuge. Throughout history, the wall has undergone some kind of modification.

A

B

C

D

E

F

G

H

Fig. 1.4. Different kinds of walls of contemporary buildings. A) Monumental walls of the synagogue in Dresden (Dresden, Germany), B) Massive, buttressed walls of the Shakespeare Theatre building (Gdańsk, Poland), C) ”Fragmented” building of a multiplex cinema in Dresden (Dresden, Germany), D) Defragmented building of the European Solidarity Center (Gdańsk, Poland), E) “Drifting” facade of the new Paris Philharmonic Hall (Paris, France), F) Surfaces wrapped around the solid of the Arcam Culture Center (Amsterdam, The Netherlands), G) Mobile plastic coating on the DR Koncerthuset Concert Hall, Copenhagen, Denmark, H) Visible coatings surrounding the block of the Fondation Louis Vuitton (Paris, France) (Source: photos by M. Kłopotowski)

The oldest of them were completely devoid of openings, more like defense structures. Today we find such solutions in structures which, due to their function or aesthetic concept, are to create an impression of inaccessible or isolated ones. The walls of buildings with "hidden" entrances create an atmosphere of mysterious and unique magic of the place. These solutions work well in sacred buildings (Fig. 1.4A) and cultural structures (Fig. 1.4B).

In many modern constructions the wall can be opened. Its fragments imply the window openings. Shutters serve not so much to cover the window opening but to create a continuous plane of the facade. These solutions are often used in residential buildings, where the authors prefer readability over standard solutions in the housing industry.

The modern wall, however, does not stick to the classical rules. Architects for decades do not want it to be vertical, continuous, or even to have the shape derived from the familiar geometry. The tools, that allow modern design, allow for the construction of buildings that seem like scattered houses of cards (Fig. 1.4C) or a puzzle from the blocks (Fig. 1.4D). The planes of the walls and solids which are created by them are separated from one another, and when we pass them we begin to worry whether a fragment will not fall on our heads. Their creation was possible thanks to computers. Modern software allows for much more. Today it is possible to model continuous space. The wall can be "bent and stretched". By grabbing a point on the screen of your computer, you can modify it in any way. The wall is no longer a plane (Fig. 1.4E). Sometimes its boundary is lost and the surface goes smoothly into the roof (Fig. 1.4F). Its implementation requires new skills, construction and building materials.

The classic wall separated the interior from the outside. It was the ultimate frontier of the building. Today's realizations become quite different. Structures are surrounded by the other "skin". Layers are made at the appropriate distance to the walls of the buildings. The space between them is a new kind of interior, as if it was a contemporary arbour coating the structure. Layers can change the shape of a building (Fig. 1.4G). "New" walls are completely useless from the practical point of view. They are purely decorative (Fig. 1.4H).

In the past, the final appearance of the wall was related to its location. The walls of the building were erected from natural local materials. The development of modernism popularized concrete. In the twentieth century, it replaced traditional brick and stone facades. Today, the development of new building materials technology gives a much broader scope. Modern architects frequently resort to classic building materials but use them in a modified manner.

Heavy concrete is used as a material that can be treated as a specific sculptural material. On the facades of the buildings, as in modernist designs, reliefs are pressed, and concrete prefabricates are used to create graphical mosaics (Fig. 1.5A). This plastic construction material is also used in the construction of rounded surfaces. Similarly, traditional stone is used (Fig. 1.4A, 1.19B).

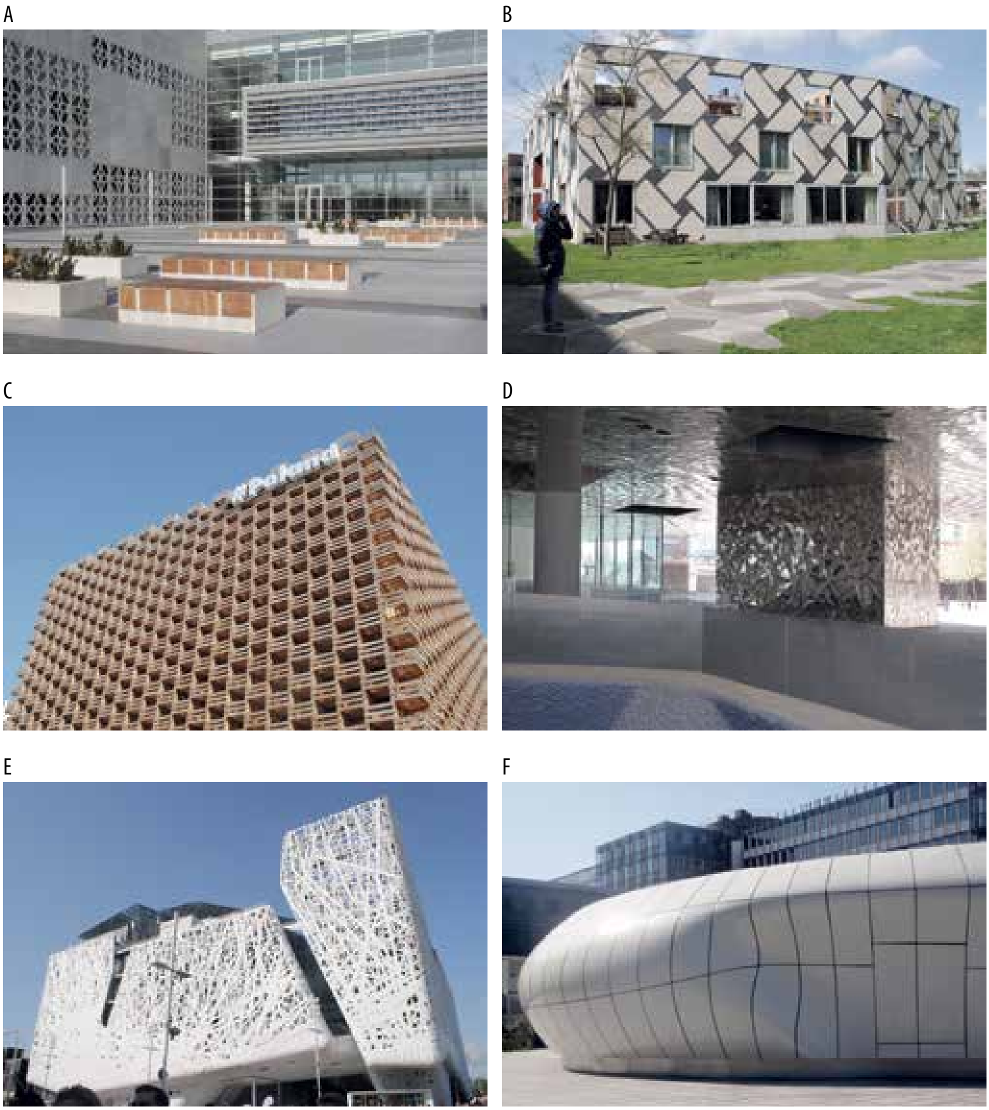

Fig. 1.5. Different building materials on the facades of contemporary buildings. A) Concrete on the elevation of the Center of Modern Education of Bialystok University of Technology (Białystok, Poland), B) Bricks on the facade of one of the residential buildings in the Funenpark Housing Estate (Amsterdam, The Netherlands), C) Wooden elevation of the Polish Pavilion from the World Exposition EXPO 2015 (Milan, Italy) D) Metal walls and ceilings in the building of Museu Blau-Museu de Ciències Naturals (Barcelona, Spain), E) Plastic facade of the Italian pavilion from the World Exposition EXPO 2015 (Milan, Italy), F) Exhibition Pavilion of Zaha Hadid (Paris, France) (Source: photos by M. Kłopotowski)

The brick, which has always been exposed by using its color and pattern resulting from the arrangement of individual bricks and their layers, is also in use today. Architects "play with" its texture and color. Contemporary designs, however, differ from classical aesthetics (Fig. 1.5B).

The walls of modern buildings are also made of natural materials such as wood or reed. Designers go back to the standard solutions that show the beauty of natural materials as well as the processed elements (Fig. 1.5C, 1.14B, 1.25A).

Another, frequently used facade material is metal. At present, most often it comes in the form of panels. Designers use a wide range of colors and textures. Metal products are used in the form of plates as well as perforated sheets and nets. The preferred type of metal is a shiny stainless steel (Fig. 1.4E, 1.5D, 1.27) (Gausa et al., 2013) and a rusting cortex (Fig. 1.4D, 1.6A, 1.14A, 1.32). These materials appear on the facades of cheap commercial buildings and prestigious public buildings.

Polymers have been used in construction since the late 1960s. Their application is constantly growing. Nowadays, this material allows to realize previously unreachable forms and textures. Plastics are used as coatings and panels. The advantage of this material is its durability and unlimited possibilities of color and texture (Fig. 1.4G, 1.5E, 1.5F, 1.30, 1.31).

A

B

Fig. 1.6. Vertical gardens. A) Caixa Forum Madrid (Madrid, Spain), B) Musée du quai Branly – Jacques Chirac (Paris, France) (Source: photos by M. Kłopotowski)

A particular type of contemporary wall is the vertical garden (Fig. 1.6A, 1.6B) (Regas et al., 2010; Herve, 2010). Its tradition dates back to ancient times. However, never before has it enjoyed such popularity as today. Green walls have become fashionable as a pro-ecological element. They are a new type of landscape architecture whose popularity has been rising due to both their aesthetic value and the need to increase the amount of greenery in the modern city. The urban vertical farms are not only multicolored flowerbeds, but also utility gardens (Fig. 1.7). Realizations of green walls are connected with a number of technological determinants. They involve the construction of the vertical garden, its maintenance and care.

Fig. 1.7. Utility vegetable garden on the elevation of the United States Pavilion from World Exposition EXPO 2015 (Milan, Italy) (Source: photos by M. Kłopotowski)

Fig. 1.8. The Monaco Pavilion from the World Exposition EXPO 2015 constructed of containers and other recycled materials (Milan, Italy) (Source: photos by M. Kłopotowski)

In modern construction business the ideas of sustainable development are readable. Most often, they depict a realization that uses recycled materials. Containers (Fig. 1.8) are the most popular materials in this field. They are modular products that are large enough and yet easy to transport. Thanks to their self-supporting structure, constructing a building from this kind of "prefabricated" elements is fast and energy efficient.

1.4. Openings

Human functioning inside a building requires room lighting. In the past, the size and shape of window openings was dependent on local conditions and was due to the tradition of the construction site. It was determined by climate conditions. In regions where it is cold and hot, traditional windows are much smaller than in the Mediterranean area. Historically, their size was also associated with technological capabilities, the ability to produce animal stomach membranes and then glass panes. The shape of the window opening has also changed during the course of history. It often gave the building a stylistic character.

Contemporary window opening is usually a rectangle. Modernists began to use vertical and horizontal openings as well as corner windows. In modern buildings, window openings are often a graphic composition of complementary squares and rectangles (Fig. 1.9A). Nineteenth-century dreams of building glass houses today result in realizations in the area of housing development and public buildings. In the Netherlands, residential houses where windows fill almost the entire facade have been erected. (Fig. 1.9B). Ideologically they refer to traditional, large windows in the tenement houses of the Hanseatic cities. Technological possibilities lead to the use of similar solutions in each climatic zone. In public buildings, glass facades have been used for decades. Interesting solution of the last decades, is the erection of glass walls, which are not to be transparent. Various prints appear on the glass surfaces of such buildings (Fig. 1.10A) or non-translucent glass is used (Fig. 1.10B).

A B

Fig. 1.9. Graphics of window openings on elevations of contemporary buildings. A) Facade of the Roma Tiburtina railway station (Rome, Italy), B) Elevations of terraced houses in Borneo East – Dock complex (Amsterdam, the Netherlands) (Source: photos by M. Kłopotowski)

A B

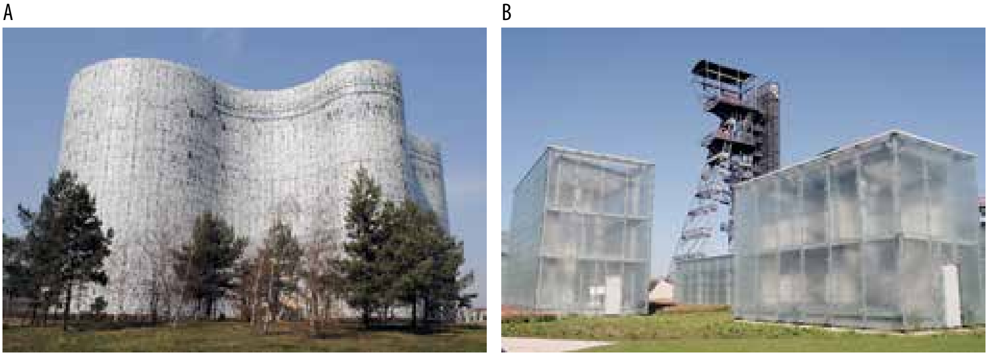

Fig. 1.10. Non-translucent glass facades of buildings. A) Prints on facades of Bibliothek KMZ – BTU Cottbus-Senftenberg (Cotbus, Germany), B) Pavilions illuminating the underground interiors of the Silesian Museum made from texture glass (Katowice, Poland) (Source: photos by M. Kłopotowski)

Fig. 1.11. Windows protected from excessive sun and light. A), Brise-soleils on elevations of Edifici CMT 22 @ (Barcelona, Spain), B) Automatically regulated translucence facade of Institut du Monde Arabe (Paris, France) (Source: photos by M. Kłopotowski)

Fig. 1.12. Window openings of non-standard shapes. A) Round windows in the building of the Integrated Student Center of Wroclaw University of Technology, Wroclaw, Poland), D) Striped windows in the Jüdisches Museum Berlin (Berlin, Germany), C) Irregular window shape in the Copernicus Science Center (Warsaw, Poland), D) Windows of different shapes from Tours Aillaud (La Défense, Paris, France) (Soure: photos by M. Kłopotowski)

The desire to create glass buildings has repeatedly been in conflict with utility needs. Excess light in such situations is regulated by different types of blinds and curtains (Fig. 1.11A) (Gausa et al., 2013). Particularly noteworthy is the building of the Arab World Institute in Paris, where each window opening is a specific mechanism, which in its aesthetics refers to the ornamentation of Arabic mashrabiyas (Fig. 1.11B) (Herve, 2010).

Contemporary windows also take different shapes, from geometrically defined lines (Fig. 1.12A) and circles (Fig. 1.12B), through the polygonal forms (Fig. 1.12C) to organic ones (Fig. 1.12D). Their shape is only a consequence of the aesthetic convention adopted by the author (Vidella, 2007).

1.5. Columns and beams

In the history of architecture, apart from the wall, one of the longest used building elements indicating the stylistics of the building are the columns and the beam based on them. Their decorations in ancient Greece and Rome uniquely attributed the structure to architectural order. This was taken over by modern architecture. In subsequent epochs, with varying precision and accuracy, reference was made to ancient patterns. Twentieth-century modernism introduced new rules. The column was replaced by a pole and the entablature by a straight beam. Construction elements devoid of architectural details were popularized in the middle of last century. Postmodernism restored decoration in architecture. Bases, columns and heads appeared in the buildings again and their elevations were crowned with ledge. This logic challenged the architecture of deconstruction by introducing free and fluid modeling of space. The form of contemporary columns depends on the architectural design of the building. We come across poles that are not vertical. Their course is diagonal (Fig. 1.13A) or curvilinear (Fig. 1.13B). Heads crowning such supports often become elaborate sculptures (Fig. 1.13C). The spatial assumptions created by these elements create unprecedented openwork structures (Fig. 1.13D), which in their design often refer to organic systems (Fig. 1.13E). Their biomorphic nature often blurs the boundaries between vertical and horizontal elements (Fig. 1.13F) (Regas & Lopez, 2010; Knofel, 2009).

A

B

C

D

E

F

Fig. 1.13. Contemporary buildings' structural support (poles) diversified in architectural and static form. A) MAXXI Museo nazionale delle arti del XXI secolo (Rome, Italy), B) Tančící dům (Prague, Czech Republic), C) Jüdisches Museum Berlin (Berlin, Germany), D) Louis Vuitton Fondation (Paris, France), E), Museu de les Ciències de València (Valencia, Spain), F) Exhibition Pavilion of Zaha Hadid (Paris, France) (Source: photos by M. Kłopotowski)

1.6. Roofs

A traditional gable roof in modern architecture appears extremely rarely. Most often we encounter it in structures that are inspired by traditional buildings. However, unlike in traditional constructions, such roofs have a deformed geometry and their roofs are covered with the same material from which the walls of the building were made (Fig. 1.14A, 1.14B, 1.15). Compositions consisting of many of these elements begin to shape the new city silhouettes today (Fig. 1.15). In their panoramas there are also rounded forms (Fig. 1.16) (Hubner & Schuler, 2012). Architects are more likely to go for flat roofs, one-sided slopes, or to design multi-walled solids (Fig. 1.17A, 1.17B). The green roofs (see Fig. 1.18A, 1.18B) refer to the past and they are becoming more and more popular as a pro-ecological solution. Large areas of lawns as well as perennial gardens are organized on the surface.

A

B

Fig. 1.14. Classic gable roofs. A) Museum of Poles Saving Jews during World War II. Museum named after Ulm Family in Markowa (Markowa near Rzeszow, Poland), B) Służew Culture House in Mokotow District (Warsaw, Poland) (Source: photos by M. Kłopotowski)

Fig. 1.15. The roofs of the Mieczysław Karłowicz Philharmonic Hall in Szczecin refer to medieval tenement houses (Szczecin, Poland) (Source: photo by M. Kłopotowski)

Fig. 1.16. Round-shaped roof of Bálna Budapest Mélygarázsa (Budapest, Hungary) (Source: photo by M. Kłopotowski)

A B

Fig. 1.17. Roofs of modern realizations with dynamic, multifaceted forms. A) Biblioteeca Jaume Fuster (Barcelona, Spain), B) MiCo Milano Congressi (Mediolan, Italy) (Source: photos by M. Kłopotowski)

A B

Fig. 1.18. Green walking rooftops. A) TU Delft Library (Delft, Netherlands), B) International Congress Center in Katowice (Katowice, Poland) (Source: photos by M. Kłopotowski)

A B

Fig. 1.19. A) Ramps leading to the observation deck located at the top of the new Paris Philharmonic Hall (Paris, France), B) The square located on the roof of the underground Dialogue Centre "Upheavals" – National Museum in Szczecin (Szczecin, Poland) (Source: photos by M. Kłopotowski)

Trees and bushes are often planted. A relatively new trend in design is changing the roofing of buildings into viewing platforms (Fig. 1.19A). Increasingly, in new developments we visit not only the building, but also the so-called fifth facade. The roof is more and more often used as a recreational space accompanying the building. In this context, a particular embodiment of the idea is the premises of the National Museum in Szczecin, Poland (Fig. 1.19B). The building is hidden underground and its roof is a public square.

1.7. Coverings

Public space which is connected to the street and the city square has begun to change its character since the foundation of Parisian passages in the first half of the 19th century. Uncovered spaces gave way to covered areas. Modern technology allows us to build more and more coverings. Increasingly, these are public places. The roofs of the Sony Center complex in Berlin (Fig. 1.20A, 1.20B) and of the Des Halles railway station in Paris (Fig. 1.20C, 1.20D) are among the most spectacular in this area. In both cases the span of the roof reaches several tens of meters (Vidella, 2007; Knofel, 2009).

Fig. 1.20. Canopies on open public spaces. A, B) Sony Center (Berlin, Germany), C, D) Châtelet (Paris, France) (Source: photos by M. Kłopotowski)

The public space of modern cities also closes in shopping centers. Spectacular designs of this type are Gold Terraces in Warsaw (Fig. 1.21). A small city, composed of several streets with pseudo-buildings, is covered with a complicated glass roof.

A B C

Fig. 1.21. A, B, C) Coverings and Interiors of the Gold Terraces Shopping Center (Warsaw, Poland) (Source: photos by M. Kłopotowski)

1.8. The sky

A modern trend is to create such architectural constructions which are "suspended" in spatial openwork forms. Their openwork nature does not protect us from atmospheric agents although we have an impression of being inside. However, it is a unique architectural form that we see against the sky. Giant arbours are found in modern parks (Fig. 1.22A, 1.22B, 1.24, 1.25B), in city squares (Fig. 1.25A), and in the vicinity of public buildings (Fig. 1.22A, 1.22B, 1.23).

A B

Fig. 1.22. Public gardens located in partially covered spaces. A) Jardins Rosa Luxemburg at Bibliothèque Vaclav Havel (Paris, France), B) Garden at the Małopolska Garden of Arts (Cracow, Poland) (Source: photos by M. Kłopotowski)

At their tops observation decks are often located, so that the surrounding area can be seen from an otherwise inaccessible perspective (Fig. 1.25A, 1.25B). The task of the structure itself is to surprise the observer by the pure fact of its existence.

Fig. 1.23. Covered observation deck at the Militärhistorisches Museum der Bundeswehr (Dresden, Germany) (Source: photos by M. Kłopotowski)

Fig. 1.24. Umbracle in Ciudad de las Artes y las ciencias Valencia (Valencia, Spain) (Source: photos by M. Kłopotowski)

A

B

Fig. 1.25. Overground walking paths seen from the ground level. A) Metropol umbrella on the square de la Encarnación in Seville (Sevilla, Spain), B) Viewing tower on the Kienberg hill at the IGA 2017 Exhibition (Berlin, Germany) (Source: photos by M. Kłopotowski)

1.9. Surprise

The contemporary architectural object must amaze the recipient. It must have features or elements that we do not expect. And at the same time those that will be expressive and memorable. They may refer to the location of the building (its foundation), its walls or roof, the material used, but also the shape of openings and other architectural details. We can not name and evaluate the architecture of such objects yet. We lack the criteria that we could do this. The variety of creative activities in this area seems to be unlimited (Fig. 1.26-1.32) (Gausa et al., 2013; Garcia Cassas, 2014).

Fig. 1.26. Colorful, as if built of blocks, facade of a residential building in the Carabanchel district of Madrid (Madrid, Spain) (Source: photos by M. Kłopotowski)

Fig. 1.27. The illusory spatial facade of Museo ABC (Madrid, Spain) (Source: photos by M. Kłopotowski)

Fig. 1.28. Inbuilt in the new building, the elevation of a 19th century tenement house with a built over glass facade – Old Brewery Shopping And Art Centre (Poznań, Poland) (Source: photos by M. Kłopotowski.)

Fig. 1.29. Surrounded by a stylized metal structure, the building of the French Ministry of Culture (Paris, France) (Source: photos by M. Kłopotowski)

A B

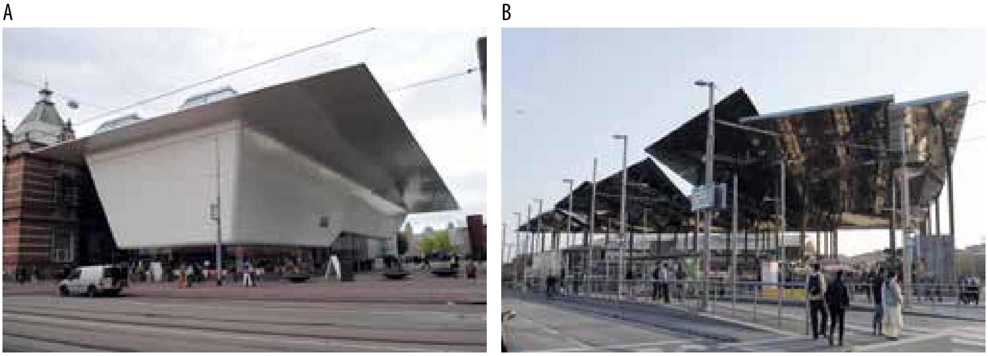

Fig. 1.30. Contemporary forms of canopies over of public space. A) Stedelijk Museum (Amsterdam, The Netherlands), B) Mercat dels Encants (Barcelona, Spain) (Source: photos by M. Kłopotowski)

Fig. 1.31. Surprising in its form and material solutions, located in the 22 @ district of Barcelona, Cibernarium green office building – in 2011 the edifice was recognized by international experts as the best building in the world – (Barcelona, Spain) (Source: photos by M. Kłopotowski)

Fig. 1.32. Surprising form of the presbytery wall of Parroquia de Santa Mónica in Rivas Vaciamadrid near Madrid (Rivas Vaciamadrid, Spain) (Source: photos by M. Kłopotowski)

1.10. Summary

Architecture is an area of art which, due to its public character, has always interacted with the recipient. It happens also today. Contemporary architects create modern constructions. When we look at them, we create an image of contemporariness. This process is continuous. We cannot say whether the icons of the architecture of our time have already arisen, whether the existing stylistic trends will continue to develop or, on the contrary, they will disappear. But we can be sure that new, even more "weird" structures will be created soon. Surely the inspiration for their creation will be the new civilization achievements of mankind.

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2. MODERN ARCHITECTURE – RESIDENTIAL BUILDINGS

2.1. Introduction

Residential buildings have been the most popular form of architecture since the earliest times. Because of their commonness, they shape the image of cities and give them general character. We are talking about white, grey or blue cities, where roofs are black or red – such reception of space is only available through homogeneous mass of housing substance. In the past, residential houses were used as counterpoints and complementary composition of assumptions in which palaces and public buildings "were gleaming". It changed a hundred years ago (Basista, 2006; Giedion, 1968). Residential houses fit in well-established architectural fashion (Kosiński, 2011). Their stylistics copies the patterns taken from the current fashionable design of public buildings. Inspired by this trend, they create their own ideas for the architecture of today (Basista, 2016; Gyurkovich, 2010). These activities, however, are subject to specific conditions resulting from the functional purpose and use of facilities. A house is not a public building, a temple or a supermarket. The ergonomics of the apartment enforces its spatial parameters and first of all lighting conditions (French, 2008; Giedion, 1968).

2.2. Housing development. Problems and social tasks

The realization of an architectural structure as a work exposed to public viewing has always given testimony to its owner. An investor's building is a testament to his affluence, but also his taste. With regard to housing development we can talk about two groups of investors. The first includes private individuals who by erecting their tenements build their social position while providing themselves a source of their income. Their designs must be safe in terms of current standards and maintain the current style (Fig. 2.1A) (Pevsner, 1980). The other group are public institutions. Their primary purpose is to meet the social needs of future residents. These investments are often building experiments. New functional, spatial and material solutions are tested.

The aesthetics of these buildings repeatedly sets new trends, but at the same time it is a visualization of the aesthetic views of decision-makers. The architecture realized in this way is becoming a materialization of economic determinants and political views. Private investments are built in prestigious locations. Most often these are detached structures. On the other hand, social activities are conducted on a large scale and they concern the realization of large housing complexes in which residential buildings are accompanied by service and education facilities. Public housing investments are inseparably linked to workers' flats. They are a natural consequence of the 19th century patronage and farm flats. Their development occurred at the beginning of the 20th century and was directly connected with the desire to improve the living conditions of urban working families (Fig. 2.1B). The purpose of the activities of the then socialists and hygienists was to lead the inhabitants of cellars and crowded chambers into bright and spacious flats (Giedion, 1968).

A B

Fig. 2.1. Housing Industry in the early 20th century. A) An expensive tenement house – La Casa Gallardo at the Plaza de España in Madrid, Spain (1914, architect: Federico Arias Rej), the most important architectural work of the last stage of Madrid Modernism; B) A model of a working-class flat of the second decade of the 20th century which used to be common in the neighbourhood of the Het Schip housing complex in Amsterdam, the Netherlands (Source: photos by M. Kłopotowski)

These measures were implemented by manufacturers, city authorities and architects themselves. It is significant that many residential social services were provided to residential homes which were intended for working families. Bakeries, shops and canteens, kindergartens and laundries were erected in residential buildings or in their neighborhood. The architecture of residential homes for workers in the 1920s began to adopt specific characteristics. Buildings grew bigger and bigger. They filled all urban quarters – as they did in the Valencian Finca Roja (Fig. 2.2A) – or they reached impressive dimensions, for example the 1100-metre long Viennese settlement Karl-Marks-Hof (Fig. 2.2B) (Villgratter, 2014). These buildings were composed of small, usually three-room flats, and their facades became more and more simplified. Over time, fashionable red brick coming from Amsterdam was replaced by wall plaster. The aesthetics of these buildings submitted to rational economic conditions.

A

B

Fig. 2.2. Workers' houses from the 1930s. A) A building modelled on Amsterdam school of architecture Finca Roja in Valencia, Spain, (1929-1933, architect: Enrique Viedma Videl), B) Karl-Marks-Hof – the most famous Viennese realization from the so-called Red Vienna period, associated with the Socialist government (1927-1930, architect: Karl Ehn) (Source: photos by M. Kłopotowski)

Housing environment has been included in the above-mentioned range till the present day. It fulfills the aspirations of the wealthy and the decision-makers and gives the conditions of social existence for the poor.

2.3. Paths to contemporary times

European residential architecture of the 20th century developed along different lines. Aesthetic views were constantly evolving. The developing technology of raising buildings often influenced its aesthetic beauty. The political and economic divisions introduced in Europe after the Second World War divided the housing developments of 1945-1989 on both sides of the "Iron Curtain". Nowadays in the period of blurring economic differences housing architecture is also being standardized. Globalization in this area is not just a fashion style but also the unification of building materials and technology of building construction.

Functional architecture was popularized in the 1929s. Buildings erected at that time, in contrast to the earlier ones, were deprived of ornaments. The external form (body of the building) was the result of functional solutions. Elevations were a natural representation of the needs for lighting individual rooms. The size of the window openings was due to needs rather than aesthetic reasons. Modernist aesthetic views, in line with contemporary philosophical views, were accepted by all social circles and groups. A good example of this trend was the Berlin Weiße Stadt residential complex (Fig. 2.3A) which was entirely occupied by workers (Knofel, 2009), as well as the luxury townhouse in Prague – Skleněný palác (Fig. 2.3B) which was considered the most prestigious address in the Czechoslovak capital. Both projects represent an international style. In their construction, simple forms of elementary solids complement one another. The structures feature large glazing, mostly metal balustrades and ornamental masts. The element that distinguishes the standard of these houses is finishing materials. In the interwar period this became the norm. Similarly looking buildings were finished with cheap wall plaster or expensive ceramic and stone lining. The prestige of the owners and residents was also realized through the expensive finishing of interiors of common parts and particularly interiors of the apartments. Almost all apartments completed at that time were already equipped with modern amenities such as: a kitchen with a stove and sink, a bathroom with a toilet and running water, central heating, and in expensive flats a servant's room for domestic help.

A

B

Fig. 2.3. Uniformization of architectural forms of residential buildings constructed in the first half of the 20th century. A) The Weiße Stadt housing complex in Berlin, Germany (1929-1931, architect Bruno Ahrends, Wilhelm Bünning, Otto Salvisberg), B) Skleněný palác in Prague, Czechoslovakia (1936-1939, architect Richard Podzemnéh) (Source: photos by M. Kłopotowski)

The workers' houses that were created in Vienna distinguished themselves against the background of these projects. A lot of new residential complexes, which by their architecture and furnishings fulfilled the aesthetic aspirations of the contemporary decision-makers, were erected in the socialist-run capital of Austria. In the so-called Red Vienna, in the 1920s through 1940s, a number of large residential urban areas were built, with commercial and service facilities (including nurseries). The apartments located in them, in spite of their tiny floor space, were equipped with kitchens and bathrooms, and the estates had common laundry facilities. Their architecture in no way resembled the modest implementation of German functionalists. On the contrary, it is approaching the style of art deco which was born at that time (Villgratter, 2014).

A B

Fig. 2.4. Vienna Workers' Houses from the turn of the twenties and thirties of the 20th century. A) Reumannhof in Vienna, Austria (1924-1926, architect Hubert Gesner) B) Wohnhausanlage Friedrich – Engels – Platz, Vienna (1930-1933, architect Rudolf Perco) (Source: photos by M. Kłopotowski)

The interwar period is also the time of technical and technological experiments. In almost all European countries there were attempts to construct residential buildings using steel structures and prefabricated elements. One of the first buildings erected in such way was built in 1932 in Rotterdam (Fig. 2.5A-B). In the Bergpolderflat building a steel support structure and prefabricated slabs and walls were used. The house designed by architect Willem van Tijen, was erected in the quarter full of traditional tenement houses grouped in district. The building was in contrast to the context. A deck-access nine-storey-block with glass staircases was placed in the middle of the lot. This realization has inspired many later urban and architectural activities.

The fascination of prefabrication in the mid-twentieth century was so great that it dominated housing industry in almost all European countries. A lot of high-rise and large-panel construction systems were introduced in Europe. The quality of prefabricated elements and consequently of the buildings was very different and the operation of such buildings was often troublesome. Structures built with this technology were leaky, with low thermal standards. Generally, positive French experiences should be mentioned (Fig. 2.7A, 2.8A-B, 2.9A-B) and the negative ones from Central and Eastern European countries (Fig. 2.5C, 2.5A-B) (Reklaite & Leitanaite, 2013; Reikate, 2015). The criticism of this way of building caused the return to traditional technology. In Western Europe it was at the turn of the seventies and eighties, and in Eastern Europe in the nineties. We are currently seeing a return to the prefabricated technology, which is due to the desired rapid pace of construction and the resulting cost-effectiveness.

A B C

Fig. 2.5. Residential architecture and prefabrication. A, B) The experimental prefabricated apartment building Bergpolderflat in Rotterdam, Netherlands (1932-1934, architect Willem van Tijen), C) Pašilaičiai residential area in Vilnius, Lithuania (architect K. Balenas, St. Garuckas, 1987) (Source: photos by M. Kłopotowski)

Particular diversity of forms of housing construction in particular parts of Europe took place immediately after the Second World War. In the Eastern European countries, which were damaged by the war, the style of socialist realism was realized. It came from the USSR and related to the historical architecture. In many cities at that time buildings were modeled on the 17th and 18th century tenement houses (Fig. 2.6A). In the Scandinavian countries, which were not destroyed during the war, local variation of modernism was promoted at that time. Social houses that duplicated functional cuboidal forms were covered with steep high roofs. Rich Western European countries were fascinated by new technological achievements. Unité d'Habitation by Corbusier created a new aesthetics, promoting a healthy, green environment of living according to the resolutions of the Athenian Charter (Fig. 2.6B) (Knofel, 2009).

A B

Fig. 2.6. Diversification of architectural forms of buildings realized in various European countries, after World War II. A) Buildings of Mariensztat housing estate in Warsaw, Poland (1948-1949, architects Zygmunt Stępiński and Józef Sigalin), B) Unité d'Habitation in Berlin (Germany) – a German "copy" of realization from Marseilles, 1947-1952 (Le Corbusier, 1957) (Source: photos by M. Kłopotowski)

The differences in forms of residential architecture on both sides of the "iron curtain" increased in the 1950s. Cold war in spatial dimension resulted in an extremely different approach to urban planning and architecture. In the cities of Eastern Europe, workers' houses were kept on a large scale in the convention of the classicizing architecture (Fig. 2.7). The emerging spatial configurations referred to the rescaled originals taken from historical cities. Berlin's Karl-Marx-Allee and Warsaw's Marszałkowska Residential District (Fig. 2.7B) are the flagship examples of this period. Monumental forms and architectural details were also transferred to modern urban planning, as it took place in Czechoslovakian Kladno – Rozdevol (Fig. 2.7A), where the historic architectural costume was imposed on a series of modern skyscrapers. The employed construction method repeatedly forced the use of traditional techniques and involve a number of craftsmen (stonemasons, bricklayers, blacksmiths, tilers, etc.). In the vast majority of Western European cities, people were fascinated by new technological and material achievements at that time. Modern prefabricated blocks of flats were built with the use of concrete and plastics on a massive scale. Cities, which were rebuilt after the war damage (such as Rotterdam), adopted a whole new spatial dimension. In their systems, traditional squares and streets were lost. All over the space, began to dominate the ubiquitous car and associated with it communication arteries, flyovers, multi-level garages and also extensive green areas. The projected population density in residential areas was then achieved by the construction of high-rise buildings. They fulfilled both postulates: of modern technology and the spatial one. These ideas are well illustrated by the West Berlin Hansaviertel (Fig. 2.8).

A

B

Fig. 2.7. Classicistic architectural forms in residential buildings were introduced obligatorily after the Second World War in the countries of the socialist bloc, as a new aesthetics. A) "Victorious People Settlement "housing complex in Kladno – Rozdevol (Czech Republic) (1952-1958, architects: Josef Havliček, Karel Filsak, Karel Bubeniček), B) Marszałkowska residential district in Warsaw (Poland) (1950-1952, group of architects under the direction of Józef Sigalin and Stanisław Jankowski) (Source: photos by M. Kłopotowski)

In a vast park, their works were realized by the most famous architects in the world. Residential blocks drown in green but they do not create a simple, easily characterized layout. They are the forerunner of a space in which the backyard and a straight way to the house are lost. At the same time, they completely negate the private space near home and replace it by the so-called conjugated enclosures (where boundaries are impossible to define) and multifunctional interiors (with hard to define usage).

A B

Fig. 2.8. Architectural response of the "Western World" to the Pro-Soviet Socialist Realism Architecture. Buildings built in 1957 in Berlin (Germany) on the premises of Hansaviertel Building Exhibition. A) A building designed by the architects Fritz Jaeneckean and Sten Samuelson, B) A building designed by architect Walter Gropius (Source: photos by M. Kłopotowski)

The fascination with the ideas of Le Corbusier and the volume of his designs implemented in the 60s and 70s of the 20th century resulted in the construction of huge housing complexes. In the suburbs of Paris were constructed: Les Courtillieres (housing estate with 1500 apartments), large housing complexes such as Sarcelles (located in the northern suburbs of Paris for 40,000 inhabitants) and La Grande Borne in Grigny (located in the southern suburbs of Paris for 13,000 inhabitants). In Amsterdam, the Bijlmermeer district was built for 100,000 people. Similar investments were made in other European countries. The Eastern Bloc countries adopted this way of shaping the housing environment in the second half of the 50s and maintained it until the early 90s. Many large settlements and residential areas were built in all the socialist countries at that time. In Poland, the most memorable are: the SuperUnit in Katowice (Fig. 2.9A), the Wave Building in the Przymorze housing estate in Gdańsk (Fig. 2.9B), or a deck-access block in Przyczółek Grochowski in Warsaw. The building, designed by Zofia and Oskar Hansen, is 1.5 km long and is considered to be the longest building in Europe.

The counter idea to mega spatial projects in housing developments in the mid-twentieth century became the buildings with single staircases, relatively small in the projection. The so-called tower blocks are characterized by an internal passageway that is surrounded by flats. These buildings perfectly fulfill modernist ideas of building houses in green space. Large areas of recreational areas were obtained in these projects thanks to the construction of skyscrapers. Diversification of their height created a new landscape dimension of the housing environment. Projections of buildings, apart from square and rectangular ones, were given central or organic shapes (Fig. 2.10A-C) (Hevre, 2010). Diffused buildings and personalized details made this architecture more attractive than ever.

A B

Fig. 2.9. Residential projects on a mega scale of the early seventies. A) The SuperUnit in Katowice, Poland – 762 flats, 15 floors, 3 entrances, 9 staircases (1967-1972, architect Mieczysław Król, B) Wave Building in Przymorze housing estate in Gdańsk, Poland – 860 – meter – long building, 1792 flats, 10 floors, 16 staircases (1970-1973, architects Tadeusz Różański, Danuta Olędzka, Janusz Morek) (Source: photos by M. Kłopotowski)

A B C

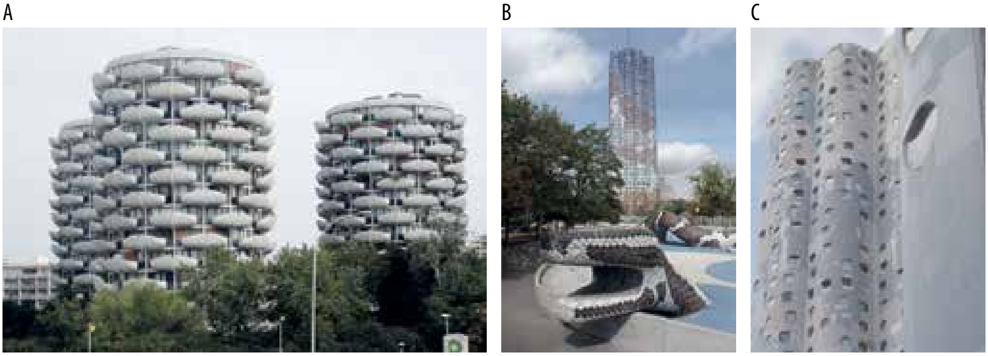

Fig. 2.10. Skyscrapers (tower blocks) of the seventies of the 20th century. A) Les Choux – Maisons-fleurs in Créteil, France (1969-1974, architect Gerard Grandval), B, C) Aillaud Tours in La Defense, Paris, France, the tallest buildings in the district have 39 floors each and are 105 m high (1977), architect Emile Aillaud) (Source: photos by M. Kłopotowski)

The desire to search for new forms of architectural expression is evident in the residential developments of the mid-1970s. The pyramid-like structures were erected without resigning from the size of the buildings. Buildings in which individual housing units overlapped each other were built in Evry near Paris. Green terraces were set up with connection to the apartments on the roofs of the piled-up solids (Fig. 2.11A).

A similar realization was made in Austria's Graz (Fig. 2.11B). Individual segments of the building are stacked one on top of the other, their layout is very different and the internal communication is at different levels. Both projects (like tower blocks) were supposed to be primarily a departure from rectangular boxes and repetitive storeys. Double-floor-flats were designed, the interior of which was supposed to resemble the solutions used in traditional single-family houses. Over time, this design has become known as organic – referring to the world of nature.

A B

Fig. 2.11. Stacked housing forms from the seventies of the 20th century. A) Piramides Housing in Évry, France (1971-1976, architect M. Andrault with his team), B) Terrassenhaussiedlung St. in Peter Graz, Austria (1965-1978, architects Eugen Gross, Friedrich Gross Rannsbach, Werner Hollomey, Hermann Pichler – Workgroup Graz) (Source: photos by M. Kłopotowski)

Coming from the same period Paris's construction Orgues de Flandre (Fig. 2.12A), or Vienna's Wohnpark Alterlaa (Fig. 2.12B), surprise by the dynamics of their form. Buildings resemble ships and space stations and reflect the fascination with space flight and hope for colonization of the universe. Similar emotions of surprise accompany the view of Les Arènes de Picasso from the Noisy-le-Grand near Paris (Fig. 2.13A) (Hevre, 2010). In case of this realization, surprising is not only the oval body of the building, but also individually designed details of supports, cornices and window openings. The residential architecture of this time became a plastic experiment. Public-funded projects are a testament of the financial well-being and technological capabilities of the country in which they were implemented. The aesthetics of these buildings is completely different from classical modernism. Its purpose is to surprise the observer. The same premises led to the Viennese realization of the Hundertwasserhaus, a building which, for the first time in our days, was strewn with variety of colors and plants planted on terraces and roofs. This building and it's idea were a surprise not only for compositional and artistic solutions, but also for the pro-ecological message about the city of the future (Vidella, 2007).

A

B

Fig. 2.12. Forms of residential houses in the early 1980s, which were supposed to surprise the viewer. A) Orgues de Flandre in Paris, France (1974-1980, architect Martin van Treeck), B) Wohnpark Alterlaa housing complex in Vienna, Austria (1973-1985, architect Harry Glück with his team) (Source: photos by M. Kłopotowski)

A

B

Fig. 2.13. A) Les Arènes de Picasso in Noisy-le-Grand, France (1985, architect Manuel Núñez Yanowsky), B) Hundertwasserhaus in Vienna, Austria (1983-1985, Friedensreich Hundertwasser) (Source: photos by M. Kłopotowski)

The eighties brought another phase of departure from modernist architecture. New housing assumptions, in their spatial arrangements, were based on the experiences of the twentieth century. They drew on both the layouts of the classical city and the ideas of the green estate. They returned to the traditional quarter development with the street and the square (Fig. 2.14A). At the same time, the house was set in a green environment, and the green courtyard was often designed inside. The scale of residential buildings was gradually decreasing. Individual buildings were designed individually. Their architectural details were stylized for historical purposes (Fig. 2.14A-B) (Herve, 2010). They returned to high roofs, unused for several decades (Fig. 2.14D). Pilasters and cornices appeared on the facades of the buildings. The window openings were surrounded by ornamental frames and at the top of the buildings appeared belvederes (Fig. 2.14C-D) (Knofel, 2009). At the end of the last century, residential architecture, maintained in postmodernist style, gained social recognition. The return to the classic formal and material solutions gave the users a sense of their robustness and durability. Classical aesthetics of forms gave a sense of timelessness (Vidella, 2007).

Fig. 2.14. Postmodernist realizations of housing development from the 1980s. A) Les Arcades du lac le Viaduc in Saint – Quentin-en--Yvelines, France (1982, architect Ricardo Bofill), B) Les Espaces de'Abraksas in Noisy-le-Grand, France (1982, architect Ricardo Bofill) C) IBA Wohnanlage in Berlin, Germany (1985, architect Rob Krier), D) An apartment Development on the Tegel Waterfront in Berlin, Germany (1986-1986, Moore Ruble with the team) (Source: photos by M. Kłopotowski)

This architecture was associated with coming back of bourgeois patterns of residence, which was in contradiction with the emerging democratic civil society which wanted to participate actively in the formation of their place of residence. The achievements resulting from the process of social participation are characterized by a great diversity of applied forms and details. In many of them the individualization of dwellings and number of architectural details (taken from the idea of the Hundertwasserhaus where each dwelling is marked on the facade) leads to aesthetic chaos (Fig. 2.15A) The resulting plastic effect also gives the impression of randomness and temporality which is not eliminated by color or material unification (Fig. 2.15B).

A B

Fig. 2.15. Multi-family houses realized as a result of the process of social participation consisting in the cooperation of an architect with a particular user. A) A Bo 100 building in Malmö, Sweden (1987-1991, architect Ivo Waldhör with the team), B) Wohnbau Alte Poststraße (1982-1984, architects Michael Szyszkowitz and Karl Kowalski) (Source: photos by M. Kłopotowski)

At the same time, since the beginning of the 1980s, many significant architectural centers have undertaken work to revive the modernist architecture.

The roots of the new housing industry date back to the 20th century. Buildings again received rectangular forms. However, unlike their prototypes, they were developed based on complex projection systems consisting of interpenetrating rectangles and circles (Fig. 2.16A) (Herve, 2010). Unlike functional architecture, the new direction, which in the course of time was named neo-modernism, operated with a whole array of architectural details. The sculptural layout of the buildings was created by a series of verandas, balconies and openwork stairs. Similarly, the solids were differentiated by their height and partially covered with sloping roofs (Fig. 2.16B).

A B

Fig. 2.16. Neomodernist housing developments from the 1980s. A) Social Housing at La Villette, Paris, France (1981-1997, architect Gérard Thurauer), B) Wienerberger Gründe in Graz, Austria (1981-1997, architects Ralph Erskine and Hubert Rieß) (Source: photos by M. Kłopotowski)

So the architectural design seemed to be fresh and new. It was well suited to compare it with the perceptions of the Deconstructivists, who based on the experiences of the past (making new sets of existing details and elements). Architects completed value of the building's space, form and detail together. The building made of many elements, which can be implemented in the cooperation with the architect and the investor, became a symbol of the end of the last century. At the same time, this trend is the last precisely identifiable one before the time of globalization.

2.4. The housing industry of the 21st century

Housing construction of our times draws inspirations from the experience of the whole last century. Contemporary housing projects are built as single buildings (complemented on plots built-up already) or units that fit in the spatial arrangements of the so-called new urbanism. It is based on land parceling. Area is divided for plots dedicated for different investment tasks. Divisions based on the orthogonal grid of streets that were characteristic to the beginning of the present century are increasingly subject to various types of distortions. Often the neighbouring streets are laid out along curved lines. This distortion is evidently translated into the spatial form of buildings and in particular the shape of their projections. Nowadays, more than ever, we come across buildings, whose projections are based on irregular polygons. They are also varied vertically (individual floors have different areas and shapes). On the facades of these buildings there is a varied range of building materials (from the traditional to the latest ones). The architectural details are surprising in both the form of the space and the material used. This trend is accompanied by the desire to exhibit engineering achievements and to take advantage of complex construction solutions that affect the spatial reception of the whole building. Architects often strive for optical play with the recipient and try to realize a building that will be seen as "more crooked" than it is in reality. In addition, they constantly illustrate new ideas that create our reality. In particular, views on environmental and sustainable development are allowed to speak.

2.4.1. Buildings

Single housing projects often occur in heavily urbanized areas. Very often their formal task is to contribute to a change in the aesthetics of a revitalized district. New architectural objects shape the new (considered as positive) image of such places. This is illustrated by the Zaha-Hadid-Haus in Vienna (Fig. 2.17A) built over an old railway viaduct or by the Turning Torso in Malmö towering over a newly built residential area (Fig. 2.17B) (Vidella, 2007; Gyurkovich, 2010). In both cases the "strangeness" of the form objects (in which borders of projections do not overlap each other and the walls are diagonal planes) is a magnet attracting further investment. The strong and surprising architectural form of these buildings seems to be necessary in order to succeed in the intended investment activities.

A

B

Fig. 2.17. Buildings being individual housing developments. A) Zaha-Hadid-Haus in Vienna, Austria (1995-2005, architect Zaha Hadid), B) Turning Torso in Malmö, Sweden (2001-2005, architect Santiago Calatrava) (Source: photos by M. Kłopotowski)

2.4.2. Compositions of solids and spatial forms

Vast majority of residential multi-family buildings are currently built in housing estates. Their basic form remains a cuboid which in specific locations is defragmented and divided. The architects' aim is to "build" buildings with "big blocks". This effect can be achieved, inter alia, by the application of different color and material for individual elementary solids. In such designed houses, individual dwellings usually coincide vertically. Differences in projections result from the frequent use of maisonettes (Fig. 2.18A). The differention of projections of individual storeys is also a consequence of the adopted architectural composition. This is especially true in urban development. Projects in which buildings fill entire urban quarters are often divided into a number of differently-sized bodies. The aim of this action is to emphasize the individual parts of the building and to create a new varied landscape of the 21st century city (Fig. 2.18B).

The urban space is also made more attractive by the introduction of objects with "deformed" bodies. Architectural activities in this area are different than the traditional way of shaping in terms of roof, walls and socle. Traditional planes give way to slants, undercuts and curved surfaces (Fig. 2.19). The blocks formed in this manner are surrounded by a number of details forming a layer around it. Such actions do not substantially affect the projections of buildings and flats. Their task is to create an image of the object considered as contemporary. The aesthetics of plastic solutions ranges from sharp, straight line cuts and planes to gentle arches, delicate curves and curved planes (Fig. 2.20).

A

B

Fig. 2.18. Compositions of solids of multi-family buildings, which are composed of cuboid elements. A) The Eko Park Residence "Cameratta" in Warsaw, Poland (1999-2004, architect Bulanda Mucha Architects, B) Edificio Vallecas 4 Madrid, Spain (2008, architects Hugo Araujo Lazare – Araujo and Brieva Arquitectos) (Source: photos by M. Kłopotowski)

A

B

Fig. 2.19. Geometrically deformed blocks of contemporary residential buildings. A) A building in Het Funen in Amstardam, the Netherlands (2003-2009, architects Piter Bannenberg, Walter van Dijk, Kamiel Klaasse, Mark Linnemann – NL Architekci), B) Social Housing in Vallecas, Madrid, Spain (2010, Architect Rueda Pizarro Arquitectos) (Source: photos by M. Kłopotowski)

A

B

Fig. 2.20. Contemporary residential buildings, surrounded by a layer of modern (non-ruled and curved) architectural details. A) The City Life Milano Libeskind Residential Complex in Milan, Italy (2004-2013, architect Daniel Libeskind), B) The City Life Milano Hadid Residential Complex in Milan, Italy (2004-2014, architect Zaha Hadid) (Source: photos by M. Kłopotowski)

Other modifications of facades and solids of residential buildings were inspired by the same premises. From the beginning of the 21st century, the tendency of formal play with window openings and numerous niches on the facades is clearly visible. The individual windows and loggias on the consecutive floors do not overlap vertically (Fig. 2.21) and their size varies. These compositions introduce a new plastic aesthetics which generates considerable complications of building solutions and internal systems. This problem concerns in particular the installation of central heating.

Quite often, the final reception of a building depends on the design of its balconies. They become the element that differentiates the outlines of individual floors. Their size and shape are often varied on each floor. They take shapes from rectangular and ruled, through polygonal to curved. The thickness of the balcony slabs, their balustrades and the openwork elements of shields create the final form of the building (Fig. 2.20, 2.21, 2.22). A new tendency in the shaping of architectural forms is the clear division of the building's body into vertical or horizontal sequences separated from one another (Fig. 2.23) (Regas & Lopez, 2010; Garcia Cassas, 2014). Formally, this kind of architects' work gives interesting artistic solutions, but actually it becomes another element that influences the complexity of the design and construction process of the building. The difficulties lie in both the building design and the installation solutions.

A B

Fig. 2.21. Varied graphics of window openings and balcony niches on the elevations of contemporary multi-family buildings. A) 145 Housing Units + FAM + PMI – Clichy-Batignolles, Paris, France (2016, architect Avenier Cornejo Architectes, Gausa Raveau Actarquitectura), B) House in Ørestad, Copenhagen, Denmark (2006, architect Bjarke Ingels) (Source: photos by M. Kłopotowski)

Fig. 2.22. Balconies surrounding a building completely change its spatial reception – Bâtiment Home in Paris XIII, France (2012-2015, architect Hamonic + Masson & Associés) (Source: photos by M. Kłopotowski)

Fig. 2.23. Dividing a building into separate elements leads to the dynamics of the architectural form – Edificio Vallecas 5, Madrid, Spain (2006-2009, architects Luis Burriel Bielza, Pablo Fernandez Lewicki and Jose Antonio Tallon Iglesias – SOMOS Arquitectos) (Source: photos by M. Kłopotowski)

An interesting fact about contemporary buildings is that they seem to be a form of architect's "play" with observer. Often its shape is not only unexpected, but even strongly contrasted with the essential body of the structure. This is happening on the glass facade of VM Houses in Copenhagen, where pointed triangular openwork balconies slide out of one another (Fig. 2.24). In result, this almost entirely glazed cuboid (balanced in proportions and scale) is perceived as dynamic and even aggressively sharp. Another type of game is played with the viewer in Edificio Vallecas 16 in Madrid. All windows of the house are equipped with shutters made of the same material and in the same colors as the facade (Fig. 2.25) (Garcia Cassas, 2014). Their complete closure causes the building to be deprived of window openings. Opening them in different sequences is never the same.

Fig. 2.24. Balconies aggressive in their form in VM Houses in Ørestad, Copenhagen, Denmark (2005, architects Bjarke Ingels and Julien De Smedt) (Source: photo by M. Kłopotowski)

Fig. 2.25. Background shutters in Edificio Vallecas 16, Madrid, Spain (2007, architect Javier Camacho) (Source: photos by M. Kłopotowski)

Contemporary urban planning is also a kind of game with the space observer. It is increasingly based on a non-orthogonal grid of streets and pedestrian passages. The purpose of such a design is to provide directional corridors and closed views in public spaces. This action builds an intimate, man-sized character of urban interiors. It fosters their individualization and builds positive relations between the inhabitants and the environment. In architectural designs, however, it leads to the creation of buildings whose projections are based on the shape of rambling polygons (Fig. 2.26). Attractive urban space solutions lead to complications in the plans of buildings and flats. This is reflected in their functional systems, mainly in fitting furniture in the polygonal rooms (Villgratter, 2014).

A B

Fig. 2.26. Residential buildings whose projections are based on rambling polygons. A) WAS – Wohnbau in Seestadt Aspern, Vienna, Austria (2015, architect AllesWirdGut), B) A house with verandas in Vienna, Austria (2008, architect RLP Rüdiger Lainer + Partner) (Source: photos by M. Kłopotowski)

2.4.3. Engineering achievements in residential construction

Residential housing increasingly draws on the achievements of engineering art. In modern residential buildings we find very large overhangs and cantilevers. The most spectacular developments in which contemporary design capabilities are used are Edificio Mirador in Las Tablas in Madrid (Fig. 2.27A) (Regas et al., 2010) and Parkrand in Amsterdam (Fig. 2.27B). In both of these projects, there were applied spatial frames suspended at high altitudes and filled with flats. The architects' aim was to create openwork forms and to distract the optical static of the building. Their size makes these compositions available on an urban scale. The examples are located in the open space and visible from a considerable distance, which is conducive to their perception. Slightly different is exposition of structures in linear spatial systems, along the communication routes. Almost always this solution is accompanied by the desire to suspend the building blocks in space. Architects and constructors implement such formal intentions by using optically slender, high and often non-vertical posts

(Fig. 2.28), and structural supports (Fig. 2.29). These elements are always correlated with their dynamic perception. Their size is a derivative of dynamic observation carried out from inside the car.

A

B

Fig. 2.27. Residential buildings with a number of dwellings inside, in which massive overhangs were built. A) Edificio Mirador in Las Tablas, Madrid, Spain (2005, architects MVRDV), B) Parkrand in Amsterdam, Netherlands (2006-2007, architects MVRDV) (Source: photos by M. Kłopotowski)

Fig. 2.28. A suspended in space structure of Wohnhausanlage Riverside in Vienna, Austria (2008, architects Coop-Himmelb (l) au) (Source: photos by M. Kłopotowski)

Fig. 2.29. Huge structural supports in the Doninpark building in Vienna, Austria (2013, architects LOVE architecture and urbanism) (Source: photos by M. Kłopotowski)

Similar formal solutions are used with regard to the scale of building. In Madrid, 102 whole flats and individual rooms were outthrust outside the main outline of building (Fig. 2.30A) (Regas & Lopez, 2010), and in the WoZoCo located in Amsterdam the entire apartments were pushed out (Fig. 2.30B). The facades of buildings are dynamic and mind-blowing. The authors of these structures evidently play with the statics of solids, human perception and even emotions.

All of the above examples are interesting architectural structures and deserve recognition for their constructional solutions. At the same time they are examples of buildings in which complex sanitary systems were designed. In particular, it applies to sewage treatment solutions in overhanging and cantilever parts.

A

B

Fig. 2.30. Residential buildings with rooms and flats in large cantilever.constructions. A) 102 outthrust social dwellings in a block of flats in Carabanchel, Madrid, Spain (2008, architects Ignacio Borrego, Néstor Montenegro and Lina Toro – Dosmasuno Arquitectos), B) The WoZoCo in Amsterdam, Netherlands (1994-1997, architects MVRDV) (Source: photos by M. Kłopotowski)

2.4.4. Contemporary building materials in the architecture of multi-family buildings

We are currently observing a strong unification of the techniques of erecting residential buildings. They are made by using concrete and ceramic materials. They serve as both structural and finishing materials – creating a specific aesthetics of buildings (Fig. 2.31) (Garcia Cassas, 2014).

A

B

Fig. 2.31. Multi-family buildings constructed with the use of traditional building materials: concrete and bricks. A) The Celosia complex in Las Tablas, Madrid, Spain (2001-2009, architects MVRDV), B) A building in Het Funen in Amstardam, Netherlands (2003-2007, architects DKV architecten) (Source: photos by M. Kłopotowski)

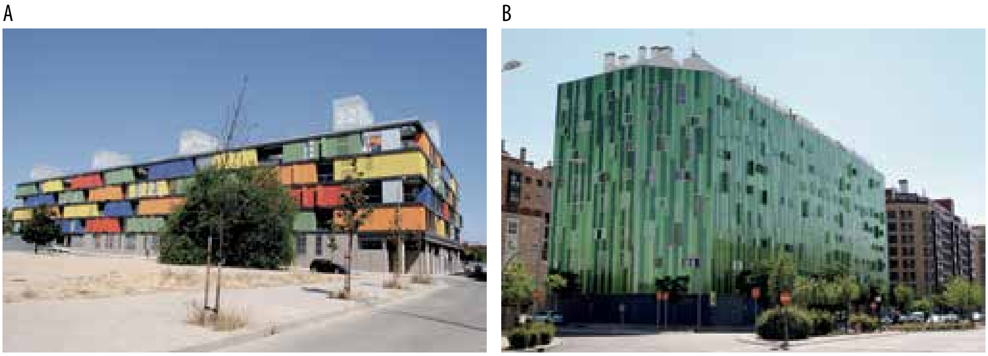

Fig. 2.32. Non-standard building materials used for the construction of multi-family buildings. A) Metal facade 82 Viviendas en Carabanchel, Madrid, Spain (2009, architects Atxu Amann, Andrés Cánovas and Nicolás Maruri – Architects of ACM), B) Façade of Edificio Vallecas 51 made from polymer, Madrid, Spain (2006-2009, architects Luis Burriel Bielza, Pablo Fernandez Lewicki and Jose Antonio Tallon Iglesias – SOMOS Arquitectos) (Source: photos by M. Kłopotowski)

Fig. 2.33. Wood as a "new" pro-ecological building material. A) Moving shutters over the balconies around the Carabanchel Social Housing, Madrid, Spain (2007, architects Farshid Moussavi and Alejandro Zaera-Polo – Foreign Office Architects), B) Wooden openwork elevations School Group and Student Housing – Clichy –Batignolles, Paris, C) Wood-finished facades of the Allegretto Housing Complex in Eko Park in Warsaw, Poland (1999-2003, architects Stefan Kuryłowicz, Paweł Gumuła, Maria Saloni-Sadowska), D) Wood-finished facades and floors in Holzwohnbau in Seestadt Aspern, Vienna, Austria (2011-2015, architects Alfred Berger, Tiina Parkkinen – Architekten Berger + Parkkinen Ziviltechniker GmbH) (Source: photos by M. Kłopotowski)

In addition to traditional ones such as concrete and brick, steel (Fig. 2.32A) and plastics (Fig. 2.32B) are increasingly used in new designs Because of that, the buildings get completely new, surprising texture of their surfaces and unmistakable colors (Garcia Cassas, 2014). At the same time, the trend of return to natural materials is very clear in modern realizations. Many of today's multifamily houses are decorated with wood (Fig. 2.33) (Gyurkovich, 2010). It is used as wall cladding or window shutter material. Wooden parts are often used for making balustrades and frame details. There are also projects in which wood is used as a finishing material for floors in external public spaces (Fig. 2.33D) (Villagratter et al., 2014). The widespread use of this material is associated with the development and popularization of the ecological architecture.

2.4.5. Ideas for sustainable development and green building in residential architecture

Special projects related to shaping the contemporary housing environment are projects based on the principles of sustainable development. In the realization of these issues ecology influences and even determines aesthetic solutions. As a consequence, plants are placed on terraces and roofs of residential buildings (Fig. 2.34). Their task is to clean the urban air and create a human-friendly microclimate of residential interiors. Trees, shrubs and vines planted in containers create a new aesthetics of multi-family buildings. In the future, these developments will become vertical parks. However, ecological solutions meet criticism because such gardens need complex irrigation and drainage systems.

A B

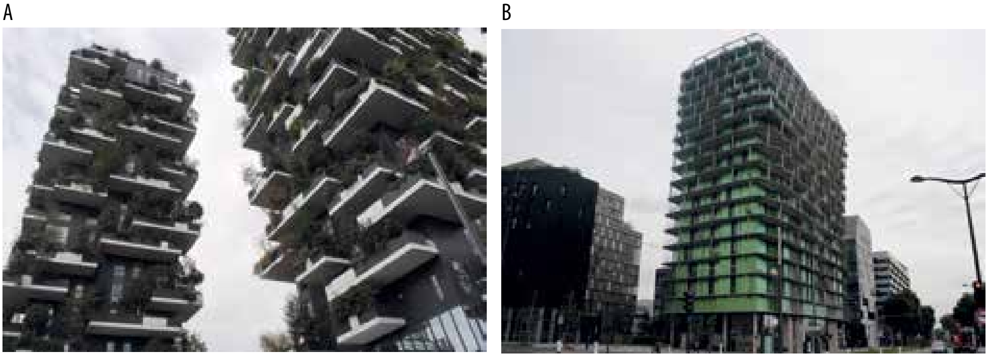

Fig. 2.34. Contemporary vertical parks – multi-family buildings with terraces and gardens on the roofs. A) Bosco Verticale in Milan, Italy (2009-2014, architect Stefano Boeri), B) The M6B2 Tower of Biodiversity in Paris, XIII, France (2016, architect Edouard Francois) (Source: photos by M. Kłopotowski)

2.5. Summary

A review of European housing developments over the past 100 years shows that these buildings have consistently been in line with the current artistic, architectural and social trends. Their quality and standard always resulted from economic conditions. That is also true today. It should also be noted that the split and division of Europe to the east and west (existing in the 20th century) has almost completely disappeared. The tendencies of globalization lead to the emergence of buildings entirely outside the context of location. Their architectural forms are subject to unify and branch of from local traditions. This is supported by the global architecture market, with developers realizing their projects almost everywhere in the world. Today's multi-family residential buildings are expected to astound recipients. This leads to the formation of "strange" mind-blowing realizations. The next few years will bring more surprises. It is therefore impossible to point out one leading aesthetic tendency, because it is now replaced by impossible to define diversity.

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3. MODERN BUILDING MATERIALS

Decisions taken both in the design process of buildings and their modernization should comply with basic requirements, such as: strength and stability, resistance to dampness and water, resistance to fire, heat insulation, sound insulation, durability, comforts and conveniences. Building materials should not have harmful effects on human health. In their production, factors that destroy the natural environment (e.g. freons that destroy the ozone layer in the atmosphere) should not be used. The aspects of utilization, safe storage and recycling possibilities are also important. Another criterion for choosing material solutions is their availability as well as local traditions. However, the deciding factor is usually the economic aspect (costs of materials, construction and assembly).

In the case of insulating materials, not only heat requirements, but also other than thermal ones are taken into consideration (including appropriate mechanical properties, noise attenuation, vibration resistance, non-flammability, moisture absorption), as well as technological and economic conditions.

3.1. Building materials and the environment

Each construction product has an impact on the environment. It is associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. The phase of producing building material is characterized by the *initial embodied energy* (associated with the acquisition of raw materials and the manufacturing process), *indirect energy* (regarding energy transport costs) and *direct energy* (related to the transport of the finished construction product and its assembly in the building). The energy related to maintenance, repairs and replacement of materials with new ones during the whole life cycle of the building is called *recurring embodied energy* (Marchwiński & Zielonko-Jung, 2012).

Considering the embodied energy, construction materials can be sorted into groups:

- low energy building materials (e.g. sand, gravel, timber, concrete, lightweight concrete),
- medium energy building materials (e.g. brickwork, lime, cement, mineral wool, glass),
- high energy building materials (e.g. steel, zinc, copper, aluminium).

The embodied energy is measured in MJ or kWh per unit of mass (e.g. kg of material). The values of embodied energy given in various literature sources may be different. The primary energy demand (in MJ-Eq/kg) of selected building materials in Spain, calculated according to the CED (Cumulative Energy Demand) method, is presented in Table 3.1 (Bribián et al., 2010).

Table 3.1. LCA results for selected building materials (Source: Bribián et al., 2010)

Building product	Density kg/m^3	Thermal conductivity λ [W/(m·K)]	Primary energy demand MJ-Eq/kg
Several types of bricks and tiles			
Ordinary brick	1800	0.95	3.562
Light clay brick	1020	0.29	6.265
Sand-lime brick	1530	0.70	2.182
Ceramic tile	2000	1.00	15.649
Quarry tile	2100	1.50	2.200
Ceramic roof tile	2000	1.00	4,590
Concrete roof tile	2380	1.65	2.659
Fibre cement, roof slate	1800	0.50	11.543
Several types of insulation materials			
EPS foam slab	30	0.0375	105.486
Rock Wool	60	0.04	26.393
Polyurethane rigid foam	30	0.032	103.782
Cork slab	150	0.049	51.517
Cellulose fibre	50	0.04	10.487
Wood wool	180	0.07	20.267
Cement and concrete			
Cement	3150	1.40	4.235
Cement mortar	1525	0.70	2.171
Reinforced concrete	2546	2.30	1.802
Concrete	2380	1.65	1.105
Wood products			
Oriented strand board	600	0.13	36.333
Particle board, indoor use	600	0.13	34.646
Sawn timber, softwood, planed, air dried	600	0.13	18.395

The greatest primary energy demand has conventional insulation with a high level of industrial processing (EPS foam slab and polyurethane rigid foam), whereas concrete has the lowest demand.

Apart from the energy consumption, there are other aspects, among others, the use of natural resources necessary to manufacture building materials and products, greenhouse effect, degradation of the ozone layer and environmental pollution.

Focussing on the life cycle can help in the decision-making process when selecting the best technology available and minimising the environmental impact of the buildings during their design or refurbishing. Often, products that are cheap (have low investment cost) can have high maintenance or waste management costs and highly technological products can have very high production costs that are never recouped.

3.2. Examples of construction of walls and materials used in residential buildings

Nowadays, both traditional materials (known for centuries) and industrialized materials (which began to be manufactured in the 20th century) are used in the construction of buildings. In recent years, new technologies have also begun to emerge which improve the properties of existing products and create new, innovative materials. Among the main criteria for making decision about the use of a building material, can be mentioned the assurance of appropriate technical properties at a minimum price, social habits and tradition. More and more often attention is paid to the protection of the natural environment, but in practice this aspect is not always considered. The type of material also depends on the construction element in which it will be used (roof structure, load bearing structure, foundation, external wall, internal wall, floor) and the type of building (single family houses, multifamily or non-residential buildings).

Depending on the degree of processing, we can distinguish traditional and low-processed materials, industrialized and new generation materials (Table 3.2).

Table 3.2. Groups of building materials depending on the degree of their processing (Source: Marchwiński & Zielonko-Jung, 2012; Addington & Schodek, 2005)

Material	Description
Traditional and low-processed materials	
soil	Use: molded and dried blocks made of clay, filling wooden frame construction, layer covering the walls. The advantages of clay are: the most easily available building material, high thermal mass, good acoustic parameters, absorption and moisture transmission, extensive plastic possibilities, ease of processing, recyclability. The disadvantages are: lack of resistance to moisture, not very high bearing properties. Pressed peat briquettes are also used.
wood	Advantages: natural, renewable material, can be used without processing (wall and roof beam structures, plank constructions, finishing material). It is necessary to impregnate it against biodegradation, flammability and to increase durability and resistance to abrasion. The wood is also processed (floor panels, plywood, chipboards, fibreboards or laminated beams). A derivative of wood is also paper, used in Japan as a construction material, however it is not suitable for the requirements of cold and temperate climates.
stone	The stone has a high thermal mass, however, due to the weight, difficulty of obtaining and the price in present times, it is not used as a construction material. It is usually a layer for finishing internal and external surfaces (floors, wall finishes).
Industrialized materials	
brick	The brick is made of clay which, after being formed into the shape of the product, is fired. It has a high thermal capacity, noble color and texture highlighting the relationship of the building with the environment and tradition. On its basis, a wide range of ceramic hollow bricks has been created. They have a lower thermal capacity but are lighter and have better thermal insulation properties.
concrete, steel, glass	These are materials that require significant technological processing and it is necessary to develop methods for their secondary processing and degrading which will be safe for the environment.
materials produced in the recycling process	These can be, for example, recycled aggregates, materials that use rubber waste, ceramic materials such as clinker brick made of shale or sewage sludge, cellulose fibres, glass cullet boards, wood waste boards or plastics.
New generation materials	
high-performance materials	These materials are highly processed, have a heterogeneous structure, consist of two or more composites to improve mechanical performance, e.g. strength or stiffness. The construction component (e.g., glass or carbon fibre) is placed in a matrix (a substance that is a binder, e.g. a resin). Sometimes, lightweight filling material (e.g. synthetic material) is used. Composite materials are not susceptible to recycling. Examples of new generation concrete: SIFCON, SIMCON, RPC, HPFRC, UHPFRC, ECC. Examples of EWP (Engineered Wood Products): LVL, LSL, OSB. An example of a metal product with improved properties is the mesh that has a structural function. The technology to produce sandwich structures is also used in construction glass products. Innovative composite products are also: GRP (Glass-Fibre-Reinforced Plastics), PMMA, polycarbonate or foil ET or ETFE, TIM (Transparent Insulating Materials).
smart materials / intelligent materials	These materials have properties that react to changes in their environment. This means that one of their properties can be changed by an external condition, such as temperature, light, pressure or electricity. This change is reversible and can be repeated many times. An example of a smart material in construction is PCM (Phase Change Material).

3.2.1. External wall constructions

Most of the currently used external wall structures have a separate load bearing layer and a separate thermo-insulation layer. This is due to different properties of individual building materials: materials with high structural strength usually conduct heat well, whereas materials with good thermal insulation properties generally have low strength. In Poland, there are mainly:

- single-layer walls (masonry) with external insulation using the External Thermal Insulation Composite System /ETICS method/ (Fig. 3.1A),
- single-layer walls with external insulation using the light dry method (ventilated facades – Fig. 3.1B, sometimes with a glass facade),
- double-layered walls (cavity walls with thermal insulation – Fig. 3.1C and sometimes additionally with an air layer – Fig. 3.1D).

Typically, the thermal insulation layer is placed from the outside of the building.

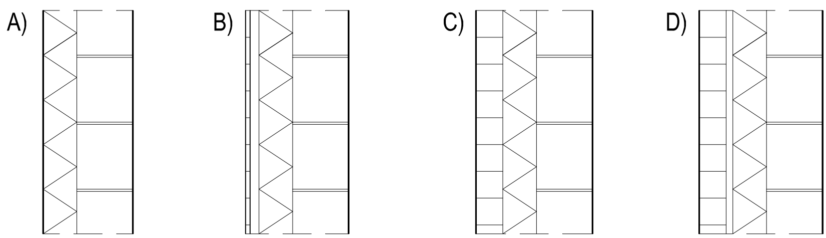

Fig. 3.1. Examples of multi-layered external wall constructions (Source: own elaboration)

Another group of masonry partitions are single-layer walls (homogeneous) made, for example, of ceramic hollow bricks or cellular concrete blocks. Systemic technologies are also used (e.g. from Styrofoam formwork moldings – Fig. 3.2A).

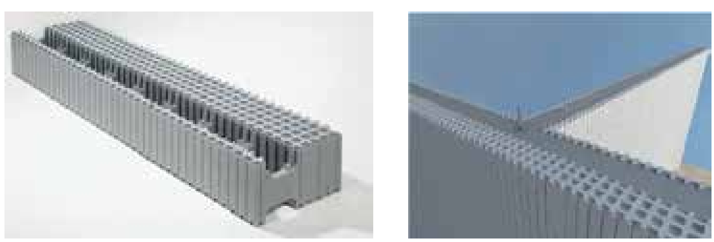

Fig. 3.2. An expanded polystyrene block (Source: WEB-1)

Wooden walls (massive – Fig. 3.3A and Fig. 3.3B or frame – Fig. 3.3C) are also used.

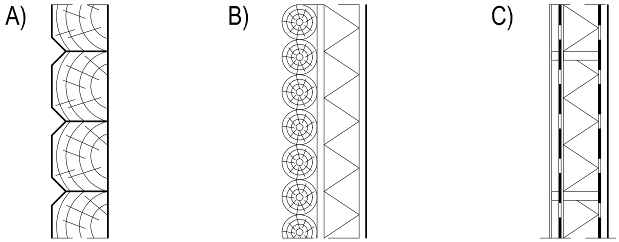

Fig. 3.3. Examples of wooden wall constructions (Source: own elaboration)

Each wall, regardless of its construction, should have a heat transfer coefficient that meets the requirements set out in national regulations. Due to the humidity phenomena occurring in the building, the walls should be designed so that the layers with the greatest diffusion resistance are located closest to the interior. With this sequence of layers, water vapor can escape from the wall in the same amount it flows in, without condensation inside the partition. In other cases, it is necessary to use a vapor barrier.

In the process of designing the material layers of external walls and their system, we should consider not only the criteria for thermal insulation, internal surface condensation and interstitial condensation due to water vapor diffusion, but also the criteria for acoustic insulation, fire protection as well as bearing capacity and durability of the structure.

In modern architecture, glazed curtain walls are used, but mainly in representative public buildings (e.g. office buildings).

3.2.2. Structures of horizontal partitions

Among the horizontal partitions of the building's outer envelope we can mention: floors on the ground or in the basement, roofs, flat roofs, ceilings under unheated attics and terraces. Proper shaping the structure of these partitions and their thermal insulation, as in the case of walls, affects the demand for thermal energy, but also must meet strength and performance criteria.

In construction there are two basic types of floor structure: one which is made of concrete and the other that is made of timber. They must be safe and fire resistant, they must also be strong enough to safely support their own weight and the weight of whatever is placed on the floor, as well as the weight of the people who walk on the floor.

In buildings without a basement, floors are built on the ground. On the board (e.g. concrete) being a structural layer, a damp-proof course (DPC) must be used and then thermal insulation and a floor finishing layer (Fig. 3.4A). In buildings with a basement, the lowest floor is below the ground level. In this case, it is recommended to put the floor on a reinforced concrete slab laid on the strip foundation (Fig. 3.4B). Foundation slabs (instead of traditional foundations) are recommended in passive buildings (Fig. 3.5).

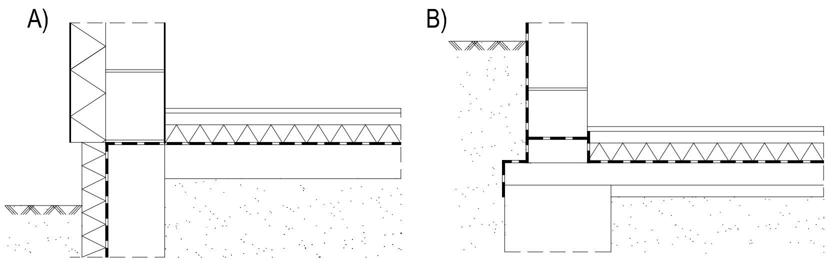

Fig. 3.4. Examples of traditional solutions for floors built on the ground and joined with the external wall (Source: own elaboration)

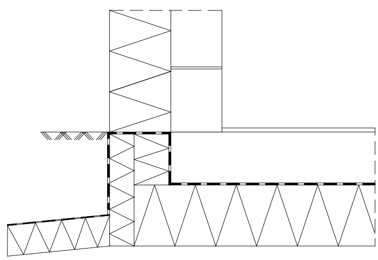

Fig. 3.5. A fragment of a foundation slab joined with an external wall (Source: own elaboration)

An alternative to a massive floor built on the ground and made of concrete slabs, is a ventilated wooden floor made of planks on joists or a suspended timber floor (Fig. 3.6).

Roofs come in all shapes and forms, ranging from flat concrete roofs to steeply pitched roofs. Their task is to secure the building against the influence of external conditions, but they are also important in shaping the appearance of buildings. Regardless of the form of the roof, its proper thermal insulation is important.

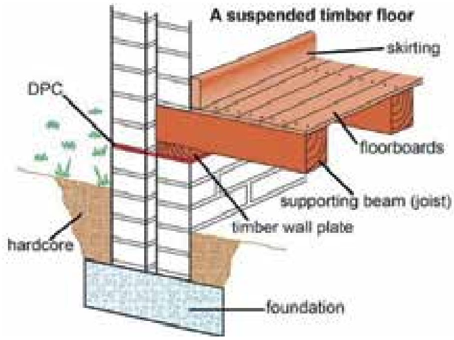

Fig. 3.6. A suspended timber floor (Source: WEB-2)

In pitched roofs (most often used in single-family residential buildings) with a heated attic, thermal insulation is placed in the roof slope and additionally under the rafters (Fig. 3.7A). In pitched roofs with unusable attic, thermal insulation is placed on the ceiling under unheated space (Fig. 3.7B and Fig. 3.7C).

A B C

Fig. 3.7. Laying thermal insulation in buildings with an attic: A) in the roof slope and additionally under the rafters, B) between ceiling joists, C) between and over ceiling joists (Source: WEB-3)

The most often used roofing materials for pitched roofs (to protect the building against atmospheric precipitation) are: metal sheets, press metal roof tiles, tiles (e.g. plain tiles), roof slates, shingles and thatch. Sometimes vegetation is also used. It is important for these roofs to efficiently discharge rainwater.

In multi-family residential buildings, ventilated roofs (Fig. 3.8A) are often used. Flat roof with tapered layers (Fig. 3.8B) is also in use. The top layer of these roofs is roofing paper. The inverted roofs and green roofs are also designed (Fig. 3.9).

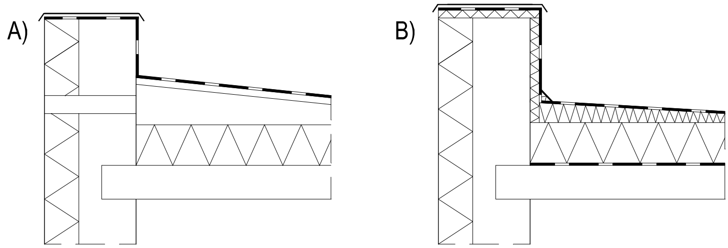

Fig. 3.8. Examples of a ventilated roof and a flat roof with tapered layers (Source: own elaboration)

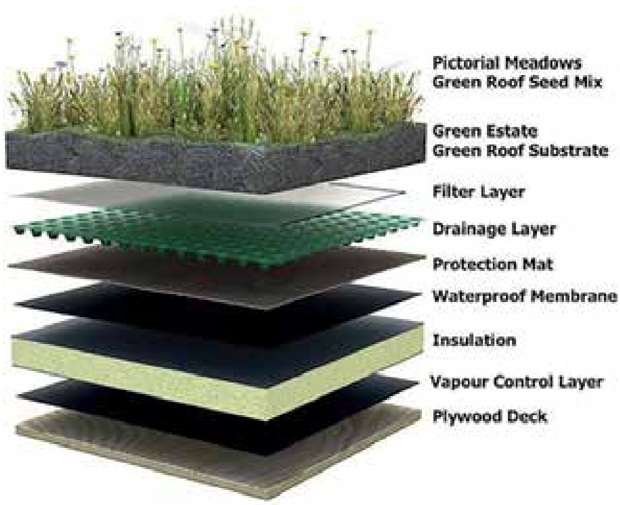

Fig. 3.9. An example of a green roof (Source: WEB-4)

3.3. Thermal insulation materials

Building envelope should be designed in accordance with the thermal quality levels specified in national legislation. Partitions of buildings in which renovations and thermal modernization are carried out should meet the same requirements as in new buildings. According to the Directive of Energy Performance of Buildings (2010/31/EU) all new buildings in EU countries must be nearly zero energy buildings by 31 December 2020. The other EU directives (Directive 2012/27/EU, Directive 2006/32/EU, Directive 2005/32/EU) also encourage the reduction of energy consumption in buildings as much as possible. Thus, the increasing pressure on high energy efficiency of buildings has resulted in the fact that the production of thermal insulation materials is now one of the most dynamically developing areas of the building materials market.

3.3.1. General characteristics of insulation materials

Thermal insulation materials are materials which significantly slow down or retard the flow or transfer of heat. They are classified according to the form (e.g loose-fill, batt, flexible, rigid, reflective, and foamed-in-place) or the material (foam plastic, organic fibre, mineral fibre). Insulating materials come usually in the form of sheets, boards, rolls or flakes. All types are rated according to their ability to resist heat flow. Thermal conductivity coefficient of thermal insulating materials is lower than 0.20 W/(m·K) (Steidl, 2010), or than 0.175 W/(m·K) (PN-89/B-04620), or than 0.10 W/(m·K) (Laskowski, 2009), or than 0.065 W/(m·K) according to the Building Research Institute.

Nowadays there is a wide range of thermal insulation materials on the market (Table 3.3). New technologies and solutions are still being developed and produced. Some of them are adapted not only to limit the heat flow transmitted by the external building envelope, but also to acquire, store and return external energy to the building.

Table 3.3. Materials for thermal insulation of building partitions (Source: Sadowska, 2010; Steidl, 2010)

Material and products for thermal insulation	Thermal conductivity λ [W/(m·K)]
Organic materials	
boards made of straw and reed	0.07-0.08
boards made of linen and hemp	0.075-0.13
boards made of wood, cork and pine bark	0.045-0.07
peat materials (peat powder, peat board)	0.09
chip-cement or chip-magnesia boards	0.07-0.15
fibreboard	0.06-0.18
cellulose, blown-in fibre cellulose	0.037-0.043
mats and boards of sheep wool	
Non-organic materials	
expanded polystyrene (EPS) and extruded polystyrene (XPS)	0.031-0.045
polyurethane rigid foam (PUR, PIR)	0.0185-0.025
foam glass	0.07; 0.12
mineral wool and its products (MW)	0.034-0.050
stone wool and its products	0.042-0.045
yarn, wool and glass wool and their products	0.045
phenolic foam (PF)	0.021-0.024
cellular glass (CG)	0.038-0.048

Material and products for thermal insulation	Thermal conductivity λ [W/(m·K)]
Biodegradable materials (made of organic fibres mixed with artificial fibres)	
hemp boards reinforced with elements of artificial fibres – flax fibre materials with additions of synthetic fibres and starch	0.038-0.045
HI-TECH materials	
vacuum insulation panels /VIP/	0.002-0.008
aerogel, nanogel, nano cellular polyurethane foam	0.004-0.018
Transparent insulations	
cellular or capillary plates with glass plaster	depending on the material used, also intended for solar energy
Phase-change isolation materials (PCM)	
organic and inorganic (plates, flakes)	0.05

Thermal insulation materials in building partitions reduce the need for heating and air conditioning and reduce energy costs. Proper insulation of buildings can also bring additional benefits by reducing pollution emissions (including CO_2). The range of economic and ecological savings resulting from the usage of thicker thermal insulation layer or material with better thermal performance depends on the type of building, climatic conditions at the location and economic conditions (materials and energy costs and co-financing options).

Thus, when selecting an insulating material, it is necessary to take into consideration its properties:

- thermal conductivity,
- diffusion or penetration of water vapour,
- flammability class,
- resistance to chemical and biological factors,
- mechanical strength.

It is also worth analysing, as in the case of other building materials, the impact on the environment (using, for example, the LCA method).

In practice, modern construction mainly uses traditional materials. In Poland, the most often used insulating material is expanded polystyrene (Fig. 3.10).

A similar trend can be seen in Europe in the group of nearly Zero-Energy Buildings (Fig. 3.11). Most frequently used is expanded polystyrene (27%).

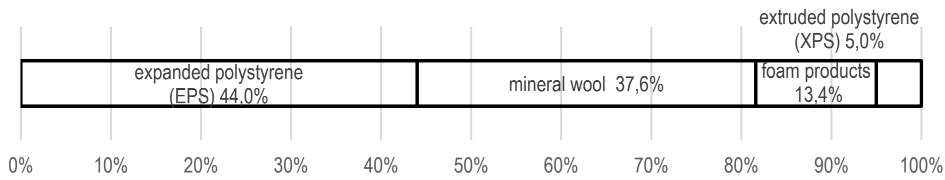

Fig. 3.10. Structure of the thermal insulation materials market in Poland in 2013 by production groups (Source: PMR)

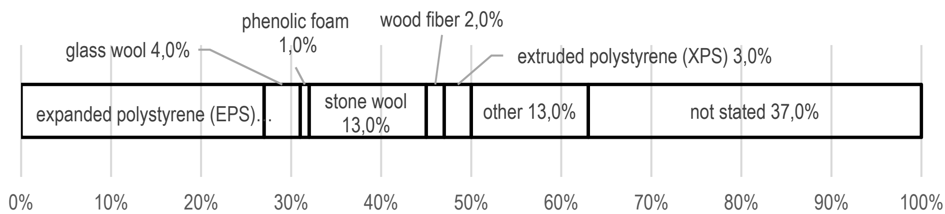

Fig. 3.11. Wall insulation materials in cold winter climates for new residential buildings – sample 111 nZEB (Source: Zebra, 2020)

Traditional insulation materials are usually used for thermal insulation of the building envelope, mainly due to their availability and price (lower than the price of modern materials). The thickness of the typical thermal insulation material (λ=0.04 W/(m·K)) essential to obtain the expected thermal transmittance of external walls is shown in Fig. 3.12. The thermal resistance of the bearing layers was assumed equal to 0.446 (m^2K)/W (one and a half brick wall made from perforated brick).

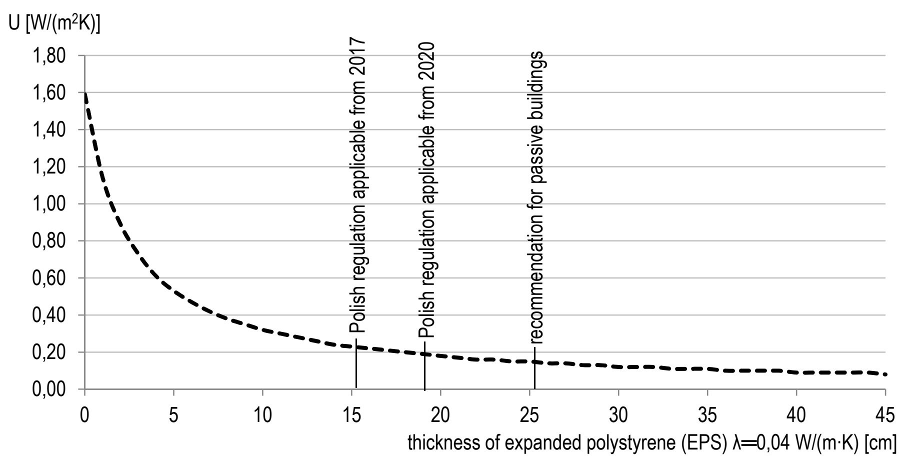

Fig. 3.12. The thickness of the thermal insulation material essential to obtain the expected thermal transmittance of external walls (Source: own elaboration)

The current requirements of thermal protection of buildings in Poland are contained in Regulation of the Minister of Transport, Construction and Maritime Economy of 5 July 2013. The maximum thermal transmittance coefficient for the walls applicable from January 2017 is 0.23 W/(m^{2}K), for roofs 0.18 W/(m^{2}K) and for floor on the ground 0.30 W/(m^{2}K). From January 2021 these requirements will be stricter (0.20 W/(m^{2}K) for walls and 0.15 W/(m^{2}K) for roofs).

The increase of the required thermal insulation of building partitions is often very difficult to obtain (with the existing thick walls it reduces the inflow of daylight) or involves many architectural and functional compromises (e.g. reducing the usable area or height of the room). Therefore, more efficient materials are sought, thanks to which it will be possible to use insulation of smaller thicknesses.

3.3.2. Properties and application of modern insulation materials in residential buildings

Modified traditional insulating materials

Some of the traditional insulation materials are modified and improved. An example can be insulating materials made of organic fibres mixed with synthetic fibres. They are cost-competitive (124 €/m^3) compared to mineral wool and glass wool and achieve thermal conductivity coefficient between 0.038 W/(m·K) and 0.045 W/(m·K). Products made from these materials (hemp boards with elements of artificial fibres: e.g. Thermo Hanf – Fig. 3.13 or flax fibre materials with additions of synthetic fibres and starch: e.g. Flachshaus) have wide application in roof trusses, roofs, floors, internal and external walls. The most important properties of these materials (Steidl, 2010) are:

- biodegradability,
- high diffusion, transmissivity and ability of moisture redistribution,
- double heat capacity compared with mineral insulations,
- ease of processing,
- high flexibility,
- high fire resistance.

Thermal conductivity coefficient of conventional thermal insulation materials does not achieve the values lower than 0.030 W/(m·K). To improve the thermal insulation properties, the focus is on reducing gaseous thermal conductivity. One possibility is to use heavier gases with a lower thermal conductivity than that of the air. For example, polyurethane foams filled with heavy gas achieve thermal conductivities less than 0.022 W/(m·K) but the conductivity may increase over time.

Fig. 3.13. Hemp insulation boards (TERMO HANF) reinforced with elements of artificial fibres (Source: WEB-5)

Aerogel

Another solution is to make the structure fine (the pores must be smaller than a few tenths of a micrometre in size) so that the gas particles under atmospheric pressure collide not only with one another but with a diverse number of walls. Aerogels or nano-structured fumed silica have values λ~0.013 W/(m·K).

Fig. 3.14. Pure aerogel sample (Source: WEB-6)

Aerogel (Fig. 3.14) is a kind of rigid foam with very low density (bulk density is 3-35 kg/m^3). Its mass consists of 90-99.8% air and of a three-dimensional amorphous solid matrix made of SiO_2 particles with average diameter of 10 nm and open nanopores in the range from 1 to 100 nm. Aerogel is extremely durable but, at the same time, extremely fragile too.

Aerogel blanket reinforced with polyethylene terephthalate fibres (PET) and textile-grade continuous filament glass fibre (Fig. 3.15) is particularly suitable for use in buildings and universal applications (with maximum operating temperatures of 200°C). It's suitable for vertical and horizontal opaque structure coating when used within cavity walls or internal counter walls.

Fig. 3.15. Continuous filament glass fibre (Source: WEB-5)

The advantages of aerogel insulation are as follows (WEB-6):

- small thickness (5 mm or 10 mm) compared to traditional insulation due to 2 to 8 times higher insulation performance as well as lower weight,
- lower weight of insulation compared to traditional materials,
- constant and high insulation efficiency for the entire period of use,
- flexible options for assembly, punching, laminating and folding,
- environmental friendliness (natural product),
- very good hydrophobic properties,
- fire resistance.

The cost of 10-mm-thick aerogel insulation mats is 43 €/m^2 (WEB-5).

Vacuum insulation panels /VIP/

Another way to reduce the thermal conductivity of the insulating material is to reduce the gas pressure in its pores. This idea is used in vacuum insulation.

The vacuum insulation panel (VIP) consists of a rigid, highly-porous core material enclosed in a thin, gas-tight outer shell (Fig. 3.16).

Fig. 3.16. A fragment of a VIP isolation (Source: WEB-7)

The material used as the core (open cell foams such as polyurethane and polystyrene, fumed or pyrogenic silica, silica aerogels, expanded perlite individually or in a mixture form, glass fibre or fibre-powder composites) determines the mechanical properties, and thus the durability of the insulation system. Inside the core, getter and desiccant are placed to ensure continuous absorption of water vapor and gases which may get into it through either permeation from the outside environment or via outgassing of core and envelope materials or both. In the case of silica core, it itself acts as a desiccant but for other core materials a small amount of silica gel desiccant is required (Bochenek, 2012). Opacifiers (e.g. silicon carbide, carbon black, titanium dioxide or iron oxide) are used to reduce the radiative conductivity of the core material by making it opaque to infrared radiation. The multilayer film covering the core usually consists of three layers: an outer protective layer (e.g. polyethylene terephthalate), a middle barrier layer (e.g. aluminum foil) and an inner sealing layer (e.g. polyethylene). There are also VIPs with metal sheet envelope which exhibit better load bearing capacity and resistance to mechanical damages but have heavier weight and a greater thermal bridging effect (Alam et al., 2011).

The thermal conductivity of these thermal insulation materials loaded with atmospheric pressure therefore ranges between 0.002 W/(m·K) and 0.008 W/(m·K).

In construction, vacuum insulation panels have been used for several years. In Europe, the greatest interest in them can be observed in Germany and Switzerland. They are used both in renovations and in newly constructed buildings. VIPs offer unparalleled heat insulation at minimum thickness (ten times higher thermal insulation than traditional insulation materials of the same thickness).

Vacuum insulation panels can provide:

- extremely low insulation thicknesses (10 mm to 25 mm),
- stable, long-term thermal performance when installed correctly and protected from damage and penetration,
- new design and construction possibilities (e.g. small specific weight).

The main disadvantages of vacuum insulation panels (Bochenek, 2012) are:

- ease of damage during assembly (the assembly needs to be performed by a skilled worker),
- no possibility of any mechanical treatment of panels on the construction site (very exact execution of the assembly plan is required before the material is ordered),
- shorter life compared to traditional insulation,
- high price compared to traditional insulation.

The very high cost is a significant obstacle to the widespread use of VIPs as a thermal insulation material in construction. However, research is being carried out on the use of alternative materials for their construction (for example, fibrous-powder composites made of traditional fibre and volcanic powder insulation), which should reduce production costs and the price of the finished product in the future.

Nowadays vacuum insulation panels are most often used as terrace insulation (because they allow to minimize the doorstep between the terrace and the inside of the building), in roofs and attics (the room height is not reduced), while the walls are insulated from the inside. The most common ranges of vacuum insulation panel thickness are 20, 25, 30 and 40 mm (Bochenek, 2012).

Transparent insulation

In a modern concept, the building's exterior walls should be interactive, with a multitude of tasks. They should dynamically react to changing environmental conditions, in a controlled way using its energy.

In case of using transparent insulation, the profits from the absorption of solar radiation in the opaque partition are considered, unlike the traditional thermal insulation that allows to use only slightly more than 1% of that radiation for heating purposes (Pogorzelski, 2005).

Transparent insulation can be used as cellular or capillary structures with glass plaster (Fig. 3.17), silica gel granulates placed between two insulating glass units or three-pane glazing with krypton filled glass (Pogorzelski, 2005).

Fig. 3.17. Transparent insulation designed for connecting with the ETICS system (Source: Kisielewicz, 2010)

TI insulation can be used alone as an element illuminating the interior or placed on a massive accumulation wall (preferably southern). It is recommended that the surface area of the system with this type of insulation does not exceed 10-30% of the wall surface (Kisielewicz, 2008; Laskowski, 2005), because in case of its greater contribution, to avoid overheating in the summer, a heat recovery and storage system should be used under the absorber surface.

Calculation of the thermal transmittance coefficient of a wall fragment with transparent insulation differs significantly from the traditional method (Kisielewicz, 2008). The equivalent thermal transfer coefficient U_{eq}, considering the heat loss because of transmittance, as well as thermal gains from absorbed solar radiation, can be determined from the Equation (3.1):

$$U_{eq} = -0,2866(I / \Delta T_{i-e}) + 0,6219 \tag{3.1}$$

where:

I – the intensity of solar radiation on the surface of transparent insulation, during the balancing period, W/m^2

ΔT_{i-e} – difference in average temperatures of external and internal air during the balancing period, K Equation (3.2) can also be used resulting directly from the thermal balance of the partition (Suchodolski, 2006):

$$U_{TI} = -\sum_{1}^{9} (q_i / \Delta T_{i-e}) / 9 \tag{3.2}$$

where:

q_i – total heat flow through the partition during the balancing period, W/m^2 The transmissivity of solar radiation, in addition to the thermal insulation of the layer, affects the energy efficiency of the partition with transparent insulation. This efficiency can be determined from the Equation (3.3) (Laskowski, 2005):

$$\eta = (\tau_t \cdot \alpha_a) \frac{R_t}{R_a + R_t} \tag{3.3}$$

where:

τ_t – solar radiation transmission coefficient through the transparent thermal insulation layer

α_a – solar absorption coefficient on the absorber surface

R_t – thermal resistance of the transparent insulation layer, considering the replacement coefficient of heat exchange through the material and external heat transfer resistance, (m^2·K)/W

R_a – thermal resistance of the structural accumulative layer of the wall and internal heat transfer resistance, (m^2·K)/W Typical transparent insulation transmits no more than 50% of the solar radiation and its thermal conductivity coefficient is at least twice as high as in the case of modern thermal insulation materials. However, with an energy efficiency equal to 30%, excess heat gains over losses are possible (Kisielewicz, 2010).

Additional advantages resulting from the use of transparent insulation include:
- positive influence on the thermal comfort of the interior due to increased operating temperature,
- simple operation, high durability and reliability without additional service and supervision,
- acquiring renewable energy, increasing independence from external energy sources and relieving the natural environment.

However, the investment cost of this insulation is high (from 186 €/m^2 without sun protection system to over 698 €/m^2 for systems based on aluminum construction). So, the use of the TI type insulation, like the VIP, is economically unjustified and its ecological attractiveness without financial support is not a sufficient argument for potential investors.

Phase-change isolation materials (PCM)

Phase-change isolation materials can also be included in the group of thermal insulation materials. These materials additionally increase the thermal capacity of the building, without significantly increasing its mass by using heat storage in the form of latent heat. By storing and releasing heat within a certain temperature range, it raises the building inertia and stabilizes indoor climate.

The phase change materials used in building applications can be either organic materials or inorganic materials.

The organic PCMs are paraffins, fatty acids and the polyethylene glycol (PEG) (Kuznik et al., 2011). They present a congruent phase change, they are not dangerous, and they have a good nucleation rate. Their advantages are:
- availability in a large temperature range,
- freeze without much super cooling,
- ability to melt congruently,
- self-nucleating properties,
- compatibility with conventional material of construction,
- no segregation,
- chemically stable,
- high heat of fusion,
- safe and non-reactive,
- recyclable.

In addition, organic PCMs are characterised by:
- low thermal conductivity,
- low volumetric latent heat storage capacity,
- flammability (depending on containment).

The inorganic PCMs are salt hydrates (Kuznik et al., 2011). The advantages of inorganic PCMs are:

- high volumetric latent heat storage capacity,
- low cost and easy availability,
- sharp phase change,
- high thermal conductivity,
- nonflammability.

The disadvantages of inorganic PCM are:

- high volume change,
- super cooling,
- segregation.

There are many different products on the market with PCM materials. Depending on the purpose (heating / cooling) and location (plasterboard, walls, plaster, floor, ceilings, windows, blinds) different technologies are used and ways to integrate them into the building structure (Sowa at al., 2017).

PCMs can be (Jaworski, 2010; Kuznik et al., 2011; Musiał, 2015) directly impregnated into gypsum, concrete or other porous building materials to form a mixed type PCMIBW or they can be enclosed in a microscopic polymer capsule. They can be shape stabilized (SSPCM) or integrated in building walls (PVC panels filled with PCM, sandwich panels with plastic rigid containers of PCM, CSM panels – Fig. 3.18 or aluminium foils, to incorporate the PCM in a multi-layer panel, tubes filled with PCM to be integrated in the wall or steel containers filled with PCM to be included in the roof slab). Fig. 3.18 shows examples of PCM products available on the market.

Fig. 3.18. Concrete block CelBloc Plus (Source: BASF SE), CSM panel (Source: Rubitherm Technologies GmbH) and SmartBoard (Source: BASF SE)

The cost of the material depends significantly on the classification of the PCM (i.e. organic, inorganic, or biomaterial).

3.4. Sustainable building materials: fine recycled aggregates from CDW

The construction sector has gone from a linear economy model based on producing, consuming and throwing away, where construction and demolition waste were deposited in landfills or dumped illegally, to a circular economy model in which it is intended to limit the consumption of new resources and encourage the use of recycled materials, so that waste is reincorporated into the production process, giving it a second useful life. Landfill is only contemplated for waste that cannot be utilised in any way.

Construction and demolition waste (CDW) means substances or objects generated in a construction or demolition work that their owner discards or intends to discard. CDW is generated in any type of civil engineering work or building, and throughout the life cycle of the work: construction phase, phase of use or exploitation and during the total or partial demolition (Fig. 3.19).

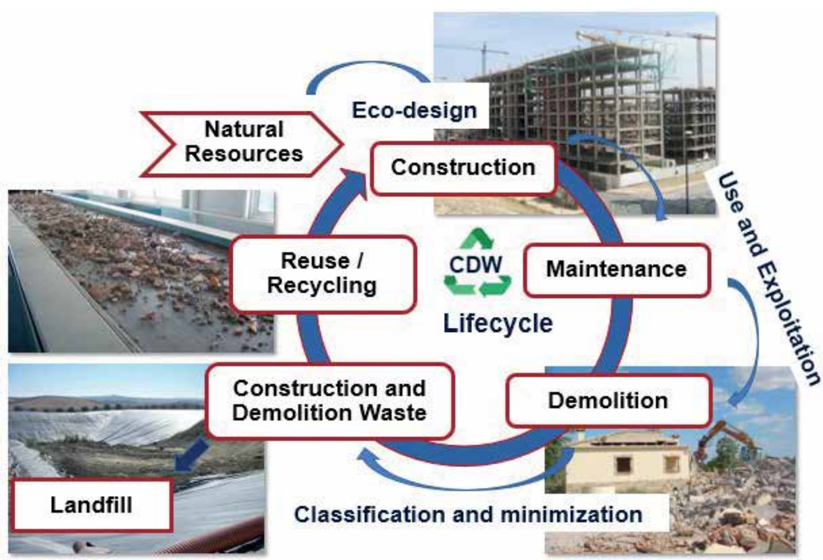

Fig. 3.19. Circular economy model in the construction sector (Source: own elaboration)

The European Commission considers CDW a priority waste stream since it represents between 25-30% of the total waste.

CDW is composed mainly of concrete, ceramics, asphalt, stone and excavation waste which are considered inert, non-hazardous waste and have a high potential to be recycled as aggregates (Fig. 3.20).

Fig. 3.20. Main recyclable components of the CDW (Source: own elaboration)

In addition, CDW is composed of other waste, such as gypsum and its derivatives, wood, plastic, steel, paper, which are inert and not dangerous, although they are considered impurities, since their presence can limit the production of recycled aggregates.

From the CDW treated in authorized recovery plants we can obtain recycled aggregates (AR) that can be used as construction material in civil engineering and building works.

The treatment plants can be fixed or mobile. The equipment used is very similar to the machinery applied in treatment of natural aggregates, including crushers, mills, screens and conveyor belts. Additionally, devices to eliminate impurities are used, such as triage booths, blowers or electromagnets (Fig. 3.21).

Recycled aggregates (RA) have physico-mechanical and chemical properties different from natural aggregate (NA), derived from their own nature. The majority of RA are composed of natural aggregates with attached mortar, or ceramic particles with or without mortar. The texture is more rough and porous. The density of the RA is lower than in natural aggregates and the absorption of water is greater.

RA have lower resistance to fragmentation than NA, this is evaluated by the Los Angeles index.

From a chemical point of view, recycled aggregates contain more sulphates and soluble salts than natural aggregates, these come mainly from the attached mortar or the presence of gypsum. The content in organic matter is not usually a problem.

Recycled aggregates are classified according to their composition. The recycled concrete aggregates (RCA) have a percentage of unbound concrete and aggregate particles greater than 90%. Mixed recycled aggregates (MRA) have ceramic and concrete particles. Asphalt recycled aggregate (ARA) is composed of more than 50% by bituminous materials.

Fig. 3.21. Elements of a recycling plant. GECORSA, Córdoba, Spain (Source: J. R. Jimenez's private archive)

Most recycled aggregates are used in embankments or as fillings in road construction. The use of RA in the manufacture of concrete or mortar would give a greater added value to these recycled materials. Most of the research has been carried out on recycled concrete aggregates and on the manufacture of structural concrete. The coarse fraction has been widely studied, whereas, the fine fraction has been paid little attention to.

This chapter presents the results of four experimental campaigns carried out by the University of Córdoba to study the possibility of using the fine fraction of recycled concrete and mixed aggregates in the manufacture of masonry and concrete mortars.

The results shown in this chapter will help foster the development of sustainable construction, since it presents alternatives to the landfill disposal of the CDW, proposes solutions to recycle these materials, thus avoiding the consumption of non-renewable natural resources such as sand. It has been shown that the production of recycled aggregates has a lower carbon footprint than natural aggregates.

3.4.1. Mortar with fine recycled concrete aggregates

Construction and demolition waste is mostly composed of concrete and masonry wastes, which have a high potential for recycling (European Commission – DG ENV, 2011). Two types of recycled aggregates (RAs) can be obtained from such CDW: recycled concrete aggregate (RCA) and mixed recycled aggregate (MRA). The manufacture of concrete made with coarse RCA has been tested successfully (Gómez & de Brito, 2009; Corinaldesi, 2010), which gives a great added value to recycled aggregates. However, the use of fine RCA impairs the new structural concrete's properties (Evangelista & de Brito, 2007; Cartuxo et al., 2016).

The manufacture of masonry mortar, with lower mechanical and durability requirements than structural concretes, may constitute a good alternative to recycling the fine fraction of RCA. There are few studies on the use of fine RCA in the manufacture of mortars (Braga et al., 2012; Neno et al., 2014). Hence, the University of Córdoba (Spain) is carrying out numerous experimental studies to test the possibility of using fine RCA in the manufacture of masonry mortar (Ledesma et al., 2014; Fernández-Ledesma et al., 2016).

This section presents the results of a work carried out by the University of Córdoba (Spain) in order to establish the maximum replacement level of natural sand by fine RCA in mortar productions.

The materials used for the manufacture of the mortars tested were: natural siliceous sand (NA), fine recycled concrete aggregate (f-RCA), cement CEM-II/BL 32.5N and a commercial admixture (NEOPLAST). NA and f-RCA met the specifications of standard UNE-EN 13139:2002 for mortar aggregates. Table 3.4 shows the main physico-mechanical and chemical characteristics of the AN and f-RCA.

Table 3.4. Characterisation of NA and f-RCA (Source: own elaboration based on Fernández-Ledesma et al., 2016)

Characteristic	Standard	NA	F-RCA
Fine content (%) [(a)]	UNE-EN 933-1/98	3.2	6.1
Maximum particle size (mm)	UNE-EN 933-1/98	4	4
Dry sample density [(b)] ρ_{rd} (g/cm^3)	UNE-EN 1097-6/00	2.63	2.20
Water absorption [(b)] (%)	UNE-EN 1097-6/00	0.79	8.26
Friability coefficient (%)	UNE 83115/89	15	23
Total sulphurs (% SO_3)	UNE-EN 1744-1	< 0.01	0.40

(a) Finer than 0.063 mm

(b) Fraction 0.063/4 mm

Five mortars with a volumetric proportion of cement-to-aggregate of 1:5 were tested. Five replacement levels (by volume) were tested: 0%, 25%, 50%, 75% and 100%. Table 3.5 shows the composition of each of the mortars tested. The aggregates were used at laboratory humidity (not pre-saturated). The water content was set experimentally to achieve a consistency of 175 ± 10 mm (UNE-EN 1015-3:1999).

Two properties were tested to evaluate the fresh mortar: bulk density (UNE-EN 1015-6: 1998) and workability (UNE-EN 1015-9: 2000). The hardened mortar was characterized according to seven properties: dry bulk density (UNE-EN 1015-10: 1999), flexural strength, compressive strength (UNE-EN 1015-11: 1999), shrinkage (UNE-83831 EX: 2010), adhesive strength (UNE-EN 1015-12: 2000), water absorption due to capillary action (UNE-EN 1015-18: 2002) and durability (UNE-EN 12370: 1999). Four different mixes of each mortar type were made.

Table 3.5. Mortar mixture proportions (Source: own elaboration based on Fernández-Ledesma et al., 2016)

	Mix proportions – dry weight				
Mortar-NA/RCA	NA (g)	RCA (g)	CEM (g)	Admixture (cm^3)	w/c
M-100/0	5262	0	1135	0.15	0.78
M-75/25	3947	1101	1135	0.15	0.83
M-50/50	2631	2200	1135	0.15	0.87
M-25/75	1316	3301	1135	0.15	0.92
M-0/100	0	4402	1135	0.15	0.97

The fresh and dry bulk density decreased linearly with replacement ratios higher than 25% (Fig. 3.22). This is due to the lower density of recycled aggregates compared to natural aggregates.

Workability decreased linearly with the incorporation of f-RCA (M-100/0: 206 min; M-75/25: 189 min; M-50/50: 185 min; M-25/75: 149 min and M-0/100: 121 min). This is due to the greater water absorption of f-RCA and the fact that the recycled aggregates were used without previous pre-saturation. Workability is a key aspect in the manufacture of masonry mortars, so this property can be a limiting property.

The compressive and flexural strength of hardened mortar decreases with the incorporation of f-RCA. (Fig. 3.23). However, from a statistical point of view (ANOVA-analysis), replacement ratios of up to 50% did not significantly affect the mean compressive strength values for any of the curing times. The compressive strength for mortar M-50/50 exceeds the value of 10 MPa required for mortar type M-10 (UNE-EN 998-2:2012) at 28 days of age.

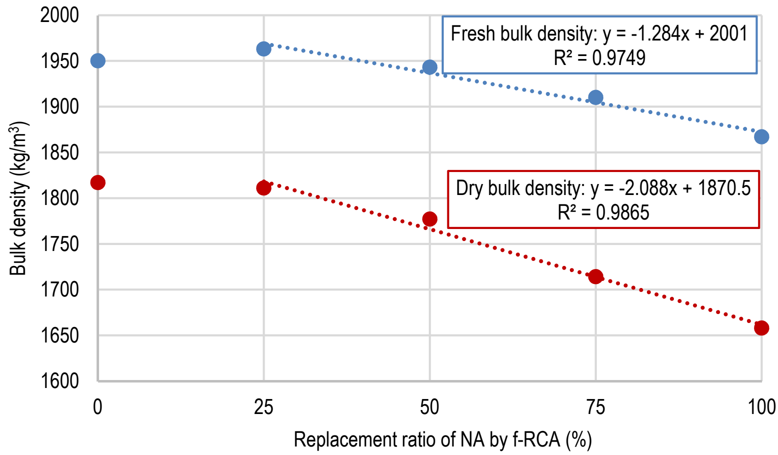

Fig. 3.22. Bulk density of fresh and hardened mortar (Source: own elaboration)

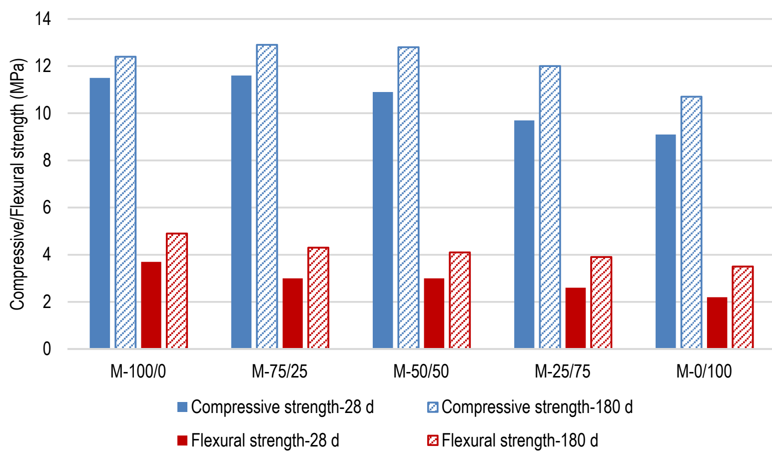

Fig. 3.23. Compressive and flexural strength of hardened mortar (Source: own elaboration)

The incorporation of f-RCA increased the shrinkage (mm/m) (Fig. 3.24). The high water/cement ratio in mixtures made with f-RCA is the main reason for the increase in shrinkage.

All mortars made with f-RCA showed similar values of adhesive strength (M-75/25: 0.26 MPa, M-50/50 and M-25/75: 0.25 MPa, M-0/100: 0.29 MPa), with the exception of the reference mortar that showed an unusually high value (M-100/0: 0.47 MPa), this data can be considered spurious.

Capillary absorption means values increased slightly with the incorporations of f-RCA (M-100/0 and M-75/25: 0.59 kg/m^{2}min$^{-0.5}$, M-50/50 and M-25/75: 0.62 kg/m^{2}min$^{-0.5}$, M-0/100: 0.67 kg/m^{2}min$^{-0.5}$).

From the point of view of durability, mortars prepared with f-RCA were less resistant to salt crystallization (15 cycles in sodium sulphate dissolution according to UNE-EN 12370:1999), which may limit their use in outdoor environments.

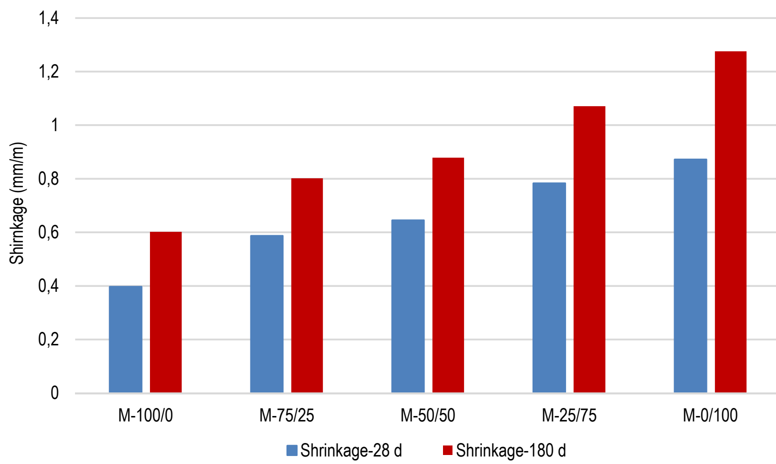

Fig. 3.24. Shrinkage of hardened mortar (Source: own elaboration)

In conclusion, the maximum recommended replacement ratio of natural sand by fine recycled concrete aggregates can be fixed at 50% by volume. The use of mortars made with recycled aggregates is recommended exclusively for indoor environments, for example for bedding mortars.

3.4.2. Concrete with fine recycled concrete aggregates

Concrete is one of the most commonly used materials in the construction sector. The manufacture of concrete produces a great environmental impact due to the large amount of natural aggregates and cement required. Concrete structures are demolished at the end of their service life generating concrete waste which can be recycled in treatment plants. In these plants, concrete rubble is crushed in an impact or jaw crusher to reduce the grain size in order to produce recycled concrete aggregates (RCA). The RCA can be screened to obtain two fractions: coarse recycled concrete aggregates (CRCA) and fine recycled concrete aggregates (FRCA).

In the last decade, research has focused on the use of CRCA in the manufacture of new concrete (Rahal, 2007; Fonseca et al., 2011). The use of FRCA has been less investigated because of the worse physico-mechanical and chemical properties of this fraction, such as greater amount of cement paste, porosity, water absorption and sulphur compounds (Evangelista & de Brito 2007). FRCA increases water absorption and chloride penetration in hardened concrete. Carbonation resistance decreases with the incorporation of FRCA (Evangelista & de Brito, 2010).

The use of superplasticizers improves the mechanical properties of concrete made with CRCA (Barbudo et al., 2013) and FRCA (Pereira et al., 2012). For this reason, the University of Lisbon – DECivil-IST (Portugal) and the University of Córdoba (Spain) carried out a joint experiment to determine the influence of a high-performance superplasticizer on the properties (mechanical, rheological and durability) of concrete made with different replacement ratios of natural sand by FRCA (Cartuxo et al., 2015; Cartuxo et al., 2016).

The objective of this study was to demonstrate that the use of superplasticizers improves the properties of concrete manufactured with FRCA and determine the maximum replacement ratio of natural sand by FRCA.

The materials used for the manufacture of the mortars tested were: two commercial limestone crushed aggregates (CNA1 6/12 mm and CNA2 12/20 mm), two commercial siliceous sands (FNA1 0/2 mm and FNA2 0/4 mm) and one fine recycled aggregate obtained from crushed concrete blocks (FRCA 0/4 mm). Table 3.6 shows the properties of natural and recycled fine aggregates.

Table 3.6 Physical properties of fine aggregates (Source: own elaboration based on Cartuxo et al., 2015, 2016)

		Standard	FRCA	FNA-1	FNA-2
Oven-dry particles density	ρ_{rd} (kg/m^3)	EN 1097-6:2003	2298	2674	2667
Saturated surface-dry particles density	ρ_{ssd} (kg/m^3)	EN 1097-6:2003	2460	2678	2674
Loose bulk density	(kg/m^3)	EN 1097-6:2003	1393	1583	1542
Voids content	%	EN 1097-6:2003	39.4	40.8	42.2
Water absorption	WA_{24} (%)	EN 1097-6:2003	7.09	0.15	0.26

A high-performance superplasticizer (SP) base on a combination of modified polycarboxylates (SikaPlast 898) was selected. The SP was added at a fixed proportion of 1% by weight of cement. The amount of water was added experimentally until achieving a similar slump of 125 ± 15 mm using the Abrams cone (NP EN 12350-2:2006).

The Faury method was used to design the different mixes. The reference concrete (RC.0) was designed with the following conditions: exposure class XC3, strength class C 25/35, slump class S3 (100 to 150 mm) and CEM-I 42.5 R.

Three replacement ratios of FNA with FRCA were tested: 0%, 50% and 100%. A total of 4 mixes were made. Table 3.7 shows the nomenclature of the mixes and the composition of 1 m^3 of each concrete mix.

The fresh concrete was characterized by the specific density according to NP EN 12350-6:2006. The hardened concrete was characterized by the following properties: the compressive strength according to UNE EN 12390-3:2009, the shrinkage according to the specification LNEC E398:1993, the creep test according to LNEC E399:1993, water absorption according to LNEC E394:1993, capillary absorption according to LNEC E393:1993, carbonation resistance according to LNEC E391:1993 and the chloride diffusion coefficient according to LNEC E463:2004.

Table 3.7. Composition of concrete mixes (Source: own elaboration based on Cartuxo et al., 2015, 2016)

		RC.0	RC-SP.0	C-SP.50	C-SP.100
Replacement ratio (%)		0	0	50	100
Cement (kg)		350.0	350.0	350.0	350.0
Water (1)		178.5	133.0	148.3	160.8
w/c ratio (1)		0.51	0.38	0.42	0.46
(w/c) ef ratio (2)		0.51	0.38	0.40	0.41
FNA (kg)	Total	900.8	969.7	480.2	0.0
FRCA (kg)	Total	0.0	0.0	413.2	820.4
CNA-1 (kg)		237.0	251.0	248.0	247.0
CNA-2 (kg)		690.0	730.0	724.0	721.0
Superplasticizer (kg)		0.0	3.5	3.5	3.5
Slump (mm)		122.5	123.5	126.0	137.0

(1) **w/c ra**tio: total water in the mix/cement content,

(2) **(w/c)** effective ratio: total water in the mix discounting the water absorbed by the FRCA in 10 min.

The addition of a regular superplasticizer had the following consequences on the concrete's properties: the effective water/cement ratio decreased up to 25.5% (RC.0 vs RC-SP.0), in the case of concrete made with 100% FRCA, the effective w/c ratio decreased by 19.6% (RC.0 vs RC-SP.100). The fresh bulk density increased up to 2.7% (RC.0 vs RC-SP.0) and decreased up to 1% with 100% incorporation ratio of FRCA.

Table 3.8 shows the properties of the hardened concrete. The compressive strength increased up to 31% (C-SP.100 vs RC.0), reaching greater mechanical properties in concrete made with FRCA and superplasticizer than in the reference concrete.

The shrinkage deformation decreased up to 16% in concrete made without FRCA (C-SP.100 vs RC.0) and increased up to 28% in concrete made with 100% FRCA (C-SP.100 vs RC.0). The creep deformation increased in concrete made with superplasticizer up to 60.5% (C-SP.100 vs RC.0). Despite the use of superplasticizer in the mixture, the use of FRCA worsens the rheological properties of concrete (shrinkage and creep deformation). This may limit the use of FRCA in structural concretes.

Table 3.8. Properties of the hardened concrete (Source: own elaboration based on Cartuxo et al., 2015, 2016)

	RC.0	RC-SP.0	C-SP.50	C-SP.100
Fresh bulk density	2372 Kg/m^3	2437 Kg/m^3	2395 Kg/m^3	2347 Kg/m^3
Compressive strength at 28 days	49.4 MPa	80.6 MPa	69.3 MPa	64.7 MPa
Shrinkage at 91 days	–0.25 mm/m	–0.21 mm/m	–0.28 mm/m	–0.32 mm/m
Creep deformation at 91 days	–0.43 mm/m	–	–	–0.69 mm/m
Water absorption by immersion	13.3%	8.62%	9.1%	12.9%
Capillarity water absorption at 72 h	0.005 g/mm^2	0.0019 g/mm^2	0.002 g/mm^2	0.004 g/mm^2
Carbonation depth at 91 days	6.75 mm	1.46 mm	3.54 mm	6.31 mm
Chloride diffusion coefficient at 91 days	$12.57 \cdot 10^{-12}$ m^2/s	$6.81 \cdot 10^{-12}$ m^2/s	$7.58 \cdot 10^{-12}$ m^2/s	$10.60 \cdot 10^{-12}$ m^2/s

The use of superplasticizer decreased the water absorption by immersion up to 35.2% in concrete made without FRCA (RC.0 vs RC-SP.0). This percentage is lower in concrete made with FRCA, in which case the absorption of water by immersion is reduced by 7.5%.

The evolution over time of the capillarity water absorption for each of the concrete mixes is well represented by the Hall equation (Table 3.9):

$$W = A + S \cdot t^{1/2} - C \cdot t \quad (3.4)$$

where W is the capillary water absorption, t is time, S is sorptivity and A and C are constants.

The capillary water absorption increased with the incorporation of FRCA up to 20% (C-SP.100 vs RC.0). However, in the mixtures made without recycled aggregates the capillary water absorption decreases up to 62% (RC.0 vs RC-SP.0).

As expected, the FRCA incorporation increased the carbonation depth. However, the use of superplasticizer can reduce this negative effect. In fact, concrete made with 100% FRCA and superplasticizer decreases the carbonation depth by 6.5% (C-SP.100 vs RC.0).

Table 3.9. Adjustment parameters of the Hall's capillary model (Source: own elaboration based on Cartuxo et al., 2015, 2016)

	A	C	S
RC0	$1.16x10^{-4}$	$6.46x10^{-5}$	$1.16x10^{-3}$
RC-SP.0	$3.63x10^{-5}$	$2.57x10^{-5}$	$4.29x10^{-4}$
RC-SP.50	$8.16x10^{-5}$	$2.98x10^{-5}$	$4.89x10^{-4}$
RC-SP.100	$6.33x10^{-5}$	$5.01x10^{-5}$	$8.37x10^{-4}$

There is a clear trend of increase of chloride diffusion coefficient by incorporating FRCA (C-SP.100 vs RC-SP.0). The use of superplasticizer decreased the chloride diffusion coefficient by up to 45.8% in concrete made without FRCA (RC.0 vs RC-SP.0). In the case of concrete made with superplasticizer and 100% FRCA, the chloride diffusion coefficient was reduced by 15.7% with respect to the reference concrete (C-SP.100 vs RC.0).

In conclusion, the simultaneous incorporation of FRCA and high-performance superplasticizer is a viable sustainable solution for structural concrete. However, the rheological properties do not improve as much as expected with the use of superplasticizers, and this should be taken into account in the design phase of elements with structural concrete.

3.4.3. Mortar with mixed recycled aggregates and non-conforming fly ash

Coal is still a major fuel for energy production in Europe (EU-28). Pulverized coal is burned in thermoelectric power plants and a big quantity of coal combustion products (CCPs) is generated. Fly ash (FA) is the most important CCP because it accounts for nearly 68% of the total amount (Bech & Feuerborn, 2011). The European Waste Framework Directive (Directive 2008/98/EC) specifies that any material considered as waste must be recovered and achieve end of waste (EoW) status before it may be used again.

The chemical composition and mineralogy of FA is determined by the coal source and the thermoelectric power plant typology. Only a part of FA is used as conforming FA in accordance with the European standard UNE-EN 450-1:2013 and UNE-EN 450-2:2006 and it is widely demanded by the construction industry, and its production is not a problem for thermoelectric power plants. The rest of FA exceeds the fineness specification and if the mass retained by the sieve 0.045 mm is over 40% UNE-EN 933-10:2010, the ash is considered non-conforming FA. Nowadays non-conforming FA is no longer demanded, or it has great difficulties being placed on the market. This justifies the need to study viable alternatives for the use of non-conforming FA.

Masonry mortar is a mixture of sand, cement and water, mineral addition (filler) and admixtures. One way to reduce natural sand consumption is to use fine recycled aggregates obtained from construction and demolition waste (CDW) as recycled sand (Jiménez et al., 2013; Ledesma et al., 2014; Ledesma et al., 2015; Fernández-Ledesma et al., 2016).

Some authors have analyzed the incorporation of the mixed recycled aggregates and non-conforming fly ash in the properties of mortars. Ledesma et al. (2015) replaced natural sand with recycled masonry sand. Jiménez et al. (2015) used recycled sand and a pozzolanic cement CEM-IV/A (V) 32.5 N, with a 29% of conforming FA. Other authors have proven that the combined effect of coal fly ash and recycled concrete aggregates (RCA) improve the cement-based material properties. Kou and Poon (2013) replaced natural gravel with coarse RCA and replaced cement by conforming FA. Silva et al. (2009) and Braga et al. (2012) used ultrafine particles of red clay brick and concrete waste, respectively, in mortar production.

The use of stockpiled non-conforming FA and recycled aggregates from masonry waste is a great opportunity to reduce natural sand consumption and promote a higher added value for some by-products currently underutilized.

This section investigates the effects of using non-conforming fly ash as filler in mortar made with natural and recycled sand from masonry waste (Torres-Gómez et al., 2016). The incorporation of powdered recycled masonry aggregates is also tested as an alternative to natural filler.

To evaluate the combined effect of non-conforming fly ash and recycled aggregates from masonry waste on mortar's properties, eight mortars were designed (Table 3.10).

In all mortars, the replacement of NA (natural siliceous sand taken from the quarry of a river) by FRMA (recycled sand obtained from crushing and screening masonry waste) was made by volume and the replacement of Si-F (siliceous filler obtained by grinding siliceous rock) by Nc-FA (non-conforming fly ash obtained from the combustion of hard coal and anthracite stockpiled in the thermoelectric power plant) and R-MF (recovery masonry filler produced in the laboratory by introducing 5.0

kg of FRMA in the “Los Angeles machine” UNE 1097-2:2010) was made by mass. The components of FRMA according to UNE-EN 933-11:2009 were: ceramics 53.9%; mortar 39.8%; natural aggregates 5.7%; concrete 0.4%; plasters 0.2%.

Table 3.10. Composition of mortars: NA (natural sand), FRMA (recycled sand from masonry waste), Si-F (siliceous filler), Nc-FA (non-conforming fly ash), R-MF (ultrafine particles recycled masonry filler) (Source: own elaboration based on Torres-Gómez et al., 2016)

Mortar type	NA (g)	FRMA (g)	NA / FRMA (% volume)	Si-F (g)	Nc-FA (g)	R-MF (g)	Si-F/ Nc-FA / R-MF (% in Mass)	CEM-I (g)	Water (g)	Admixture (cm^3)
M1	3500	0	100/0	300	0	0	100 / 0 / 0	500	605	0.1
M2	3500	0	100/0	150	150	0	50 / 50 / 0	500	587	0.1
M3	3500	0	100/0	0	300	0	0 / 100 / 0	500	579	0.1
M4	1750	1424	50/50	300	0	0	100 / 0 / 0	500	709	0.1
M5	1750	1424	50/50	150	150	0	50 / 50 / 0	500	683	0.1
M6	1750	1424	50/50	0	300	0	0 / 100 / 0	500	681	0.1
M7	3500	0	100/0	0	0	300	0 / 0 / 100	500	648	0.1
M8	1750	1424	50/50	0	0	300	0 / 0 / 100	500	754	0.1

Table 3.11. Characterization of NA, FRMA, Si-F, Nc-FA and R-MF (Source: own elaboration based on Torres-Gómez et al., 2016)

Characteristic	NA	FRMA	Si-F	Nc-FA	R-MF	Limit Set by UNE-EN 13139:2003
Fines content (%)[(a)]	3.2	9.0				≤8
Sand equivalent (%)	83	86				No limit
Dry density[(b)] ρ_{rd} (g/cm^3)	2.63	2.14				No limit
Water absorption[(b)] (%)	0.79	9.00				No limit
Friability coefficient (%)	15	32				No limit
Acid soluble sulphates (% SO_3)	<0.01	1.04				≤0.8
Total sulphurs (% SO_3)	<0.01	1.04	0.20	0.122	1.38	≤1
Water soluble chlorides (% Cl^-)	<0.01	<0.01	0.014	0.046	0.03	≤0.15
Soluble salts 1:2 (%)	0.128	1.159				≤1
Bulk density (g/cm^3)			0.69	0.91	0.83	–
Particle density (g/cm^3)			2.42	1.94	2.34	–

[(a)]**Finer t**han 0.063 mm; [(b)] fraction 0.063/4 mm.

Table 3.11 shows the physico-chemical and mechanical properties of NA and FRMA. Both types of sands had a similar percentage of sand equivalent. FRMA showed higher content of fines, higher water absorption, lower density and lower resistance to fragmentation. Regarding the chemical properties, FRMA showed slightly higher values than those required by UNE-EN 13139:2003 for the following properties: acid soluble sulphates, total sulphur compounds and soluble salts. No organic compounds that could alter the setting of cement were detected. No alkali-silica and alkali-silicate reactivity was detected.

The main crystalline phase was quartz for both NA and FRMA aggregates, and the degree of presence of calcite was low (Fig. 3.25). The NA sample presented a small amount of dolomite, and FRMA showed a small amount of gypsum.

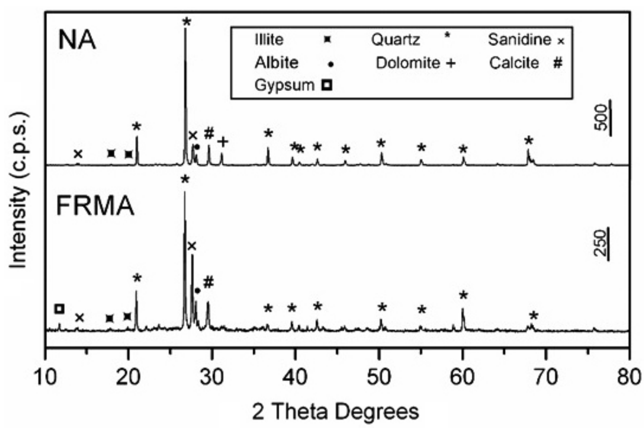

Fig. 3.25. PXRD patterns of NA and FRMA aggregates (Source: own elaboration based on Torres-Gómez et al., 2016)

The main compound of Si-F was quartz, while the R-MF showed quartz and calcite (Fig. 3.26) and for Nc-FA quartz and mullite and a small amount of calcite and hematite. The particle shape was analyzed using a scanning electron microscope. Fig. 3.27 shows the big amount of spherical particles contained in Nc-FA. In contrast, the Si-F and R-MF are composed of angular particles.

The particle size distribution curves of fillers (Fig. 3.27) showed a wide distribution in particle size in all samples, although Si-F presented a narrower size distribution than R-MF and Nc-FA. Si-F had a smaller particle size with a maximum distribution of around 30 microns and a very uniform particle size. Nc-FA had a larger particle size with a maximum distribution of around 70 microns. R-MF has the largest size with a maximum of around 90 microns.

Table 3.11 shows the dry particle density and the bulk density of all filler materials. The Si-F had a higher density of particles, followed by the R-MF and Nc-FA. However, the Nc-FA presented the highest bulk density; this can be explained because its particle size distribution is more continuous than the Si-F (Fig. 3.27), and therefore, it fills the voids between particles better.

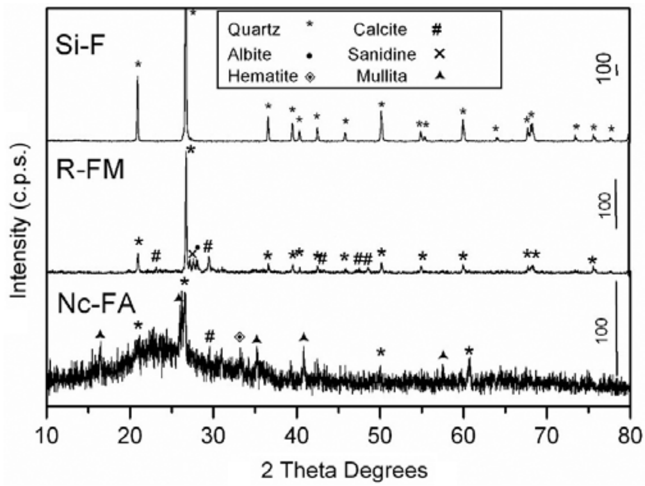

Fig. 3.26. PXRD patterns of Si-F, Nc-FA and R-MF (Source: own elaboration based on Torres-Gómez et al., 2016)

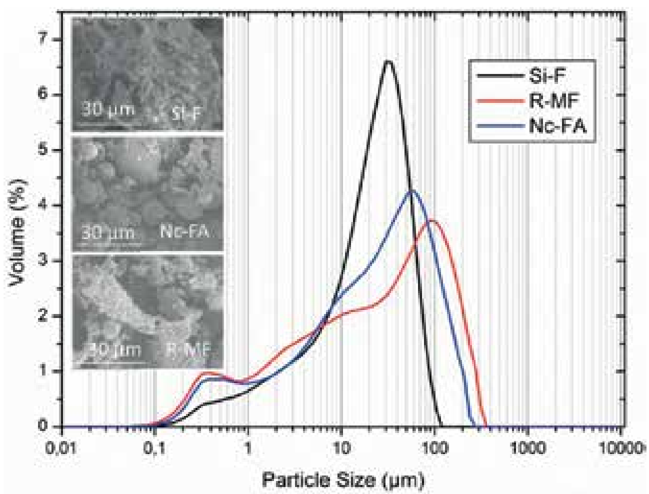

Fig. 3.27. Particle size distribution and SEM images of Si-F, R-MF and Nc-FA (Source: own elaboration based on Torres-Gómez et al., 2016)

The spherical shape of Nc-FA particles improves the workability of mortars and allows using less mixing water for a given consistency. The greater bulk density of Nc-FA improves the bulk density of the fresh and hardened mortar and improves the mechanical strength (M3 vs. M1 and M6 vs. M4) in mortars made with siliceous sand and mixing siliceous natural sand and recycled sand from CDW, respectively. The water absorption by immersion and the water vapour permeability decrease as the replacement ratio of Si-F with Nc-FA increases. However, the capillary water absorption slightly increases. Therefore, the replacement of Si-F by Nc-FA is a viable alternative and allows producing more environmentally-sustainable mortars.

The combined effect of recycled sand from masonry waste and Nc-FA (M6 vs. M1) slightly decreases the mechanical strength; hence, it is also considered a viable and environmentally-friendly alternative. However, it impacts the workability very negatively. The water absorption by immersion and the water vapour permeability increase, but the capillary water absorption decreases compared to the reference mortar.

Incorporating recycled sand from CDW increases shrinkage, although the increases may be acceptable. Although the joint use of recycled sand from CDW with Nc-FA presents a shrinkage only 9% higher than the reference mortar (M6 vs. M1).

The practice of recycling masonry waste and the non-conforming fly ash is an alternative that allows reducing the consumption of natural sand.

Substituting Si-F with R-MF is not a good alternative, since workability is negatively affected, density and mechanical resistance decrease, and the drying shrinkage of the mortars significantly increases.

3.4.3. Mortar with recycled ceramic masonry aggregates

Masonry waste is made of ceramic bricks, mortar and other components some of which are recognized as harmful for recycling, such as gypsum.

Most studies about the use of pure ceramic waste do not include ceramic masonry waste, but rather from ceramic industry waste: clay roof tiles (Sánchez de Rojas et al., 2006), ceramic sanitary ware (Medina et al., 2012) and brick (Silva et al., 2009; Silva et al., 2010; Gomes & de Brito, 2009). Finely crushed ceramic waste has been used for cement production (Puertas et al., 2008), as a substitute of cement for mortar production (Naceri & Hamina, 2009) and as an addition to mortar (Silva et al., 2008). The coarse fraction of ceramic waste has been used as recycled aggregate in concrete production (Medina et al., 2013) and fine fraction as recycled sand in mortars (Silva et al., 2010; Corinaldesi & Moriconi, 2009).

Jimenez et al. (2013) concluded that replacement ratios up to 40% in volume of natural sand for recycled masonry waste sand would not have a significant effect on mortar properties; In this section were included the effects of the replacement ratio of natural sand by recycled sand from masonry waste in fresh and hardened mortar, including studies over a long period of time and of durability (Ledesma et al., 2015).

From the environmental point of view, the use of fine recycled aggregates (FRA) has the following advantages: 1) it minimizes the sand mining from rivers and seashores; 2) it minimizes energy consumption and CO_2 emissions generated by crushing quarry rocks for sand production, and 3) it prevents illegal deposits and landfill of the fine fraction of CDW. Based on the life cycle analysis (LCA), the use of recycled aggregates from CDW has great environmental benefits over natural aggregates.

The recycled masonry aggregates (RMA) are obtained from ceramic masonry waste (Fig. 3.28). The masonry waste was crushed and sieved in a recycling plant to obtain two fractions: 8/40 mm and 0/8 mm. The main components from the coarse fraction of the RMA determined in accordance with the UNE EN 933-11:2009 were red ceramic bricks (53.9%) and masonry mortar (39.8%). Other minor components were also present, such as unbound aggregates (5.7%), concrete (0.4%) and gypsum particles (0.2%).

Fig. 3.28. Ceramic masonry waste (Source: J. M. Fernández Rodriguez's private archive)

The RMA had almost three times more particles smaller than 0.063 mm than the natural aggregate (NA) used as a reference. Table 3.12 shows the physico-mechanical characteristics of both aggregates. NA had a greater sand equivalent, greater dry density, less water absorption and lower friability coefficient. Both sands were also characterized from the chemical point of view. The RMA exceeded the limit of 1% in acid soluble sulphates (1.04%), total sulphurs (1.04%), both expressed in SO_3, and soluble salts (1.159%), established for aggregates used in the production of mortars.

The RMA was classified as non-hazardous because the concentration of sulphate ions from the eluate (UNE-EN 12457-4:2003) was over the limit established to inert materials (European Council Decision, 2003). The majority of these sulphates derived from gypsum particles, detected during the composition test and the DRX analysis (Table 3.13).

Table 3.12. Physico-mechanical properties of NA and RMA (Source: own elaboration based on Ledesma et al., 2015)

Characteristic	NA	RMA
Sand equivalent (%)	94	86
Dry sample density [a] ρ_{rd} (g/cm^3)	2.63	2.14
Water absorption [a] (%)	0.79	9.0
Friability coefficient (%)	15	32
[a] Fraction 0.063/4 mm		

Table 3.13. Mineral phases of NA and RMA (Source: own elaboration based on Ledesma et al., 2015)

Mineral phase	Mineral relative abundance	
	NA	RMA
Albite $Na(Si_3Al)O_8$	*	**
Calcite $CaCO_3$	**	**
Dolomite $CaMg(CO_3)_2$	**	
Illite $KAl_2Si_3AlO_{20}(OH)_2$	*	*
Quartz (SiO_2)	******	*****
Sanidine (Na,K) $(Si_3Al)O_8$	**	***
Gypsum $CaSO_4{\cdot}2H_2O$		*

The bulk density of fresh and hardened mortar decreased linearly with the replacement ratio of NA by RMA. This was due to the lower density of RMA with respect to NA. This is not a limitation to the use of recycled sand in mortar production.

The main advantage of a lighter mortar is that for the same volume of mortar the amount of mass to be transported is smaller. For the same mass of aggregates, the use of recycled sand produces a greater volume of mortar. By contrast, a lighter mortar absorbs more water than usual as a consequence of a greater volume of porous materials. This phenomenon can have a negative effect on the durability of mortar in outdoor environments. For indoor uses, the use of lighter mortar is not a limiting property.

The recycled sand used in this study had more than three times as many fine particles as the reference natural sand. Additionally, the friability coefficient of the recycled sand was more than twice higher than that of the natural sand, which increases the amount of fine particles broken during the mixing process. This explains why the mean values of the occluded air were slightly lower with the incorporation of RMA.

A linear decline in the measured mean values of workable life with the amount of RMA was observed. Statistically, significant differences between mean values were found for replacement ratios greater than 25%. This was due to greater water absorption of the recycled sand and because no extra water was added during mixing.

A linear fall of the mean values of bulk density of hardened mortar was observed, which was due to the lower density of RMA. Silva et al. (2010) and Jimenez et al. (2013) also showed a linear fall of the bulk density of hardened mortar as the replacement ratio increased.

Regarding to compressive and flexural strengths, the evolution of the curves was similar for all mortars, showing an increase in mechanical strength as a function of time. The mechanical strength decreased as the replacement ratio of RMA increased. The differences between the mechanical strength of the reference mortar and of the mortar with 50% replacement level decreased with the curing time, reaching a minimum at 180 days.

The moisture content of the broken specimens, after the compressive strength test, was measured. A linear increase of moisture in the samples was observed as the replacement ratio increased (all samples underwent the same environmental conditions). This can be explained by the greater water absorption of RMA compared to NA. This interesting factor had not been revealed by other authors; however, it may cause the increase of humidity or freeze-thaw resistance problems if these mortars are used in outdoor environment.

The mortars all behaved in a similar way over that period of time resulting in greater dry shrinkage in the mortars with greater amount of RMA. This can be due to the greater w/c ratio needed by these mortars during mixing. The largest dimensional changes occurred in the first 28 days of curing coinciding with the loss of water by evaporation. The weight of the specimens stabilized after 28 days of curing. The evolution of the loss of mass was similar in all mortars, but the greater loss of mass occurred in those with the greatest replacement ratio. This was explained by the greater w/c ratios of the mortars with RMA.

The mean values of the adhesive strength showed no statistically significant differences with replacement ratios below 75%, due to the dispersion of results in the pull-off test. The mean values decreased linearly as the recycled masonry aggregates content increased.

Due to the higher water absorption of RMA, the capillary water absorption of the mortars increased linearly as the amount of RMA increased, reaching up to 91% more than the reference mortar in the case of 100% replacement ratio.

In conclusion, a maximum replacement ratio up to 50% of natural sand by recycled masonry sand can be admitted in indoor environments without significantly affecting the hardened mortar properties, although specific studies with different kinds of admixtures to increase the workable life and reduce the water/cement ratio should be carried out. In an outdoor environment, freeze-thaw resistance studies should be carried out to confirm that high replacement ratios do not affect the durability of mortar.

The findings of this study can reduce natural sand mining from river and seashores, minimize energy consumption and CO_2 emissions and global warming, prevent illegal deposits and landfill of the fine fraction of CDW and meet the requirements of the European Waste Framework Directive. This demonstrates the practical relevance of this study to promote the use of sustainable materials in the construction sector.

3.5. The effect of green walls on buildings

When it comes to the greening of buildings, there are a number of approaches used nowadays, such as facades covered with climbing plants or green-wall systems (built with prefabricated modular panels). These offer economic, environmental and social benefits. Given the growing interest in restoring the environmental balance of urban areas, technological innovations have emerged in environmentally-beneficial building practices. The implementation of green walls is not a new concept and can offer many advantages as a part of urban landscaping, such as environmental benefits and energy savings in buildings. Incorporating vegetation could be a sustainable approach for greening both new and existing buildings. Green-wall systems, also known as vertical gardens, are built using modular panels, each one containing its own soil or other growing media, such as coconut coir, rice husks, felt, perlite or rock wool. These technologies are based on hydroponic cultivation, using balanced nutritional solutions to provide all or part of the nutritional and watering requirements of the plant (Rivas-Sánchez et al., 2017).

3.5.1. Benefits of green walls

The benefits of green walls can be categorised as aesthetic, environmental and economic, or a combination thereof. The greening of buildings improves visual, aesthetic and social aspects of urban areas, which in turn has a great effect on the financial value of a building and helps to improve human health. Urban greening is recognised as having a therapeutic effect, as demonstrated in a series of studies; for example, hospital inpatients who can see vegetation from their windows recover more quickly than those who cannot (Ulrich & Simons, 1986).

The environmental benefits of greening buildings operate on various levels. Some depend on there being a large surface area, and so the benefits only become evident with large buildings or large areas, while others work in line with the scale of the building.

This review separately addresses three benefits of vertical urban greening systems: environmental, economic and social.

3.5.1.1. Environmental benefits

Temperature

Temperature is an important criterion when it comes to comfort, which can be affected by lifestyles. Several factors such as function, culture, aesthetics, environment and technology influence the greening design of a building (Oral et al., 2004), but compared with rural areas, modern building materials such as concrete retain more heat during the day. The construction of green areas in cities is the key to reducing the effects of urban heat islands, since plants absorb shortwave radiation (Kleerekoper et al., 2012). Moreover, they help keep their surroundings cooler thanks to the shade the plants provide (Newton, 2004), and by evaporation and transpiration (Alexandri & Jones, 2008; Sheweka & Mohamed, 2012). The implementation, therefore, of vertical vegetation systems is an appropriate way to reduce urban heat islands in urban areas (Taib et al., 2010).

The urban heat island phenomenon can result in city temperatures being 2-5°C higher than those in rural areas, primarily due to the number of artificial surfaces compared to plant coverage. Surfaces with vegetation intercept radiation, reducing the warming of urban surfaces. In urban areas, the effect of evapotranspiration and shade created by plants used in green walls can significantly reduce reflected heat. A study carried out by Onishi et al. (2010) shows a temperature reduction of 2-4°C due to vegetation coverage.

Evapotranspiration, shade, humidity levels and temperature also affect the microclimate of the building, both inside and out. In warmer climates, the cooling potential can result in significant energy savings on air conditioning (Alexandri & Jones, 2008). The cooling potential of green walls has been a topic of discussion in numerous studies. Field measurements carried out by Bartfelder & Köhler (1987) in Germany, on a wall covered in vegetation and a bare wall, show a temperature reduction in the green wall of between 2 and 6°C when compared to the bare wall. Another study by Wong et al. (2010a) on buildings in Hortpark (Singapore) — one with plant coverage, the other without — shows a maximum reduction of 11.6°C. Figure 1 shows a photograph taken using an infrared camera in the Netherlands during the summer, where it can be seen that the bare surfaces appearing as red are warmer than the area covered in vegetation which appears in green and blue.

Green walls and green facades have different characteristics that can influence the abovementioned cooling potential, and can also affect insulation properties. Among other aspects, it depends on the depth of the foliage (creating a layer of air and shade on the facade), water content, properties of the material and possible air cavities between the different layers.

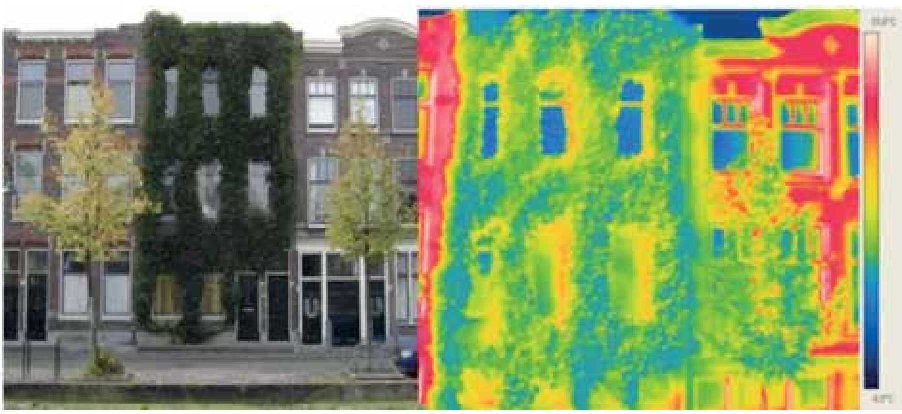

Fig. 3.29. A photo of a facade covered in Boston ivy (Parthenocissus) planted on the ground and grown directly up the facade. On the right: a photo of the same location, taken with an infrared camera (Delft, Netherlands, summer 2009, 12 p.m. air temperature 21°C) (Source: Ottelé, 2010)

Noise

Another major environmental benefit of green walls is their capacity to control noise and their potential use as a noise-reduction barrier (Van Renterghem and Botteldooren, 2009; Wong, 2010b). They can also reduce sound reflection and noise disturbance (Shiah et al., 2011).

Air

Green-wall systems provide several environmental benefits. For example, the plants in the vegetation cover on buildings absorb dust and clean the air (Donahue, 2011), thus acting as a natural air filter. Furthermore, during photosynthesis, the plants take in carbon dioxide and release oxygen (Darlington et al., 2001). This freshens the air and reduces carbon dioxide emissions.

The larger scale benefits primarily centre on improvements in air quality, biodiversity in the city as well as the mitigation of the urban heat island effect (Köhler, 2008). The air quality improvement is primarily due to the fact that vegetation absorbs fine dust particles as well as gaseous pollutants such as CO_2, NO_2 and SO_2. Carbon dioxide is used by plants for photosynthesis, releasing oxygen and producing biomass; nitrogen and sulphur dioxide are converted into nitrates and sulphates in the plant tissue. Fine dust particles, especially the smallest sizes (<10 μm), primarily sticks to the outside of the foliage (Ottelé et al., 2010; Stemberg et al., 2010) as can be seen in Figure 2. Dust particles smaller than 2.5 μm have significant effects, mainly in densely populated urban areas, as they can get into the respiratory system, causing damage to human health (Powe & Willis, 2004).

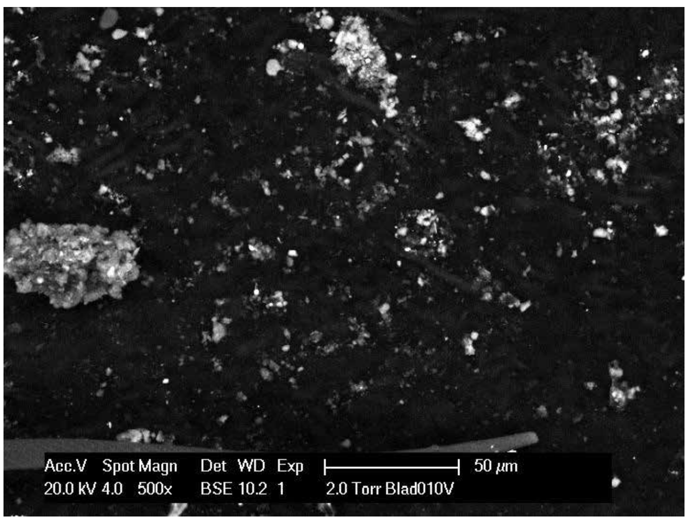

Fig. 3.30. Microphotography of particles on the upper part of a leaf (Hedera Helix) (Source: Stemberg, 2010)

3.5.1.2. Economic benefits

In recent years, growing attention has been focused on the economic benefits of green-wall systems. One way to use these systems is to set them on the windows of buildings so that the vegetation creates shade (Bass et al., 2003). The efficient use of daylight and the reduction of problematic glare are some of the benefits of green-wall systems that provide enough shade (Kim et al., 2012), thus leading, over time, to lower electricity demand. Due to the capacity of green-wall systems to reduce temperature, they are an appropriate solution for reducing the energy demand for cooling buildings, improving their energy efficiency and subsequently cutting costs.

Furthermore, green walls can act as permeable surfaces and control rain water. The use of green-wall systems can reduce water consumption in the building given that they act like a filter for the rain water and, when using certain materials, it has been shown that they do not interfere with the physical or chemical properties of the water (Rivas-Sánchez et al., 2017). This allows the water to be reused for purposes that do not require potable water, such as in toilets and for irrigation. Green-wall systems are suitable to eco-retrofitting projects that aim to improve people's lives and the environment, and are less expensive than demolishing and reconstructing buildings (Birkeland, 2009).

3.5.1.3. Social benefits

The use of green-wall systems with their associated social benefits date back to ancient times. Take for example the Hanging Gardens of Babylon, which is one of the best-known examples from antiquity (Binabid, 2010). Connecting with nature is a biologically innate process: in ancient times, landscapers would use greening in buildings and recreational areas in diverse ways for their aesthetic qualities. Plants create spaces for recreational and leisure activities. It has also been proved that contact with nature has a psychological impact, and improves the health and welfare of humans (White et al., 2011). Moreover, reduced stress is achieved through proximity to green zones (Nielsen & Hansen, 2007). It can thus be seen that human beings naturally need vegetation in cities and urban areas, changing grey areas into green spaces. A study consisting in an online survey compared a house with no vegetation to others with different types of vegetation. It showed that for all those surveyed, houses with green-wall technology were aesthetically more appealing than those without (White et al., 2011).

3.5.2. Effects of green walls

Temperature reduction and cooling effects on buildings using green-wall systems

Temperature reduction is one of the key properties of green-wall systems. In addition to creating shade, the cooling effects of plants are effective at lowering temperatures. This in turn helps to reduce the demand for cooling energy and energy use. Energy efficiency refers to the capacity of a building to operate with minimum levels of energy consumption (Perini & Rosasco, 2013). This section reviews several studies on vertical vegetation systems used to reduce temperature, energy consumption and the demand for cooling energy.

Various research papers have sought to determine the effectiveness of green-wall systems and their influence on the thermal transfer value, energy use, cooling effect, temperature variance, etc. These studies vary depending on the different climate conditions.

In an experiment with traditional green walls, Köhler (2007, 2008) found that the magnitude of the shade effect depends on the density of the foliage. Ivy is the species that provides the maximum cooling effect, comparable to the shade of trees, with differences of up to 3°C in interior temperature (Stec et al., 2004).

In the Mediterranean region of Greece during the winter months, a thermal comparison was carried out on a bare wall and a green wall to show the dynamics of the thermal properties and the temperature variation. The results show that covering the wall surface with plants has thermal benefits for both exterior and interior surfaces, and reduces loss of heat flow (Eumorfopoulou & Kontoleon, 2009).

In the "Bioshader" experiment carried out at the University of Brighton (United Kingdom) (Miller, 2007), a green wall was positioned on an office window, and was then compared to another office without plants. The green wall resulted in interior temperatures 3.5-5.6°C lower than the exterior ones. Solar transmittance measurements ranged from 0.43 for one layer of leaves, to 0.14 with five layers of leaves. This equates to a 37% reduction in solar radiation crossing one layer of leaves, and up to an 86% reduction with five layers of leaves.

The thermal effects of green walls on buildings were tested in an experiment in Singapore to better understand the temperature and power consumption of green-wall systems. TAS simulation software was used to simulate a hypothetical ten-storey building in three different scenarios: one with opaque walls, one with seven windows on each floor and another with an all-glass facade. These scenarios were compared with similar set-ups with the addition of a green-wall system. Measurements of the mean radiant temperature and the cooling load were taken, based on a hypothetical building in a tropical climate. It was found that the heat transfer through the concrete wall is reduced by using green walls (Wong et al., 2009). Green-wall systems reduce excessive solar energy on the building wall; they are thus useful for concrete buildings and also they reduce the thermal transfer of transparent surfaces. Indeed, glass facades 100% covered by a green-wall system can effectively reduce the mean radiant temperature (Wong et al., 2009).

The above studies show that green walls can provide a cooling potential on the surface of the building, which is very important during hot periods of the year, especially in warm climates. Consequently, green-wall systems are a good way to create natural shading that reduces the temperature, they protect the facades of building against direct solar radiation and they provide shade. Moreover, the natural cooling effects of plants through evaporation reduce the temperature, heat flow, thermal transfer, etc., and lead to the reduction in the energy demand for climate control in buildings. Ultimately, therefore, green walls reduce energy consumption.

Change in the effect of wind on buildings due to green walls acting as a block

Green-wall systems on buildings act as a barrier against the wind and thus block the effects of the wind on the building facade. This effect depends on the density and penetrability of the foliage, as well as the orientation of the facade and the direction and speed of the wind.

One way to increase the energy efficiency of a building is to block winter winds, given that cold wind plays a key role in reducing the temperature inside buildings. Dinsdale et al. (2006) showed that using green walls to protect buildings against cold winds reduces heating demand by 25%.

McPherson et al. (1988) used computer simulation to test the effects of irradiation and wind reduction due to vegetation. They analysed energy performance in comparable dwellings in four American cities from four different climate zones. They showed that the planting for cold climates should be designed to reduce the impact of winter winds while providing solar access to southern and eastern facing walls. The same criteria also apply in temperate climates, although it is important to avoid blocking summer winds (McPherson et al., 1988).

Furthermore, when considering the use of vegetation to modify the effect of the wind on buildings, care should be taken not to obstruct ventilation in the summer nor to facilitate air circulation in the winter.

3.6. Overall benefits

The installation of green-wall systems to block solar radiation and the use of plants with natural cooling properties through evaporation and transpiration can lead to notable reductions in temperature. Furthermore, plants reduce the effects of solar radiation and reduce ambient temperature.

The cooling effects of green-wall systems reduce the demand for cooling energy and result in energy efficiency in buildings, namely the ability of the building to operate and function with minimum levels of consumption. These features of green-wall systems offer several environmental and economic benefits.

A comparison of related studies reveals that thermal performance is commonly evaluated using small-scale models. Employing this method means that the variables are easier to manage and the results are entirely attributable to the effect of the green-wall systems.

Furthermore, there is limited research into the energy-saving capacity of green-wall systems in real-world case studies. Studying the parameters that have the greatest effect on the thermal performance of green-wall systems could help optimise their thermal efficiency.

Temperature reduction and the economic benefits of green-wall systems are not as widely valued as their aesthetic impact, and people generally use these systems for decorative reasons. There need to be greater incentives to use these systems for their economic and environmental benefits, namely to use them more effectively to reduce energy demand.

Raising public awareness about the application and benefits of these systems is needed if more green walls are to be used on buildings. The lack of publicly-available information about the economic and environmental benefits is the reason why owners and investors do not request the implementation of green-wall systems due to the initial outlay despite the fact that installing them is actually relatively cheap and offers numerous advantages.

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WEB-5 https://e-termoizolacje.pl

WEB-6 http://izomat.net/index.php/aerozel

WEB-7 http://www.vacuum-panels.co.uk/service/vacupor-nt-b2-s/

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4. MODERNIZATION OF EXISTING BUILDINGS

4.1. Improving energy efficiency of buildings

New buildings are constructed to demanding energy performance levels set by national legislation, therefore existing buildings require improvements in their envelops and systems to decrease energy consumption.

4.1.1. Characteristics of the renovation market

Under the existing Energy Performance of Buildings Directive, all new buildings in EU countries must be nearly zero-energy buildings by 31 December 2020 (public buildings by 31 December 2018). Majority of existing buildings were constructed prior to introducing any formal energy performance requirements, as a result of which the quality of the building stock is considerably below that which can be achieved today. Therefore, they need appropriate modernization, that is improvement of existing building technical features of a building which should lead first of all to reduction in energy demand. This operation not only limits heat losses and energy costs but also improves the exploitation conditions of rooms in the building. It can be an independent modernization venture or within the frames of rebuilding or complete refurbishment. As shown in table 4.1 (Firląg, 2016; BPIE et al., 2016) we can distinguish three stages of renovation.

In ZEBRA (Nearly Zero-Energy Building Strategy 2020) three renovation levels are also defined: “low”, “medium” and “deep”. Their definition is different across EU countries and corresponds to different levels of energy savings. For that reason, ZEBRA developed an indicator of “major renovation equivalent” where the total cost of the renovation relating to the envelope or its systems is higher than 25% of the value of the building, or more than 25% of the surface of the building envelope undergoes renovation. The building’s final energy demand for heating can be reduced by 50 to 80%.

Table 4.1. Stages of building renovation and estimated cost of the renovation work (Source: Firląg, 2016; BPIE et al., 2016)

Stages of building modernization	Activities to achieve the desired degree of renovation	The annual costs of the renovation (defined in 2013) regarding m^2 of heated usable area	
		In residential building	In non-residential
Light renovation	– modernization or replacement of heat source	40 €	40 €
Medium renovation	– modernization or replacement of heat source together with – replacement of window and door joinery or thermal insulation of a façade	75 €	80 €
Complex renovation	– total or partial replacement of energy sources, the use of renewables or the use of high-efficiency cogeneration, – replacement of the central heating and DHW with insulation (in accordance with current technical and construction regulations), – replacement of window and door joinery, – insulation of the whole external envelope (façades, flat roof and the ceiling/ floor), – repair of balconies.	125 €	170 €

As a result of thermal modernization carried out under current energy performance standards, the final energy consumption for heating, ventilation and hot water preparation can be reduced by approximately 25-50% and index of demand for usable energy for heating and ventilation may be about 70-80 kWh/m^2 per year. The greatest benefit could bring comprehensive thermal modernization, but its conducting requires high investment costs (table 4.1).

In recent years, the issue of deep modernization or modernization to the NZEB (nearly zero-energy building) or passive standard has been increasingly discussed (Węglarz, 2015; Firląg, 2016). Because of deep thermal modernization, the final energy consumption for heating, ventilation and hot water preparation can be reduced by approximately 70% and index of demand for usable energy for heating and ventilation may be about 20 kWh/m^2 per year.

The savings that can be achieved depend on type of the building, construction period, but also on the state of it previous retrofit. The EU building stock is quite heterogeneous. According to the buildings database (the EU Building Stock Observatory) published by The European Commission to track the energy performance of buildings across all Member States, most of the floor area belongs to residential buildings. The share varies considerably, from around 60% in Slovakia, Netherlands and Austria to more than 85% in the southern countries like Cyprus, Malta and Italy. A breakdown of non-residential buildings by categories is not homogeneous and depends on the economic structure of each sector. On average, three quarters of the service floor area is covered by offices (including both private and public; 30%), wholesale (27%) and education (16%). In Poland, the highest share in all non-residential buildings have office and education buildings (26% each) and commercial buildings (25%).

In Polish non-residential buildings most of the energy is consumed by heating, ventilation and air conditioning (HVAC) (37%), followed by lighting (32%) and electrical appliances (24%). In residential buildings energy is used mainly to meet space heating requirements (69% of total energy consumption). In Fig. 4.1 is shown the structure of energy use in households and non-residential buildings in Poland in 2012.

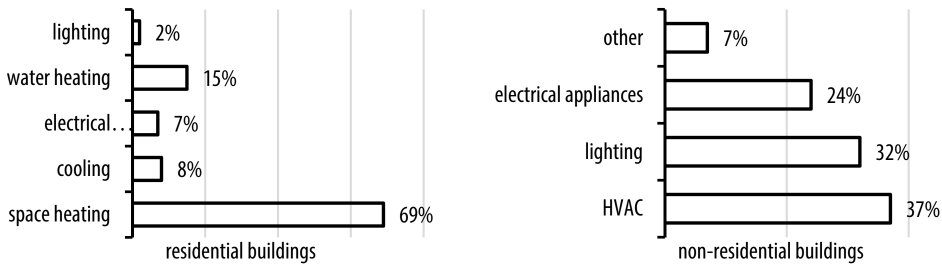

Fig. 4.1. Structure of energy use in buildings in Poland in 2012 (Source: BPIE et al., 2016)

Percentage of stock that has been modernized in Poland is shown in table 4.2.

Table 4.2. Thermal modernization statistics (Source: NAPE SA, 2012)

Construction period	Percent of stock that has been thermally modernized [%]
up to 1945	7
1946-1966	11
1967-1985	16
1986-1992	14
1993-2002	8
2002-2008	new buildings constructed under prevailing obligatory performance standards
after 2008	

According to the Central Statistical Office, approximately 50% of residential buildings in Poland have been insulated but below optimal levels. More than 70% of single-family houses have inadequate thermal insulation. Most of the buildings without thermal insulation were built before 1989. Additionally, heating technology is outdated. The most popular fuel is highly polluting coal, burned in old coal-fired boilers (Firląg, 2016). Only 1% of all houses in Poland can be considered energy efficient, primarily those that have been built in the last few years.

Thermal balance and the share of heat losses through individual building components depend upon technical condition, thermal quality as well as building geometry. Sample percentages are shown in table 4.3.

Table 4.3. Structure of heat losses through individual building components existing single-family building

building element	
walls	20-30%
roof	10-25%
windows	15-25%
basement / floor on the ground	3-6%
ventilation (natural)	30-40%

4.1.2. Current and modern solutions used for modernization

Traditional insulation materials (e.g. polystyrene or mineral wool – table 4.4) are commonly used for thermal insulation of building envelope, mainly due to their availability and price (lower than the price of modern materials).

One of the most popular methods of executing thermal modernization of external walls is ETICS (External Thermal Insulation Composite System). The thermal insulation material with a thin layer of plaster as a finishing component, is fastened to the outside wall. A layer of structural material (concrete or masonry) reduces the temperature fluctuations in the room and levels off differences in temperature on the inner surface of the wall (due to possible defects in the insulation layer).

Sometimes, especially in historic buildings, there is a need to insulate the walls from the inside. This method has some risks. One of them is the possibility of dampening the wall. Due to the low external temperature, the temperature inside the wall decreases considerably, causing condensation at the contact of the structural layer and thermal insulation. External walls do not have the possibility to accumulate heat which adversely affects the microclimate of the rooms. Another disadvantage is the occurring of thermal bridges which are difficult to eliminate while conducting thermal insulations from the inside. In this case, in addition to providing adequate thermal insulation of the wall, considering the humidity phenomenon is very important.

Table 4.4. Current and modern building solutions (Source: Staniaszek et al., 2014)

	Commonly used technologies	Modern solutions and technologies
Envelope insulation	Traditional insulation materials: – stone wool, glass wool, slag wool, – expanded polystyrene (EPS) and extruded polystyrene (XPS), polyurethane foam, – blown-in fibres wool or cellulose, – thermal spacer.	Modern materials: – nano-cellular polyurethane foam, – aerogel, – vacuum insulated panels – VIP.
Envelope prefabrication	– prefabrication sandwich panels.	– prefabricated façade and roof modules used to construct a new building envelope outside the existing building, – installation of prefabricated façades with solar thermal collectors.
Windows	Windows with low thermal conductivity: – double or triple glazed, – filled with noble gases like argon, krypton, xenon, – low-E coating applied to the glass to reduce radiant heat transfer, – shutters and window louvres, – automatically controlled louvres.	Windows with very low thermal conductivity: – increased insulation of the window frame, – vacuum windows, – dynamic glass (glass adapting to external conditions): thermal and electrochromic.
Roofing	– cold roof (covered with reflective material), – green roof (covered with vegetation).	– materials reflecting thermal radiation resistant to weather and UV radiation, – roof-integrated PV panels.

The current requirements of thermal protection of buildings in Poland are laid down in the Regulation of the Minister of Transport, Construction and Maritime Economy of 5 July 2013. For reconstructed buildings, external walls should meet the thermal insulation requirements included in the Regulation and window area should meet partial requirements. The maximum thermal transmittance coefficient for the walls, from January 2017, is 0.23 W/m^{2}K, for roofs 0.18 W/m^{2}K, and for the floor on the ground 0.30 W/m^{2}K. From January 2021 these requirements will be stricter.

The thickness of thermal insulation materials essential to obtain the expected thermal transmittance of external walls is shown in table 4.5. It was assumed that the thermal resistance of the bearing layers equaled 0.20 m^{2}K/W.

The thickness of insulation material should be determined not only by the minimum technical requirements, but it also needs to be based on the economic criterion. The issues concerning the choice of appropriate thickness of thermal insulation in building walls and optimal heat transfer coefficient have been described in many scientific papers (Attlmayr, 1974; Becher, 1974; Bogusławski, 1969, Bruckmayer and Lang 1972; Eichler, 1982; Górzyński, 1985; Kunze, 1976; Kisielewicz, 1976; Kozierski, 1968; Laskowski, 2005; Petzold, 1975; Pogorzelski, 1998; Robakiewicz, 1998; Sanecki, and Skoczek, 1966; Stachniewicz, 2002). Practical ineffectiveness of static methods that do not take into account changes in the value of money over time were also discussed by Kisielewicz and Rudczyk-Malijewska (Kisielewicz, 1976; Rudczyk-Malijewska, 1999). In other publications (Laskowski, 2005, Pogorzelski, 1998; Rudczyk-Malijewska, 1999; Stachniewicz, 2002) several modifications of the formula to calculate the NPV were made.

Table 4.5. Essential thickness of insulation for external walls (Source: KAPE S.A., 2012)

Type of insulation material	Design thermal conductivity λ [W/m·K]	thickness of insulation material [m]				
		with the expected wall heat transfer coefficient U				
		$0.20 W/m^2K$	$0.15 W/m^2K$	$0.12 W/m^2K$	$0.10 W/m^2K$	$0.08 W/m^2K$
Mineral Wool	0.034-0.045	16-21	21-28	27-36	33-43	41-55
Polystyrene (expanded) EPS	0.031-0.042	14-19	20-26	25-33	30-40	38-51
Polystyrene (extruded) XPS	0.034-0.040	16-19	21-25	27-32	33-39	41-49
Cellulose	0.037-0.043	17-20	23-27	29-34	36-41	45-52
Polyurethane Foam	0.025-0.035	12-16	16-22	20-28	24-34	30-42

For newly designed buildings this indicator is calculated as given by Equation 4.1:

$$NPV = -Kd + G_0\left(\frac{1}{R_0} - \frac{1}{R_0 + \frac{d}{\lambda}}\right)\sum_{t=1}^{n}\frac{(1+s)^t}{(1+r)^t}, \qquad (4.1)$$

where:

K – cost of insulation material with assembling (€/m³),
d – thickness of the thermal insulation layer (m),
G_0 – quotient of annual heating cost referenced to 1 m² of wall area and thermal transmittance coefficient characterizing it ((€·K)/W),
R_0 – thermal resistance of the septum layers, i.e. structures, lining excluding heat insulation, together with heat transfer resistances on the surfaces of the partitions ((m²·K)/W),
λ – thermal conductivity of the thermal insulation material (W/(m·K)),
n – the assumed number of years of operation of the design thermal insulation (–),
s – growth rate of heating cost over inflation rate (%),
r – discount rate (%).

In the studies of other authors (e.g. Laskowski, 2005), slightly differing modifications of the formula 4.1 were made but did not alter its substantive meaning. This formula has a different form in case of thermal modernization of existing buildings. However, all modified formulas, after bringing them into the form of the NPV=f(d), allow, after using the extremum condition of the NPV function (Equation 4.2), to obtain the same equations to determine the optimal thickness of insulation material (Equation 4.4) and the optimum heat transfer coefficient (Equation 4.4).

$$\frac{\partial NPV}{\partial d} = 0\,, \tag{4.2}$$

$$d_{opt} = \lambda\sqrt{\frac{G_0\sum_{t=1}^{n}\frac{(1+s)^t}{(1+r)^t}}{\lambda K}} - R_o\lambda, \tag{4.3}$$

$$U_{opt} = \sqrt{\frac{\lambda K}{G_0\sum_{t=1}^{n}\frac{(1+s)^t}{(1+r)^t}}}. \tag{4.4}$$

The quotient of the annual heating cost, referenced to 1 m^2 of the wall area and heat transfer coefficient characterizing this wall, in the case of the double tariff (heating from the district heating network) can be calculated (Pogorzelski, 1998) as given by Equation 4.5:

$$G_0 = 12A(t_i - t_e) + BL_{Sd}\,, \tag{4.5}$$

where:

- A – fixed monthly fee associated with the distribution and transmission of energy (€/MW),
- B – variable fee charge for heat (€/GJ),
- L_{Sd} – number of degree-days of heating period (1K·1day).

In table 4.6 we present the results of the calculation (done using formulas 4.3 and 4.4) of optimal thickness of polystyrene for insulating one and a half brick wall in an apartment building in Warsaw heated from the district heating network.

The optimum thickness of insulation in this case was 0.55 m, and the thermal transmittance of wall after the thermal retrofitting (0.07 W/m^{2}K) was much less than the value required by the current regulations for typical buildings.

Table 4.6. Values of parameters affecting the optimum thickness of wall insulation material and results of calculations of d_{opt} and U_{opt} (Jezierski & Sadowska. 2016)

Input data									Result of calculation	
λ	K	R	L_{Sd}	B	r	s	VAT	t	d_{opt}	U_{opt}
W/(m·K)	zł/m³	m²·K/W	K·days	zl/GJ	%	%	%	year	m	W/(m²K)
0.04	120	0.7	3686	0.50	6.5	3	23	30	0.553	0.069

The optimum value of the thermal transmittance coefficient can also be determined by the cost-optimal method according to Equation 4.6:

$$K_{CZ,j} = K_{M,j} + \sum_{i=1}^{30} (K_{E,j} \cdot R_d(i)) , \tag{4.6}$$

where:

$K_{CZ,j}$ – unit cumulative cost index for variant *j* (€/m²),
$K_{M,j}$ – costs of thermal insulation of the external partition for variant *j* (€/m²),
$K_{E,j}$ – operating costs due to heat loss through 1m² partition for variant *j* (€/m²),
$R_d(i)$ – discount factor for the year *i*, in which the infiltration, the change in energy prices and the discount rate were taken into account (–).

Table 4.7. Traditional and modern solutions and technologies used in installation systems (Source: Staniaszek et al., 2014)

	Commonly used technologies	Modern solutions and technologies
Ventilation and heating	– automatic (humidity sensitive) air diffusers and humidity sensitive ventilation grilles, – mechanical ventilation, – hybrid ventilation, – efficient recuperators – supply and exhaust ventilation with heat recovery.	– advanced control systems of ventilation efficiency.
Installation of hot water and central heating	– high efficiency boilers, – RES – biomass boilers, heat pumps (air, ground), – solar collectors (vacuum and flat), – photovoltaic panels; – heating mats (electrical) for floor and wall heating, – fan heaters, radiant heating, – automatic control and thermostatic valves, – aerators to DHW installations.	– hybrid systems – solar collectors cooperating with heat pump systems – micro cogeneration – cogeneration – Stirling engine.

This approach seems more appropriate nowadays because under Directive 2010/31/EU on the Energy Performance of Buildings, new energy requirements should be determined using the cost-optimal method.

Increasingly popular during modernization of buildings is the use of modern technologies for installation of heating, hot water or ventilation, as well as the use of renewable energy sources (table 4.5). In Poland, it is mainly biomass energy obtained in the combustion process or solar energy that are used for hot water heating or electricity (Firląg, 2016). Unfortunately, it is often the case that the installations of renewable energy sources are poorly designed (oversized) or used in inappropriate buildings (e.g. solar collectors in education buildings that are not used in the summer).

Significant improvements in energy efficiency require application of not only modern solutions and technologies but also numerous legal, organizational and financial instruments. According to the Status Report (BPIE 2016), public funding for renovation needs to be increased, in Poland notably for single family houses. The focus should shift towards carrying out comprehensive, deep renovations. Sub-optimal measures such as low insulation thicknesses should not be permitted under publicly funded schemes, and financial schemes need to be devised which offer an attractive and engaging way for building owners to invest in renovation.

4.2. Retrofitting of education buildings

Public buildings, including a huge and important group of education buildings, are most often renovated structures together with the residential housing.

4.2.1. Energy consumption in education sector

The energy consumption in buildings located in the EU countries is higher than for instance in industry. It is estimated as 37% of final energy in most places, however in some countries, for instance in the UK, even more – 39% of the global usage (Perez et al., 2008). One of the most significant groups in the public buildings sector are schools where energy is used for heating, cooling, hot water production, lighting and electrical appliances (Gaitani et al., 2010), but the overall energy distribution depends greatly on the climate. For example, in the UK heating accounts for over 60% of delivered energy (Gaitani et al., 2010), while in Poland for about 70%. Countries like Spain, Greece or Italy use most energy for cooling (Dimoudi A. & Kostarela P., 2009). In some countries – for instance in Mexico – energy usage is mostly connected with electrical devices, which consumes 35% of global energy, and only 7% is used for heating (Perez et al., 2008; Rosas-Flores et al., 2011). The overall distribution also depends on the building envelope type, number of users and local price policy, although the environmental factors are also important. Countries all over the world try to reduce CO_2 emission, which can be greatly aided through the comprehensive buildings retrofitting (including HVAC systems, hot water preparation, lighting and improving thermal insulation of the building structure). On 12 December 2015, 195 countries taking part in the 2015 United Nations Climate Change Conference, COP 21 agreed to sign the Paris Agreement on the reduction of emissions as part of the method for reducing greenhouse gases. The local energy policy was shown in several papers. The problem of energy consumption in the UK was discussed (Taylor et al., 2010, Ward et al., 2008). The consumption heating demand of schools in Greece was presented (Santamouris et al., 2007; Dascalaki and Sermpetzoglou, 2011; Theodosiou and Ordoumpozanis, 2008) which varied from 32 to 139.2 kWh/(m^2·year). The research conducted in Turkey, where the average energy consumption in residential buildings is about 200 kWh/m^2 per year, much more than the average value in Europe which is 100 kWh/m^2 per year, showed that 47% of energy could be saved (Cakmanaus, 2007). Corgnati et al. (2008) discussed the main thermal consumption indexes in the schools located in Italy. According to Desideri and Proietti (Desideri and Proietti, 2002), thermal energy savings, after introducing improvements, could reach 38%. Similar audits were conducted in other countries, for instance Spain (Asdrubali et al., 2008).

4.2.2. Characteristic energetic parameters of schools in Bialystok (Poland)

With the aim to describe situation in education buildings in Poland, the data was collected from all public schools (primary, medium and high) located in Bialystok, where the energy was supplied from the city power plant. Schools in Bialystok differed significantly in their volume, envelope parameters, but they were representative of the situation in most major cities in Poland. The analysis was carried out on a group of 43 buildings (single schools and units). The total volume for each building was various, so schools were divided into 3 groups:

I – volume below 15000 m^3 (16 buildings),
II – volume between 15000 and 30000 m^3 (17 buildings),
III – volume above 30000 m^3 (11 buildings).

The monthly energy consumption was recorded by heat meters located in each building and data was provided by the technical office of MPEC. The data was gathered over 5-year period. The majority of buildings in the sample had thermal insulation of external elements and double or even triple-glazed windows (table 4.8).

It should be emphasized that the average indoor temperature in most buildings was 20°C (only in 2 schools it was 19°C and in the remaining 12 schools 21-23°C), which was connected with the thermal comfort conditions. Ventilation heat loss in the examined buildings ranged between 21% and 69% of total loss. The value depended on the building envelope standard and the number of users.

Table 4.8. Parameters of schools located in Bialystok (source: own elaboration)

Group	School No.	Year of construction	U value [W/m²K]			Year of the building's modernization	Radiators / pipes	Heating system regulation	Average temperature [°C]
			windows	walls	roof				
Small schools	1	1956	1.7	0.24	0.2	2006	Changed in 1986/1986	Yes	20
	2	1959	1.7	0.23	0.2	2006 (part)	Old/old 1959	yes	21
	3	1919	1.7	0.20	0.2	2008	Old/old 1960	yes	20
	4	1972	1.7	0.30	0.3	2003 (part)	Old/old 1972	yes	20
	5	1952	3.0	1.20	1.0	2003	Old/old 1952	Yes/no	20
	6	1983	1.7	0.24	0.2	2005	Old/ changed in 2005	Yes	20
	7	1984	1.7	0.8-0.3	0.3	2003 (part)	Old/ changed in 2005	Yes/no	20
	8	1973	1.7	0.23	0.2	2007	Old/old 1973	Yes	20
	9	1930	1.7	0.23	0.2	2006	changed in 2006	Yes	20
	10	1948	2.0	1.0	0.2	2002 (part)	Old/ changed in 2002	Yes	20
	11	1960	1.7	0.8-0.3	0.2-8	2008 (part)	Old/changed in 2008	Yes	20
	12	1959	1.5	0.20	0.2	2010	changed in 2010	Yes	23
	13	1984	2.6/1.5	0.86	0.8	–	Old/changed in 2002	Yes	20
	14	1964	3.0	1.15	0.8	–	Old/old 1964	Yes/no	21
	15	1960	1.7	0.26	0.3	2002	Old/old 1960	Yes	22
	16	1977	2.0	0.26	0.3	2002	Old/old 1977	Yes	20

Group	School No.	Year of construction	U value [W/m²K]			Year of the building's modernization	Radiators / pipes	Heating system regulation	Average temperature [°C]
			windows	walls	roof				
Miedium-sized schools	1	1976/81*	1.7	0.23	0.2	2007	Old/old 1981	Yes	20
	2	1983	2.6	0.85	0,8	–	Old/old 1983	Yes	20
	3	1974	1.7	0.23	0.2	2006	Old/old 1974	Yes	20
	4	1966	1.7	0.23	0.2	2007	Old/old 1966	Yes	21
	5	1979	1.7	0.24	0.2	2006	Old/old 1979	Yes	20
	6	1983	1.7	0.24	0.2	2007	Old/ changed in 2007	Yes	20
	7	1982	2.6/1,5	0.75	0.8	–	Old/old 1982	Yes	20
	8	1988	2.6	0.85	0.9	–	Old/old 1968	Yes	20
	9	1988	1.7	0.20	0.2	2008	Old/ changed in 2008	Yes	21
	10	1969	1.7	0.24	0.2	2005	Old/ changed in 2005	Yes	22
	11	1967	1.7	0.20	0.2	2008	Old/ changed in 2008	Yes	20
	12	1970	1.7	0.23	0.2	2005	Old/ changed in 2005	Yes	21
	13	1928	1.7	0.24	0.2	2005	Old/old 1968	Yes	20
	14	1971	1.7	0.24	0.2	2004	Old/old 1971	Yes	21
	15	1970	1.7	0.20	0.2	2009/11	Old/ changed in 2011	Yes	22
	16	1971	1.7	0.88	0.2	2005	Old/old 1971	Yes	20
large schools	1	1991	1.7	0.20	0.2	2008	Old/old 1991	Yes	22
	2	1999/2002*	1.7	0.30	0.3	–	New 2002	Yes	20
	3	2001/2003*	1.7	0.30	0.3	–	New 2003	Yes	20
	4	1963	1.7	0.25	0.3	2005	Old/old 1963	yes	22
	5	2010	1.5	0.20	0.2	–	New 2010	yes	19
	6	1973	1.7	0.20	0.2	2010	Old/new 2010	yes	20
	7	1983	2.6/1.7	0.80	0.8	–	Old/old 1983	yes	19
	8	1988	2.6/1.7	0.75	0.5	–	Old/old 1988	yes	20
	9	1982	1.7	0.22	0.2	2007	Old/new 2007	yes	20
	10	1983	1.7	0.22	0.2	2007	Old/new 2007	yes	20
	11	1987	1.7	0.20	0.2	2009	Old/new 2009	yes	20

* in case of different parts of buildings

In Fig. 4.2 we show the thermal energy consumption for heating per unit area E_A (kWh/m^2 per year) calculated as the ratio of the thermal energy consumption in one year to the total heated area of the building.

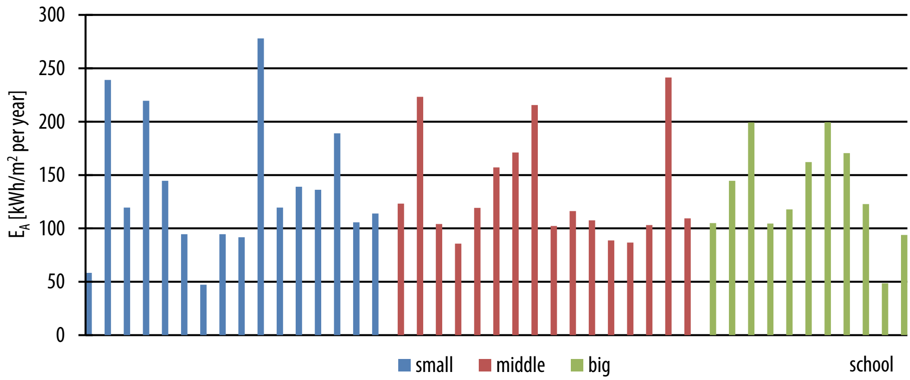

Fig. 4.2. Thermal energy consumption for heating per unit area E_A (Source: Krawczyk, 2016)

As shown by Balaras (Balaras et al., 2006), the average heating energy consumption in Poland is 261.1 kWh/(m^2·year). In Bialystok, the highest value of 241.5 kWh/m^{2}yr was observed for a middle-sized school. The value obtained for a group of schools in Bialystok is lower and amounts to an average of 135.0 kWh/(m^2·year) (in small schools 136.9 kWh/(m^2·year), middle-sized schools 134.7 kWh/(m^2·year) and in large schools 133.5 kWh/(m^2·year) although it is slightly higher than values showed by Cholewa and Siuta-Olcha (Cholewa & Siuta-Olcha, 2015) for residential buildings in Poland (86-113 kWh/(m^2·year))This shows the changes that have occurred in energy consumption and building parameters over the last few years. According to Casalas (Casalas, 2005), the average value for Spain was about 75.0 kWh/(m^2·year).

Schools built between 1980 and 2000 reached different values, depending on the range of modernisation done. The highest E_A values were observed at schools with high U for walls and roofs, with old windows, whereas lower values were recorded in buildings in which thorough modernization of the building envelope had been carried out. Concluding, the differences in energy consumption were connected with the year in which schools were built or renovated, the inside temperature, the school type and location (the number of students was lower in the area with lower population density) as well as the number of weekly working hours. Real effects of improvements done in the building envelope and HVAC systems in a school were investigated and described by Krawczyk (Krawczyk, 2014). The results of her analysis showed that the archived effect was the decrease in energy consumption on the level of 33%, while the planned energy consumption reduction was about 59-71%. The source of difference could be partly explicated by the increase of indoor temperature (before modernization some classrooms were underheated). It is worthy to note that theoretical expectations could differ from actual savings.

4.3. Retrofitting of residential buildings

The building stock by type of dwellings differs significantly across the EU. In the United Kingdom and Ireland, single-family dwellings are the dominant type (above 80%), while in Spain and Estonia, multi-family dwellings represent more than 70% of all dwellings. If we look at the EU average, there is an almost equal share of both types of dwellings, with the average of 49% for multi-family dwellings.

4.3.1. Energy performance of single-family buildings in climatic conditions of northeast Poland

In Poland single family buildings constitute almost a half (46.4%) of all residential buildings (according to the data from the Central Statistical Office of 2012). Their energy efficiency is often very low. Almost every fourth of all single-family buildings were erected before WWII and over half of them in the times of socialism. Many facilities were constructed single-handedly or by small companies based on the simplest construction and with the use of the cheapest materials. According to the studies conducted by the Institute of Environmental Economics (IEE) in 2014 almost 70% of Polish single-family houses are heated with the use of coal boilers and furnaces. Nearly 60% of all single-family houses use very inefficient solid fuel boilers which emit a significant amount of pollutants (Firląg, 2016). It has disastrous consequences for air quality in the country.

To investigate the energy performance of single-family houses located in north-eastern Poland, a group of 52 objects was selected (table 4.9). These buildings were constructed between 1940-1988. The owners decided to implement a comprehensive thermo-modernization with the use of the Thermo-Renovation Fund. Therefore, energy audits were prepared which included the calculation of the demand for heat in the state before the thermo-modernization. These results have been verified by long-term operational data. The heat demand was also calculated after the treatments recommended in the audits. In the analysed buildings there was natural ventilation. It was not proposed to replace it with a mechanical one because of the economic inefficiency of this solution during the modernization of existing buildings. In none of the buildings EK was lower than 65 kWh/(m^2yr).

Table 4.9. Parameters of single-family houses located in northeast region of Poland (Source: own elaboration)

Building nr	The year of construction	Heated area [m^2]	Cubature [m^3]	Energy consumption for heating per unit area [kWh/m^2 per year]	
				Before modernization	After modernization
1	1981	292.70	756.3	200.22	97.91
2	1971	244.40	642.8	192.80	84.95
3	1980	224.00	539.0	198.67	103.18
4	1980	236.70	560.2	203.54	93.07
5	1955	163.10	385.7	228.91	89.14
6	1983	273.20	723.1	222.34	66.91
7	1940	68.46	173.2	343.22	107.16
8	1958	128.30	321.3	422.22	79.56
9	1979	184.25	437.2	200.87	91.45
10	1986	176.60	425.2	192.85	128.41
11	1977	221.60	533.9	240.40	87.58
12	1964	127.10	343.8	396.79	107.92
13	1970	306.20	728.5	169.85	70.68
14	1986	382.57	927.1	205.87	80.04
15	1960	269.80	635.9	198.40	84.17
16	1978	45.22	113.1	559.38	128.61
17	1966	188.22	478.7	338.10	102.46
18	1960	255.50	610.3	243.73	85.02
19	1954	177.70	476.1	395.75	101.20
20	1954	190.00	508.5	298.05	87.79
21	1984	238.30	568.8	118.16	70.58
22	1970	108.40	296.0	383.48	112.46
23	1955	184.60	459.0	265.55	75.45
24	1971	119.58	298.9	330.75	85.79
25	1984	152.25	404.1	467.66	102.98
26	1989	228.00	651.0	456.99	110.35
27	1982	287.00	634.3	231.70	93.28
28	1985	175.80	453.2	126.48	90.53
29	1952	287.79	801.4	167.58	65.06

Building nr	The year of construction	Heated area [m^2]	Cubature [m^3]	Energy consumption for heating per unit area [kWh/m^2 per year]	
				Before modernization	After modernization
30	1988	201.44	502.0	209.18	89.41
31	1964	122.70	383.0	363.67	112.45
32	1967	99.98	250.0	242.71	104.72
33	1987	149.95	412.0	360.19	78.07
34	1980	238.17	570.7	215.55	90.83
35	1970	282.41	729.0	219.31	94.87
36	1961	139.18	334.7	219.24	78.88
37	1973	165.84	447.8	287.62	121.85
38	1960	165.07	431.6	186.67	69.47
39	1986	229.55	551.0	210.91	96.97
40	1985	230.40	557.0	146.29	112.31
41	1988	233.86	565.0	158.51	88.69
42	1970	126.90	364.4	324.31	94.48
43	1985	210.20	600.5	208.69	79.72
44	1978	188.00	461.8	238.09	80.68
45	1980	194.15	514.7	271.10	85.57
46	1980	231.09	607.9	233.33	90.10
47	1974	120.80	302.0	346.28	93.89
48	1986	117.10	318.0	221.85	104.72
49	1984	161.46	456.0	251.73	65.26
50	1974	189.00	450.0	222.94	86.19
51	1982	224.70	606.7	414.65	78.44
52	1985	180.60	415.0	254.43	83.65

In Fig 4.3, 52 buildings were compared with three energy-efficient buildings also built in the climate conditions of north-eastern Poland (Sadowska, 2011). They were built in the years 1999-2003, and in the following years they were monitored in order to confirm their low energy consumption. In these buildings more than the standard thickness of thermal insulation was used (in the three-layer walls and the roof 18-cm-thick layer of mineral wool was laid, in the roof additionally 0.02 m layer of polystyrene, in the floor on the ground 0.01 m layer of polystyrene). The supply and exhaust ventilations with heat recovery and a ground heat exchanger were installed. These solutions enabled to obtain indicators of energy demand lower than 55 kWh/(m^{2}yr).

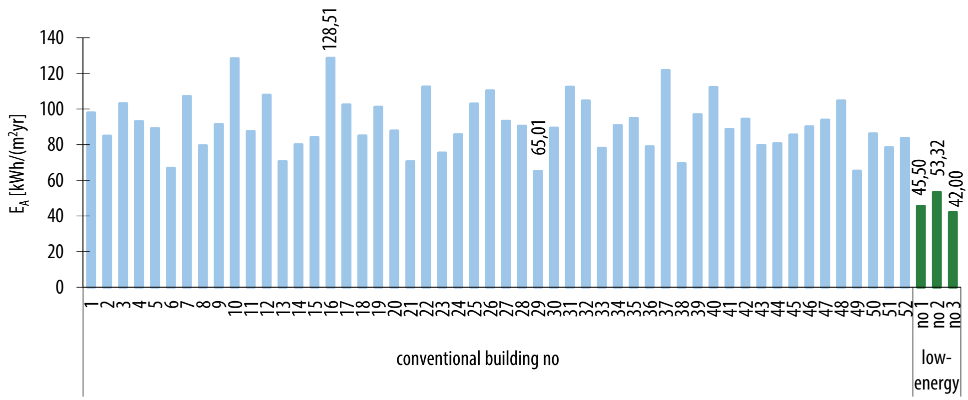

Fig. 4.3. Energy consumption for heating per unit area in 52 conventional single-family houses and 3 low-energy buildings (Source: own elaboration)

The average heating energy consumption obtained for a group of single-family houses with natural ventilation, located in northeast region of Poland is 91,63 kWh/(m^2yr). The use of a mechanical ventilation system with heat recovery in low-energy houses has allowed to obtain energy consumption equal to 42.00 ÷ 53.32 kWh/(m^2yr).

4.3.2. Predictable effects of thermal retrofitting of apartment buildings

Seven apartment buildings, constructed between 1959 and 1993 in the Podlaskie Voivodship, were analysed (Sadowska, 2014). Their basic data is shown in Table 3.8.

Table 4.10. Parameters of apartment buildings (Source: own elaboration)

Building nr	number of			Heated area [m^2]	Cubature [m^3]
	staircases	floors	flats		
1	2	4	16	868.80	3 990.0
2	3	4	24	1 304.40	5 948.0
3	6	5	60	3 712.00	15 666.0
4	3	12	89	3 938.57	17 194.0
5	1	5	25	1 088.50	5 294.0
6	3	5	45	1 791.06	8 536.0
7	1	2+attic	10	418.50	2 714.0

The external walls of the buildings have been modernized to meet the requirements of thermal protection according to the Regulation of the Minister of Transport, Construction and Maritime Economy of 5 July 2013. All the buildings had natural ventilation. Four locations were analysed: Suwalki (climatic zone V), Bialystok (climatic zone IV), Warsaw (climatic zone III) and Szczecin (climate zone I). Differences in the heat demand of the same buildings located in different parts of Poland are significant (table 4.9).

Table 4.11. Energy consumption in apartment buildings (Source: own elaboration)

Building nr	location of the building			
	Suwalki	Bialystok	Warsaw	Szczecin
	Energy consumption for heating per unit area [kWh/m² per year]			
1	101.6	93.0	81.4	70.2
2	98.7	90.2	78.9	68.0
3	88.3	82.5	72.6	63.0
4	93.6	85.4	77.8	64.5
5	111.6	104.0	89.6	84.0
6	108.5	100.0	88.2	76.9
7	117.1	108.7	96.7	85.5

Energy consumption for heating per unit area of buildings located in Suwalki is higher than the ones located in Szczecin, from 33% (in case of building No. 5) to 45% (buildings 1, 2 and 4). For buildings in Bialystok, these differences range from 24 to 33%, and in Warsaw from 7 to 21%. For buildings located in Bialystok, the difference is 24 to 33%, while in Warsaw it is 7 to 21%. The lowest unit energy consumption of 63.0 kWh/(m^2·year) was achieved in building no. 3 located in Szczecin. Buildings located in the north-eastern region of Poland have higher E_A values, ranging from 82.5 to 117.1 kWh/(m^2·year) and differ between the location in Bialystok and Suwalki by 7-10% (Polish climatic zones IV and V).

4.3.3. Case study: deep thermal renovation

In order to show the possibilities of reducing thermal energy consumption after deep thermal modernization, an apartment building located in north-eastern Poland was chosen. Improvements of the envelope, installations (with the use of renewable energy) and lighting were proposed to meet deep thermal renovation requirements (Polish regulations of thermal protection which will come into force on January 1, 2021). This building (table 4.12), constructed of prefabricated reinforced concrete slabs, needed renovation due to its high energy consumption. The walls were insulated with 0.05 m of expanded polystyrene and the ventilated flat roof had 0.08 m-thick insulation of mineral wool.

Table 4.12. General information about the analysed apartment building (Source: own elaboration)

Time of construction	1970s
Number of flats / occupants	40 / 110
Area	2 971.3 m^2
Usable area	2 248.0 m^2
Cubature	8 918 m^3
Number of floors / staircases	5 / 4

Another insulating layer of 0.15 m of expanded polystyrene was mounted on the walls. The roof was sealed, and an additional insulation layer of 0.26 m of mineral wool was applied, which increased the total insulation thickness to 0.34 m. The existing windows were replaced (table 4.13). The insulation of the floor in the basement was not considered. The connection to the district heating supply was maintained. A new central heating installation was made. Thermostatic valves were installed in the domestic hot water system.

In addition, lighting in the administrative part of the building was replaced with LED lighting. Six pieces of PV panels (10.10 m^2) were installed on the roof (with the power of 1.5 kWp and the annual electricity production of approximately 1572 kWh).

Table 4.13. *U*-values of the building construction elements (Source: own elaboration)

U-values [W/m^2·K]	Before retrofitting	After retrofitting
External wall	0.28; 0.73$^{*)}$	0.20
Basement walls	0.83; 1.14; 1.31; 2.32	0.18; 0.19; 0.19; 0.20 (t_i<16°C)
Vestibule walls	1.93	0.23 (t_i<16°C)
Roof	0.61	0.13
Roof of the vestibules	3.35	0.25 (t_i<16°C)
Windows (flats)	2.00	0.90
Windows (staircases. basement. vestibules)	2.60	1.40 (t_i<16°C)
External doors	5.10	1.30
$^{*)}$ external bearing walls were previously insulated with 8 cm polystyrene.		

The calculations show the possibilities of energy consumption reduction due to deep thermal modernization of an apartment building (table 4.12). The expected value of

EP=65 kWh/(m^2·year) in accordance with Polish national regulations that will come into force in 2021 has not been achieved. There is a possibility to reduce EP value by providing a renewable source of energy for the hot water system (e.g. using panel solar collector – assuming 50% share *EP*=53.47 kWh/(m^2·year).

Table 4.14. Results of calculation (Source: own elaboration)

	Before retrofitting	After retrofitting	Savings	
Final energy demand [kWh/m^2·year]				
Space heating	102.70	23.92	78.78	76.71%
Domestic hot water	62.08	44.35	17.73	28.56%
Total	164.78	68.27	96.51	58.57%
Primary energy [kWh/m^2·year]				
Space heating	119.13	27.75	91.38	76.71%
Domestic hot water	72.01	51.44	20.57	28.56%
Total	191.14	79.19	111.95	58.57%

The use of LED lighting in the administrative part of the building reduced the energy demand for lighting from 1.74 kW/m^2year to 0.64 kWh/(m^2·year) and the installation of PV panels cut down the energy usage to 0.53 kWh/(m^2·year).

In conclusion, it should be noted that using proper window type and insulation thickness to meet the maximum *U*-values of walls does not guarantee that the building will achieve the expected value of *EP* factor. Primary energy factor *EP* depends mainly on the source of heat and it can be significantly reduced using renewable energy sources.

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5. ENERGY CERTIFICATION

The efficient use of energy resources and reduction of environmental pollution are priority tasks today. Certification of energy performance of buildings is one of the ways to reach these tasks.

5.1. Energy performance certification of buildings

The certification of building energy performance is a process that determines the energy consumption of a building and classifies the building on an energy performance scale.

The certification process is based on the Directive of the European Parliament and the European Council "On Energy Performance of Buildings" (the recast Directive 2010/31; STR1, 2011; STR2, 2016).

The aim of the certification is to facilitate more efficient energy use because it is an important part of the policy and of the applied measures necessary to comply with the "Kyoto Protocol to the United Nations Framework Convention on Climate Change" (STR1, 2011; STR2, 2016).

Energy performance certification is one of the ways of reducing the CO_2 emissions into the environment by implementing the European Council directive on limitation of carbon dioxide emissions by increased efficiency of energy consumption in the building sector (STR3, 2016).

On 30 November 2016 the Commission proposed an update to the Energy Performance of Buildings Directive to help promote the use of smart technology in buildings and to streamline the existing rules.

Finally, on 19 December 2017 a political agreement was reached on the proposals. Among the updates we could find provisions on smart technologies and technical building systems, including automation and e-mobility. The legal text of this political agreement is expected to be published in 2018 (WEB-1).

Buildings in Spain are classified in six categories according to energy efficiency scale: A, B, C, D, E, F, G. Buildings in Lithuania are classified in nine classes according to energy efficiency scale: A++, A+, A, B, C, D, E, F, G (REG-1, REG-2). A++ class is the highest, it indicates an almost no-energy-consuming building (REG-1, REG-2).

Class G refers to an energy-efficient building. Methodology of evaluation of energy efficiency in Poland is significantly different. The Polish legislation (REG-9, REG-10) introduced an obligation to compare the calculated values of energy indicators with the maximum values delivered by regulations. Contrary to many other EU countries, no energy classes were recommended. The final result is presented in the graph (Fig. 5.1) showing if the EP factor in the evaluated building is lower or higher than the maximum value recommended for a new structure, according to the Polish law. Maximum values are depicted in a Polish regulation (REG-11).

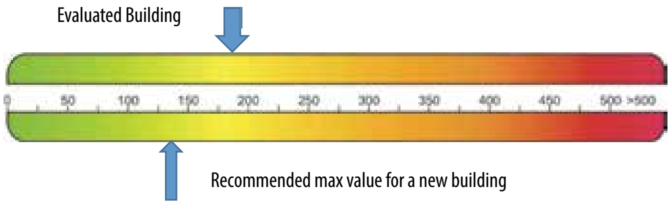


Fig. 5.1. A part of the Polish Energy Certificate presenting the EP values (Source: own elaboration)

Participants in the Spanish Energy Efficiency Certification Process are (REG-3):

- a certification customer (owner of a residential house, flat or building),
- a recognized expert by the Spanish Administration authorized to certify buildings,
- an institution appointed by the Spanish Administration supervising the certification process and registering the energy efficiency certificate of the building.

When renting or buying real estate, the owner of the property is obliged to submit the certificate of energy efficiency of the house (flat or building) to the tenants or new owners.

Participants in the Lithuanian certification process are:

- a certification customer,
- an expert with a licence to certify buildings,
- an institution appointed by the Ministry of Environment supervising the certification process.

In Poland, according to REG-11, parties participating in the certification process are similar to those in other countries.

5.2. Methodology for evaluation of energy performance of a building

Energy efficiency indicators of a building are the indicators according to which the building energy efficiency class is determined.

5.2.1 Energy efficiency indicators in Lithuania

Energy efficiency indicator C1 describes the energy efficiency for heating, ventilation and cooling. The C2 value of the energy efficiency indicator describes (REG-2, STR2, 2016):

- thermal properties of the walls and structure of the building and the building envelope for calculating specific heat loss,
- thermal energy consumption for the heating of the building,
- the efficiency of energy consumption for the preparation of hot domestic water,
- technical indicators of the mechanical ventilation system with recuperation,
- the energy from renewable resources.

Calculation of C1 energy efficiency indicator (STR2, 2016):

If $$\frac{\sum_{m=1}^{12} Q_{PRn.H,m} + Q^{I}_{PRn.E}}{\sum_{m=1}^{12} Q_{R.PRn.H,m} + \sum_{m=1}^{12} (Q_{R.E.\lg,m} \cdot f_{R.PRn.E})} \geq 1,$$

then $$C_1 = 1 + \frac{\sum_{m=1}^{12} Q_{PRn.H,m} + Q^{I}_{PRn.E}}{\sum_{m=1}^{12} Q_{R.PRn.H,m} + \sum_{m=1}^{12} (Q_{R.E.\lg,m} \cdot f_{R.PRn.E})} \tag{5.1}$$

If $$\frac{\sum_{m=1}^{12} Q_{PRn.H,m} + Q^{I}_{PRn.E}}{\sum_{m=1}^{12} Q_{N.PRn.H,m} + \sum_{m=1}^{12} (Q_{N.E.\lg,m} \cdot f_{N.PRn.E})} \leq 1,$$

then $$C_1 = \frac{\sum_{m=1}^{12} Q_{PRn.H,m} + Q^{I}_{PRn.E}}{\sum_{m=1}^{12} Q_{N.PRn.H,m} + \sum_{m=1}^{12} (Q_{N.E.\lg,m} \cdot f_{N.PRn.E})} \tag{5.2}$$

Other cases: $$C_1 = 1 + \frac{\sum_{m=1}^{12} Q_{PRn.H,m} + Q^I_{PRn.E} - \sum_{m=1}^{12} Q_{N.PRn.H,m} - \sum_{m=1}^{12} (Q_{N.E.\lg,m} \cdot f_{N.PRn.E})}{\sum_{m=1}^{12} Q_{R.PRn.H,m} - \sum_{m=1}^{12} Q_{N.PRn.H,m}} \quad (5.3)$$

where:

$Q_{N.PRn.H,m}$ – the standard monthly non-renewable primary energy consumption for the heating of the building, kWh / (m² month),

$Q_{R.PRn.H,m}$ – non-renewable primary energy consumption for the heating of the building, kWh/(m²· month);

$Q_{PRn.H,m}$ – the calculated monthly non-renewable primary energy consumption for the heating of the building, kWh/(m²· month);

$Q^I_{PRn.E}$ – calculation according to Equ. 5.4-5.5 (STR2, 2016):

$$Q^I_{PRn.E} = \sum_{m=1}^{12} Q^I_{PRn.E,m} \quad (5.4)$$

$$Q^I_{PRn.E,m} = (Q_{E.\lg,m} + Q_{E.vent,m} + Q_{C.E,m} - Q_{E.SK+WE+HE,m}) \cdot f_{PRn.E} + Q_{PRn.E.SK+WE+HE,m} \quad (5.5)$$

where:

$Q_{E.lg,m}$ – monthly calculated electrical energy consumption for the heating, kWh/(m²·month);

$Q_{E.vent,m}$ – monthly calculated electrical energy consumption for fans of mechanical ventilation systems of the building, kWh/(m²·month);

$Q_{C.E,m}$ – monthly calculated energy consumption for cooling, kWh/(m²·month);

$Q_{E.SK+WE+HE,m}$ – monthly calculated consumption of electricity produced by solar collectors, wind power plants and hydro-power plants in the building, kWh/(m²·month);

$Q_{PRn.E.SK+WE+HE,m}$ – monthly calculated consumption of primary energy supplied to the building from solar collectors, wind power plants and hydro-power plants, kWh / (m² month);

$f_{PRn.E}$ – primary energy factor for electricity.

Calculation of energy efficiency indicator C2 (STR2, 2016):

$$C_2 = \frac{\sum_{m=1}^{12} Q_{PRn.hw,m}}{\sum_{m=1}^{12} Q_{N.PRn.hw,m}} \quad (5.6)$$

where:

$Q_{N.PRn.hw,m}$ – the standard monthly non-renewable primary energy consumption for the preparation of hot water, kWh / (m² month);

$Q_{PRn.hw,m}$ – monthly calculation of non-renewable primary energy consumption for DHW, kWh/(m²· month).

A building shall be marked with a certain energy performance class considering the values of the qualifying indicators C1 and C2 as follows (REG-2; STR2, 2016):

- B class: $0.5 \leq C_1 < 1$ ir $C_2 \leq 0.99$,
- A class: $0.375 \leq C_1 < 0.5$ ir $C_2 \leq 0.85$,
- A+ class: $0.25 \leq C_1 < 0.375$ ir $C_2 \leq 0.80$,
- A++ class: $C_1 < 0.25$ ir $C_2 \leq 0.70$.

5.2.2 Energy efficiency indicators in the Spanish legislation

The energy rating is expressed through several indicators that explain the reasons for a good or bad energy behaviour of the building (REG-3, REG-5, REG-6). These indicators have been obtained from the energy consumption of the building in the climatic conditions determined for normal operating and occupancy, which include the energy consumed by heating, cooling, ventilation, production of hot water and, where appropriate (only for non-residential buildings), lighting in order to maintain thermal and lighting comfort conditions as well as indoor air quality (REG-4, REG-7, REG-8).

The indicators are obtained on an annual basis and refer to a unit of useful surface of the building. The main or global indicators of energy efficiency are:

- annual emissions of CO_2, expressed in kg $CO_2/(m^2year)$,
- annual consumption of non-renewable primary energy, expressed in kWh/(m^2year).

These main indicators include the impact of heating, cooling, production services of sanitary (domestic) hot water and lighting – for purposes other than private residential, as well as reduction of emissions or non-renewable primary energy consumption derived from the use of renewable energy sources.

Spanish rating scale for buildings for private residential use (housing)

Buildings destined for private residential use (housing) are classified, for each of the indicators of energy efficiency, using a scale of seven letters, which goes from letter A (the most efficient building) to letter G (the least efficient one), according to Table 5.1 (REG-3).

Table 5.1. Energy rating and indices for private residential buildings use (Source: REG-3)

Class			Index		
A			C1	<	0.15
B	0.15	≤	C1	<	0.5
C	0.5	≤	C1	<	1.00
D	1.00	≤	C1	<	1.75
E	1.75	≤	C1		
			C2	<	1.00
F	1.75	≤	C1		
	1.00	≤	C2	<	1.50
G	1.75	≤	C1		
	1.50	≤	C2		

C_1 and C_2 indices expressing the energy rating of single-family homes and blocks of flats are obtained through the following formulas:

$$C_1 = \frac{\left(R \cdot I_o / \bar{I}_r\right) - 1}{2\left(R - 1\right)} + 0.6 \qquad (5.7)$$

$$C_2 = \frac{\left(R' \cdot I_o / \bar{I}_s\right) - 1}{2\left(R' - 1\right)} + 0.5 \qquad (5.8)$$

where:

I_o – the value of the indicator of the analysed building (annual emissions of CO_2, annual consumption of non-renewable primary energy),

$\bar{I}_r$ – the average value of the reference park indicator of new buildings for private residential use (living place).

R – the ratio between the value of $\bar{I}_r$ and the value of the indicator corresponding to the 10th percentile of the park of reference of new buildings for private residential use (housing).

$\bar{I}_s$ – the average value of the reference indicator of existing private residential buildings (living place).

R_o – the ratio between the value of $\bar{I}_s$ and the value of the indicator corresponding to the 10th percentile of the park of reference of existing buildings for private residential use (housing).

The values of I_r, R, $\bar{I}_s$, R_o corresponding to different Spanish climatic zones are included in Regulation 9 .

Energy efficiency indicators in Poland

According to law (REG-11), in Poland there are 3 main energy indicators: EP, EK, EU and one ecological indicator E_{CO2}. The relation between them is shown in Fig. 5.2.

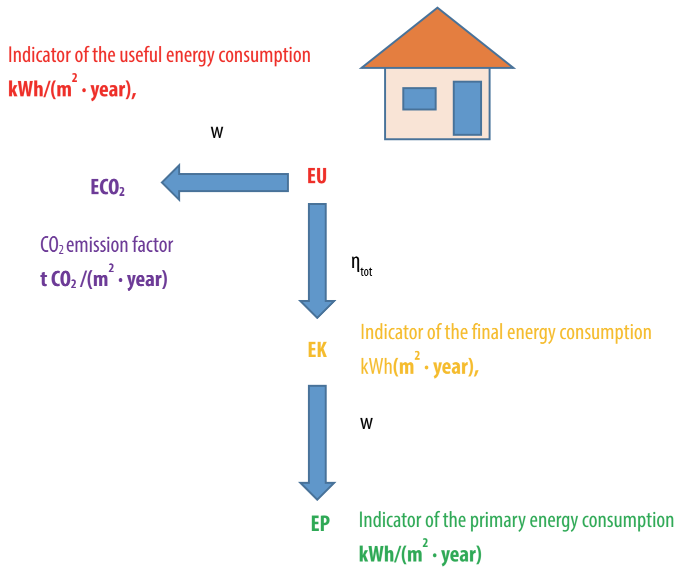


Fig. 5.2. Schema of the relation between EP, EK and EU (Source: own elaboration)

The EU is the indicator of the useful energy consumption that is estimated based on standards and regulations. To obtain the EK (indicator of final energy consumption), it is necessary to take into account total efficiency of the systems (heating, hot water and cooling) that is calculated based on equation 5.9:

$$\eta_{tot} = \eta_g \text{ (or COP)} \cdot \eta_d \cdot \eta_s \cdot \eta_e \tag{5.9}$$

where:

η_g (or COP) – eficiency of generation (–),
η_d – efficiency of distribution (–),
η_s – efficiency of storage (–),
η_e – efficiency of regulation (–).

Moreover, after including the factor depending on the fuel type, we will estimate the EP (indicator of primary energy consumption).

Besides, the Polish regulation (REG-12) sets the maximum value of the EP. Total EP consists of 3 main components (equation 5.10, Table 5.2):

$$EP = EP_{H+W} + \Delta EP_C + \Delta EP_L; \ [kWh/(m^2 \cdot year)] \quad (5.10)$$

where
EP_{H+W} is part of EP connected with heating, ventilation and hot water,
ΔEP_C is part of EP connected with cooling (kWh/(m²·year),
ΔEP_L is part of EP connected with lighting (kWh/(m²·year).

Table 5.2. Maximum EP_{H+W}, ΔEP_C, ΔEP_L

Type of building	EP_{H+W} kWh/(m²·year)	EP_{H+W} kWh/(m²·year)	ΔEP_C kWh/(m²·year)	ΔEP_C kWh/(m²·year)	ΔEP_L kWh/(m²·year)	ΔEP_L kWh/(m²·year)
	2017	2020	2017	2020	2017	2020
Single family houses	95	70	$\Delta EP_C = 10\ A_{f,C}/A_f$	$\Delta EP_C = 5\ A_{f,C}/A_f$	$\Delta EP_L = 0$	$\Delta EP_L = 0$
Residential buildings	85	65				
Health centres	290	190	$\Delta EP_C = 25\ A_{f,C}/A_f$	$\Delta EP_C = 25\ A_{f,C}/A_f$	$t_0 < 2500$ $\Delta EP_L = 50$ $t_0 \geq 2500$ $\Delta EP_L = 100$	$t_0 < 2500$ $\Delta EP_L = 25$ $t_0 \geq 2500$ $\Delta EP_L = 50$
Public buildings	60	70				

$A_{f,C}$ – heated or cooled area in m², A_f – cooled area in m², t_0 – time of system usage in h.

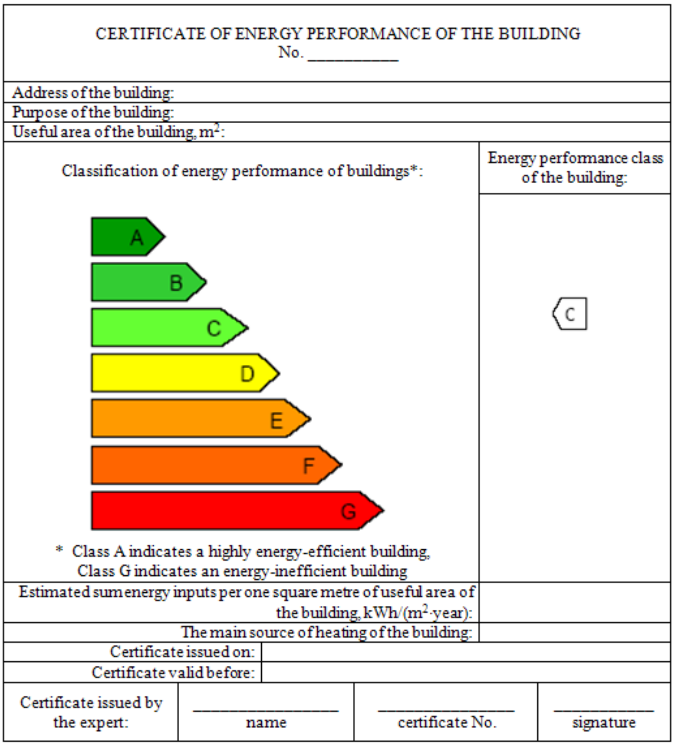
5.3. THE CERTIFICATE OF ENERGY PERFORMANCE OF A BUILDING

The energy performance certification of a building is needed to assess the energy performance of a specific building by classifying it as an energy efficiency class.

Certificate is a document, which contains the following data (STR2, 2016):

- address of the building,
- purpose of the building,
- useful area of the building,
- energy performance class of the building,
- estimated sum of energy inputs per one square metre of the useful area of the building,
- data about the main source of heating of the building by specifying one of heating sources,
- reference number of the certificate of the building,
- date of issuing of the certificate,
- validity date of the certificate,

- name, certificate number and signature of the expert who issued the certificate of the building (Fig. 5.3).



CERTIFICATE OF ENERGY PERFORMANCE OF THE BUILDING
No. __________

Address of the building:
Purpose of the building:
Useful area of the building, m^2:

Classification of energy performance of buildings*:	Energy performance class of the building:
A B C D E F G	C
* Class A indicates a highly energy-efficient building, Class G indicates an energy-inefficient building	
Estimated sum energy inputs per one square metre of useful area of the building, kWh/(m^2·year):	
The main source of heating of the building:	

Certificate issued on:	
Certificate valid before:	

Certificate issued by the expert:	______ name	______ certificate No.	______ signature

Fig. 5.3. An example of a Certificate issued in Lithuania (Source: STR2, 2016)

The Spanish energy efficiency certificate shall conform to the model (REG-9), and may contain additional annexes, when these prove necessary. Fig. 5.4 shows a typical Spanish Certificate of Energy Efficiency in Buildings.

Data presented in the Spanish Certificate:

- building data,
- type of building to be certified,
- data of the expert issuing the certificate,
- energy rating obtained, expressed in non-renewable primary energy consumption and CO_2 emissions,
- four appendices including additional data of the certification process.

CERTIFICATE OF ENERGY EFFICIENCY OF THE BUILDING

BUILDING DATA:

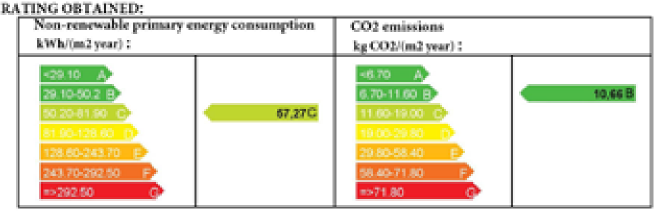
Name of the building			
Address			
City		**Postal code**	
Province		**Autonomous community**	
Climatic area		**Year of construction**	
Regulation			
Registry number of the building			

Type of building or part of building to be certified	
☒ New construction building	☐ Existing building
☒ Households	☐ Non residential building
☒ Single family home	☐ Whole building
☐ Block house	☐ Part of the building
☐ Whole building	
☐ Part of the building	

Data of the expert issuing the certificate:

Name and surname		**NIF/NIE**	
Company		**NIF**	
Address			
City		**Postal code**	
Province		**Autonomous community**	
E-mail		**Phone**	
Qualification			
Recognized energy rating procedure used and version:			

ENERGY RATING OBTAINED:



The undersigned technician declares responsibly that he has made the energy certification of the building or of the part that is certified in accordance with the procedure established by current regulations and that the data contained in this document and its annexes are true:

Date 00/00/0000

Signature of the certifying technician:

Appendix I. *Description of the energetic characteristics of the building.*
Appendix II. *Energy rating of the building.*
Appendix III. *Recommendations for the improvement of energy efficiency.*
Appendix IV. *Tests, verifications and inspections carried out by the certifying technician.*

Register of the Competent Territorial Organ:

Fig. 5.4. An example of a Certificate issued in Spain (Source: M. R. de Adana's private archive)

The main results of calculation of energy inputs, the assessment of measures to improve energy performance of a building and the calculation results of energy inputs are shown in table 5.3 (STR2, 2016).

Table 5.3. Fragments of calculation results of energy inputs of a building (Source: STR2, 2016)

No.	Energy inputs	Estimated annual energy inputs per one square metre of the useful area of a building, kWh/(m^2·year)
1.	Loss of heat through the walls of a building	
2.	Loss of heat through the roof of a building	
3.	Loss of heat through the external ceilings of a building	
4.	Loss of heat through partitions touching the soil	
5.	Loss of heat through the windows of a building	
6.	Loss of heat through the external entrance door of a building except for the loss when the door is open	
7.	Loss of heat through the linear thermal bridges of a building	
8.	Loss of energy through the ventilation of a building	
…		
12.	Heat inflow to a building from the outside	
13.	Internal heat emissions in a building	
14.	Electricity consumption in a building	
15.	Energy inputs for hot water preparation	
…		

Energy-consuming buildings are buildings complying with the requirements of the A ++ energy performance class (very high energy performance buildings, where energy consumption is almost zero or energy consumption is very low; most of the energy consumed comes from renewable sources, either local or non-local) (REG-2, STR2 2016). Low-energy buildings are buildings matching the requirements of the B, A and A+ energy performance class (STR1, 2011; STR2, 2016).

An example of the main page of Polish Energy Certificate is shown in Fig. 5.5.

ENERGY EFFICIENCY CERTIFICATE FOR A RESIDENTIAL BUILDING a single family house			
VALIDITY DATE	10.10.2028	CERTIFICATE NUMBER	1/2018
THE EVALUATED BUILDING			
TYPE OF BUILDING	residential		
ADDRESS	Bialystok		
WHOLE / PART OF THE BUILDING	whole building		
YEAR OF CONSTRUCTION	2017		
YEAR OF COMMISSIONING	2017		
YEAR OF FITTING INSTALLATIONS	2017		
NUMBER OF FLATS	1		
USABLE AREA (A_f, m²)	110.00		
PURPOSE OF THE EVALUATION	○ **NEW BUILDING** ○ RENTAL/SALE ○ EXISTING BUILDING ○ EXTENSION OF BUILDING		

COMPUTATIONAL DEMAND FOR NON-RENEWABLE PRIMARY ENERGY [1)]

EP – the evaluated building 144.3 kWh (m² • year)

WT 2014[2)] technical conditions for a new building

CONFIRMATION OF COMPLIANCE WITH WT 2014[2)] CONDITIONS			
DEMAND FOR PRIMARY ENERGY (EP)		DEMAND FOR FINAL ENERGY (EK)	
THE EVALUATED BUILDING	144.3 kWh (m² year)	THE EVALUATED BUILDING	48.1 kWh (m² year)
A BUILDING ACCORDING TO WT 2014	125.0 kWh (m² year)		

1) Energy performance is established by comparing a single unit of non-renewable primary energy EP necessary to meet the energy demand of the building for heating, cooling, ventilation and usable hot water (overall effectiveness) with reference value.
2) The regulation of the Minister of Infrastructure of 12 April 2002 concerning technical conditions to be met by buildings and their location (Dz.U. Nr 75. pos. 690, with later amendments); complying with the conditions is obligatory only for a new building.

Attention: energy performance is established for climatic conditions in place of reference: Bialystok and for normal conditions of use defined on page 2.

EXPERT ISSUING THE CERTIFICATE	
FIRST NAME AND SURNAME	Dorota Krawczyk
CONSTRUCTION LICENCE NUMBER OR REGISTRATION NUMBER	
DATE OF ISSUE	10.10.2018
DATE, STAMP AND SIGNATURE	

Fig. 5.5. The Polish energy certificate, page 1 (Source: D.A.Krawczyk's private archive)

5.4. An example of energy certificate

To show differences between national methodologies and final documents, a single-family house has been analysed.

5.4.1. A Certificate for a house in Spain

A single-storey residential building is located in the city of Cordoba. The house is L-shaped. Fig. 5.6-5.7 show different views of the house.

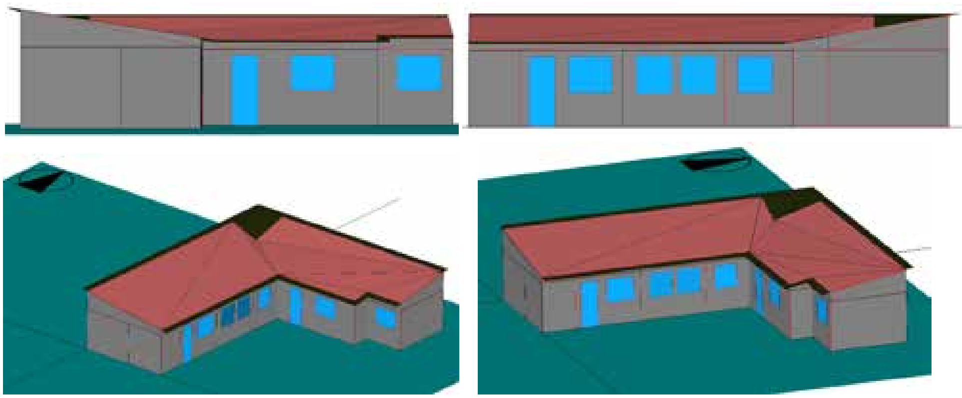


Fig. 5.6. Views of the residential house prepared in HULC (Source: M.R.de Adana's private archive)

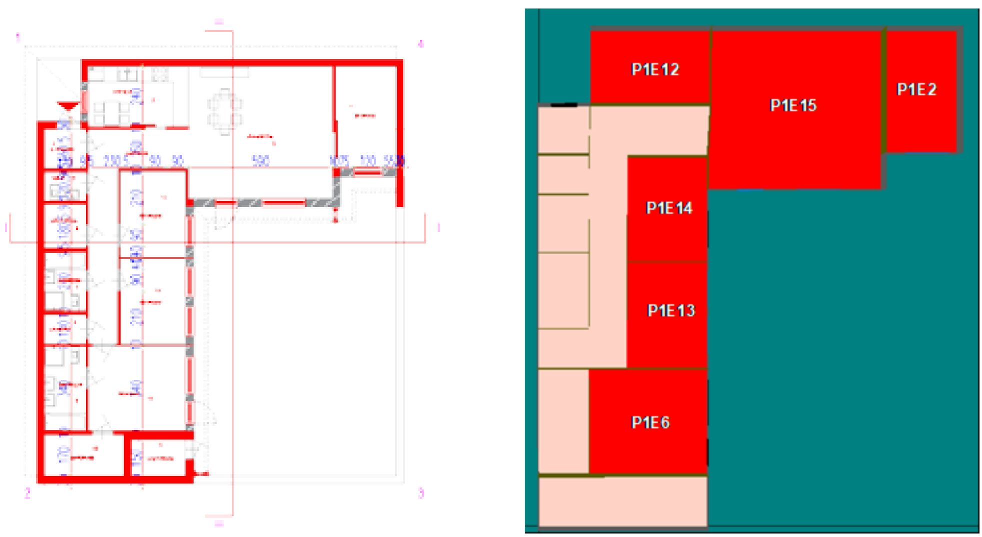


Fig. 5.7. The plan of the residential house in AUTOCAD and HULC (Source: M.R.de Adana's private archive)

Living room, kitchen and four bedrooms of the house are identified as rooms equipped with HVAC systems. Fig. 5.8 shows the air-conditioned rooms of the house.

Room	Hulc	HVAC system
Bedroom 1	P1E2	YES
Living room 2	P1E15	YES
Kitchen 3	P1E12	YES
Bedroom 12	P1E6	YES
Bedroom 13	P1E13	YES
Bedroom 14	P1E14	YES

Fig. 5.8. Rooms of the house equipped with HVAC systems (Source: M.R.de Adana's private archive)

The proposed HVAC system is composed of two multisplit heat pumps for the cooling/heating demand and a boiler for the domestic hot water (DHW) demand. Fig. 5.9 shows the proposed HVAC system.

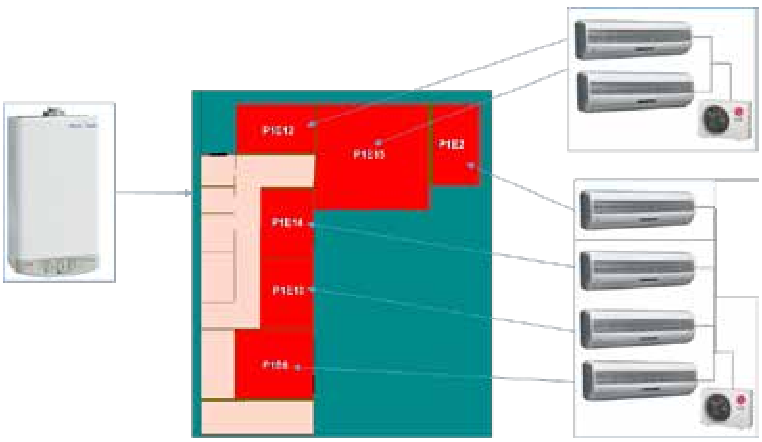


Fig. 5.9. HVAC systems in the residential house (Source: M.R.de Adana's private archive)

70% of the calculated DWH demand is covered by a solar thermal system. The DHW demand is 90 litres per day. The natural gas boiler has a thermal power of 15 kW and an efficiency of 90%.

The four bedrooms are equipped with a multisplit HVAC heat pump system with the characteristics shown in Fig. 5.10.

Indoor units		UT_P1B2	[illegible]	[illegible]	[illegible]
Nominal cooling capacity	kW	1	1	1	1
Nominal sensible cooling capacity	kW	0.6	0.6	0.6	0.6
Nominal heating capacity	kW	1.1	1.1	1.1	1.1
Airflow rate	m^3/h	300	300	300	300

Outdoor unit		[illegible]
Nominal cooling capacity	kW	4
Nominal cooling consumption	kW	1.5
Nominal heating capacity	kW	4.5
Nominal heating consumption	kW	1.17

Fig. 5.10. Characteristics of the multisplit HVAC heat pump system for the bedrooms (Source: M.R.de Adana's private archive)

The living room and kitchen are equipped with another multisplit HVAC heat pump system with the characteristics shown in Fig. 5.11.

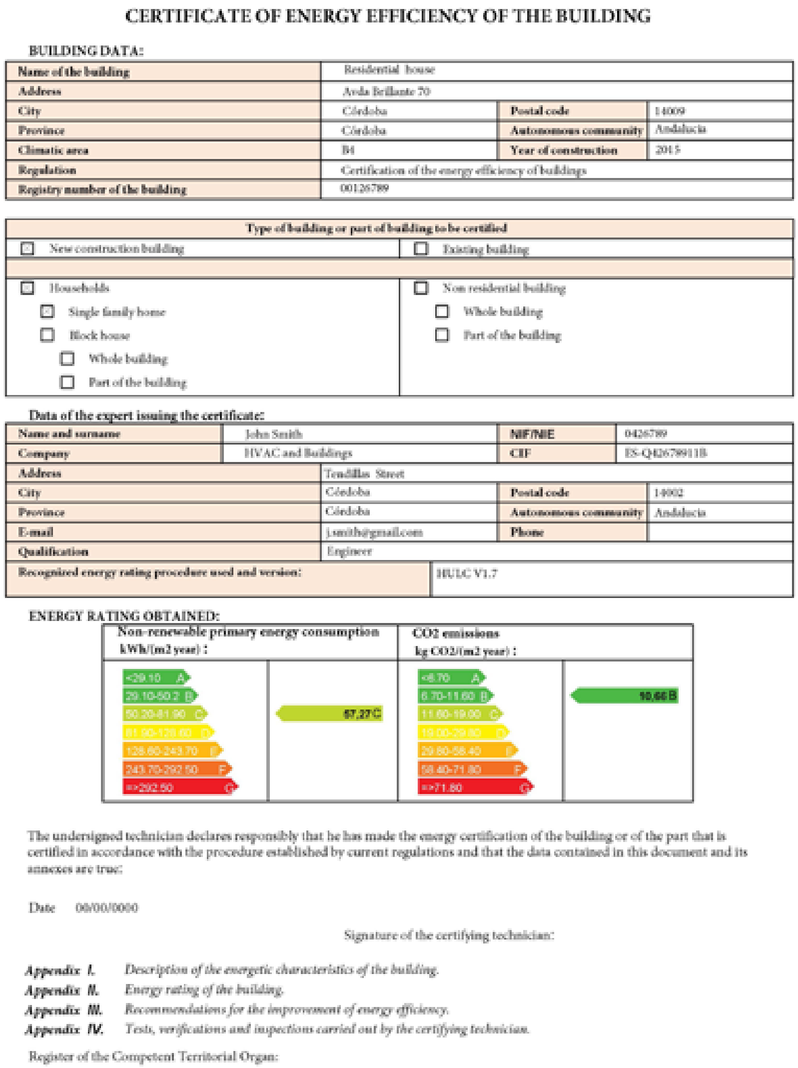
Indoor units		[illegible]	[illegible]
Nominal cooling capacity	kW	2.5	1
Nominal sensible cooling capacity	kW	1.6	0.6
Nominal heating capacity	kW	2.75	1.1
Airflow rate	m^3/h	750	300

Outdoor unit		[illegible]
Nominal cooling capacity	kW	4
Nominal cooling consumption	kW	1.5
Nominal heating capacity	kW	4.5
Nominal heating consumption	kW	1.17

Fig. 5.11. Characteristics of the multisplit HVAC heat pump system for the living room and the kitchen (Source: M.R.de Adana's private archive)

The HVAC system is composed of two multisplit heat pumps for the cooling/heating demand and a boiler for the domestic hot water (DHW) demand. Fig. 5.11 shows the proposed HVAC system.

The residential house and HVAC systems are defined in the Spanish software HULC to calculate the energy efficiency and obtain a certificate of energy efficiency. An example of the certificate of energy efficiency is shown in Fig. 5.12.



CERTIFICATE OF ENERGY EFFICIENCY OF THE BUILDING

BUILDING DATA:

Name of the building	Residential house		
Address	Avda Brillante 70		
City	Córdoba	Postal code	14009
Province	Córdoba	Autonomous community	Andalucia
Climatic area	B4	Year of construction	2015
Regulation	Certification of the energy efficiency of buildings		
Registry number of the building	001267789		

Type of building or part of building to be certified	
☒ New construction building	☐ Existing building
☒ Households	☐ Non residential building
☒ Single family home	☐ Whole building
☐ Block house	☐ Part of the building
☐ Whole building	
☐ Part of the building	

Data of the expert issuing the certificate:

Name and surname	John Smith	NIF/NIE	0426789
Company	HVAC and Buildings	CIF	ES-Q4267891IB
Address	Tendillas Street		
City	Córdoba	Postal code	14002
Province	Córdoba	Autonomous community	Andalucia
E-mail	j.smith@gmail.com	Phone	
Qualification	Engineer		
Recognized energy rating procedure used and version:	HULC V1.7		

ENERGY RATING OBTAINED:

Non-renewable primary energy consumption kWh/(m2 year) :		CO2 emissions kg CO2/(m2 year) :	
<29.10 A		<6.70 A	
29.10-50.2 B		6.70-11.60 B	10,66 B
50.20-81.90 C	57,27 C	11.60-19.00 C	
81.90-128.60 D		19.00-29.80 D	
128.60-243.70 E		29.80-58.40 E	
243.70-292.50 F		58.40-71.80 F	
=>292.50 G		=>71.80 G	

The undersigned technician declares responsibly that he has made the energy certification of the building or of the part that is certified in accordance with the procedure established by current regulations and that the data contained in this document and its annexes are true:

Date 00/00/0000

Signature of the certifying technician:

Appendix I. *Description of the energetic characteristics of the building.*
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Register of the Competent Territorial Organ:

Fig. 5.12. An example of Spanish certificate of energy efficiency for a residential house (Source: M.R.de Adana's private archive)

5.4.2. Improving energy efficiency

Different actions can be considered to improve the energy efficiency of the residential house. A schematic overview of some of these actions is shown in Fig. 5.13.

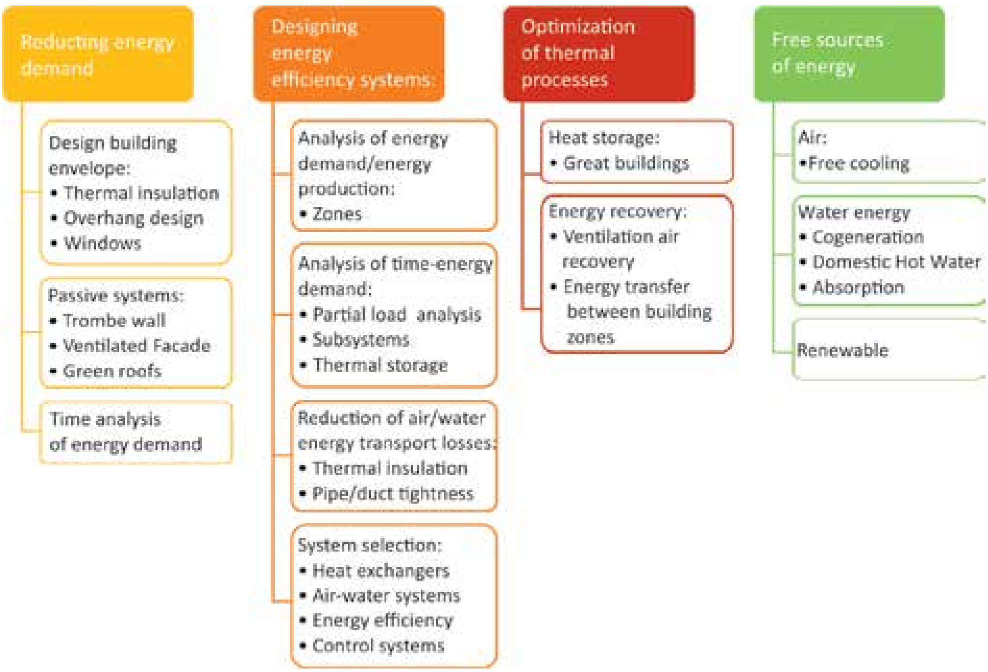

Fig. 5.13. Examples of actions to improve the energy efficiency in buildings (Source: own elaboration)

5.4.3. A certificate for a house in Poland

The same house located in Bialystok, Poland was analysed. Due to Polish climatic conditions, all rooms in the house are heated. A two-pipe water system was chosen with panel radiators and PeX pipes located on the floor (Fig. 5.14).

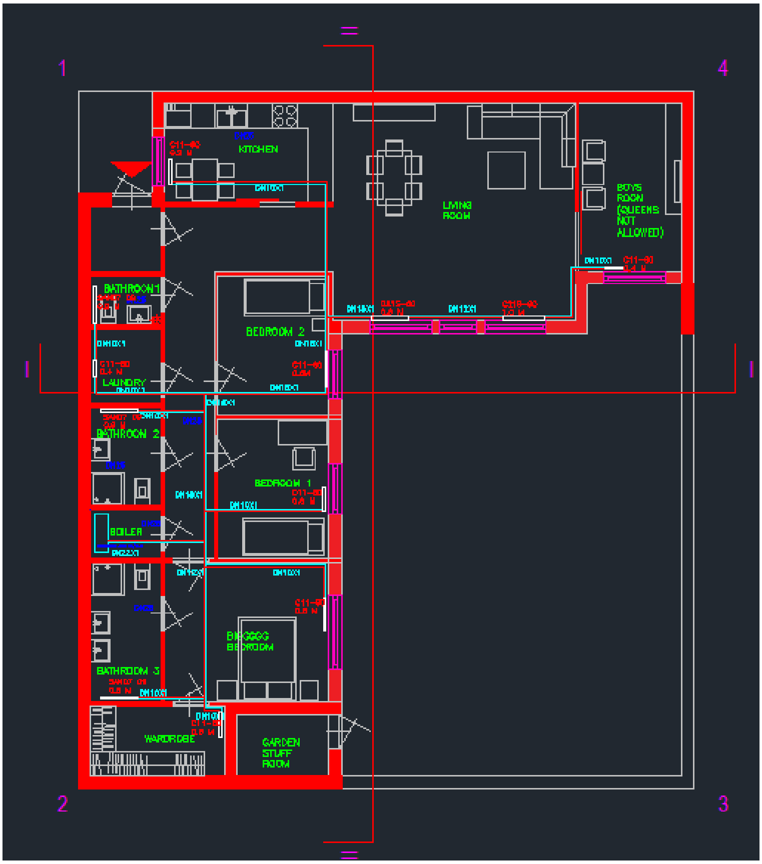

Fig. 5.14. The plan of the residential building with the heating system (Source: a teamwork of VIPSKILLS students)

All calculations including U values of walls, roof and floors, heat losses and energy consumption were conducted using Audytor OZC Sankom software that allows to prepare energy certificates according to Polish methodology. Data about the type of the building, its habitants, energy sources and the HVAC and DHW systems efficiency was introduced and final document was obtained which is presented in Fig. 5.15. The following assumptions for calculations were made:

- T-pipe heating system with PEX-Al-PEX pipes in floors and panel radiators,
- 4 habitants,
- a ground heat pump as an energy source for heating and hot water,
- air conditioning in the living room and the kitchen (multisplits).

Energy Efficiency Certificate No…				
Technical specifications of the building				
Intended use of the building				single family house
Number of storeys				1
Useable floor area				110.00 m^2
Useable floor area with adjustable temperature				110.00 m^2
Regular operating temperatures**		Winter	: 20.0	°C
Occupancy of the useable floor area		100.0		0.0%
Total volume				321.2 m^2
Compactness ratio of the building**				0.84
Number of users/ /inhabitants				4
Type of building structure		Traditional		
Building *envelope*		House has only 1 floor. All U values are lower than maximum values according to Polish law.		
Heating system		We choose tee pipe system. Our energy source is heat pump. We have 2 pipes system.		
Ventilation system		natural ventilation		
Air-conditioning system				
Domestic hot water preparation system				
Computational energy demand				
Annual final energy demand per unit**				
Energy carrier	Heating and ventilation	Hot water	Auxiliary devices	Total
Electrical energy – mixed energy *generation / production*	36.1	7.1	4.5	48.1
Division of energy demand				
Annual useable energy demand per unit**				
	Heating and ventilation	Hot water	Auxiliary devices	Total
Value**	120.0	17.8	4.5	143.7
Share [%]	83.5	12.4	3.1	100.0
Annual final energy demand per unit				
	Heating and ventilation	Hot water	Auxiliary devices	Total
Value**	36.1	7.1	4.5	48.1
Share [%]	75.1	14.7	9.3	100.0
Annual primary energy demand per unit**				
Value**	Heating and ventilation	Hot water	Auxiliary devices	Total
Share [%]	108.4	21.2	13.5	144.3
	75.1	14.7	9.3	100.0
Total annual demand for non-renewable primary energy per unit**				
1) including air-conditioning				144.3

Fig. 5.15. An example of Polish certificate of energy efficiency for a residential house (Source: own elaboration)

References

EN 15217:2007 *Energy performance of buildings. Methods for expressing energy performance and for energy certification of buildings* (and its national attachments to Lithuanian standard LST EN 15217:2007). Lithuanian Standards Board

EN 15603:2008 *Energy performance of buildings. Overall energy use and definition of energy rating* (and its national attachments to Lithuanian standard LST EN 15603:2008). Lithuanian Standards Board

EN ISO 13790:2008 *Energy performance of buildings. Calculation of energy use for space heating and cooling* (and its national attachments to Lithuanian standard LST EN ISO 13790:2008). Lithuanian Standards Board

EN 15316-1:2007 Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies – Part 1: Lithuanian Standards Board

EN ISO 6946:2007 Building components and building elements. Thermal resistance and thermal transmittance. Calculation method (and its national attachments to Lithuanian standard LST EN ISO 6946:2008). Lithuanian Standards Board

EN ISO13370:2007 Thermal performance of buildings. Heat transfer via the ground. Calculation methods (and its national attachments to Lithuanian standard LST EN ISO 13370:2008). Lithuanian Standards Board

REG-1, 2016 Lietuvos Respublikos statybos įstatymas Nr. I-1240, pakeistas 2016 Nr. XII-2573 (Republic of Lithuania Law on Construction No. I-1240 amended and supplemented 2016 No. XII-2573). LRS, TAR, 2016-07-13, Nr. 20300

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WEB-2 Lithuanian Standards Board. http://www.lsd.lt/

DOI: 10.24427/978-83-65596-71-0_6

6. INTELLIGENT BUILDINGS AND AUTOMATIC CONTROL

6.1. Introduction

Automation systems can be classified according to an array of criteria, which includes length, complexity, application and integration. The application of these systems to the field of habitability defines a specific use of equal or greater complexity to industrial automation. The integration of automation and control systems into buildings improves its operating characteristics, providing them with better services and operations easy to use.

Considering the scope of application, the automation of processes can be classified into three degrees of automation called:

The **monitoring** of the magnitudes of the system to determine the technical and economic aspects.

The **control mode** by the user completes the monitoring and provides information on actions to control the installations in accordance with pre-established criteria.

The **automatic control** has a structure of a closed loop. It includes the acquisition of information and its treatment to provide the actions on the process. The user is still required for the monitoring work. The classic elements of this system are sensors, control system and actuators (Huidobro & Miller, 2004).

Considering the scope of application, the automation of processes is called:

- Domotics (automation of houses),
- Immotics (automation of buildings),
- Urban domotics (automation of cities),
- Macromatics (greater scope automation).

DOMOTICS refers to housing control and automation applied to:

Energy Management: Optimization of services, real time consumption control adapted to energy prices, strategic disconnections, optimal air conditioning, blinds and awnings, among others.

Comfort: Inside and outside lighting, remote communications control, remote sound/music control, voice and special sound recognition, remote door/window operation, remote lighting operation, air conditioning remote control, heating storage, real time scenarios, cleaning and maintenance.

Gardening: Valve control, watering control, water consumption optimization, remote fertilization, environmental monitoring.

Security: Medical alarm, theft alarm, gas alarm, water alarm, CO_2 alarm, fire alarm, smoke alarm, fire service and police communication, presence control and simulation, access control, access restrictions, CCTV surveillance, safety deposit boxes, anti-sabotage systems, security maintenance.

Communication: Internet, preventive maintenance, fax, email, databases, video-conference, events communications, TV, remote communication, print services, telemarketing, advertising time slots, GSM, GPRS, radio.

IMMOTICS refers to the automation processes applied to other buildings, such as schools, universities, museums, hotels or offices.

URBAN DOMOTICS applies to traffic control, temperature, urban transport, suburban transport, emergency resources, pollution, control of utilities (electricity, water, gas, steam). Its application to the generation, transport and consumption of electric energy is a developing area called SMARTGRIDs.

MACROMATICS: by GPRS and satellites (weather, ozone layer, natural disasters, ecological disasters, navigation aid, air control, border control).

6.2 Connectivity and protocols

6.2.1. Automation architecture

Automation structures oriented towards the control of buildings are composed of different layers of integration with physical components (hardware) and logical and programming systems (software), which interact according to different design architectures. The operation of the systems depends on the load on either its physical or its logical structure, allowing the designer to develop levels of automation under digital, combinational or sequential systems.

Digital systems: Physical systems modeled by logical relationships among the output variables (actions) and input variables (data), in a series of predetermined discrete states.

Combinatorial system: A logical system in which the output variables are only functions of the input variables.

Sequential system: The output variables depend on the input variables and also on the order in which they change. Sequential systems are similar to systems with memory.

The systems described above can be implemented under wired or programmed technology based on factors such as scope, complexity, cost, construction integration, expansion flexibility, etc.

Wired technology: The automation is done through modules (electromagnetic relays, pneumatic logical modules or electronic cards) connected by wires or cables. The desired operation of the automation is achieved as a result of the choice of these modules and inter-connection by wiring. All partial logical operations are executed any time giving the results, at the same time, depending on the entries.

Programmed technology: The automation is carried out through the programming of devices (electronic cards, microprocessors, computers and PLCs). The desired operation is achieved by both electronic devices (hardware) and by the logical schema translated into a list of instructions stored in the memory of the program (software). The program written in the memory replaces the choice of elementary functions and the wiring, which would require the automatic version, called "wired technology".

Depending on where the intelligence of the domotic system resides, there are several different architectures:

Centralized architecture: a centralized controller receives information from multiple sensors and, once the information is processed, it generates the appropriate commands for the actuators.

Distributed architecture: the intelligence of the system is distributed through all the modules (sensors or actuators). It is typical of the systems of wiring, either in bus or wireless networks.

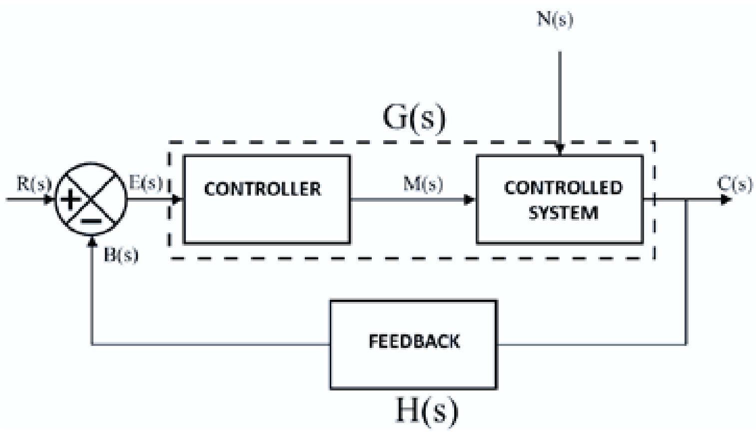
Mixed architecture: the decentralized architecture of computers with several small devices is able to acquire and process the information from multiple sensors and transmit them to the rest of devices distributed throughout the house.

The main needs that appear in the building control could be summarized in 5 functions:

- search/scan,

- alarm,
- register,
- display of states,
- automatic regulation (control).

For any of the previous architectures, the control scheme has reference and feedback signals, affected by the corresponding perturbations according to the control diagram shown in Fig. 6.1.



R(s):	Reference input	M(s):	Operated variable
C(s):	Controlled Variable	N(s):	Perturbations
B(s):	Main feedback	G(s) = C(s)/E(s)	
E(s):	Error signal	H(s) = B(s)/C(s)	

Fig. 6.1. Control standard structure (Source: own elaboration)

6.2.2. I/O devices

The devices responsible for detecting the parameter to be controlled, as well as the ones dedicated to interacting with the system (input/output devices), operate through elements accountable for converting and conditioning physical signals into electrical ones and vice versa, as shown in Fig. 6.2. The elements of the sensor/actuator chain are described below.

Transductor: It is a device that receives the information input as a physical magnitude and then converts this information into another physical magnitude.

Sensor: It is an electric signal transductor. It converts a physical magnitude signal into an electrical signal.

Transmission: It is a "conditioner" that transforms the signal from the transducer into a standard signal.

Analog: 4-20 mA DC # 10-50 mA # 0-20 mA # 1-5 V

Digital: 24v DC # 48v DC # 220v AC.

Signal converter: It is a device that changes the normalized signal into another standard sign with the same physical nature as the input.

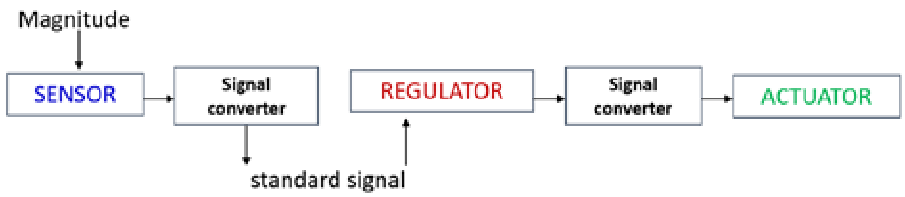


Fig. 6.2. Standard signal transformation (Source: own elaboration)

Classifications of input and output devices in automation systems are presented in tables 6.1-6.2.

Table 6.1. Classification of input devices in automation systems (Source: own elaboration)

INPUT DEVICES		
Position	Mechanical devices	limit switch (lever, rod, piston); network switch
	Electronic devices	optical, inductive and capacitive proximity detectors
	Angular position	incremental and absolute encoders
Force/strength/pressure	Sensor	force/strength to deformity
	Transductor	strain gauges, piezoelectric, inductive, tactile sensors
	Transmitter	variable resistor, Wheatstone bridge
Temperature	Sensor	thermocouple, resistance thermometer, thermistor, optic fiber, pyrometer
	Transductor	variable resistor, Wheatstone bridge
Level	Sensor	float, rotate vanes, pressure, conductivity, capacity, ultrasounds, optical, radar

Table 6.2. Classification of output devices in automation systems (Source: own elaboration)

OUTPUT DEVICES		
Actuators	They are usually power receptors that convert the electrical input signal into a mechanical action	motors: electric (rotation or linear), pneumatic, hydraulic
		cylinders: electric, pneumatic, hydraulic
		servo valves
Pre-actuator	It is a part of the controlled system, as well as of the control equipment because it receives the order from the control device and then it executes such order on the corresponding actuator	contactors
		electro valves

6.2.3. Home networking technologies and protocols

The automation and control systems must connect devices that work with diverse levels of electrical signals, different speeds of process, and physical or wireless media. Such adaptation of communications and interaction with external media is produced through different protocols, which establish the standardized procedure to assign priorities, define functionality and optimize the automation. These protocols also establish rules for the operation of control networks, data networks, and interconnection of devices. Below are shown the main protocols used in automation systems in the field of Domotics, as well as a description of its main characteristics.

Interconnection of devices: IEEE 1394 (FireWire), Bluetooth, USB, IrDA

Control and automation networks: KNX, LonWorks, X10, ZigBee, Z-Wave, Bus SCS, LCN

Data networks: Ethernet, HomePlug, HomePNA, Wi-Fi

Table 6.3. Main protocols for Domotics and their characteristics (Source: own elaboration)

PROTOCOL	POWER NET	RADIO FREQUENCY	OPEN SOURCE
C-BUS	NO	YES	NO
IN-BUS	NO	YES	NO
INSTEON	YES	YES	YES
KNX	YES	YES	NO
UPB	YES	NO	NO
X10	YES	YES	NO
Z-WAVE	NO	NO	YES
ZIGBEE	NO	YES	NO

InBus: It is a protocol of communication among different electronic modules, not only for home automation functions.

X10: It is a communication protocol for remote control of electrical devices through the use of electrical outlets without new wiring. It is the most common protocol developed in open source software. This protocol is unreliable with electrical noise.

KNX/EIB: Bus from European installation with more than 20 years and more than 100 manufacturers of products that are compatible with one another. It uses its own wiring and gateways to be applied in wireless systems or even to package the information over the internet or other TCP/IP network.

ZigBee: It is a standard protocol, with reference to protocol IEEE 802.15.4 of wireless communications.

OSGi: It stands for Open Services Gateway Initiative. Open specifications for software that enables designing supporting platforms which can provide multiple services.

LonWorks Protocol: It is an open standard ISO 14908-3 for the distributed control of buildings, housing, industry and transport.

Universal Plug and Play (UPnP): It is an open architecture and software that allows the exchange of information and data with the devices connected to a network.

Modbus: It is an open protocol which allows communication through RS-485 (Modbus RTU) or via Ethernet (Modbus TCP). It is an open source protocol that has been in the market for the longest time and whose devices are manufactured by a large number of companies. Manufacturers are continuously using this protocol device.

BUSing: It is a distributed automation technology, where each of the connected devices has its own autonomy. It is 'useful' by itself.

INSTEON: It is a protocol of communication by double band through current carrier and radio frequency.

6.3. Smartgrids

From a global context, the intelligent electrical network (SMARTGRID) can be defined as the dynamic integration of the developments in electrical engineering, energy storage and the advances in information and communication technologies in the field of electricity and distributed energy resources (generation, transmission, distribution, storage and marketing, including alternative energies). The SMARTGRID allows for the coordination of areas of protection, control, instrumentation, measurement, quality and administration of energy, etc., by a single management system with the primary objective of performing an efficient and rational use of energy in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply (Source: WEB-1).

Fig. 6.3. Real time SMARTGRID control and monitoring (Source: NASA archive)

According to the previous concept, other actors could also be integrated into the field of the measurement and control, such as gas sources and water service. Thus, smart grids would be a part of intelligent cities (Fig. 6.3).

The efficiency of the intelligent electrical grid is based on the optimization of the production and distribution of electricity to achieve a better balance of supply and demand between producers and consumers. Using smart meters, this network enables consumers to choose best hourly rates, as well as discern between the hours of consumption, which would allow for a better use of the network. This system also allows the user to map and anticipate the energy consumption with more precision.

The irruption of the renewable energies in the energy landscape has changed dramatically the energy flows in the electricity grid. Nowadays users not only consume, but also produce electricity through the same network. So, the flow of energy is now bidirectional. A smart network sends electricity from vendors to consumers using bidirectional digital technology to control consumer needs.

A common element of these networks is the application of digital processing and communication to the electrical network for the management of the essential information from the intelligent network.

Some main characteristics of the Smartgrids are:

Flexibility
- adaptable to the changing needs of the system,
- bidirectional.

Safety
- intensive in the use of infrastructures,
- able to operate in a protected way with simplicity and security,
- providing the necessary information in real time.

Efficiency
- allowing the grid to satisfy the energy needs by minimizing the needs for new infrastructures.

Open development
- allowing safe integration of renewable energies,
- facilitating the development of the electric markets,
- creating new business opportunities.

Sustainability
- respectful of the environment,
- socially accepted.

6.4. The Internet of Things

The Internet of Things (IoT) refers to the digital interconnection of everyday objects with the Internet. It was initiated through research in the field of Radiofrequency Identification in Network (RFID) and sensor technologies.

The Internet of Things should codify about 100 billion objects and follow their movement (it is estimated that every human being is surrounded by at least 1000 objects). With the latest generation of Internet applications (IPV6 protocol), this system can instantly identify any type of object.

The connection of the device to the network through low-power radio signals is the most active field of study on the Internet of Things. The main reason for this fact is that the signals of this type need neither Wi-Fi nor Bluetooth. However, different alternatives that need less energy and that are more economical are being investigated under the name of "CHIRP Networks".

Currently, the term Internet of Things is used for the advanced connection of devices, systems and services that go beyond the traditional M2M (machine-to-machine) and cover a wide variety of protocols, domains and applications. Applications for the

Internet-connected devices can be divided into three main branches: consumption, business, and infrastructure.

The ability to connect embedded devices with limited CPU, memory, and power capabilities enables the IoT to have applications in almost any area. These systems can be responsible for collecting information in different environments, from natural ecosystems to buildings and factories, so they can be used for environmental monitoring and urban planning.

There are other applications of the IoT: in the automatic heating, water supply, electricity, the management of energy, and even in intelligent transport systems. Other examples of consumer applications include entertainment, home automation and household appliances (washing machines, dryers, robotic vacuum cleaners, air purifiers, ovens, refrigerators) that use Wi-Fi for remote control (Nordrum, 2016).

The monitoring and control of operations of urban and rural infrastructure such as bridges, railways and wind farms is a key application for the IoT. It can be used for the surveillance of any event or change in the structural conditions that may compromise safety. This solution can improve the handling of incidents, the coordination of the response to emergency situations, the quality and availability of services, and additionally, it can reduce the cost of operation in all areas related to infrastructure.

6.5. Friendly environment in automation

The previous systems need an interface that allows easy and intuitive communication with a user who is not familiar with programming languages or electronic systems. To this end, the SCADA system (Supervisory Control and Data Acquisition) has been designed. It is a series of software applications specially designed to be used in computers that control and supervise the processes. Main characteristics of the SCADA system are, on the one hand, quick and easy access to the house/building control system and, on the other, the representation of variables.

It is necessary to emphasize its comfortable and friendly environment, which is achieved through its graphical interface where the process of control and supervision is represented. This interface can be displayed on different devices, as required in each case (monitors, touchscreens, etc.).

SCADA systems allow for communication with different devices (e.g. regulators or PLCs) to control any process from the display device (the computer monitor). In addition, control can be modified by the user through SCADA in a simple way. The use of this device can also modify the control variables in real time in a very intuitive way, because the interface generated with the SCADA is graphic, which makes it simple to understand. Therefore, the SCADA not only shows the different problems generated in the system, but it also gives guidance on the procedures to solve them.

Fig. 6.4. Friendly environment graphical scale examples (Source: own elaboration)

Usually, the term SCADA can be confused with HMI (human-machine interface). All SCADA systems have a GUI user-PC, but not all control systems with HMI belong to the SCADA type. The difference between these two types of devices is the monitoring function that SCADA can perform through its interface. The main supervisory functions are:

- acquisition and storage of data,
- graphic representation of variables,
- performing action control,
- open and flexible architecture with adaptation,
- connectivity with other applications,
- supervision of variables through a monitor,
- transmission of information with field devices,
- databases: management of data in low access times,
- presentation, graphical representation of the data via interface,
- exploitation of data acquired by quality management,
- alert to the user for detected changes.

6.6. Security

The automation and control systems, including the domestic sphere, in addition to providing functionality, must be secure and robust. To achieve this, common risks that may affect the system must be known, so that they can be evaluated.

Therefore, the following items must be ensured:

- protection of electricity supply,
- protection against viruses or malware,
- protection against unauthorized access.

PROTECTION OF ELECTRICITY SUPPLY

The stable electrical current must be maintained, as well as the correct distribution of the electrical fluid and the balance between phases. Continuity of supply can be guaranteed by:

- the UPS in direct mode (from the power net to the UPS, and from the UPS to the installation),
- the UPS in reserve mode (it works only in case of fault of the power net).

Table 6.4. shows electricity supply faults and their effects on installations, whereas Fig. 6.5-6.6 present the UPS operation for electricity protection (conversion AC/DC/Ac or direct supply).

Table 6.4. Electricity supply faults and their effects on installations (Source: own elaboration)

Characteristics UNE-EN 50160	Automation and control effects	
	Severity	Probability
Frequency	MEDIUM	VERY LOW
Voltage variation	MEDIUM	MEDIUM
Quick variations	LOW	LOW
Voltage hollow	MEDIUM	VERY HIGH
Short breaks	HIGH	HIGH
Long breaks	VERY HIGH	MEDIUM
Overvoltage	MEDIUM	MEDIUM
Imbalance in voltage	LOW	VERY LOW
Harmonics	MEDIUM	VERY LOW

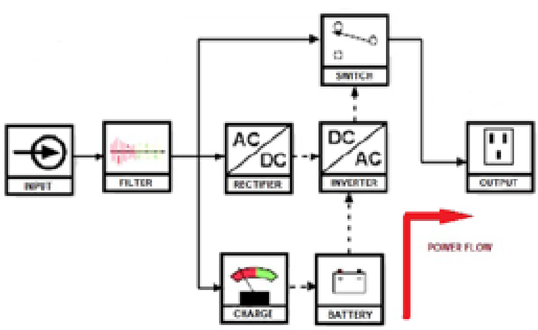


Fig. 6.5. UPS operation for electricity protection by AC/DC/AC conversion (Source: own elaboration)

The most frequent input electrical signal defects are:

Transients or peaks: by network discharges, such as lightning or start/stop of high power machines. They cause damage to electronic devices and a loss of computer data.

Solution: the use of suppressor filter or a direct UPS.

Voltage short variations: by motor connections and stops, and other inductive loads. They cause resets in computers and electronic equipment.

Solution: the use of a line conditioner or a direct UPS.

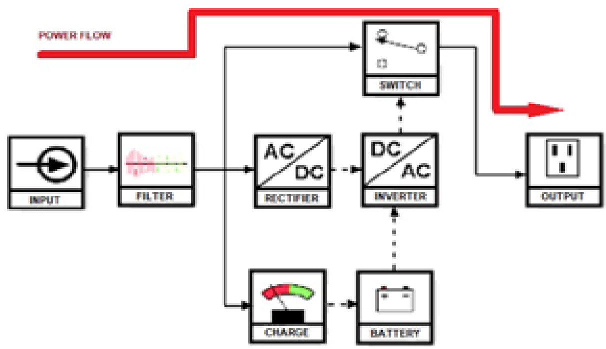


Fig. 6.6. UPS operation by direct supply (Source: own elaboration)

Overvoltages: for management of the electricity distribution network. They cause serious damages in electric and electronic devices.

Solution: the use of a line conditioner or a direct UPS.

Cuts and micro-breaks: failures in the distribution network, lightning and human factors. They cause damage to computers and electronic equipment.

Solution: the use of a direct UPS (on-line).

VIRUS PROTECTION

Industrial and domestic automation and control systems are exposed to the destructive action of external software such as viruses or worms, which can cause improper (even dangerous) operation of the system. An antivirus must be installed, which will slow down the system, but at the same time will improve its security.

In the field of Smartgrids, millions of new devices connected to these networks could become a potential target for hackers. In a sense, a dumb meter is a less hackable device, and therefore a safer one.

To solve the problem of a high number of new meters necessary for the Smart Grid, each of which will take an IP address, the IPV6 allows the new systems to accommodate in a relatively straightforward and secure way.

Smart switches will also be needed for the Smart Grid, which will have to be sturdier than the standard ones used in homes or offices, to operate in hostile environments.

UNAUTHORIZED ACCESS

The operating systems used in computerized automation equipment take measures to prevent or thwart undue connections to the network resources. To monitor and register the strength of systems against undue access, periodic audits should be done on the use of resources.

70% of the IoT devices have security vulnerabilities in their passwords. Thus, there is a problem with data encryption or access permissions and 50% of mobile device applications do not encrypt the communications. These security failures may allow for an interception of the video signal from a CCTV camera, or for revealing the password to the Wi-Fi network where a connected coffee machine transmits information without encryption. Data encryption before uploading the data to the cloud can help reduce this vulnerability.

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7. MODERN SOLUTIONS IN HEATING SYSTEMS

7.1. Heating systems

A heating system is a complex system which is used to generate and transfer heat to all heating devices within a building.

The heating system components (Fig. 7.1) (Lapinskienė & Laukys, 2011; Bilinskienė et al., 2012) are:
- boiler room of the building,
- heating devices (to transfer heat to the room areas),
- pipelines (the pipes which transfer heat from the boiler room to heating devices),
- other equipment.

Heating systems should be designed in accordance with the requirements of the technological process intended for the building (STR1, 2005). The desired level of comfort and specific requirements of customers must be assessed. All components of the heating system (heating devices, piping materials, control and regulating equipment) must be chosen according to the requirements of fire safety and hygiene standards (STR1, 2005).

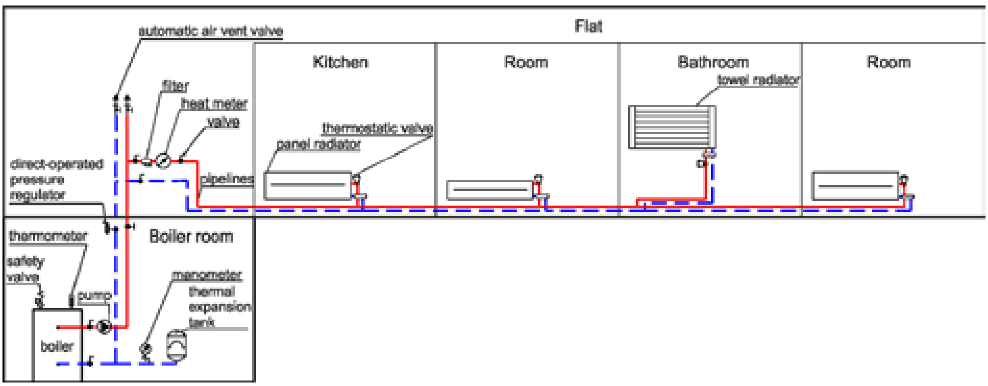
The heating system needs to be designed so that the boiler room of a building provides technical means to ensure heat transfer to all devices (STR1, 2005; Bilinskienė & Graudinytė, 2012). The heating systems of apartment buildings are designed in such a way that it is possible to estimate the heat consumption in each apartment, without entering them. The systems must be tested and approved for use in accordance with (STR1, 2005) Technical Construction Regulation requirements.

When designing the most energy efficient building engineering systems (STR2, 2016; STR3, 2017), priority should be given to the systems which report the lowest non-renewable primary energy factor and the highest value of the renewable primary energy factor, as well as the maximum efficiency of the installations in these systems (STR2, 2016).

Energy performance design requirements for a building heating system (STR2, 2016) are as follows:
- in heating system design decisions, the priority should be given to heat sources with the highest efficiency;

- in heating system design solutions, the priority must be given to control devices to comply with the regulation of heating in the whole building with thermostatic valves and indoor or outdoor thermostats;
- the projected annual thermal energy consumption for heating in the building energy performance class in Lithuania should comply with (STR2, 2016) Technical Construction Regulation requirements.

A



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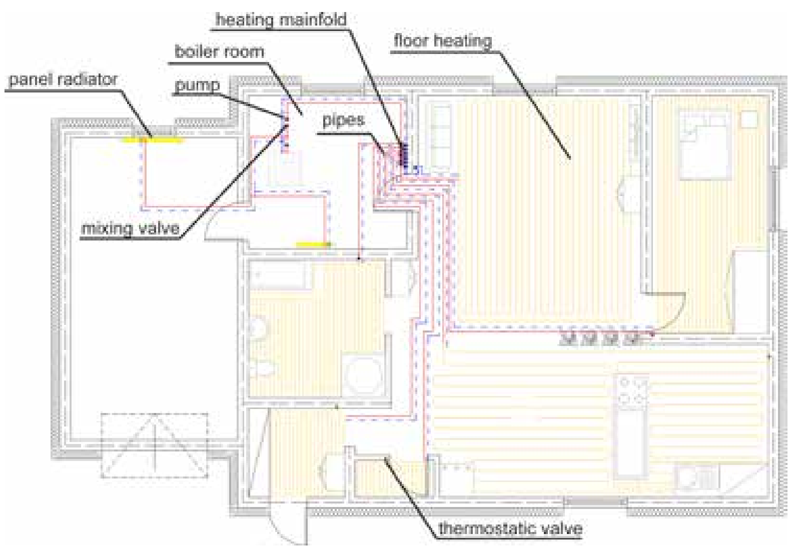


Fig. 7.1. Main components of a heating system. A) Schema, B) Example of heating system in a house (Source: own elaboration)

Classification of heating systems:

- Water heating systems. The heat in these systems is carried by water or, when there is a danger of frost, by ethylenglycol. The heat in these systems is carried by

water or, when there is a danger of frost, by ethylenglycol. These system are the most popular in Lithuania.
- Steam heating systems. They were used in industrial objects with steam boiler-rooms.
- Electric heating systems. These systems are used for heating of separate properties or small buildings, or for the buildings that are far away from another heat source. These systems disadvantage is a high cost of maintenance.
- Gas heating systems. They are used for heating of industrial or non-residential buildings where heating can be turned on periodically.

The infrared-heating system can be used for heating of non-residential and public buildings as well as for spaces with heavy thermal losses, for example: covered terraces, exhibition halls, airports, etc.

- Air-heating systems are being used more and more often since the heating and cooling spaces, places where required fresh air flow rate.

Water-heating systems have the advantage that the thermal energy is transported more efficiently by water than by air, which means that water has a lower energy requirement to provide the same heating capacity.

In panel surface heating systems, with heating elements installed in building structures (floor, ceiling), the surface temperature requirements are as follows (STR1, 2005; Juodis, 2009):
1) for the bathroom floor, as well as heated swimming pool tracks and benches – 33˚C;
2) for rooms, where people are temporarily on the floor – 35˚C;
3) for rooms, where people are constantly on the floor – 29˚C;
4) for the ceiling, in case the height of the building is 4-6 m, – 38˚C;
5) for the ceiling, in case the height of the building is 3.5-4 m, – 36˚C;
6) for the ceiling, in case the height of the building is 3-3.5 m, – 33˚C;
7) for the ceiling, in case the height of the building is 2.8-3 m, – 30˚C;
8) for the ceiling, in case the height of the building is 2.5-2.8 m, – 28˚C.

The surface temperature of the special-purpose buildings, like kindergarten and hospital wards, in the underfloor heating, must not exceed 35˚C (STR1, 2005).

The radiating heating devices with a surface temperature of more than 150˚C must be installed above the working area so that the radiation intensity in the work area does not exceed the permitted value (STR1, 2005).

Heating systems classification (Šarupičius, 2012; Lapinskienė & Laukys, 2011). Depending on heat generation mode, heating systems can be divided into:
1) the renewable energy sources (geothermal or solar energy),
2) the central heating systems (the heat is supplied from the city heating networks),

3) the electrical sources for heating system,
4) the gas, solid or liquid fuel systems.

Heating systems can also be classified depending on the type of users (STR1, 2005; Lapinskienė & Laukys, 2011):
1) local (direct) heating systems – when all the main elements of the system (boiler, pipes, heating device) are for a single user;
2) central (indirect) heating systems – when this equipment is separated, the heat is generated in a boiler and then is distributed to several users.

Heating system schemes classification depends on the mode of the heating flow through a heating device (STR1, 2005; Pieńkowski et al., 1999):
1) double-pipe heating systems,
2) single-pipe heating systems.

We may also classify the heating systems depending on the position of stands, vertical or horizontal system schemes (Šarupičius, 2012; Bilinskienė et al., 2012; Siemiończyk & Krawczyk, 2013).

In the case of horizontal distribution of heating installations, the following systems are most popular:
1) pipes distributed in a single-pipe loop,
2) pipes distributed in a two-pipe loop on the floor's perimeter,
3) heating system pipe tees set,
4) distribution system in which radiators are connected individually to the central heating manifold.

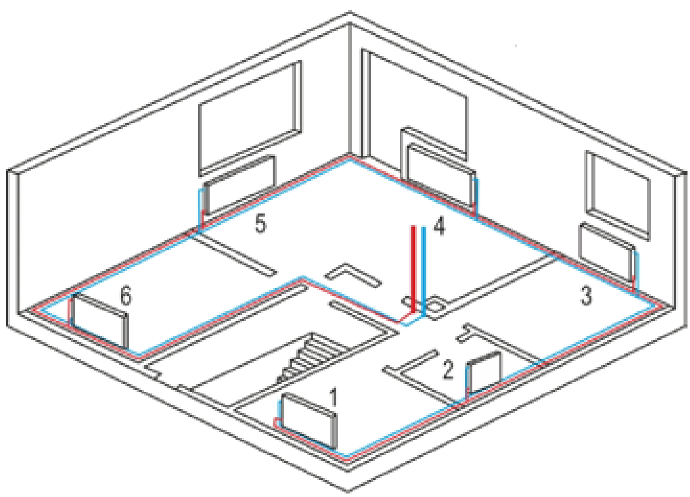


Fig. 7.2. Pipes distributed in a two-pipe loop (Source: D.A. Krawczyk's private archive)

Fig. 7.2 shows a system with pipes distributed in a double loop around the floor, while Fig. 7.3 presents a system with radiant heat manifolds. In Fig. 7.4 radiant heat manifolds can be seen. Figures 7.4A-B show the connection of the central heating installation in a two-pipe loop and the connection to the central heating manifold respectively.

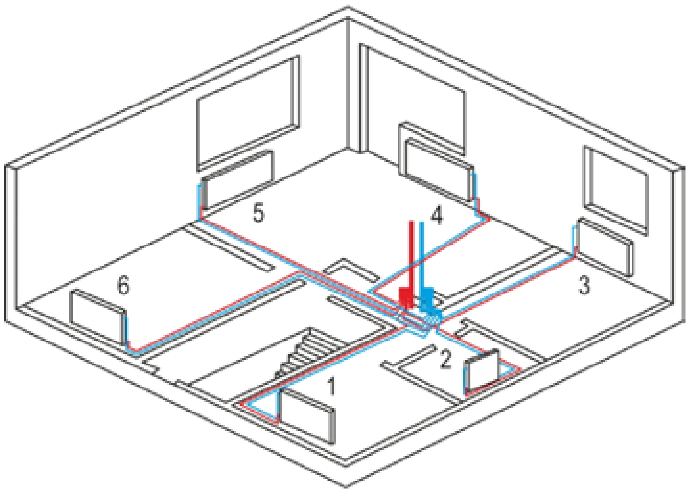


Fig. 7.3. Heating system with radiant heat manifolds (Source: D.A. Krawczyk's private archive)

A

B

Fig. 7.4. The connection of the central heating installation: A) pipes distributed in a two-pipe loop B) the radiant heat manifolds (Source: T.J. Teleszewski's private archive)

7.2. Heating devices

The heating device type, its performance, external appearance, temperature of the heating surface must comply with the requirements of hygiene norms, fire safety rules and the purpose of the room (STR1, 2005). The amount of heat from the heating device placed in the room must be sufficient to maintain the designed temperature of the room (STR1, 2005). The power of the heating device must compensate for the heat loss from the room. For each heating device or a group of devices, the heat transfer must be regulated by the variable heat output in the heated room or by the needs of the room users.

Fig. 7.5. Examples of heating devices. Radiators: A) panel radiator, B) column cast iron radiator C-D) different surfaces of panel radiators (Source: A) Bilinskienė at al., 2012, B) Bilinskienė, 2017, C) photo by D.A. Krawczyk, D) photo by E. Szatyłowicz)

Heating devices must be available for cleaning, maintenance and repair. Heating appliances should have the heating surface easily accessible for cleaning (STR1, 2005; Bilinskienė & Graudinytė, 2012).

There are a lot of forms and colors of heating devices (Andruszkiewicz & Krawczyk, 2015). Radiators are most often manufactured as sectional (mostly from metal elements that can be assembled to the desired size) and panel (two welded and stamped steel panels). Examples of heating devices are given in Fig. 7.5.

Due to their construction, we can divide radiators into:
1) panel radiators (Fig. 7.5A),
2) column radiators (Fig. 7.5A, 7.7A-B),
3) towel radiators (Fig. 7.8A-D),
4) finned tube radiators (Fig. 7.9A-B).

Plate radiators, depending on the model, heat the room by emitting heat with the whole surface (radiation) or – when they have the ribbing – by radiation combined with convection. They can have one, two or three plates connected to one another (with or without ribs). The number of panels affects the thickness of the device and its performance – in this case, more does not mean better. In single panel radiators, a single plate optimally transfers heat to the room through radiation. In addition, these radiators can be equipped with convection fins. Double panel radiators are used in rooms with large surfaces, where there is not enough space on the wall to fit a very wide single panel radiator. Their efficiency in relation to single boards is lower, because the heat radiating through the second panel does not go entirely into the room and is partially reflected by the first one. Therefore, they are designed in such a way that the power of the internal board is about 30% smaller than the external one. Triple panel radiators are used mainly where technical conditions (limited length of the wall in relation to the surface of the heated room) do not allow the installation of a longer double panel radiator. Fig. 7.6 shows the view of a single panel radiator (Fig. 7.6A), a double plate radiator (Fig. 7.6B) and a triple panel radiator (Fig. 7.6C).

In order to determine the type of heater, numerical digits are used:
- type 10 – single panel, without ribs,
- type 11 – single panel with convection fins,
- type 20 – double panel without ribbing,
- type 2l – double panel with single convection fins,
- type 22 – double panel with double fins,
- type 30 – triple panel without ribbing,
- type 33 – triple panel with triple convectional fins.

A B C

Fig. 7.6. View of the ribs in different types of flat heaters: A) 11, B) 22, C) 33 – radiator with the top cover removed (Source: T.J. Teleszewski's private archive)

The advantage of a radiator is the possibility of determining precisely its power – by attaching the appropriate number of ribs. We can make minor corrections to their number even after the entire installation. Column heaters are most often produced as cast iron radiators, aluminium radiators and steel radiators.

A cast iron radiator is most often characterized by large water capacity, and hence large thermal inertia. This type of heater heats up slowly, but also slowly releases heat. Cast iron radiators work well in gravity installations because they generate small hydraulic losses. The parameters of a cast iron radiator make it work well with solid fuel boilers. The advantage of cast iron radiators is their high resistance to corrosion, and thus high durability of the installation. Another asset of the radiators is a large share of heat exchange by radiation, which increases the comfort of living in the room.

Aluminium radiators are made of aluminium alloys containing, among others, silicon and copper. They have many advantages over cast iron radiators. They are light and have lower water capacity – and hence lower thermal inertia. The aluminium radiator will heat up faster than the cast iron one and after turning off the power supply it will stay warm for a short time. The smoothness of the surface of the aluminium radiator makes cleaning easier. Aluminium radiators cannot be installed in installations made of copper due to the formation of electrochemical corrosion cells (Pieńkowski at al., 1999).

There is also a steel variant of segment heaters. They are made of steel pipes and profiled sheets. The individual elements are joined by welding. Other parts are also welded, and the heater is ordered to size, given the number of ribs.

Fig. 7.7A-B shows an example of a column cast iron radiator from the eighties of the twentieth century (Fig. 7.7A) and a contemporary column chromed steel radiator (Fig. 7.7B).

A B

Fig. 7.7. Examples of radiator heaters: A) column cast iron radiator from the 1980s, B) contemporary column chromed steel radiator (Source: A) photo by T.J. Teleszewski, B) photo by D.A. Krawczyk)

A B C

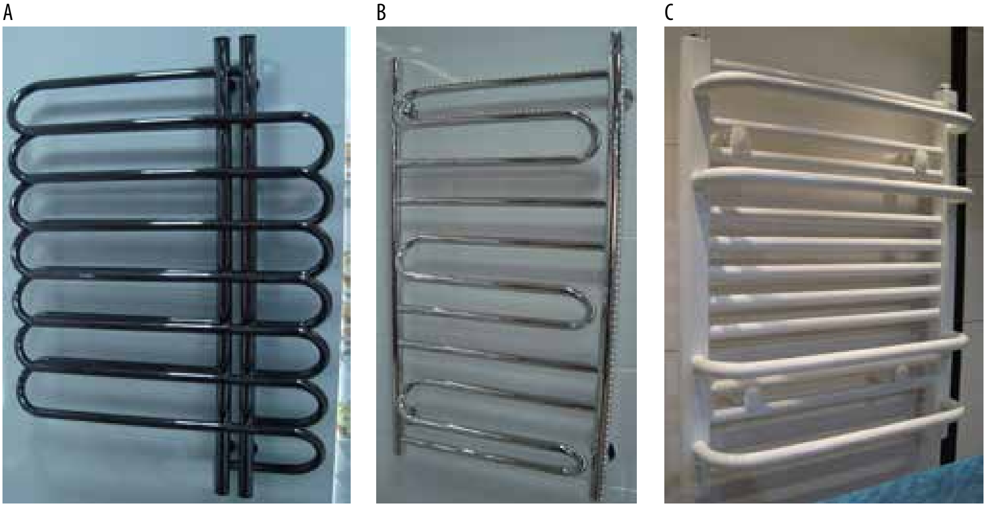
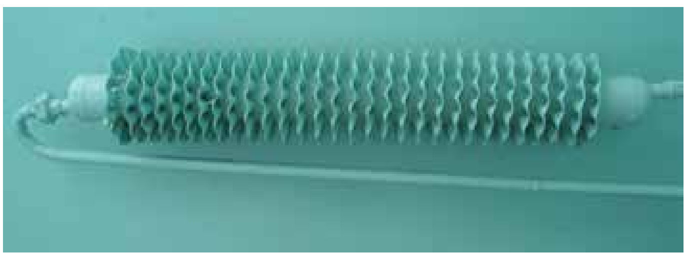


Fig. 7.8. Examples of shapes of towel radiators (Source: T.J. Teleszewski's private archive)

Towel radiators are usually made of two vertical pipes connected by horizontal tubes of smaller diameter and round, rectangular or oval cross-section. Ladder radiators are one of the most popular heating systems found in bathrooms. The special impregnation of the ladder radiator makes it resistant to moisture. In addition, it can also act as a hanger or towel dryer. Increasingly, bathroom radiators are available in various shapes and colours fulfilling at the same time decorative functions. Depending on the type of connection, bottom, side and central heaters are available. They are also characterized by different heating power and the possibility of connecting electric heaters to them. Figure 7.8 shows various shapes of ladder radiators.

A finned tube radiator (Fig. 7.9A) consists of a tube and a sheet metal ribbon attached to it; this ribbon is shaped in such a way that it forms a helical spring which is tightly placed on the pipe (adhering to the pipe not with its plane, but with the edge) acting as a heat sink (heat dissipater). Finned tube radiators are used mainly in industrial, storage and high temperature installations that use steam or water as a heating medium with working pressure of up to 1.6 MPa. Typically, ribbed pipe radiators are placed horizontally, about a meter above the floor. Sometimes, when there is a need to dissipate significant power (and when space conditions prevent the installation of a single long pipe), two or more finned tube radiators are installed one under another (Fig. 7.9B).

A



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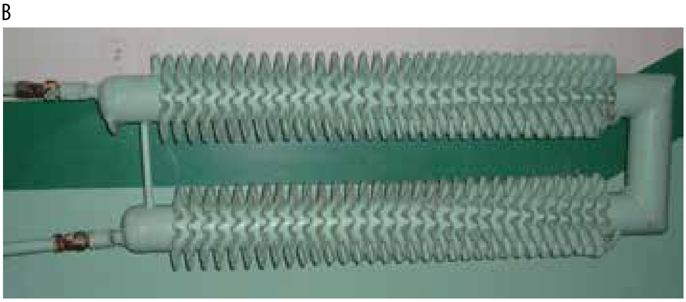


Fig. 7.9. An example of a configuration of finned tube heaters: A) a single-row single radiator, B) a single-row double radiator (Source: T.J. Teleszewski's private archive)

The thermal efficiency of installed radiators can be reduced as a result of all kinds of obstacles. The proper air circulation around the radiator, which determines the quality of heat transfer to the surrounding air, is limited even by curtains and lace curtains. If a valve with a thermostatic head is covered, then it will not react correctly to changes in temperature in the heated room. As a result, the hot water supply to the radiator will be cut off whenever the temperature behind the cover reaches the set value. In this way, only the space behind the cover will be well heated, and the room will remain unheated. All kinds of covers also limit the radiator's efficiency by up to several percent. Fig. 7.10 shows exemplary radiator covers that contribute to reducing the thermal efficiency of radiators. Opened radiators under normal conditions guarantee that heat can spread freely in rooms, and the radiator reaches the heating power planned by the installation designer. The rules for selecting radiators, including covers, can be found in PN-B-02401:1975.

Fig. 7.10. Examples of radiator covers (Source: T.J. Teleszewski's private archive)

Convectors are mostly installed in commercial office buildings (STR1, 2017) which have large glass facades. Convectors are made of finned tubes connected in parallel, which the heated air passes through (Lapinskienė & Laukys, 2011; Bilinskienė &

Graudinytė, 2012). Floor convection heaters are mounted into the floor, especially in places where it is not possible to install high radiators (Lapinskienė & Laukys, 2011; Bilinskienė & Graudinytė, 2012). If the floor convection heater is not enough, more powerful heat source is selected. For this purpose, floor convection heater with a fan is developed (Fig. 7.11). Convection heaters can be installed in rooms with high heat loss. The fan rotation speed can be easily adjusted depending on the heat demand for the premises.

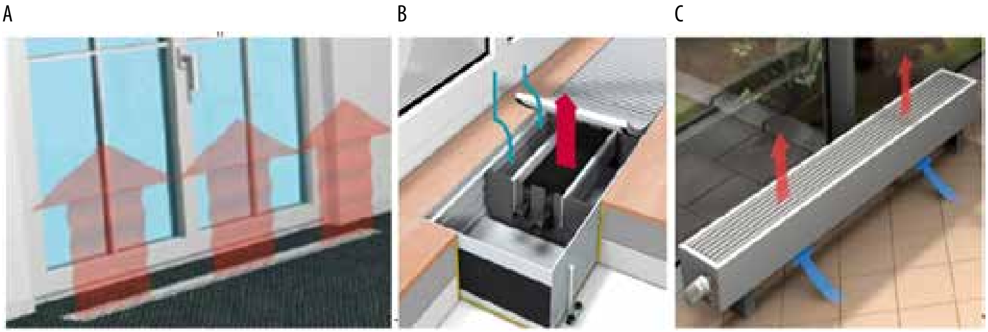


Fig. 7.11. Examples of heating devices. Convectors (Source: Bilinskienė at al., 2012; Bilinskienė, 2017; R. Bilinskienė's private archive)

Freestanding convection heaters (Fig. 7.11) are adapted in low spaces with large area windows. Heating registers are the most popular of all the convection heaters, so that their usability is significantly higher. They are suitable for individual use in the interiors, which is important for the compactness and the materials used (Lapinskienė & Laukys, 2011; Bilinskienė & Graudinytė, 2012).

Main steps in heating device selection can be listed (Lapinskienė & Laukys, 2011; Bilinskienė & Graudinytė, 2012; Pieńkowski et al., 1999):

- Selecting a device in a manufacturer's catalogue (considering aesthetical and hygiene requirements, shape, width, height); this device must be accompanied by heat emission tables.
- Determining heat emission of the selected type the radiator for proper water supply and return temperature (for example, 80/60°C, 70/55°C) and design indoor temperature (for instance 20°C).
- Finding enlargement coefficients to increase the nominal emission in case the device is hidden in the floor or covered with grills, because then the heat emission is smaller.

Heating devices are installed under the windows in a room. In special heating buildings, kindergartens and hospitals, the heating devices must be not less than 75% of the window length. When a heating device is located below the windows, the heat output must cover heat losses through partitions up to 4 m high from the floor (STR1, 2005; Bilinskienė & Graudinytė, 2012). Heating devices must be installed on the lowest floors of the staircase of a building (STR1, 2005; Bilinskienė & Graudinytė, 2012).

At present, there is a tendency to create custom-made heating devices by designers. These are usually tubular radiators in which the heating medium can circulate through square pipes (Šarupičius, 2012). Manufacturers of these devices, as well as in standard cases, present the tables where there are indications of the device heat power having concrete temperature values (Šarupičius, 2012).

7.3. Space heating systems

There are different forms of space heating – floor, ceiling, wall, water heating systems, infrared heating, air heating, etc. (Fig. 7.12).

A B C D E

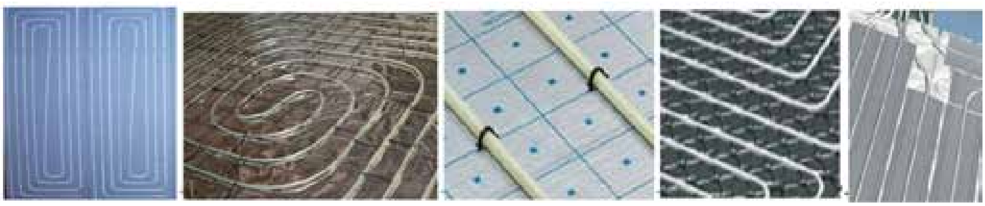


Fig. 7.12. Examples of space heating systems (Source: R. Bilinskienė's private archive)

The most popular of these systems are (Bilinskienė et al., 2012):
- the profiled panel,
- insulating plates,
- dry system plates.

The profiled panel system: it can be used in residential and public spaces; for high-loads and for the outer layer of ready-mix and cement mixture, the upper surface has a compacted structure of loops; the loops help capture the heating pipes tightly.

Insulating plates adapted for fastening with pins: the rolls of insulating coating adapted for fastening with pins are laid in parallel lanes all over the entire length of the room. To install the pipes easier, surface markings should be the same. Niches and corners of the room should be lined with coating residues. Dry system plates: the minimum plate height (25 or 30 mm) seems to work well particularly in old buildings or renovation projects.

The surface of a building structure with mounted plastic pipes is used for floor or ceiling heating. Flowing via pipes, the heat carrier warms up the building structure, which reflects heat into the premises. This is a highly-efficient, economical and hygienic heating method.

It must be noted that the temperature of the heat medium supplied to the floor heating system is two times lower than that of a radiator. The disadvantage of such installation is that this is an inertial heating system (Šarupičius, 2012a).

7.4. Heating system equipment

The following pipelines are used in the heating systems (Lapinskienė & Laukys, 2011; Bilinskienė & Graudinytė, 2012; Bilinskienė et al., 2012):

- the main supply/return pipeline – for supplying, return and distributing hot water from/into the heating source into/from the stands (Fig. 7.13);
- the main stand – designed to supply hot water to the main pipelines;
- supply/return stands – for supplying or collecting hot water to/from the heating devices (Fig. 7.13);
- transit pipelines, where the heat released from them is not used for heating the working (or service) area (STR1, 2005).

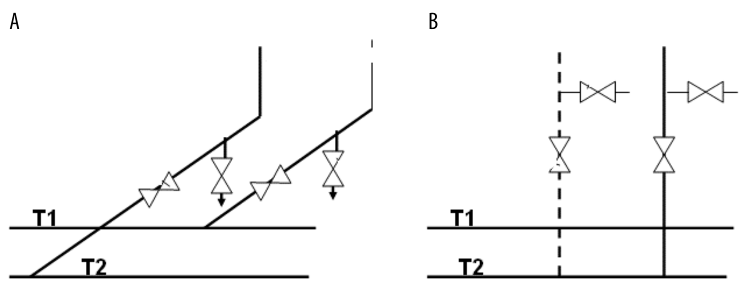


Fig. 7.13. Heating system pipelines plan and scheme (Source: R. Bilinskienė's private archive)

Materials for producing heating system pipes are: plastic, plastic composite, copper and steel (STR1, 2005; Bilinskienė et al., 2012). The pipes used in heating systems shall, under normal operating conditions, be resistant to the chemical and mechanical effects of temperature and pressure (STR1, 2005). Heating and heat supply pipes in a building can be installed open or hidden – in closed channels, niches, engineering communications tunnels or building constructions. When pipelines are installed hidden in building constructions, they must have no connections (STR1, 2005; Bilinskienė et al., 2012).

The pipes of the collector heating systems must be installed in the floor construction, but in such a way that they can be replaced without touching the floor.

The configuration, fittings and heating devices of the heat supply systems must be reliable in all possible operating conditions. The heat user needs to be capable of controlling the thermal energy of the devices by adjusting the system's hydraulic and thermal settings and by switching the appliances on or off.

Part of the heating system pipelines and stands must have closing, hydraulic balancing and regulating fittings (Fig. 7.14) as far as they are needed for the system to be started, controlled, and comfortably operated (STR1, 2005; Bilinskienė et al., 2012).

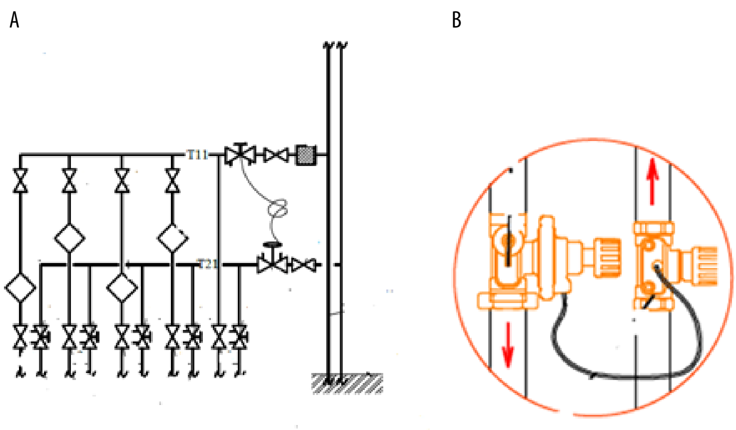


Fig. 7.14. Heating system pipelines plan and scheme (Source: R. Bilinskienė's private archive)

For regulating the temperature and pressure, direct-operated regulators are most commonly used. An example of a direct-operated pressure regulator is shown in Fig. 7.15. Fig. 7.16 shows an example of a direct-operated temperature regulator.

Fig. 7.15. An example of a direct-operated pressure regulator installed on a central heating system (Source: T.J.Teleszewski's private archive)

A thermostatic heating device valve (Fig. 7.16) together with a thermostat form the automatic regulation equipment. The thermostatic valve has 6 steps from * (freezing protection) to 5.

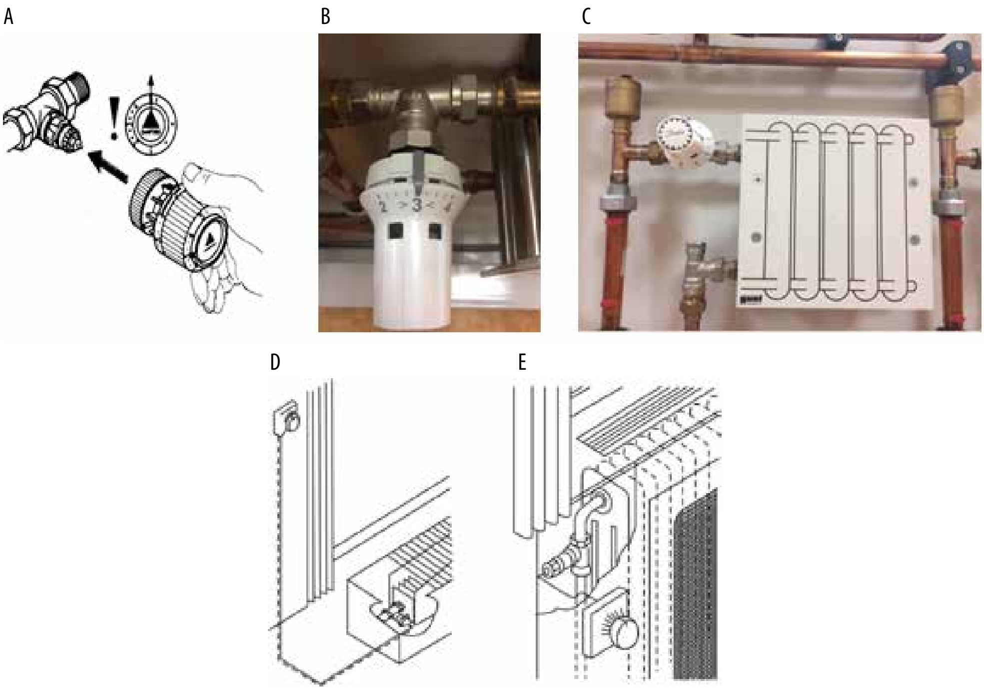


Fig. 7.16. A thermostatic valve (Source: A-C R. Bilinskienė's private archive, D-E D.A. Krawczyk's private archive)

The maximum velocity of water or steam in the heating system pipelines should be adjusted so that the noise in the pipelines does not exceed the permissible noise levels (STR1, 2005; Bilinskienė et al., 2012). The length of the steam heated system, when the condensate flows in front of the steam, must not be longer than 6 m (STR1, 2005; Bilinskienė et al., 2012).

Heating and heat supply pipes in buildings must be inclined as follows (STR1, 2005; Bilinskienė et al., 2012):

- water, steam and condensate pipes – not less than 0.2%;
- steam pipes, when moving the vapour – not less than 0.6%;
- it is permissible to lay pipes without sloping, when the water flows with the velocity of not less than 0.25 m/s.

Heating and heat supply pipelines must be accompanied by the equipment for the air discharge and for emptying the pipelines, as well as by the equipment for compensating the thermal expansion (STR1, 2005; Bilinskienė et al., 2012).

The heat insulation of the heating and heat supply pipelines must be installed in accordance with the requirements for thermal insulation installation (STR1, 2005; Bilinskienė et al., 2012).

Thermal insulation is an insulation for heating pipes with a temperature higher than the environment, used to reduce heat loss. The shells of stone wool of different thickness or mats with aluminium foil are commonly used for thermal insulation (Bilinskienė et al., 2012; Šarupičius, 2012a).

Thermal insulation should have the following features:

- low heat transfer coefficient λ (W/(m·K);
- resistance to the maximum operating temperature of the installation and temperature differences;
- resistance to the working medium in the installation;
- resistance to the environment, including the action of microorganisms and rodents;
- resistance to static and dynamic loads during installation of insulation as well as subsequent installation work;
- non-flammability or very low flammability;
- chemical inertness towards the insulated material.

Standard insulation usually consists of two layers: a thermal insulation layer, which must have a low heat transfer coefficient and a protective coat that protects the insulation from mechanical damage and the impact of the environment.

The following materials are most commonly used in thermal insulation:

1) Foamed polyethylene (Fig. 7.17A-B) has the following characteristics: coefficient of thermal conductivity t=+40°C from 0.035 to 0.045 W/(m·K), operating temperature from -45°C to +105°C, high flexibility.
2) Foamed polyurethane (Fig. 7.17C-D) has the following characteristics: coefficient of thermal conductivity t =+40°C from 0.03 to 0.04 W/(m·K), working temperature from -45°C to +135°C, sound absorption, lower resistance to dampness.
3) Foamed polystyrene is characterized by the following features: coefficient of thermal conductivity t=+40°C from 0.03 to 0.04 W/(m·K), operating temperature of up to +80°C, very low weight, mainly used for insulating fittings.
4) Mineral wool and glass wool (Fig. 7.17E) are intended primarily for use in thermal insulation of high temperature pipelines and ventilation ducts. Wools are characterized by very good fire resistance (rock wool up to 1000°C, glass wool up to 600°C), non-flammability and resistance to microorganisms and rodents. The thermal conductivity coefficient for mineral wool lagging, measured at + 200°C, is about 0.060 W/(m·K).
5) Elastomer insulations (Fig. 7.17F) are characterized by resistance to high temperature differences and variability of atmospheric conditions. They are also resistant to UV and water vapour. In addition, they prevent the spread of fire, even though they are combustible materials. Their main applications are air-conditioning, refrigeration systems and solar installations.

Protective coats, manufactured most often in the form of sheets, can be made of the following materials:

1) aluminium tape (Fig. 7.17E),
2) plastic film (Fig. 7.17B),
3) asphalt pavement on aluminium tape,
4) galvanized steel sheet.

Insulation thickness e_1 can be determined according to the following formula (PN-EN ISO 8497: 1999, PN-B-02421:2000):

$$e_1 = \frac{D\left(\frac{D+2e}{D}\right)^{\frac{\lambda_1}{0.035}} - D}{2}, \tag{7.1}$$

where:

D – outer diameter of the insulated pipe (mm),

e – the thickness of the specific insulation layer according to Tables 7.1, 7.2 or 7.3 (mm),

λ_1 – value of the heat transfer coefficient of the insulation material at 40°C (W/(m·K)).

Fig. 7.17. Examples of insulation: A) foamed polyethylene without an outer coating, B) foamed polyethylene with an outer coating of polyethylene film, C-D) foamed polyurethane in a PVC housing, E) mineral wool with an aluminium foil coating, F) elastomer insulations (Source: A-C T.J. Teleszewski's private archive, D-E R. Bilinskienė's private archive)

Table 7.1. Minimum thicknesses of the insulation layer on the heating network lines in underground intransitive channels and in buildings as well as central heating and hot water installations in heated rooms with a design temperature greater than or equal to 12°C (Source: according to PN-82 / B-02402)

Nominal diameter of the pipe	Thickness of the insulation layer (mm) at the temperature of the medium being transferred				
	up to 60°C	95°C	135°C	150°C	200°C
=<20	15	20	30	35	45
25	15	20	30	35	45
32	15	25	35	40	50
40	15	25	40	40	50
50	20	25	40	45	60
65	20	30	45	50	60
80	25	35	50	55	65
100	25	40	55	60	75

Table 7.2. Minimum thicknesses of the insulation layer on the lines of the central heating and hot water installations in heated rooms, with a design temperature equal to or less than 12°C (according to PN-82 / B-02402) and in unheated rooms with a design temperature greater than or equal to -2°C (Source: according to PN-82 / B-02403)

Nominal diameter of the pipe	Thickness of the insulation layer (mm) at the temperature of the medium being transferred				
	up to 60°C	95°C	135°C	150°C	200°C
=<20	30	30	35	40	50
25	30	30	40	45	55
32	30	35	45	50	55
40	30	35	45	50	60
50	35	35	50	55	65
65	40	40	55	60	70
80	40	45	60	65	70
100	45	50	65	70	80

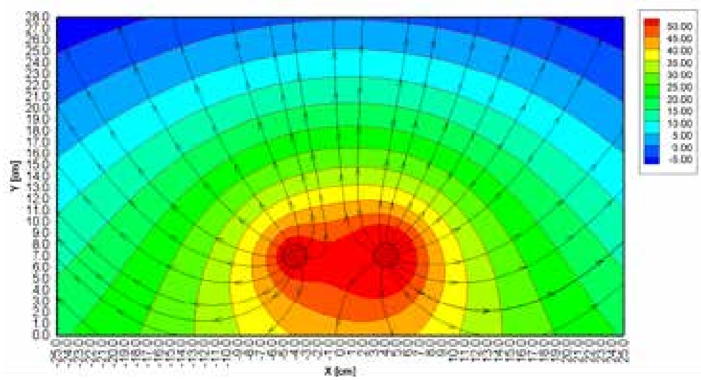
Table 7.3. Minimum thicknesses of the proper insulation layer on the overhead lines of district heating networks and central heating and hot water installations in unheated rooms with a design temperature equal to or less than -2°C (Source: according to PN-82/B-02403)

Nominal diameter of the pipe	Thickness of the insulation layer (mm) at the temperature of the medium being transferred				
	up to 60°C	95°C	135°C	150°C	200°C
=<20	50	45	45	50	55
25	50	45	50	55	60
32	50	45	55	60	65
40	50	45	60	60	65
50	55	50	60	65	70

Nominal diameter of the pipe	Thickness of the insulation layer (mm) at the temperature of the medium being transferred				
	up to 60°C	95°C	135°C	150°C	200°C
65	60	55	65	70	75
80	60	55	70	75	80
100	65	65	75	80	90

Figures 7.18A-B show the temperature field of non-insulated central heating pipes (Fig. 7.18A) and insulated central heating pipes (Fig. 7.18B) located in the external wall of a residential building determined by the boundary element method. In the case of a wall in which there is a pipe without insulation, the temperature field around the duct is clearly visible in comparison to the insulated duct. Examples of simulations of the impact of central heating installations and hot water installations on the creation of thermal bridges can be found in the literature (Teleszewski & Sorko, 2010, Teleszewski & Rynkowski, 2011).

A



B

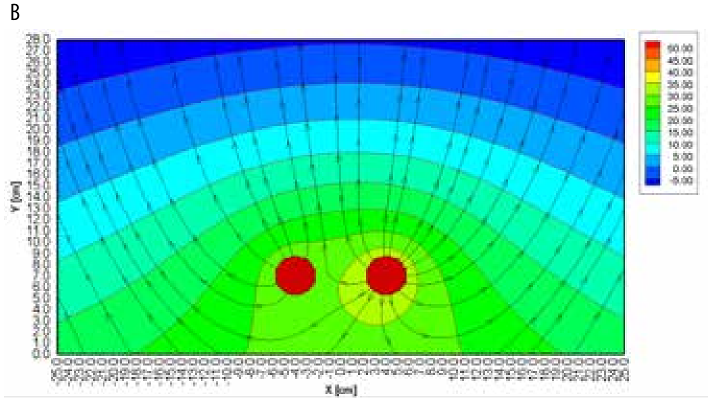


Fig. 7.18. Heat flow lines and temperature field in the wall section in the case of the central heating pipe line located in a furrow: A) without thermal insulation, B) with thermal insulation (Source: own elaboration)

Minimum insulation thickness of heating system pipes in Poland is regulated by law (Reg1, 2017) and depends on a diameter of pipes. For small pipes (20-35 mm) it is set at level 20 mm, for average diameters of pipes (35-50 mm) it is 30 mm, while for bigger pipes thickness of isolation should be at least equal to the inner diameter of the pipe.

Heating supply systems can be central (CHSS) and local (LHSS). The local heating supply systems are those in which heating energy is generated for several buildings or the local boiler-rooms are installed inside the buildings. If compared with central systems, local systems are more effective for smaller buildings, or for those that are situated further from the heating network (Bilinskienė et al., 2012; Šarupičius, 2012).

In central heating installations, in order to force the flow of the medium through the installations, glandless circulation pumps are most often used. In the design of a glandless pump, all rotating parts inside the motor are immersed in the medium to be pumped. It is not necessary to seal the shaft with a stuffing box or mechanical seal, which is needed for standard pump designs. The pumped liquid lubricates the shaft bearings and cools the engine components. Fig. 7.19 shows the view of installed circulation pumps in the boiler room, while Fig. 7.20 presents the construction of a glandless circulation pump. Pump selection is based on calculations of hydraulic central heating installations. The intersection of the system characteristic with the pump curve is the duty point (Fig. 7.21). The selected pump should be characterized by the highest efficiency. Examples of calculations of hydraulic central heating installations can be found in the literature (Pieńkowski et al., 1999 Part 1; Pieńkowski et al., 1999 Part 2).

A B

Fig. 7.19. Circulation pumps in a boiler room (Source: photos by T.J. Teleszewski)

Currently, in central heating installations, the most frequently used is the type of pump regulation which changes the rotational speed of the pump impeller. This is also the most effective form of regulation, because it adjusts the pump's power to the changing operating conditions of central heating installations. Most often, two control modes are used (Bidstrup, 2002):

1) proportional pressure (Fig. 7.22A),
2) constant pressure (Fig. 7.22B).

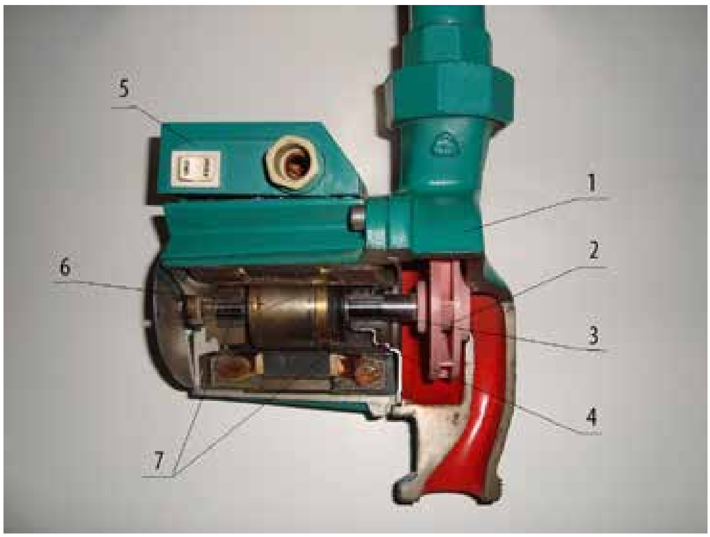


Fig. 7.20. The construction of a glandless pump: 1 – pump housing, 2 – impeller, 3 – shaft, 4 – stator housing, 5 – control box, 6 – rotor, 7 – thrust bearing (Source: T.J. Teleszewski's private archive)

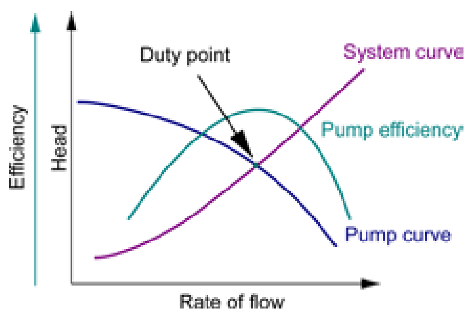


Fig. 7.21. Determination of the operating point for a given pump and central heating installation system (Source: own elaboration)

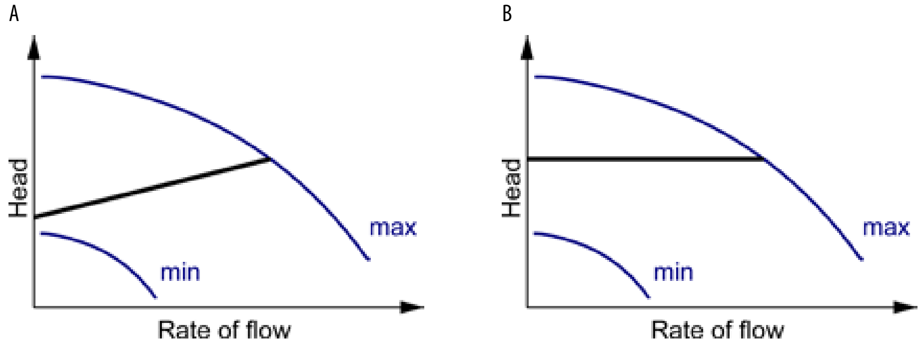


Fig. 7.22. Control modes: A) proportional pressure, B) constant pressure (Source: own elaboration)

Constant control of the pressure difference is the most optimal at high pressure losses on the heater/cooler in relation to head friction losses, while proportional pressure control is recommended when the supply pipes are relatively long and the head friction losses override head losses for local resistances in the receiver (Bidstrup, 2002).

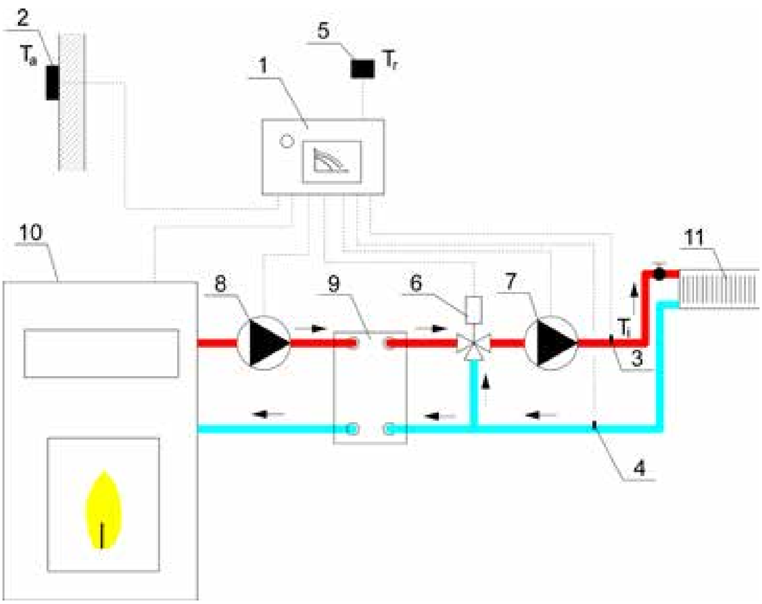


Fig. 7.23. An example of a schematic diagram of "weather regulation": 1 – controller, 2 – external temperature sensor, 3 – heat circuit temperature sensor, 4 – heat circuit temperature sensor, 5 – room temperature sensor, 6 – mixing valve (three-way valve with actuator), 7 – pump heating circuit, 8 – pump heating circuit, 9 – heat exchanger, 10 – heat source (boiler), 11 – radiators (Source: own elaboration)

Currently, central heating installations are equipped with so-called "weather regulators" or "climatic regulators" that regulate the temperature of the heating medium depending on the outside temperature T_a. Fig. 7.23 shows a typical weather regulation scheme. The outside air temperature T_a determines the building's heat demand. Adjusting the heating system according to the outside temperature of the building brings greater economic benefits than regulating it based on the internal temperature T_r. A weather-compensated heating system ensures that the room temperature is evenly maintained and the energy is properly used, as the supply water temperature is regulated depending on the outside temperature T_a. The weather regulation is based on the programmed heating characteristic called "the heating curve" or "the gradient of heating characteristic" (Fig. 7.24). This curve determines the relationship between the outside air temperature T_a and the water temperature T_i coming out of the boiler or heat exchanger. A heating medium with a temperature adjusted to the current outdoor temperature is supplied to the radiators. The supply water temperature is read from the temperature sensor (3) (Fig. 7.23), while the outside temperature is read from the temperature sensor (2). The actuator in the weather regulation can be a boiler (10), a mixing valve (6) or a circulating pump (7) The regulator can be additionally equipped with an internal room temperature sensor (5). This option enables automatic correction of the programmed heating characteristics.

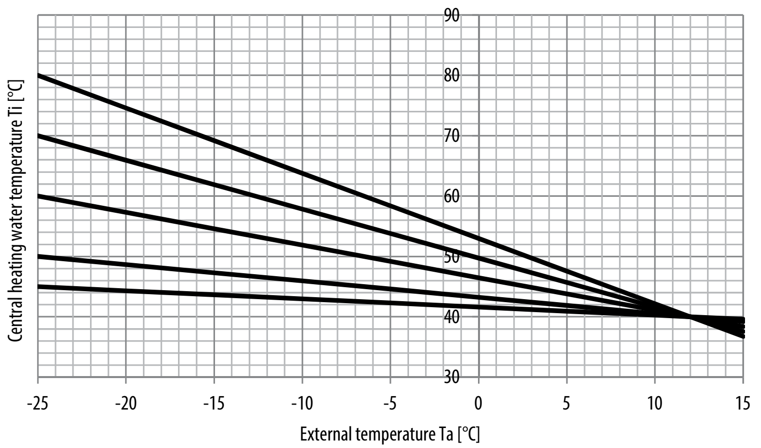


Fig. 7.24. Gradient of heating characteristic (Source: own elaboration)

7.5. The role of building planning for HVAC systems selection

The good operation of heating and ventilation systems is just a small part of the conditions for creating healthy and comfortable microclimate conditions in a building. In residential buildings the air quality is often determined by the construction materials, the maintenance of the building, etc. The most important projecting solutions for HVAC systems are made by the architect at the first sketch (possible location of technical rooms, energy source, comfort level requirement, etc.). Energy efficient building has to be designed to ensure proper indoor thermal comfort and air quality, and also less energy consumption. The main stages of the energy efficient building design are (STR2, 2016; WEB-1; WEB-2; Gluosnis, 2004):

1) the energy saving and heat retention requirements analysis,
2) the possible building HVAC systems analysis, which includes: building structure, hygiene requirements, energy demand, area and space demand, heat power for building services, etc.

It is the architect who projects solutions that determines the efficiency of a building by selecting its shape, fenestration, building construction thermal properties, building services installation and maintenance, etc. The building design solutions and the HVAC system selection depend on the building location. The local climate zone must be considered when selecting design solutions. There are different dominant systems and solutions for: cooling, air conditioning (in Spain) or heating, ventilation (in Lithuania, Poland). The climate zone has a major effect on HVAC system design solutions. The building construction solutions are very important, too. The better the building is insulated, the lower energy supply is needed for its heating (Poland, Lithuania) or cooling (Spain). The efficiency of a building may be understood in different ways. The most efficient "zero energy" buildings do not need external energy supply, heat losses are compensated by solar heat and internal gains. In a big project work, the architect, as the head of the enterprise, is responsible for the project completeness and quality. The thermal engineer is responsible for selecting and designing HVAC systems solutions. The project quality depends on the project manager, good communication between designers, architects, and engineers, and their design solutions (STR2, 2016; WEB-1; WEB-2; Gluosnis, 2004).

Apartment windows in residential buildings may be positioned in one or two opposite facades. Double-sided apartments are better ventilated due to the difference in pressure from the wind. On the upper floors of buildings, where the wind blows strongly, apartments may be cooled off (Juodis, 1998). Maintaining the projected temperature inside these apartments could be resulting in overheated apartments with one-sided window exposure on the lower floors. The one-sided apartments facing the south, south-east, or south-west, could be overheated or the air inside might be too hot during the summer season.

The right planning and designing of buildings, the properly selected materials for the walls and adequate maintenance can support the operation of heating, ventilation, air conditioning systems and create healthy microclimate in the building (STR1, 2005; STR2, 2016).

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DOI: 10.24427/978-83-65596-71-0_8

8. MODERN SOLUTIONS IN VENTILATION AND AIR CONDITIONING SYSTEMS

8.1. Microclimate hygiene requirements

Microclimate can be defined as a set of physical and chemical properties that we observe in a relatively small enclosed space, which has influence on living beings, for instance people, animals, etc. The main parameters are air purity and chemical composition, indoor temperature, relative humidity, velocity of air, and also temperature of the surrounding areas, lighting, noise level, furniture, color of walls and air ions (ASHRE, 2004; ASHRE, 2007). All components of the microclimate can significantly influence human mood, mental and physical performance, work efficiency and health condition (Skwarczyński & Dumała, 2002). It is worthy to note that comfort of a human being can be decreased by physical, chemical and biological pollutants. In case of the physical ones, the most important are noise and vibration, while in the group of biological pollutants we can distinguish for instance dust or bacteria. Most tests of Indoor Air Quality (IAQ) examine chemical components like nitrogen dioxide, sulphur dioxide, carbon monoxide, carbon dioxide or volatile organic compounds. The standards show indoor environment classes, although they differ in names: A, B, C in EN ISO 7730 (ISO 7730:2006), 1, 2, 3, 4 in EN 13779 (PN-EN 13779:2008) or I, II, III, IV in EN-15251 (EN 15251:2007) (Table 8.1).

Table 8.1. Categories of indoor environment according to EN-15251 (Source: EN15251:2007)

Category	Characteristics
I	High quality – rooms used by people sensitive to environmental factors and prone to discomfort, for instance small children, ill elderly people, etc.
II	Normal level – rooms in new and retrofitted buildings
III	Average acceptable level – existing buildings
IV	Buildings which do not fulfill the conditions from I-III categories and could be acceptable only for a brief period.

Recommended conditions for room microclimate according to PN-78/B-03421 and PN-EN 13779:2008 standards are the following:

a) For people with a low metabolism, for example writing or taking part in meetings, lectures – the air temperature in winter should be in a range of 20-22°C, while the recommended range in summer is 23-26°C, relative humidity (RH) 40-55%, maximal air velocity 0.2 m/s in winter and 0.3 m/s in summer.
b) For people with an average metabolism, for instance performing some manual work in laboratories – the air temperature in winter should be in a range of 18-20°C and 20-23°C in summer, RH 40-60%, maximal air velocity 0.2 m/s in winter, whereas 0.4 m/s in summer.

The range of recommended air temperature for classrooms is shown in the table below (2002/91/EC). The values depend on classroom categories: A – high level of expectations, B – average level and C – low requirements (Table 8.2).

Table 8.2. The range of recommended air temperature for classrooms (Source: 2002/91/EC)

Type of room	Category	Temperature [°C]	
		Winter (good clothing insulation)	Summer (low clothing insulation)
rooms in schools	A	21.0	25.5
	B	20.0	26.0
	C	19.0	27.0

Spanish regulations (UNE-EN 13779:2008, Ministerio de Industria, Energia y Turismo 2007, Comentarios al RITE-2007) settle interior design conditions of the operating temperature and humidity depending on the metabolic activity of the people, their clothes and the PPD factor (predicted percentage of dissatisfied users), percentage of estimated dissatisfied persons for a given thermal sensation in a big group, according to the following two possibilities:

a) for people with sedentary lifestyle, metabolic activity of 1.2 met, grade of clothing 0.5 clo in summer and 1 in winter, PPD between 10 and 15%:
   - in summer – temperature 23-25°C, RH 45-60%,
   - in winter – temperature 21-23°C, RH 40-50%;
b) in cases of other metabolism, the temperature and humidity values should be taken from the UNE-EN ISO 7730:2007 standard. The range of recommended air temperature for conference and office rooms is shown in Table 8.3 for three room categories.

Another important parameter of the microclimate is CO_2 concentration. Too high a level could provoke headaches, decline in concentration, eye diseases, breathing difficulties etc.

Table 8.3. The range of recommended air temperature for conference and office rooms (Source: UNE-EN ISO 7730:2007)

Type of the room	Category	Temperature [°C]	
		Winter (good clothing insulation)	Summer (low clothing insulation)
conference rooms, offices, main hall, classrooms	A	22.0±1.0	24.5±1.0
	B	22.0±2.0	24.5±1.5
	C	22.0±3.0	24.5±2.5

More general guidelines concerning the quality of air inside facilities are contained in the PN-EN 13779:2008 standard. Table 8.4 presents a classification of indoor air quality developed on the basis of the above mentioned standard. The recommended concentration of carbon dioxide in rooms equals 1000 ppm. This minimum sanitary requirement is recommended by the European Office of WHO 2000 (Air Quality Guidelines for Europe 2000) and by ASHRAE 2004 and 2007.

Minimum indoor sanitary conditions, i.e. minimum amount of ventilation air for a person in an hour's time ensuring the feeling of comfort during the stay in each room vary between countries, and they are defined differently by various standards. The minimum sanitary requirement in Germany according to DIN 1946-2 equals 50 m^3/h, whereas in case of WHO 2000 and CR EU 17520 for A category buildings, the air inflow stream is equal to 36 m^3/h, and similarly, 35 m^3/h in accordance with ASHRAE, 2007. The still applicable Polish standard of 1983 (PN-83/B-03430) defines the minimum stream at 20 m^3/h, but another Polish standard of 2008 (EN 13779:2008) recommends the values between 22 and 54 m^3/h. Swedish standards, for that matter, recommend the value of as low as 9 m^3/h, while the British ones opt for 25 m^3/h (Recknagel et al., 2006).

Table 8.4. Classification of indoor air quality (Source: PN-EN 13779:2008)

Category	Description	Increase of CO_2 concentration above the CO_2 concentration in the outdoor air	Max indoor CO_2 concentration while the outdoor level is 400 ppm	Outdoor air stream volume per 1 person
		ppm	ppm	m^3/h per 1 person
IDA 1	High indoor air quality	below 400	below 800	above 54
IDA 2	Medium indoor air quality	400-600	800-1000	36-54
IDA 3	Moderate indoor air quality	600-1000	1000-1400	22-36
IDA 4	Low indoor air quality	above 1000	above 1400	below 22

The Indoor Air Quality (IAQ), interpreted broadly, refers to the environmental characteristics inside buildings that may affect human health and comfort. IAQ characteristics include the concentrations of pollutants in the indoor air, as well as the air temperature and humidity. According to STR1 (2005) the air may be classified as:

- outdoor – the air entering the system or directly the room from the building environment;
- supplied – the treated air with the inflow into the room or system of air;
- indoor – the air in the room;
- overflow – the air that gets from one room to another through the openings or is supplied by ventilation systems;
- extracted – the air getting out of the room;
- removed – the air getting out into atmosphere;
- recirculating – the air supplied to the air treatment equipment.

The air quality categories (STR1, 2005):

- the removed air – referring to air pollutants getting out into the atmosphere;
- the exhaust air – referring to air pollutants being extracted from the indoor air:
- the indoor air – referring to air cleanliness in the room.

The same document (STR1, 2005) shows characteristics of the air flow into the operation zone:

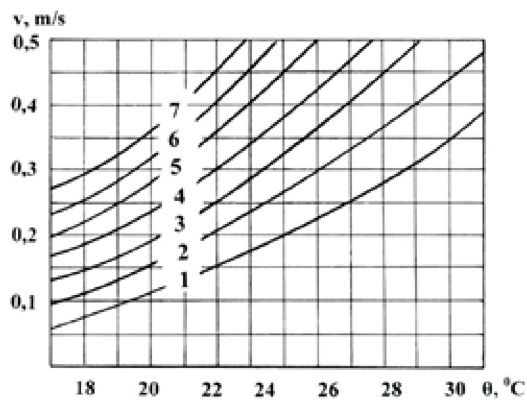

Fig. 8.1. The operation zone air flow characteristics, where: v – maximal air velocity, m/s; Te – the air temperature at the measuring point, 1-7 – air characteristics (Source: STR1, 2005)

The microclimate and air quality parameters are determined by the category of the environmental quality in the room that can be: high (A), average (B) or low (C). These values are different in summer and winter seasons (STR1, 2005). The parameters of the microclimate in the air conditioned rooms must be within the limits of thermal comfort conditions. In some cases and in production premises, they may be within the limits of thermal environmental conditions (STR1, 2005).

The hygiene norms for Lithuania (HN 69:2003) provide indoor air normative values and requirements. The thermal comfort and environmental requirements are set to the working area (operating zone), and are divided into categories for two year seasons (winter and summer). There are three categories of work regarding the degree of difficulty: easy work (Ia, Ib) (Table 8.5), medium difficulty (IIa, IIb) and hard physical work (III).

Table 8.5. Thermal comfort conditions for easy work in Lithuania (Source: HN 69:2003)

Season	Easy work categories	Air temperature, °C	Relative humidity, %	Maximal air velocity, m/s
Winter	Ia	22-24	40-60	≤ 0,1
	Ib	21-23		
Summer	Ia	23-25	40-60	≤ 0,1
	Ib	22-24		≤ 0,2

Depending on the force that determines air circulation, indoor air circulation could be (Šarupičius, 2012; Juodis 2009): flowing, thermal (prevails in places where there are powerful heating sources and the air circulation is determined by convective flows that come from hot devices), filling (fresh air is supplied by the whole surface of ceilings or walls) while pushing the polluted air through the floor, or the openings, located in the lower areas of a room or on the opposite wall), or mixed (in case of the flowing circulation the air is supplied by a single or several flows that move and mix the indoor air) (Šarupičius, 2012; Juodis, 2009).

The rates of air flow per unit of floor area are given in Table 8.6 (STR1, 2005).

Table 8.6. Indoor air flow for different rooms in schools (Source: STR1, 2005)

Type of rooms	Classrooms, laboratories	Conference hall, meeting rooms	Library, reading rooms	Gym, sports activities rooms
Design value of air m^3/h per unit of floor area $1m^2$	10.8	21.6	7.2	7.2
Design value of air m^3/h for person	21.6	28.8	14.4	43,2

Thermal comfort defines such thermal climate conditions in which a person feels contented. The person may be dissatisfied by factors that affect everyone – cold, heat or discomfort (Lapinskienė & Laukys, 2011; Juodis, 2009). It is impossible to determine the ideal thermal conditions or warm environment that would satisfy everyone.

By setting the values for a sufficient amount of thermal climate, it is agreed that these value are satisfactory for 80% of people, whereas 20% may be dissatisfied. The thermal environment could be: comfortable (less than 5% are dissatisfied), moderate and unacceptable (more than 20% people are dissatisfied) (Juodis, 2009; Bilinskienė, 2017).

8.2. Outdoor air parameters

Outdoor air parameters (STR1, 2005; Bilinskienė et al., 2012) can be divided into:

1) Group A – the calculated and installed microclimate systems will not be able to operate in the microclimate conditions for up to 10% of their annual operating time;
2) Group B – the calculated and installed microclimate systems will not be able to operate in the microclimate conditions for up to 2% of their annual operating time.

In winter season, if there are no specific construction or technological requirements, the heating, mechanical ventilation and air conditioning systems function/ operate in accordance with the parameters of the outdoor air of group B (STR1, 2005; Bilinskienė et al., 2012). The outdoor air temperature is 5˚C for natural ventilation systems.

Tables 8.7 and 8.8 present the design outdoor air parameters for evaluation of energy performance of a building (STR2, 2016).

Table 8.7. Average wind speed per month in Lithuania (Source: STR2, 2016)

Month number												
v_{wind}	1	2	3	4	5	6	7	8	9	10	11	12
	4,1	3,8	3,8	3,5	3,2	3,0	2,9	2,7	3,2	3,6	4,0	3,9

Table 8.8. Term tm days per month and average outdoor air temperature per month in Lithuania (Source: STR2, 2016)

Month number												
t_m, days	1	2	3	4	5	6	7	8	9	10	11	12
	31	28	31	30	31	30	31	31	30	31	30	31
$\theta_{e,m}$, °C	–5,1	–4,4	–0,7	5,5	11,9	15,4	16,7	16,2	11,9	7,2	2	–2,4

Design outdoor temperature for heat loss calculation (Bilinskienė et al., 2012) in Vilnius is –23°C. It is normal for Lithuanian climate zone, thermal comfort and climate have to be ensured in buildings when the outdoor temperature is –24°C.

In case of Poland and Spain, several climatic zones are selected and in each one the design outdoor temperature and average monthly temperature are established at different level.

8.3. Ventilation and air conditioning

Ventilation is a system which exhausts the air from a room replacing it with the fresh air (Šarupičius, 2012; Bilinskienė, 2017). Ventilation and air-conditioning systems must be selected according to the purpose of the building and the use of special features, to guarantee the normative indoor climate and clean air under normal use and outdoor weather conditions (STR1, 2005). Natural ventilation is used in cases where the supply or exhaust air is not clean, and the user, without harming others, can provide microclimate and clean air directly regulating the amount of air entering the room, or when the outdoor air is infiltrated into the room (STR1, 2005). Mechanical ventilation is used in cases where there is no natural ventilation or it is not possible to keep normative air parameters in a room. The mechanical and natural ventilation can work together (STR1, 2005). There are strict building energy efficiency requirements for a building ventilation system (STR2, 2016):

1) In the design of mechanical ventilation systems, priority should be given to ventilation system equipment with a maximum efficiency, the lower value of non-renewable primary energy factor used by the ventilating unit and the higher value of the renewable primary energy factor.
2) If the building is equipped with a system for mechanical ventilation with recuperation, the value of the energy efficiency class of the building (or its part) and the energy consumed by the recuperator fans shall comply with the requirements of Regulation (STR2, 2016).

All ventilation systems can be divided into several groups according to the following features (Šarupičius, 2012; Juodis, 2009):

1) depending on the source of pressure and the mode of air transferring, it can be natural or forced ventilation;
2) depending on the area of usage, it can be exhaustion or indraft ventilation;
3) depending on the size and number of rooms served, it can be local or closed circulation ventilation;
4) depending on the construction, it can be channel or non-channel ventilation.

Heating, ventilation and air conditioning systems are combined with one another (STR1, 2005):
1) Air supply systems can be used as heating air systems.
2) In some cases, air conditioning systems may be used as heating systems.
3) When the room is air-conditioned, it must not be naturally ventilated.

If a ventilation system is installed professionally and qualitatively, it helps to preserve the equipment in production premises, protects the construction of the building and prolongs the exploitation period of many materials. The used air must be discharged in the best way which does not endanger human health, nature and structures (STR1, 2005). Fig. 8.2 presents supplied and exhaust air categories EHA1-4.

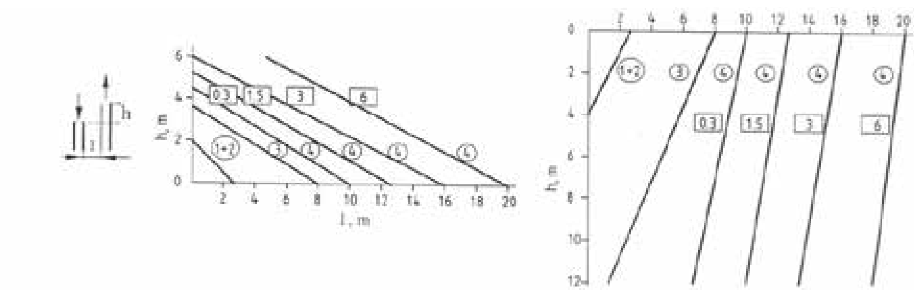

Fig. 8.2. Supplied and exhaust air categories EHA1-4 (Source: STR1, 2005)

The treatment efficiency of the exhaust air, its location and method of discharging shall be chosen so that at the specific points the air pollution does not exceed the permissible concentration (STR1, 2005).

8.4. Natural ventilation system

The natural ventilation (Fig. 8.3A) is the simplest method to ventilate buildings, when the air comes in through the building cracks, windows, vents, micro-ventilation cavities of new type windows, doors or special openings. The air is extracted by vertical draught ducts in natural mode when heated indoor air rises up. They are usually installed in toilets, bathrooms and kitchens (STR1, 2005; Šarupičius, 2012). Natural ventilation can be divided into (Šarupičius, 2012; Bilinskienė, 2017):
1) organized natural ventilation, when special elements are designed for the air to get in and out, the measurement and location of these elements are known;
2) disorganized natural ventilation, when the air penetrates through cracks and gaps, the size and location of which are unknown.

The disadvantages of natural ventilation are (Šarupičius, 2012; Juodis, 2009):
1) The incoming air is not heated when it is cold outside, for instance, during winter, the ventilation may cause a cold draught which might influence people's health.
2) The air is not cleaned and filtered, it may bring in insects, dust and other dirt.
3) Dust is common in buildings situated close to busy streets. Besides, the street noise is common through the natural ventilation of such buildings.
4) It is difficult to control the volume of incoming air and rooms can be ventilated too much or too little.
5) In summertime, when the outdoor and indoor temperature is almost equal, the air almost stops circulating.
6) Huge heat losses cause high heating prices.

The air in natural ventilation system is usually removed through the ventilation pipes on the roof.

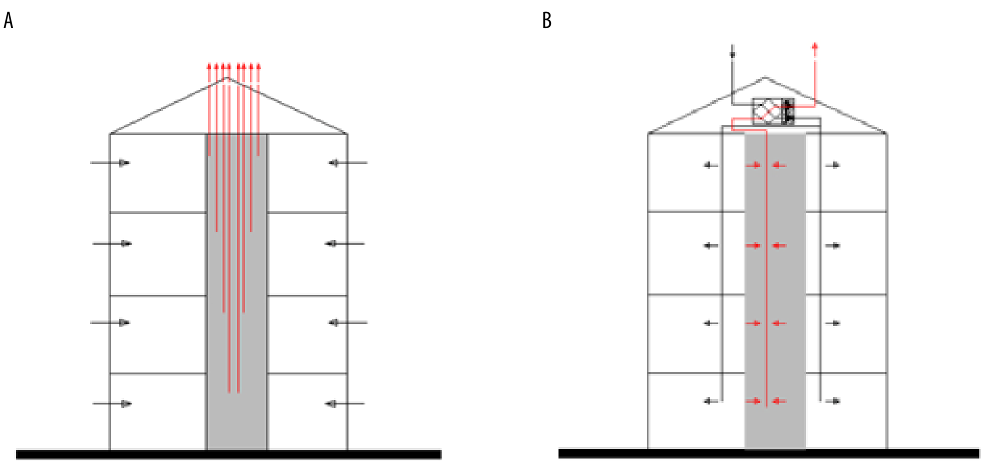

Fig. 8.3. Principal plan and scheme of ventilation system pipelines: A) the natural ventilation system, B) the mechanical ventilation system (Source: STR1, 2005; Šarupičius, 2012; Bilinskienė, 2017)

8.5. Mechanical ventilation system

The building must be ventilated and heated in such a way so as to maintain the standard air quality by using energy efficiently (STR1, 2005; STR2, 2016). The mechanical ventilation system (Fig. 8.3B) can be divided into (Šarupičius, 2012; Juodis, 2009):
1) depending on the purpose: extractive – that extracts the used air, and supplying – that supplies the fresh air;

2) depending on the use of fresh and used air: straight flow, with partial circulation, and re-circulative;
3) depending on the air circulation channel ventilation – branched or collector systems, and non- channel ventilation systems.

The advantages of mechanical systems are: while operating, a required volume of air is supplied regardless of the air temperature outside; system operating process and ventilation intensity could be controlled according to the preferences; the supplied air is heated or cooled to the temperature required, it is filtered (Bilinskienė, 2017; Juodis 2009). The disadvantages of the mechanical system are: the installation of this system is rather expensive, while operating, mechanical systems are quite noisy, electricity is continuously used. A specified volume of clean air must be supplied to the room in accordance with the requirements of health regulations. The amount of clean outdoor and recirculated air supplied to the room must be set at a level that does not exceed the air pollution in the Hygiene Norms (HN) (STR1, 2005). The air delivered to the room and coming in from other rooms must be cleaner than the air removed from the room. In order to determine the degree of air pollution emitted by public or industrial buildings (STR3, 2017), it is necessary to estimate the amount of emissions during the production process, the amount of pollutants from the internal equipment, people, etc. (STR1, 2005).

8.6. Air conditioning systems

Air conditioning is used where it is necessary to maintain a constant temperature and relative humidity indoors, or cool the air supplied, or when there are special air purity requirements (in medical institutions, clean rooms and etc.). The process of creation and maintenance of the artificial climate within rooms or buildings is called air conditioning (STR1, 2005). The air is conditioned when natural and mechanical ventilation systems are not capable of ensuring the level of indoor air temperature, relative humidity, circulation and cleanness regulated by the Hygiene norms (HN). The air conditioning systems (Juodis, 2009; Bilinskienė, 2017) can be:

1) Variable air volume systems. These systems are used in buildings which require cooling, but where some spaces need different amounts of cooling or where cooling load changes during a day. Individual control of room temperatures is achieved in this system. The most popular is the system with extracted air recirculation.
2) Constant volume systems: these are systems with an air handling unit, which supplies air only at fixed temperature. The advantage of the constant volume system is lower cost, the disadvantage – that it is not energy effective.

3) Dual duct systems: this type of air conditioning system requires separate heated and cooled air streams in individual ducting systems. This is the main reason why two pipe systems with separate heated and cooled air ducts are not popular in Lithuania.

The air conditioning system may be divided into: comfort, technological or comfort-technological. The purpose of the comfort air conditioning system is to create optimal hygienic work and living conditions, whereas technological systems are designed to create the best air conditions for technological process (Juodis, 2009; Šarupičius, 2012). The air conditioning system includes a cooling coil, humidifier or dehumidification equipment.

8.7. Ventilation and air conditioning equipment

The ventilation and air conditioning solutions are adopted according to the features of the building, technology, microclimate, energy supply and operating conditions (STR1, 2005). The building ventilation and air conditioning as well as the architectural building solutions are combined with one another throughout all stages of projecting (STR1, 2005; Juodis, 2009). Ventilation equipment is comprised of air supply and exhaust devices, silencers, air distribution and extraction devices (Šarupičius, 2012a; Bilinskienė, 2017).

Fig. 8.4. AHU construction (Source: R. Bilinskienė's private archive; WEB-1,3)

The basic functions of a central air handling unit (AHU) are (Fig. 8.4):
1) to deliver fresh air into the distribution system and the room space;
2) to filter out any solid pollutants;

3) to extract polluted air from the room space;
4) to heat the air to the required temperature.

The main air handling unit (Fig. 8.4) components: fans, filters, heating coil, heat recovery unit, etc.

Fig. 8.5. Location of the AHU: A-B) in the basement, C-D) on the roof (Source: photos by T.J. Teleszewski)

A general view of the air handling unit located in the basement is shown in Fig. 8.5A-B, while Fig. 8.5C-D shows the air handling unit installed on the roof.

The air ducts (Fig. 8.6) are used in ventilation and air conditioning systems to supply and extract air. Air ducts could be installed with thermal or sound insulation. With reference to their cross section, air ducts are divided into two main groups: round and rectangular. The fans are (Šarupičius, 2012; Bilinskienė, 2017) designed to cause air circulation inside the room and air ducts (Fig. 8.6). Fans are the main source of noise and vibration in ventilation systems (HN 33:2007).

Fig. 8.6. Air duct types (Source: Bilinskienė, 2017; WEB-1,2; R. Bilinskienė's private archive; T.J. Teleszewski's private archive)

Depending on the principle of operation fans can be divided into:
1) axial fans (the air flows parallel to the shaft, Figs. 8.7A-D),
2) centrifugal or radial fans (the air flows in a radial direction relative to the shaft, Fig. 8.7E),
3) mixed flow fans (the air flows in both axial and radial direction relative to the shaft),
4) cross flow fans (the air flows in an inward direction and then in an outward radial direction, Fig. 8.7F).

Fig. 8.7. Examples of fan constructions: A), B) an axial fan for installation in the ventilation duct and on the roof, C), D) axial fans installed on the roof, E) a centrifugal fan, F) a cross flow fan installed in the AHU unit (Source: Bilinskienė, 2017; WEB-1; R. Bilinskienė's private archive; photos by T.J. Teleszewski)

Fig. 8.8A-D show the following types of fan impellers: axial impellers (Fig. 8.8A-B), a centrifugal impeller (Fig. 8.8C) and a cross flow fan impeller (Fig. 8.8D). Due to the way the fan impeller is connected to the motor shaft, the fans can be divided into:

1) direct drive fans (the impeller is directly connected to the motor shaft, Figs. 8.7A-E).

2) belt drive fans (a transmission system using a flexible belt to transfer power, Fig. 8.7F)

Fig. 8.8. Examples of fan rotor designs: A), B) axial fan impellers, C) a centrifugal impeller, D) a cross flow fan impeller (Source: photos by T.J. Teleszewski)

Depending on the purpose of usage, fans can be produced of various materials: steel, plastic, stainless steel, etc.

The basic technical parameters of the fan selection are the flow rate of the fan V and the pressure p. In the case of typical ventilation, the required flow rate V [m^3/h] is determined on the basis of the volume of the ventilated room V_p [m^3] and the assumed number of air changes per hour k [1/h]:

$$V = V_p k \,, \tag{8.1}$$

To determine the required pressure, Bernoulli equation (Fig. 8.9) can be used:

$$\frac{p_1}{\rho g} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + z_2 + \frac{v_2^2}{2g} + \Delta p_s \,, \tag{8.2}$$

where

v_1, v_2 – velocity in sections 1 and 2 (m/s)
p_1, p_2 – pressure in cross-sections 1 and 2 (Pa)
z_1, z_2 – height of the cross-section of the channel in relation to any chosen reference level (m),
ρ – air density (kg/m³),
g – gravity (m/s²).

Hydraulic losses Δp_s are divided into major losses Δp_l and minor losses Δp_m:

$$\Delta p_l = \frac{l \lambda v^2 \rho}{8 R_h} \,, \tag{8.3}$$

where

l – length of the channel (m)
R_h – hydraulic radius (m)
λ – Darcy-Weisbach friction factor.

The hydraulic radius is equal to the ratio of the cross-sectional area of channel A to its circumference P:

$$R_h = \frac{A}{P} \,, \tag{8.4}$$

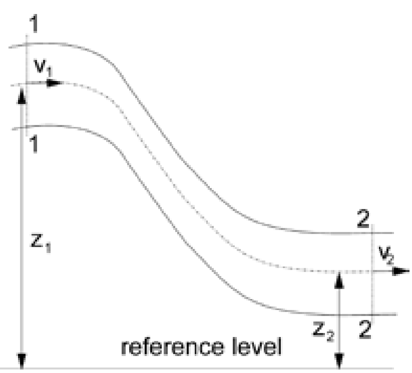

Fig. 8.9. Auxiliary drawing for the Bernoulli equation (Source: own elaboration)

Minor losses are expressed in the function of dynamic pressure:

$$\Delta p_m = \zeta \frac{\rho v^2}{2}, \tag{8.5}$$

where

ζ – minor loss coefficient (–).

The intersection of the system characteristics with the characteristics of the fan is the fan work point (Fig. 8.10). The fan duty point should correspond to the maximum fan efficiency (Fig. 8.10).

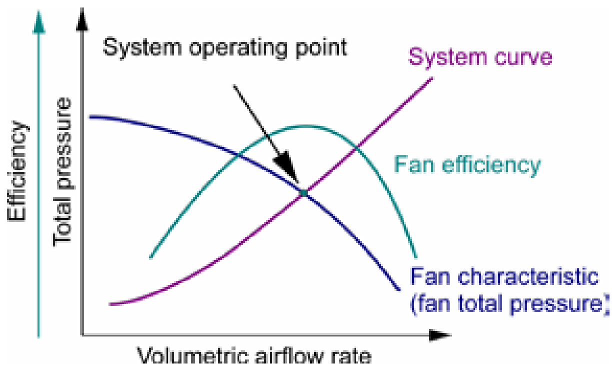

Fig. 8.10. Fan work point (Source: own elaboration)

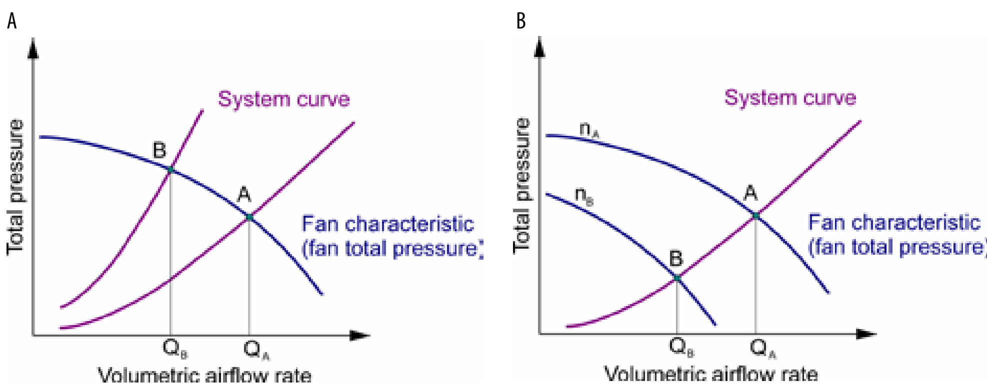

Fig. 8.11. Fan flow rate control: A) regulation by throttling, B) regulation by changing the rotational speed of the fan impeller (Source: own elaboration)

The flow rate of the fans can be regulated by throttling or by changing the rotational speed of the fan impeller. Fig. 8.11A shows an exemplary throttle regulation of the fan output from point A to point B through the operation of the air damper. The reduction in airflow rate from Q_A to Q_B has resulted in additional hydraulic losses, which is why the regulation is unfavourable in terms of energy. Fig. 8.11B shows an example of the operation of the regulation by changing the rotational speed of the fan impeller. In the case of this adjustment, the reduction of the output from Q_A to Q_B was achieved by reducing the rotational speed from n_A to n_B. The rotational speed change of the fan impeller in this case also involves a reduction in fan power, which is beneficial from the energy point of view of the fan. The rotational speed control of the fan impeller is implemented by using frequency converters (Fig. 8.12), which are additionally connected by automatic control systems.

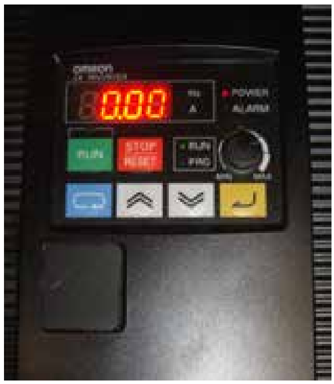

Fig. 8.12. A frequency converter control panel (Source: T.J. Teleszewski's private archive)

Fig. 8.13. An example of application of a throttle regulation: 1 – an air damper. 2 – an electric actuator, 3 – a fan, 4 – a ventilation duct (Source: T.J. Teleszewski's private archive)

Photo 8.13 presents an exemplary application of throttling regulation, while Fig. 8.14A-B present exemplary construction for air dampers for round ducts (Fig. 8.14A) and for rectangular ducts (Fig. 8.14B).

A B

Fig. 8.14. An air damper for a circular duct (A) and for a rectangular duct (B) (Source: T.J. Teleszewski's private archive)

Sources of noise in ventilation system can be: a fan, air circulation during duct and local obstacles (elbows, valves) (Šarupičius, 2012a; Bilinskienė, 2017). Noise silencers used in ventilation systems are divided into tubular and laminar.

Fig. 8.15. Noise silencer types (Source: Bilinskienė, 2017; R. Bilinskienė's private archive; WEB-1)

A noise silencer (Fig. 8.15) consists of a perforated inner canal, for the air flow, a noise absorbing material and an external shell.

Air distribution in ventilation systems (Juodis, 2009; Bilinskienė, 2017):

1) Chilled beams – they are used for ventilation and cooling systems where required for individual regulation of the temperature.
2) Displacement diffusers – the air is supplied into the customer area and extracted from the upper zone of the room. Diffusers give for customer comfort, good air quality and high ventilation efficiency.
3) The another equipment.

The air in ventilation, conditioning or air heating systems is warmed up by heaters. Heaters (Fig. 8.16) could be classified as (Juodis, 1998; Bilinskienė, 2017): water, stream and electric.

Fig. 8.16. Types of heaters (Source: Bilinskienė, 2017; WEB-2,3; T.J. Teleszewski's private archive)

Coiled heating elements for an electric heater and hot water coils are shown in Fig. 8.17A and 8.17B-C, respectively.

The filters (Fig. 8.18) for dust and air-blast dry filters must be installed in front of the fan in mechanical ventilation systems (STR1, 2005).

Heating, ventilation and air conditioning equipment should be arranged so as to minimize the risk of fire or fire explosion (STR1, 2005). Central heating and ventilation pipes that pass through the walls should be protected against the spread of fire to the adjacent rooms. Fig. 8.19 shows the protection of a pipe with an intumescent pipe collar which prevents the spread of fire and smoke to the neighbouring fire zones.

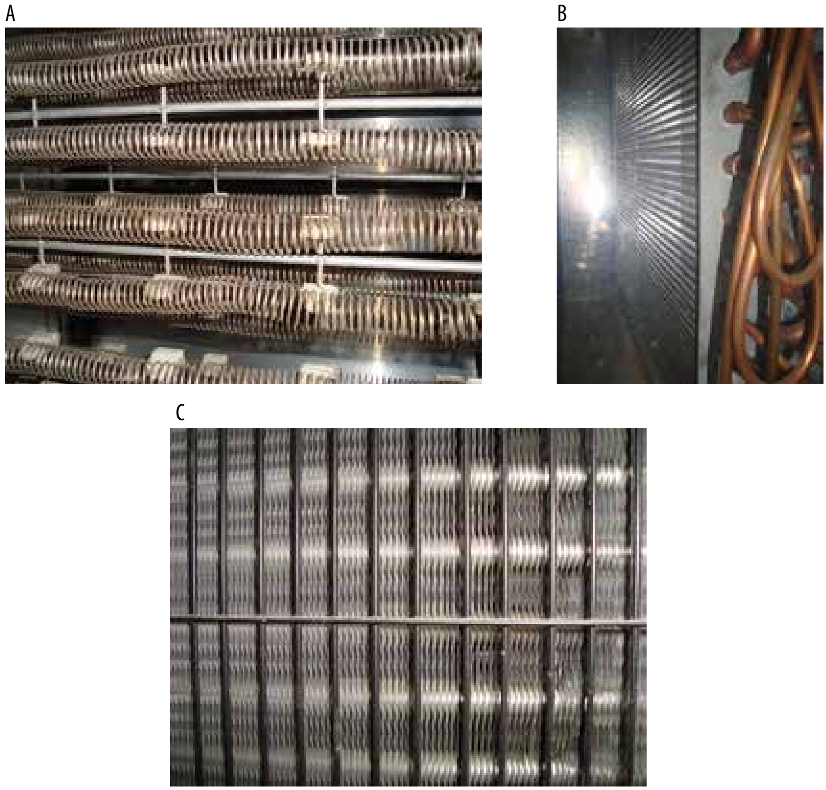

Fig. 8.17. Elements of the air heating section: A) coiled heating elements for an electric heater, B-C) hot water coils (Source: T.J. Teleszewski's private archive)

Fig. 8.18. Types of filters (Source: Bilinskienė, 2017; WEB-1,2,3)

Fig. 8.19. Intumescent pipe collars (Source: photo by T.J. Teleszewski)

8.8. Heat recovery ventilation

Heat recovery ventilation (HRV), also known as mechanical ventilation heat re-covery (MVHR), is an installation that reduces heat loss caused by building ventilation. Heat recovery ventilation makes it possible to significantly reduce the energy needed to heat the air blown into the building. It is therefore a must in an energy-saving construction. Heat recovery ventilation is used both in public buildings and in private homes. The main element of the heat recovery installation is air-to-air heat exchanger which employs a cross-flow or counter-flow heat exchanger between the inbound and outbound air flow. The recovery of warm air from the used air stream as the main assumption of the HRV is possible thanks to the thin walls of the HRV unit, which separate the two streams, at the same time allowing for the transfer of energy without mutual mixing. It is a process subject to control and regulation. Air purification is carried out by appropriate filters that also capture allergens, which is why this type of ventilation is especially recommended for asthmatics and allergy sufferers. A favourable microclimate in a house results from constant air circulation and from heating the air streams flowing into the house by the HRV filtration. The HRV eliminates the need for additional airing of the apartment or unsealing of windows or doors.

The HRV operation is as follows (Fig. 8.20): the air intake sucks clean air from the outside. Then, through ventilation ducts, it passes to a ventilation unit with a heat exchanger, where after passing through the inlet channel, it flows through filters responsible for catching dust and pollen. At the same time, the used (contaminated) air is extracted from the bathroom, toilet, wardrobe and kitchen rooms through the ventilation ducts attached to the heat exchanger.. The streams of used air passing in the adjacent channels in the device give off the heat to the incoming streams, which means that it goes back to the building. The exhausted and cooled air is thrown out through the launcher. The distribution of clean and heated air is carried out inside the building. The amount of supply and exhaust air is the same. The view of a heat exchanger is shown in Fig. 8.21.

Fig. 8.20. An example of using HRV in a single-family home (Source: own elaboration)

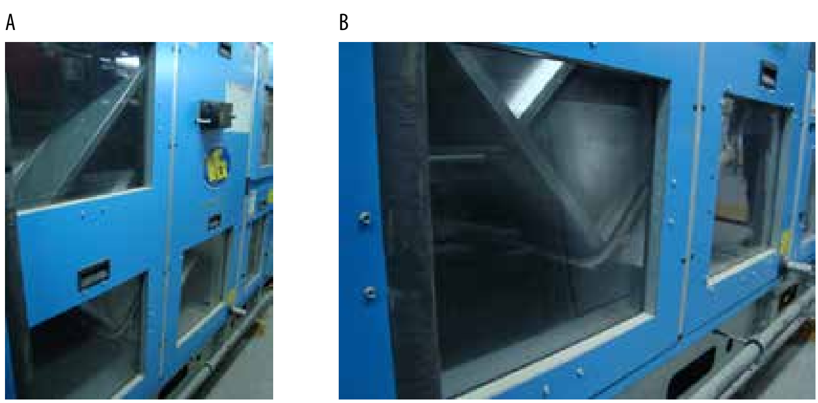

Fig. 8.21. An air heat exchanger (Source: photo by T.J. Teleszewski)

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WEB-1 Pastato vėdinimo ir oro kondicionavimo sistemų įrengimas. Statybos taisyklės. (Rules of building ventilation and air condition systems installation. Construction rules). http://www.statybostaisykles.lt/node/2970

WEB-2 Pastato vėdinimo sistemų įranga. (Equipment of ventilation system). https://www.systemair.com/lt-LT/Lithuania

WEB-3 Pastato vėdinimo sistemų įranga. (Equipment of ventilation system). http://vtsclima.lt/VTS-Lietuva.html

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9. SMOKE EXTRACTION GARAGES

The dynamic development of motorization causes inadequate parking places in the city centers as well as in their outskirts. The emergence of new residential buildings and public utilities results in the need to create new parking spaces. Due to the problem of limited development space as well as the high cost of building plots, investors decide to create one or multi-storey closed garages (Gładyszewska-Fiedoruk & Nieciecki, 2012 a, b). The area of these garages often reaches several tens of thousands of square meters. For these new parking spaces, an adequate and effective ventilation system should be provided, which at the same time functions as a residential ventilation system, and has a fire ventilation function as a means of protecting escape routes and rescue teams during a fire.

Ventilation consists in maintaining proper air quality in a ventilated room or part thereof. Contamination and exhausted air are thrown outwards, and then the outside air is introduced with the proper parameters. By smoke ventilation we mean a fire ventilation system that removes smoke and hot fire gases directly from the ceiling of the area of smoke extraction, ensuring that smoke is kept in a strictly defined area above the heads of evacuees. On the other hand, fire ventilation is a ventilation system designed to remove smoke and hot gases which may result from a fire and provide compensating air of the requisite quantity (Węgrzyński & Krajewski, 2019).

9.1. Ventilation systems in garages

The residential ventilation system provides suitable conditions for the short-term residence of people, by keeping the concentration of gaseous pollutants at a safe level. Harmful substances and gases in the air such as propane butane or carbon monoxide are eliminated by the appropriate ventilation system. The design of the installation must meet the requirements of technical and building regulations. Mechanical ventilation, which is mandatory, controls the unacceptable concentration of carbon monoxide. To determine the amount of supplied and discharged air, the following aspects are taken into account: the number of parking spaces, engines' idle time, distance to the exit gate, types of engines of vehicles in running order, parking occupancy rate, daily distribution of parking space (hot and cold engine operation). The amount of ventilation air for garages of varying cubic capacity may vary from 1.5 to 6 air changes per hour. In a closed garage of average height, the volume of clean air supply is approximately 27 m^3/h per square meter of floor area (Gładyszewska-Fiedoruk & Nieciecki, 2012 a, b). Correct calculations are the basis for the selection of ventilation fans supplying the ventilation system (WEB-1). Based on the Regulation of the Minister of Infrastructure of 2002, with subsequent changes and additions on the technical conditions to be met by the buildings and their location, the ventilation conditions to be met in the garages were determined. In closed garages, ventilation should meet the following requirements (Gładyszewska-Fiedoruk & Nieciecki, 2012 a, b; Systemair, 2014):

- At least natural ventilation, the ventilation holes placed in the opposite or side walls, or in garage doors, with total net area of ventilation holes of not less than 0.04 m^2 for each parking stall separated from others by partitions, – in unheated overground parking lots or built inside other buildings.
- Providing at least 1.5 air changes per hour – in heated overground or partially sunken garages with no more than 10 parking spaces.
- Mechanical ventilation, controlled by sensors for carbon dioxide concentration – in other garages not mentioned above and in inspection channels for professional car maintenance and repair or in multi-station parking.
- Mechanical ventilation, controlled by sensors for propane-butane gas concentration – in garages where propane-powered cars are parked and in the ones built below the ground level.

In open garages, however, natural ventilation should be provided to meet the following requirements (Systemair, 2014):

- The total size of uncovered openings in the outer walls on each storey should be less than 35% of the total wall area, allowing the use of permanent shutters therein, without limiting the openings.
- The distance between the pair of opposite walls and the unopened holes should not be greater than 100 m.

9.2. Fire ventilation system for multi-location garages

9.2.1. Division of fire ventilation systems

Depending on the type of equipment, fire ventilation systems can be divided as follows (Węgrzyński et al., 2014a):

- Smoke and Heat Exhaust Ventilation System (SHEVS) – designed to provide smoke removal from the layer stored under the ceiling and to maintain a smoke-free space through which people can evacuate;

- Smoke and heat control system – designed to keep smoke in the area between the source of fire and the place where it is disposed so as to ensure that rescue teams have easy access to the source of fire.
- Smoke clearance dilution – a system that is designed to remove smoke and mix it with infiltrating compensation air to reduce its temperature and toxicity.

Schematically, the division of ventilation systems together with the most frequently used system and devices is shown in Fig. 9.1 below.

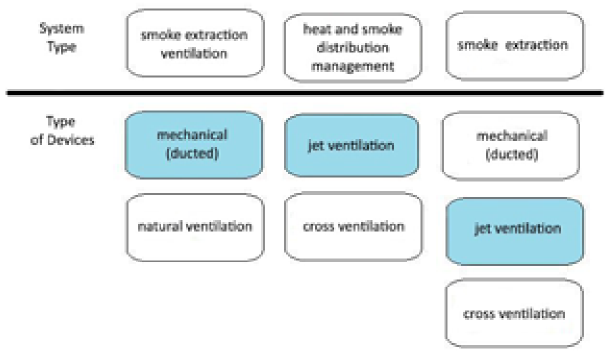

Fig. 9.1. Division of fire ventilation systems due to their type and type of equipment used, with the most commonly used systems in closed garages (Source: ALNOR, 2017; Gładyszewska-Fiedoruk & Nieciecki, 2012 a, b; Węgrzyński et al., 2014a)

Evaluation of fire ventilation systems can be made using the criteria listed in Table 9.1 (Węgrzyński et al., 2014 b; Sztarbała, 2013).

Table 9.1. Criteria for assessing fire ventilation systems (Source: own elaboration based on data from Sztarbała, 2013; Węgrzyński et al., 2014B)

Criterion	Smoke exhaust ventilation	Smoke and heat control	Smoke removal
During the evacuation			
Temperature	Under the ceiling – 200°C		
Smokiness	At the height up to 1.8 m – 60°C		
Radiation	Smoke under the ceiling of the storey at the height up to 1.8 m – 0.105 g/m^3 (Range of visibility of evacuation signs glowing with their own light – 10 m)		
During rescue and firefighting operations			
Temperature	At a height of 1.5 m, less than 120°C, in the distance of above 15 m from the source		

Criterion	Smoke exhaust ventilation	Smoke and heat control	Smoke removal
Smokiness	At a height of 1.5 m, less than 0.105 g/m^3 (visibility of evacuation signs glowing with their own light – better than 10m), at a distance of over 15 m from the source of fire	At a height of 1.5 m, less than 0.105 g/m^3 (visibility of evacuation signs glowing with their own light – better than 10m), at a distance of over 15 m from the source of fire	Zone may be smoky
Radiation	To 15 kW/m^3 at a distance of 15 m from the source of fire, 2.5 kW/m^3 in the other area	To 15 kW/m^3 at a distance of 15 m from the source of fire to the fire, 2.5 kW/m^3 in the other area	To 15 kW/m^3 at a distance of 15 m from the source of fire, 2.5 kW/m^3 in the other area
Access to the source of fire	Smoke in two layers – the source of fire is visible and access is facilitated	Possible access to the fire source at a distance up to 15 m from its location using a smoke free way	The whole area of the smoke zone – the fire area should be small enough to quickly locate the fire

9.2.2. The purpose of applying fire ventilation in garages

Fire-extinguishing systems are used to separate smoke-free zones and hot combustion products in areas of firefighting. In the event of fire, they allow for lowering the temperature and bringing air from the outside into the space. Fire-extinguishing systems can also be used as ventilation under normal building operating conditions. Depending on the type of product, they have a fire resistance of 60 to 120 minutes.

The basic purpose of using fire ventilation in garage enclosures is to provide appropriate evacuation conditions, enable effective operation for rescue teams and protect building structures. It is also important to safeguard evacuation routes against the smoke, by using appropriate smoke suppressors in the fire zone and preventing the spread of smoke to the rest of the garage (REG-2).

Basic ways of reducing hazards caused by smoke and hot fire gases include (Skaźnik, 2013):

- the use of physical barriers – doors, gates and other closures of openings for which fire resistance or smoke tightness is required, in appliances providing automatic closing of the opening in case of fire;
- ensuring a stable separation of the smoke layer from the smoke-free zone;
- smoke control by providing overpressure in protected spaces (differential pressure);
- smoke removal from the place of fire to the withdrawal point.

The choice of how to reduce hazards is strictly dependent on the conditions that must be maintained during the evacuation and rescue operation. It is assumed that for rooms with the height of up to 1.8 m from the floor, the minimum visibility without smoke should be up to 10 m, and the temperature should not exceed 60°C. For garages higher than 2.5 m above the floor, the temperature should not exceed 200°C in the floor area. Smoke extraction should ensure a safe escape of the rescue crews, 15 minutes after the outbreak of fire at a distance of 10 m from the source of fire. Due to specialist firefighters' equipment, it is acceptable to carry out firefighting for a period of 30 minutes at temperature not exceeding 100°C. This is illustrated in Fig. 9.2.

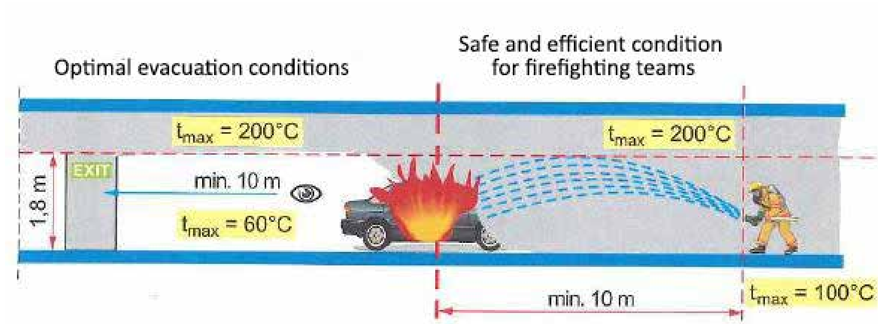

Fig. 9.2. Acceptable conditions for firefighting in a garage depending on the purpose of system operation (Source: based on data from ALNOR, 2017; Mizieliński & Kubicki, 2012)

9.2.3. Basic legal requirements for smoke removal from garages

The necessity to use automatic mechanical smoke exhaust systems for passenger cars is a result of technical and construction regulations. These regulations require the mechanical removal of smoke for garages with more than 10 parking spaces and obligatory for underground garages with the total area exceeding 1500 m^2 (REG-1).

Division of the area of the fire zone in the closed garage:
- overground garage – max. 5000 m^2,
- underground garage – max. 2500 m^2.

It is necessary to increase the fire zone by 100% if:
- fixed automatic fire extinguishers are used,
- walls separating up to two parking places were built with fire resistance class of the minimum EI30, from the floor to the ground with clearance under the ceiling of 0.1 to 0.5 m in height.

On each floor of the garage with a total area exceeding 1500 m^2, there should be at least two escape routes (Fig. 9.3) and the distance to the nearest emergency exit should be:
- in a closed garage – maximum 40 m,
- in an open garage – maximum 60 m.

The distance to the nearest exit can be increased only if there is:

- fixed fire extinguishing equipment – by 50%,
- automatic smoke extraction system operated by smoke detectors – by 50%.

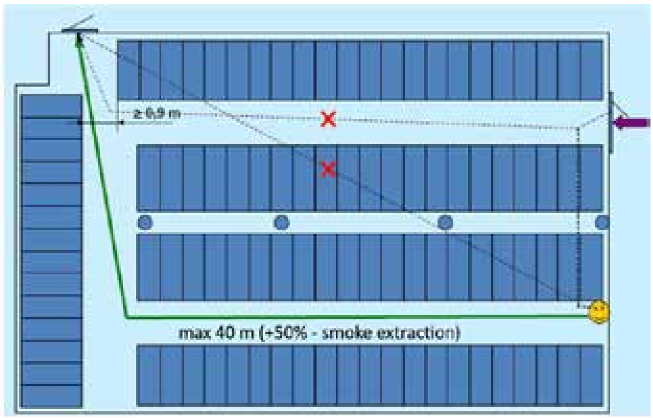

Fig. 9.3. Required distances to escape routes (Source: based on data from ALNOR, 2017; Zaforymska, 2017)

9.2.4. Main requirements for installation of smoke extraction system

Smoke extraction requirements (REG-1):

The smoke extraction installation should remove the smoke with an intensity that ensures there is no smoke or high temperature during the evacuation of people in protected passageways and evacuation routes.

There should be maintained constant supply of outdoor air to the enclosed garage, thus supplementing the exhaust air with the smoke.

Requirements for smoke extraction ducts, due to fire integrity and smoke tightness criteria (REG-1):

- Cables serving one fire zone should have at least a fire resistance class E600S, that is at least the same as the fire resistance class of the ceiling. It is acceptable to use a lower smoke class E300S, provided that the calculated smoke temperature does not exceed 300°C.
- Cables serving more than one fire zone should have at least the EIS fire resistance class, which means at least as high as the class of the ceiling.

Requirements for shut-off flaps in smoke extraction ducts, due to fire integrity and smoke-tightness criteria (REG-1):

- Shut-off flaps serving one fire zone should be started automatically and have at least the same fire resistance class – E600S AA – as the ceiling. It is acceptable to

use a lower smoke class E300S, provided that the calculated smoke temperature produced during the fire does not exceed 300°C.
- Shut-off flaps serving more than one fire zone should have at least a fire resistance class EIS AA, such as the class of the ceiling.

Requirements for smoke extraction fans (REG-1):
- smoke extraction fans F_{600} 60 – if the predicted smoke temperature exceeds 400°C;
- smoke extraction fans F_{400}120 – in other cases, unless the analysis of smoke temperature calculations and the safety of rescue teams is possible.

Requirements for smoke flaps in gravitational smoke extraction (REG-1):
- class B_{300} 30 – for flaps opened automatically,
- class B_{600} 30 – for flaps that are only opened manually.

All the above smoke extraction components should meet the standard PN-EN 1351 – 4:2008 Fire classification of construction products and building elements, Part 4: Classification based on the results of fire resistance testing of smoke diffusion control systems.

Fire-fighting devices in the facility should be constructed in accordance with the fire protection design agreed upon by a fire protection expert and shall only be approved for use on condition of carrying out appropriate testing and fire conditions can be increased only if there isappropriate testing and validation for the equipment in question (PN-EN 1351-4:2008).

9.3. Division of garage smoke systems

Due to the practical and economic aspects, ventilation systems are commonly used to combine two functions – life saving and fire protection. Please note that in this situation, the fire protection conditions should be a priority in designing a two-way system. In the case of closed garages, only mechanical ventilation systems (Fig. 9.4 and 9.5) should be used. Until recently, the garage ventilation system was often used as a duct system that served as both the ventilation and the smoke extraction system in the event of fire. At present, more and more often the jet fan ventilation system is used, flow fans are installed directing the flow of smoke or the flow of clean air throughout the garage space or the underground car park.

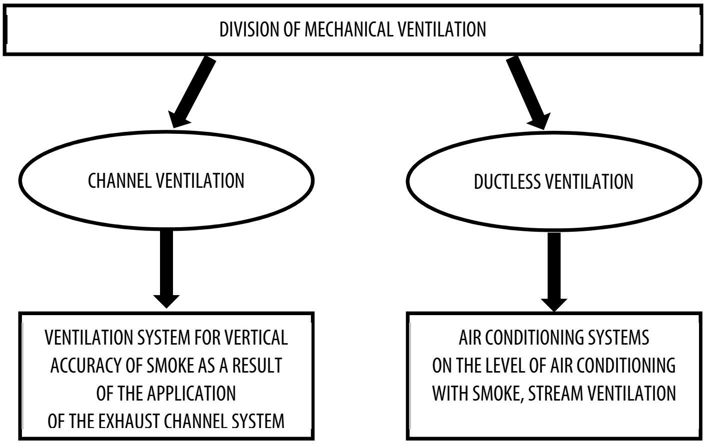

Fig. 9.4. Fire protection systems used in closed garages (Source: own elaboration based on data from Mizieliński & Kubicki, 2012)

The operation of both installation systems will be discussed in more detail below.

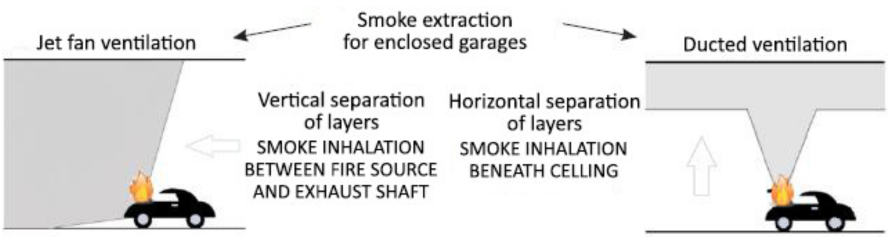

Fig. 9.5. Division of the garage fire protection ventilation system (Source: based on data from ALNOR, 2017)

In order to ensure the correct operation and efficiency of smoke extraction systems, technical inspections and maintenance work are required to be performed at periods established by the manufacturer, but not less than once a year.

9.3.1. Construction and principle of operation of fire ventilation systems

Traditional duct fire ventilation system consists of the following components:

- ventilation ducts,
- ventilation grilles,
- exhaust fans,
- fire dampers.

All these components must meet the operational requirements in the event of fire.

In order to ensure proper operation of the duct system (Fig. 9.6), the garage must be divided into smoke zones using smoke curtains (pos.1). Their aim is to stop the spread of smoke to the rest of the garage. In case of fire, smoke is removed through the grating on the ducts (pos. 2). There is a clear division into the hot smoke layer under the ceiling and the smoke-free layer (pos. 3). Compensatory air is supplied in such a way that it does not cause smoke to fall (pos. 4).

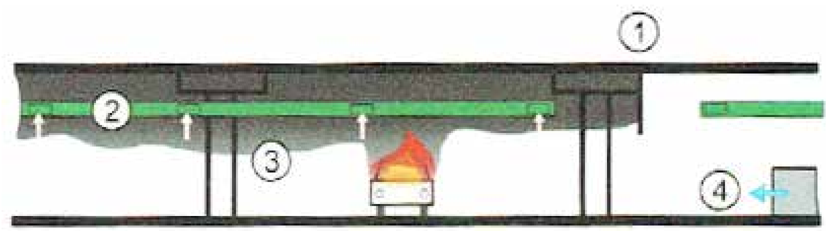

Fig. 9.6. Principles of operation of the smoke ventilation duct system (Source: based on data from Węgrzyński & Krajewski, 2015)

The following conditions must be met in order for the installation to meet fire safety requirements (Mizieliński & Kubicki, 2012):

- two-speed or inverter-controlled fans (variable speed) need to be installed,
- adequate amounts of exhaust air under normal and fire conditions must be ensured.

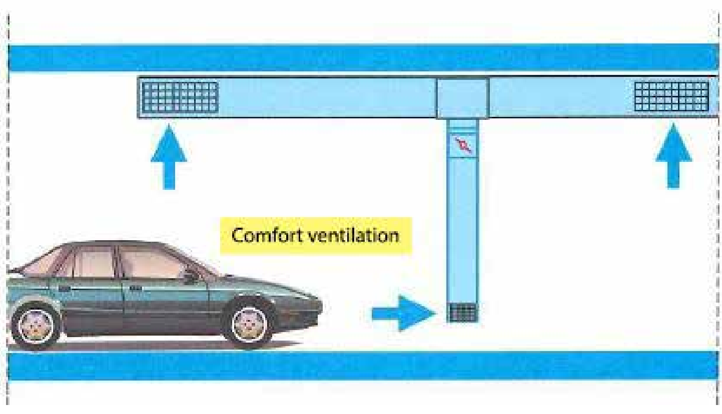

Fig. 9.7. Operation of the duct ventilation system in normal conditions (Source: based on data from ALNOR, 2017; WEB-1)

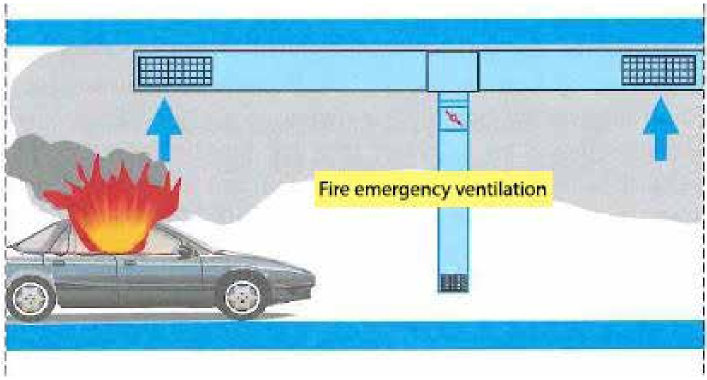

Fig. 9.8. Operation of duct ventilation system in fire conditions (Source: based on data from ALNOR, 2017; WEB-1)

Exhaust grates should be located at two heights above the floor level (Figs. 9.7, 9.8):
- at a height above 1.8 m – removing lighter fractions of impurities,
- at less than 0.8 m above the level of the floor – removing impurities heavier than the air.

During normal operation of the installation, about 60% of the air is removed from the ceiling space, while the remaining 40% from the floor level. In the event of fire, the lower extractor is cut off and 100% of the fire output of the air is drawn through the upper grilles. A typical flow diagram of the duct system for smoke extraction is illustrated in Fig. 9.9.

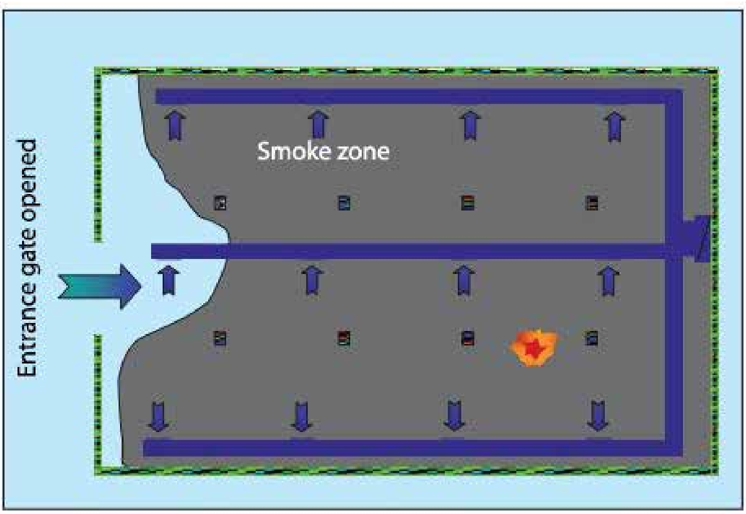

Fig. 9.9. Duct system in smoke function (Source: based on data from ALNOR, 2017; WEB-1)

Conditions for proper ventilation of the ventilation duct (NBN S 21-208-2):

- required garage space:
  - required area of the smoke zone: 2600 m^2,
  - maximum length of the smoke zone: 60 m;
- minimum required height of the garage:
  - with the use of sprinkler system: 2.8 m,
  - without sprinklers: 3.8 m;
- required height of the smoke-free layer:
  - with the use of sprinkler system sprinklers: 2.5 m,
  - without sprinklers: 3.5 m;
- the smoke layer should remain at least 0.3 m below the lowest element of the ceiling;
- requirements for system components:
  - smoke exhaust fans with sprinkler system: 200°C/1h,
  - smoke exhaust fans without sprinklers: 300°C/1h,
  - exhaust channels: 200°C/1h.

Such high demands are to ensure the free movement of people, both evacuees and rescue workers. Garages that do not meet the above requirements should be covered by ductless ventilation system.

9.3.2. Construction and principles of operation of ductless fire ventilation systems

The fire ventilation system is based on the use of parallel axial flow fans (jet fans). Most commonly used devices are those of circular cross-section and diameters from 315 to 450 mm. The fans are equipped with silencers on both sides, i.e. on the inlet and outlet side. The installation site of these units is the upper part of the garage space and in the human habitation zone. Jet fans process relatively small amounts of air, but with considerable speed. In this way, the air flow is of up to 40 m.

The jet fan ventilation system consists of the following elements:

- fet fans;
- air intake system at the time of smoke extraction: mechanical ventilation with air supply fans (aeration) or air supply through the ventilation openings or entry gates due to negative pressure caused by the exhaust fans;
- main exhaust fans;
- air supply and exhaust shafts fitted with grilles that function as an air intake and exhaust system;
- jet fans, other than the ones used during smoke exhaust operation.

The role of jet fans in normal conditions is to force the orderly flow of air masses in the whole volume of the garage, from the supply air holes to the air extraction points. (Fig. 9.10). The performance of the ventilation system is adjusted by the automation system to the momentary demand for fresh air. The signal to change the operating parameters of the equipment is the concentration of carbon monoxide (CO) or LPG in the garage, measured by appropriate sensors. This solution gives a lot of flexibility to the system and allows for its optimal operation, in terms of both economics and efficiency of air exchange in the facility (Król, 2014).

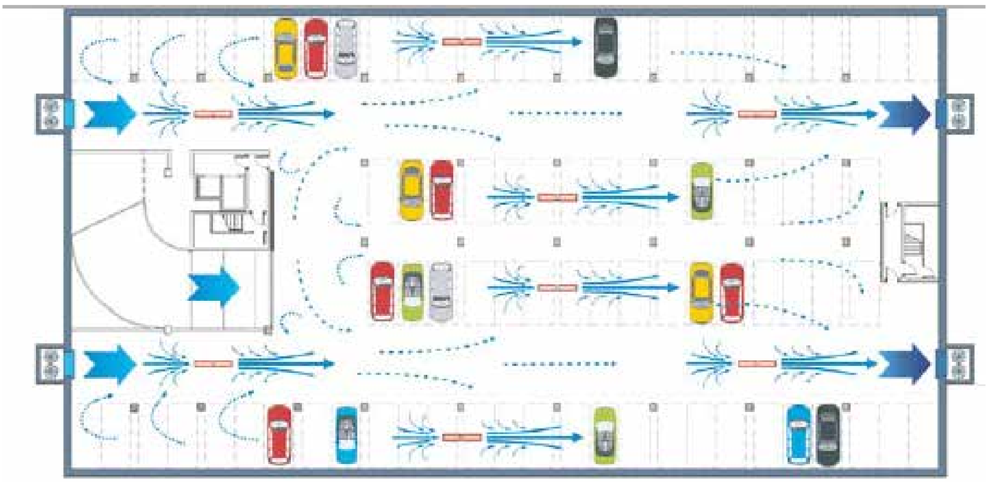

Fig. 9.10. Operation of jet fans for garage ventilation (Source: based on data from Król, 2014)

Proper operation of the CO and LPG detectors depends on their proper location in the garage. Detectors should be arranged according to the following rules:

- on walls, supports, pillars at the height of not less than 180 cm from the floor;
- away from the supply openings;
- near the exhaust holes;
- in places not exposed to direct external air supply, water vapor, water, car exhaust, dust, etc.

All system components used in ductless ventilation must meet the requirements imposed on ducted fire ventilation.

The primary role of the system under fire conditions is to limit the spread of smoke within the garage and to turn it as quickly as possible to the exhaust points, whereby the contaminants are removed to the outside of the building (Fig. 9.11). In the event of a fire alarm, the system automatically switches to fire mode. The installation at this point achieves the highest possible performance. At the same time, the entrance gate to the garage is opened, through which the external air is let in, compensating air flows due to the negative pressure caused by the exhaust fans. Due to the use of jet fans operating in the reverse system, the direction of the air flow in the garage can be adjusted to the location of fire. Achieving full flexibility of the system also requires the use of variable flow fans in the exhaust and supply system. At the same time, ensuring adequate airflow in the event of fire, may undoubtedly require additional fans. Additional fans will only be used in fire conditions, otherwise they will remain in working order.

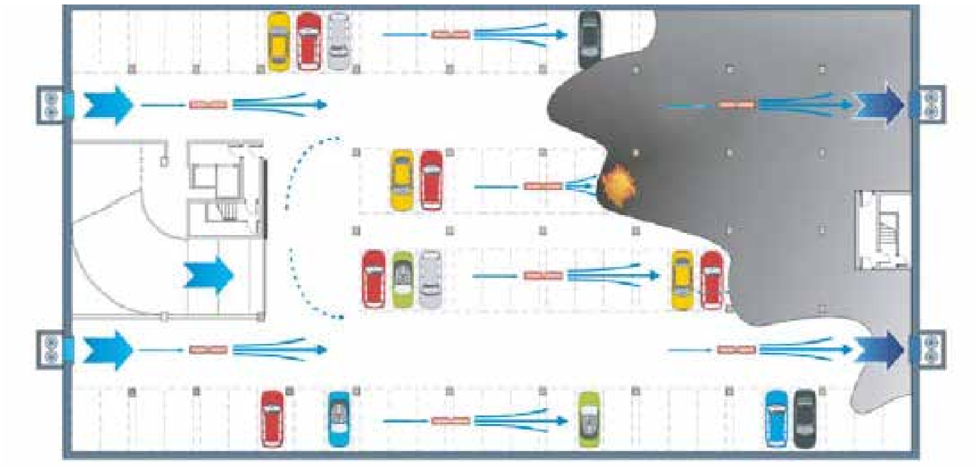

Fig. 9.11. Operation of jet fans for the needs of fire ventilation (Source: based on data from Król, 2014)

A general diagram showing the operation of the system using jet fans is presented in Fig. 9.12.

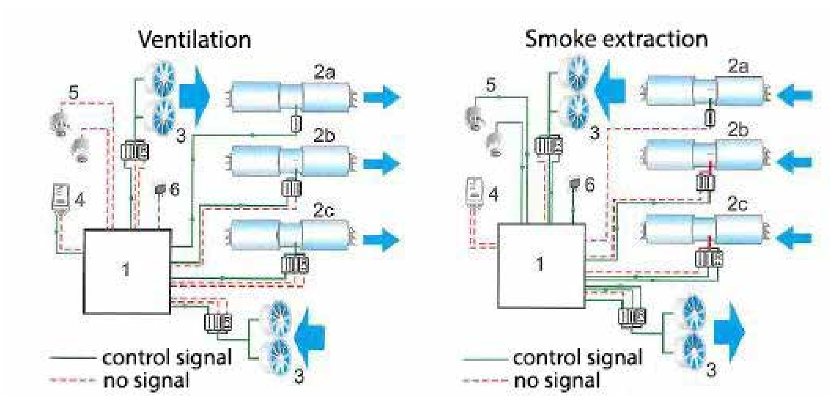

Fig. 9.12. Control of the ventilation system in home and fire ventilation (Source: based on data from ALNOR 2017, Król 2014)

After performing all necessary calculations and preliminary selection of system components, it is advisable to perform the appropriate simulations using CFD programs to verify the correctness and effectiveness of the adopted system. Numerical analysis allows verification of the correct distribution of supply and exhaust openings and jet fans in the garage space. Computer simulations will also allow you to correctly set the system start-up time to optimize the protection of escape routes. The complete design of the ductless system should consist of the following components (Fig. 9.13):

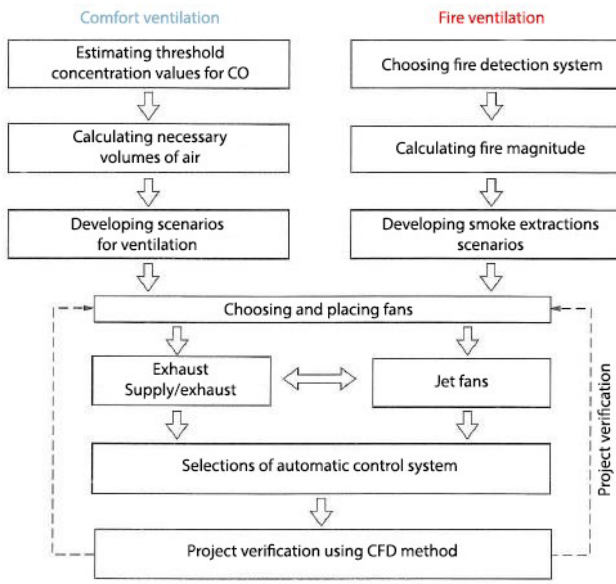

Fig. 9.13. Design procedure for ductless system (Source: based on data from ALNOR, 2017; Mizieliński & Kubicki, 2012)

During the work on selection and placement of fans, the following aspects should be taken into account (WEB-2):

- jet fans should be positioned so that the flow is directed towards the exhaust points;
- the aggregate capacity of the jet fans cannot exceed the total amount of air supplied to the garage;
- jet fan should be positioned so that the air velocity at the contact points of the individual planes is not less than 1 m/s;
- for the modelling of the fan system in a parking area, only the airflow generated on the discharge side is taken into account; the suction side is not considered;
- smoke should be directed in such a way as to allow the rescue crew to move freely;
- smoke during the spread must not occupy a surface greater than the permissible area of the smoke zone (the allowable area of the smoke zone is 2600 m^2);

- the minimum efficiency of the BS-7346-7: 2006 smoke system is 10 ACH/h;
- jet fans should be switched on with a delay, only after evacuation. The delay time is based on the RET (Required Evacuation Time). This time is calculated taking into account the appropriate evacuation time, fire detection time, alarm time, event recognition time and event response time.

9.3.3. Compensating air supply

A very important element of a garage fire ventilation is the need to provide a sufficient amount of complementary air flow through the entry ramps, garage doors (open during fire) or other openings dedicated to this purpose. This is a condition for its normal and undisturbed functioning. Taking into account the effectiveness of the fire ventilation system, it is desirable that the compensating air grates are located in the lower part of the space so that when the smoke is exhausted, clean air from the outside pushes the smoke layer up to the ceiling area (Smardz & Paliszek-Saładyga, 2011).

One of the most common causes that lead to too fast a drop of smoke is the induction of air from the garage space to the supply air with too high a velocity of the compensation air (Fig. 9.14). This induction depends on the supply air velocity and the distance from the upper edge of the supply point to the base of the smoke layer (WEB-3).

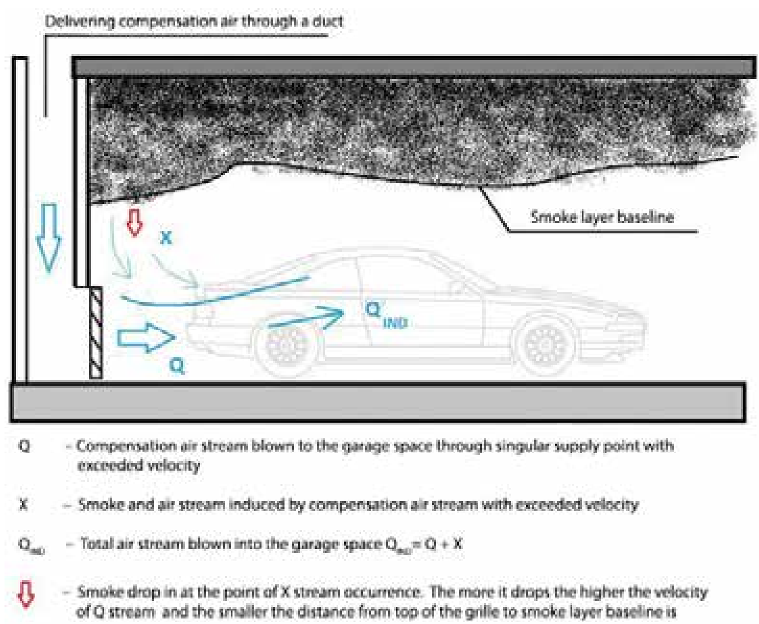

Fig. 9.14. Sketch showing the principle of inducing air and smoke through the supply point causing the smoke to fall during the operation of smoke extracting through a duct (based on data from ALNOR 2017; WEB-3)

The TR 12101-5 standard and associated with it BS 7346-4 standard indicate that the distance from the upper edge of the supply point to the base of the smoke layer should be no less than 1m unless the compensation air velocity is less than 1 m/s. This case is very common in typical garage projects with a smoke exhaust system because it involves the use of the gate as a compensating hole (Fig. 9.15) (BS 7346-4:2003; CEN/TR 12101-5; Gładyszewska-Fiedoruk & Nieciecki, 2016).

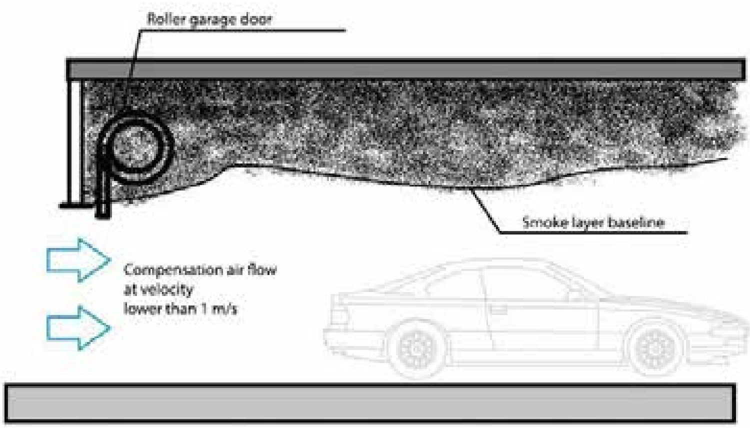

Fig. 9.15. Using the entrance gate as a compensation hole (based on data from ALNOR, 2017; WEB-3)

The compensation air velocity of 1 m/s also appears in the NFPA 92 standard. This value is given for the compensation air stream during contact with the smoke or smoke convection column in the smoke collector. For the sake of simplicity in terms of such records, it can be assumed from the standards that the local limit of air velocity for which a laminar flow (without induction) ends and a turbulent one starts, is about 2 m/s. The speed in the compensation hole will always be different at every point of the hole. For safety reasons, this speed should not exceed 2 m/s. For design purposes it is therefore recommended to adopt an average design speed of 1 m/s (NFPA 92).

Bearing in mind the above guidelines, it is best to locate the place of supply of compensating air as far away from the smoke as the adjacent smoke zone. From the point of view of ensuring the proper efficiency of the installation and the means needed to achieve the intended purpose, this is definitely the best solution. The air velocity in the evacuation zone, i.e. at passages and crossings, should not exceed 5 m/s.

However, it should be borne in mind that the resulting air movement and induction method should not significantly affect the smoke zone in which the fire has been detected.

Another alternative is to feed the compensating air through smoke channels in the neighbouring smoke zone by reversing the activation of the smoke extraction fans. Although the grilles on the ducts are located under the ceiling, the air effectively loses its velocity and flows under the smoke curtain adjacent to the smoke zone thus protecting the zone against the inflow of smoke. In order to comply with the above guidelines, always apply compensation air from two opposite sides of the garage (Gładyszewska-Fiedoruk & Nieciecki, 2016).

9.3.4. Simplified scenario for the operation of a fire system

In order to guarantee proper operation of a fire ventilation system one should (Węgrzyński & Krajewski, 2015):

1. stop the functioning ventilation system,
2. isolate fire zones (doors, fire gates) including automatic lowering of smoke curtains,
3. control fire dampers included in the fire ventilation system,
4. open gravity compensating air sources (external gates, dampers on gravity aeration channels,
5. turn on the exhaust fans with full or limited capacity,
6. in case of jet ventilation, after the evacuation time ends, activate full-flow and exhaust fans.

It is very important that the fire alarm system performs a fire scenario only for the first detected fire location. Turning-on the exhaust or supply fans should always follow the clearing of shut-off or fire flaps. When smoke is detected, the smoke exhaust system is activated in the fire zone.

Improper operation of the system by not blocking the fire scenario for the first smoke zone may cause the system shutdown for this zone. Small amounts of smoke entering the neighbouring smoke zone can trigger the system in this zone and stop it for the fire zone.

9.3.5. Commissioning of fire ventilation systems

It is a condition for the use of fire-fighting equipment to carry out appropriate tests that confirm the correct operation of the fire-fighting equipment. During these tests, hot air and smoke are used instead of fire in the building without causing damage to the structure, installation or interior trim. Smoke spreading under the ceiling activates the fire detection system which instantaneously sends signal to the fire safety system, following the fire scenario set up for the facility.

During the hot smoke test, first and foremost, the following aspects are assessed: the length of time of maintaining the two separate layers of smoke, the ability of the system to locate the source of fire and confine the smoke to a single smoke zone. The test also checks the start-up time, performance of all the system components, as well as its cooperation with other security systems located in the building. The test fire power used in the hot smoke test should not be less than 300 kW for garages equipped with fixed water fire extinguishers and not less than 450 kW in other garages. When the garage height exceeds 3.2 m, it is advisable to increase the fire power to reach a higher temperature of the smoke layer under the ceiling (AS 4391-1999). If there is a sprinkler system in the garage, it should be adequately protected from uncontrolled water discharge.

Hot smoke tests also verify:

- the effectiveness of maintaining smoke in the under-floor layer for the evacuation of people;
- not mixing of smoke and compensating air;
- the limitation of smoke ingress outside the smoke zone in which the test is being conducted, and the correctness of the implementation of solid or active excrements (smoke curtains);
- the correctness of operation of the fire detection and alarm system;
- the impact of location, size and number of supply points on the quality of the smoke extraction system;
- the correctness of the designed and manufactured smoke extraction system – visual assessment;
- in case of smoke and heat spread control systems, the assessment of whether or not a source of fire is available at a distance of no more than 15 m.

Hot smoke tests provide the possibility of detecting beforehand defects and failures in fire protection system implementation that cannot be detected through simplified tests or by setting off individual detectors. Warm smoke test is currently the most realistic method for verifying the functioning of smoke and other fire safety systems, such as: detection, alarm and control automation systems.

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