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Microclimate in Buildings and the Quality of Life in the Context of Architectural Design

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Microclimate in Buildings and the Quality of Life in the Context of Architectural Design

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Abstract. Consumer lifestyle, caused by the dynamic development of the economy, affects the development of the built environment. More and more buildings are created with different functions absorbing significant amounts of energy both during the implementation or operation. They have an increasing impact on the environment. Despite the fact that the paradigm of sustainable development determines the attitude on the demand side, quite frequently public utilities are implemented as if separated from the broader context, as "icons" of architecture. The foregoing often has a negative impact on the quality of the natural environment as well as on the quality of life and health of the users. Such objects can be realistically sustainable, yet they require the implementation of the concept of the built environment resulting from the principles of sustainable development, i.e. in which all of the components, including architectural substance, technical infrastructure, biologically active areas (acting multi-layered structure) are characterized by high environmental performance and provide users with the proper conditions for life and work. They should also assist human development across the complexity of existence, giving the possibility of implementing the needs of individual users while at the same time over-running the development of the entire community both now and in the future. For this reason, it becomes necessary to ensure the healthy and eco-friendly built environment for users. The field of research described in the article includes the methods of shaping the microclimate in an efficient manner in the architectural objects enabling the avoidance of "sick buildings" syndrome risk and the implementation the high-quality environment for the users spending more and more time in them. The objective, in the context of architectural design, is to present the relationships between technological systems and architecture while attempting to optimize solutions.

1. Introduction

In the concepts of sustainable cubature buildings, the impact on the environment is considered in terms of the location and orientation of buildings in relation to the directions of the world, the use of local building materials, advanced technological systems and infrastructure as well as adjustment to users' needs. The amount of energy and raw materials used for the implementation, operation and expected demolition of buildings in terms of their environmental impact is analysed using a holistic approach.

In sustainable communities the notion of sustainability refers both to cubature buildings and the environment. Built environment concepts are expressed in sustainable spatial-functional solutions, housing form and density, the density of roads, power engineering infrastructure, water and sewage systems, attention to natural conditions and biologically active areas. These concepts also encompass the limitation of circulation by locating in the vicinity primary daily-life elements, such as places of residence and work as well as widely defined services and recreation.

Although human life is subjected to and governed by phenomena taking place in nature, today's architecture often separates its users from nature. Closed high-tech building systems constitute a barrier in relation with the context of a place, climate and the natural environment. To maintain comfortable living standards, artificially created environments require significant energy inputs entailing the consumption of significant amounts of fossil fuels. Although on the way of evolution humans accepted a new environment and as a result acquired ability to live in the world of technology (technosphere), their need for the contact with nature has remained unchanged [1].

Since the end of the previous century the consumer lifestyle has been remedied by the revival of an architectural vision based on landscape and bioclimatic site qualities involving the use of innovative and effective technologies aimed to optimise the use the aforesaid qualities. In most cases, the so-called *eco-tech approach* involves:

- abandoning air-conditioning systems for natural ventilation and heating based on the so-called *double skin*, i.e. facades composed of two layers between which air can flow but which also enable the accumulation of heat;
- use of energy elements acquiring energy from renewable energy sources and compiled with the structure of buildings;
- use of automatic shading elements integrated with facades and controlling (by responding to the movement of the sun and air) the access of natural light and solar radiation to the interior (see Figure1);
- use of internal atria as systems of natural additional lighting of interiors;
- use of greenery on roofs and elevations integrated with the surrounding greenery, thus forming permeating systems enlarging a biologically active surface in urbanised areas.

Figure 1. Elements of solar architecture on the office building facades in Weiz, Austria and Heerlen, Holland (photo by B. Majerska-Pałubicka)

An ecological vision in design solutions leads to the integration of passive and active systems, combining traditional bioclimatic architecture with innovative modern solutions and technologies in hybrid systems, becoming an important factor leading to sustainability. Passive systems integrated with active systems, using highly efficient and renewable energy technologies for heating, cooling and lighting demonstrate the possibility of obtaining a new level of ecological efficiency. In addition, sustainable architecture-related references to solar energy and resultant wind energy, climate, day and night rhythms, seasonal changes and the possibility of implementing effective modern technologies in integrated systems appeal to creators' designing ambitions and aesthetic aspirations, providing the possibility of obtaining a high quality of designed buildings. Design strategies are increasingly often characterised by the pursuit of simplicity and widespread availability of applied technologies. Design integration is required at the earliest concept stage, yet it brings significant advantages such as a high efficiency of implemented solutions and enables the integration of land development, architecture and technology.

Performed analyses revealed that solutions aimed at the obtainment of sustainability in the built environment should be based on hybrid solutions enabling the use of [2]:

- passive bioclimatic architecture, where the creation of optimum microclimate conditions in buildings is based on local conditions, climate, landscape topography, local renewable energy sources and tradition;
- local and natural building materials to limit transportation;
- effective technologies related to the use of renewable sources of energy, treated as the supplementation of passive solar technologies;
- ground as the thermal insulation of buildings;
- zero-energy and emission neutral systems leading to plus-energy and zero-emission solutions.

In the context of solar design, citing Christian Schittich [2], it should be emphasized that the holistic approach to design excludes the reduction of architecture to separate elements, e.g. solar collectors or photovoltaic systems on the roof. The building should be perceived as a complex configuration, i.e. a total energy concept, providing the best possibilities of using locally available natural sources of energy, e.g. solar, wind or geothermal. Passive and active indicators complement one other, from the orientation and zoning of a building to the integration of technical systems generating hot water or energy. Active building shells (casings) acquire new significance as they are adjusted by intelligent control systems responding to variable effects and weather conditions.

2. Energy-effective buildings

When considering the sustainable built environment it is assumed that all objects composing it are also sustainable (e.g. energy-saving buildings satisfying primary requirements related to energy consumption restrictions). However, the objective is to build zero-energy buildings nearing plus-energy objects. Their technological systems generate (out of renewable sources) energy sufficient to cover, at least, the necessary demand during the operation of such objects and create the optimum quality of life for the present and future generations. According to reference publications, the improvement in energy efficiency in buildings is the most cost-efficient approach enabling a significant reduction of greenhouse gas emissions. Along with the development of renewable energy sources, the aforesaid improvement in energy efficiency considerably reduces climatic changes and improves the quality of life. Changes in management principles and the use of energy-efficient technologies can reduce energy consumption by approximately 35%. However, energy efficiency obtained traditionally, i.e. through individual solutions, does not hold the key to the future of sustainable building engineering. It is necessary to coordinate efforts and adopt a holistic approach [3].

Demand for energy in buildings is connected with the primary stages of the investment process, excavation, production, distribution and the transport of building materials to a construction site, implementation, operation and adaptation or, the demolition of buildings (if any), disposal and the recycling of the remaining building materials. Because of this, energy consumed by a building during its entire life should be approached from three different perspectives, and viewed as follows:

- built-in energy, i.e. energy used to excavate raw materials, produce, distribute and transport building materials to the construction site and energy accumulated in a building during its erection, repairs and improvement works;
- operating energy, i.e. energy used during the operation of a building for heating, cooling, ventilating, air-conditioning, lighting, water heating, daily life purposes etc.;
- processing energy, i.e. energy necessary during the demolition of an object and the use or disposal of waste building materials.

Presently, when implementing the assumptions of sustainable development, demand for energy at each investment stage becomes an equally important issue. However, the period of building operation, i.e. usually the longest building life cycle, is characterised by a high demand for energy, constituting approximately 80-85% of the total demand for energy [3]. The reduction of energy consumption can also be obtained by optimising the technology used for the excavation of raw materials and the production of building materials. Materials and solutions characterised by very good technical parameters and high quality as well as structural materials having smaller cross-sections and characterised by higher strength make it possible to reduce amounts of building materials used during construction, restrict energy consumption during the production of building materials and shorten the time of construction. In addition, the consumption of built-in energy can, directly or indirectly, be reduced by using the following solutions:

- designing of buildings lasting longer, being more durable, needing fewer or even not needing repairs, which additionally reduces necessary operating energy,
- preferring materials, the production of which can involve the use of renewable energy and minimising the use of energy-consuming materials;
- using locally available raw materials and building materials, the production and transport of which require less energy;
- avoiding materials generating fewer problematic emissions and less waste;
- using highly recyclable materials, which additionally reduces the demand for processing energy;
- providing the possibility of segregating materials during repairs and demolitions, which additionally reduces the consumption of processing energy;
- using flexible solutions allowing changes and adaptation to user's present needs and requirements, which additionally reduces the demand for operating and processing energy.

The above-presented analyses reveal the existence of a correlation between the efficiency of solutions affecting the consumption of built-in energy and the efficiency of the consumption of operating and processing energy. Demand for energy during the operation of a building is, to a significant extent, demonstrated by demand for electric, heating or cooling energy. Electric energy is used to satisfy primary needs connected with lighting, powering appliances related to building operation, monitoring and living functions. Heat is used to prepare hot utility water and to heat buildings, whereas the cool is used to lower internal temperature and protect against overheating (in air-conditioned systems). In addition to the rationalisation of demand and consumption of operating energy, the optimisation of demand for energy and heat in buildings is obtained through the minimisation of heat losses through the building's external barrier, including external walls, ground floors, slab roofs, roofs, window and door framework as well as by reducing heat losses in various, particularly ventilating, systems. The efficiency of optimisation is affected by location, functional and spatial solutions, form, areas of external barriers in relation to the cubature and the manner of operation. Related research has revealed that the quality of applied structure and building materials is also of significant importance. Depending on materials and structural solutions as well as on the structure and tightness of the building's external barriers, heat losses can reach up to between 40% and 70% of the total demand for [4]. The use of appropriate protections and solutions including the installation of tight window and door framework characterised by low heat transfer coefficient, the use of efficient thermal insulation and the elimination of thermal bridges decrease heat losses, thus passively reducing demand for heat. Presently, significant attention is paid to the building's external barriers having the form of shells responding to weather conditions [4].

The rationalisation of operating energy consumption is also achieved by the management [5], monitoring and automatic or manual control of the operation of electrical appliances, including lighting, heating and cooling systems. The distribution and consumption of energy is adjusted using high-performance heat/cold acquiring recuperators, automatic control, controllers, control systems and thermostatic valves in synchronised control systems. A new approach includes the synchronisation of various solutions and the integration of applied heat sources in hybrid solutions. One of the most convenient solutions is based on the Modular Energy System (MES) of energy (heat) supply to buildings [6].

For many years, the measure of the development of energy-saving technologies in building engineering has been the demand for thermal energy necessary to heat 1 square meter of the utility area of a building. According to related reference publications, in 1966 in Europe the average demand for thermal energy stood at 350−240 KWh/sq. m. to reach 120−160 KWh/sq. m. in the years 1993-97. Since 2000, the consumption in buildings regarded as energy-efficient amounted to 60−30 KWh/sq. m. and has been gradually decreasing. Presently erected buildings which are based on a passive-house concept are characterised by the maximum demand for energy restricted within the range of 15−12 KWh/sq. m. Passive technologies are treated as a stage leading to buildings characterised by the zero-demand for final energy used for heating, cooling and lighting or even generating energy from renewable energy sources [3].

In the context of an increase in energy efficiency, the principal technical development is visible in the sector of residential and commercial buildings. This sector imposes radical requirements entailing the necessity of using the latest energy-efficient technologies. New successfully introduced energy and environmental standards for assessment and certification such as the German energy certificate 'Passivhaus', BREEAM, LEED, Swedish 'Minerze' and 'NetZero Buildings' etc., facilitate the implementation of solutions reducing the consumption of built-in and operating energy (heating, cooling, hot utility water, lighting as well as the powering of household appliances and technological equipment) without compromising the utility comfort.

3. Microclimate of interiors

The conditions of internal microclimate should provide users with a healthy environment. Modern technological achievements enable the obtainment of any comfort parameters in rooms, yet costs of such an obtainment grow proportionally to requirements, both in terms of investment and running costs. Therefore, the design of objects friendly both in relation to the environment and users requires the participation of an interdisciplinary team of specialists, usually coordinated by an architect responsible for the development of optimum design solutions. The above-named solutions should take into consideration contemporary spatial, functional, technical, material, energy-related, ecological, economic as well as social and cultural needs. To meet such a challenge, architects’ knowledge must be extended and include sectoral issues, often related to the shaping of interior microclimate. Assumedly, the implementation of rationalised solutions aimed to reduce energy consumption without compromising the obtainment of appropriate parameters in rooms should help achieve economic, ecological and social benefits.

Material surroundings with which a human comes into contact, intentionally or accidentally, when staying in confined spaces, are primarily composed of air (characterised by specific physical composition, pressure, temperature, humidity and motion), impurities (dusts, gases and biological elements), radiation (electromagnetic and ionising), sounds, ultrasounds, vibration and objects, substances, humans, animals and plants (in the material sense). The human organism is able to adapt to the surrounding conditions. In spite of this, the range of allowed changes in air parameters responsible for proper heat exchange is relatively narrow. It is necessary to try and obtain the state of thermal balance between the organism and its surroundings, i.e. balance providing the sense of thermal comfort [7][8]. Parameters related to the aforesaid balance include the temperature of air in the room, the temperature of surrounding planes, the relative humidity of air in the room, the velocity and directions of airflow in the room where people are present as well as factors not related to thermal conditions such as cleanliness, the hygienic condition of air in the room, acoustic noise, the degree of ionisation and the necessary amount of fresh air. Human comfort requires the complete balance between heat discharge by a human and the amount of heat (heat economy) in the room. Ignoring the factors affecting interior microclimate results in the disturbed operation of the user’s body as well as affects user’s physical and mental condition. As can be seen above, proper microclimate conditions in confined spaces are essential to avoid the “sick building syndrome” and provide wellbeing and health to users, who, along with the progress of civilisation, spend more and more time in confined spaces, variously separated from the surrounding effect and external climate.

The microclimate of confined spaces (rooms) depends on numerous factors including weather conditions, atmospheric air pollutants, types and physical features of building materials used in a given object, architectural, structural and functional solutions, heating system, ventilation manner, natural and artificial lighting, technologies and object implementation as well as providing internal space with natural elements such as water and greenery etc. In turn, factors affecting thermal conditions of interiors include thermal comfort requirements, internal thermal and humidity loads of rooms, external thermal load of a building and operating conditions of technical equipment responsible for maintaining optimum thermal conditions in rooms. Thermal comfort has been the subject of extensive scientific publications, yet, as regards architects, important knowledge concerned with thermal and humidity loads as well as internal and external, static and dynamic loads is connected with the location and spatial, structural and material solutions and, obviously, the function of an object. The operating conditions of technological equipment are concerned with the design and operating solutions of heating and air-conditioning devices. The sensation of thermal comfort in a confined space is not an explicit notion; it is connected with the above-named parameters but is also related to user’s activities affecting the need for discharging excess heat from the body and adequate wear (changing in relation to various activities and seasons of the year) [7][8]. The sizes of the above-named heating and air-conditioning devices as well as the amount and cost of generated energy are also significantly dependent on architectural and structural solutions. The appropriate formation of the thermal characteristic of an object can reduce its thermal load, i.e. provide an answer to a question whether it is necessary to install expensive, both in purchase and maintenance terms, air-conditioning equipment.

The exchange of heat between an object and its surroundings has two types of sources, i.e. external and internal. External heat loads, more obvious to architects, taken into consideration when designing external barriers and performing thermal calculations, result from heat exchange between rooms and external surroundings of an object and depend on external climate conditions as well as heat gains or losses through the building's external barriers. External heat loads are also imposed by varying temperatures on both sides of the barrier and affected by the heat influx triggered by the solar irradiance of certain external barriers of a building. Heat exchange is diversified and dependent on seasons of the year, the time of the day, weather conditions, atmospheric transparency, dynamics of temperature changes and air motion as well as the dynamic and static thermal characteristics of a building. External thermal loads are significantly influenced by the shape and compactness of the object expressed by the proportion of the area of the external walls of a building to its cubature. The lower the aforesaid ratio, the more favourable energy-related results. The type of external barriers used in an object is also important, i.e. the fewer the glazed areas in external barriers, the more advantageous the balance.

Internal loads depend on humans and equipment generating heat in rooms. Internal loads include heat gains from lighting appropriately adjusted to the function and nature of an object and following appropriate lighting-related standards. Internal loads depend on light intensity as well as on the type and design of fixtures (e.g. ventilated or not). Fixtures can be responsible for a difference in heat emissions up to 35% [9][10]. Internal thermal loads are also affected by technological and technical equipment installed and operating in rooms. Heat gains depend on the performance of motors installed in the aforesaid equipment, operation time, etc.

Calculations should also make allowances for the mass of a building, i.e. the size of the building as well as applied structural and building materials combined with their ability to accumulate heat and cold. The time span of a day/year is characterised by cyclical fluctuations in the temperature of air in rooms and that of the building structure. In objects characterised by the significant thermal capacity of structural weight the aforesaid fluctuations are delayed. Microclimate conditions in rooms are created by ongoing dynamics interacting with appropriately selected technical and technological equipment. In

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light-structured objects characterised by low thermal capacity the above-named interactions are directly sensed in rooms and the creation of interior microclimate depends on technical equipment.

Thermal loads of rooms and objects are also affected by the form/shape of a building. An increase in the area of external barriers of a building is accompanied by an increase in external loads and by a decrease in internal loads. The above-presented phenomenon is particularly noticeable on the highest floors and in the basement, i.e. where the areas of external barriers are the largest.

4. Technology versus architecture

The condition of air in buildings results from the formation of variable independent factors, i.e. the above-mentioned internal and external loads, and of dependent factors including air processing resultant values. Heating, ventilating and air-conditioning systems should fulfil specific tasks connected with maintaining appropriate parameters of microclimate required in rooms, e.g. temperature, humidity, airflow velocity, assimilation of excessive heat and humidity, protection against air infiltration and outside impurities as well as against the propagation of smells, smoke and flames (in the event of fire). The above-named systems should be characterised by flexible operation under total and variable thermal loads. The adjustment of microclimate parameters involves the selection of appropriate phases of air processing in air-conditioning chambers. Sensors (located in rooms) monitoring the temperature and relative humidity of air pass information about the condition of air and indicate a required range of processing (controlled automatically or manually by users). Internal microclimate parameters are adjusted (within the limits of comfort) in relation to outside temperature. The exceeding of comfort limits in rooms (picked up by sensors) triggers an immediate change in the parameters of supplied air and adjusts them to required values.

In view of the foregoing, buildings should be provided with central ventilating and air-conditioning systems or individual air-conditioners. In large-spaced objects it is convenient to use central systems characterised by the constant amount of processed air, whereas in multifunctional service objects, composed of many smaller and specialised rooms used at different times, a favourable solution should be based on individual systems. It should also be noted that certain cases may require the use of mixed systems [11].

The saving of energy in multifunctional objects, characterised by individualised operation times and varying microclimate-related requirements in separated rooms, requires the zoning of systems within the function-technology relationship. The zoning of functions having the same thermal characteristics enables the effective grouping of rooms along with their technological systems. The form of a building and its functional solutions are affected by the type of a ventilating and air-conditioning system and its location as well as by the type and manner of system-related piping, wiring and cabling in an object.

Control rooms of central ventilating and air-conditioning systems are usually located in the basement or on underground floors. In such cases, air-conditioned rooms are only provided with sensors and air supply and exhaust systems. Air treatment units can also be located outside buildings e.g. on terraces or 'roof-tops'. In terms of mixed systems, air treatment units along with cooling units are located at lower levels, whereas exhaust systems are located on the roof. Because of the quality of drawn air it is advisable to locate the air intake in the greenery outside a building. In such a solution air is supplied to air-conditioning chambers through an underground conduit, thus offering the possibility of using accumulated ground heat to treat drawn air. The location of technological equipment units in one area and at the same level is convenient because of the effective use of the building area, the possibility of energy recovery and the enhancement of service.

The use of the above-presented solutions requires the collaboration of an architect, constructor and experts. The decision-taking process requires arrangements concerning location, spatial, functional and structural solutions as well as the selection technological systems affecting required comfort parameters, availability of equipment, structural interaction with buildings as well as fixing, operating (repairs and maintenance) and, very important, economic aspects.

Providing required microclimate conditions in building rooms requires the supply of significant amounts of energy for generating heat in the winter and providing cool air in the summer. Energy efficiency is obtained using energy-saving equipment as well as by recovering "used" heat and applying unconventional sources of energy. The obtainment of energy efficiency requires the selection of appropriate equipment for the recuperation and recovery of energy and is connected with providing the above-named equipment with necessary space. In addition, energy efficiency requires the appropriate form of an object and related functional solutions. Technological devices significantly affect the architecture of buildings.

5. Conclusions

Undoubtedly, the quality of the environment is a factor affecting the quality of life. The notion of quality refers to a group of physical, i.e. natural, technical and social, features incorporated into the environment, with which a human comes into contact when living. Each intervention into the above-defined natural environment quality precluding the recovery of the environment should be recognised as a factor reducing the functional qualities of the environment in relation to the requirements of a human body. For this reason, when creating a microclimate in buildings it is necessary to take into consideration the rationalisation of air-conditioning-related energy consumption as well as the complex, i.e. technical and economical, optimisation of expenses related to the implementation and operation of an entire building and power engineering project.

The primary elements of the design process include important correlations between architecture and technology as well as their effect on the form of a building, elevation solutions, glazing, the installation of technological elements, the possibility of limiting the consumption of energy and materials, the use of waste heat (e.g. from lighting, technological equipment, humans, solar radiation), structural, materials and functional solutions (e.g. horizontal and vertical zoning) and land development.

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