ENERGY EFFICIENCY METHODS BASED ON WEATHER-RESPONSIVE CONSUMPTION

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ABSTRACT:

Rising energy consumption, along with limited resources and the pronounced effects of climate change, places increasing demands on energy systems. A conceptual solution to these issues is energy efficiency- using less energy to perform the same tasks. With the aim of long-term environmental preservation, key energy-saving methods have been achieved in alignment with weather conditions. The use and coordination with renewable energy sources are becoming the main advantages of selected methods. Solar light and wind energy play a dominant role. Small changes, such as reducing the operating hours of the air conditioning system and adjusting the orientation of the building, can lead to annual energy savings. On the other hand, the inability to influence climate conditions is one of the major disadvantages. The variability of weather conditions depending on the geographical location, terrain, surroundings, as well as the season itself, further complicates the processes of energy saving. This research paper is dedicated to the analysis of energy efficiency under different weather conditions and explores methods for energy savings that can be applied in such environments. It provides recommendations building design strategies and the efficient operation of artificial energy sources in order to achieve energy efficiency.

KEYWORDS:

energy efficiency, impact of climatic conditions, solar energy, natural daylight, wind energy, natural ventilation, stack effect, building orientation, heating and air conditioning

1 INTRODUCTION

The global population growth is leading to a continuous increase in demand for water, energy, and natural resources, which causes the emergence and deepening of various environmental and social problems. As a consequence of the excessive use of fossil fuels (non-renewable energy sources), there is an increased emission of carbon dioxide (CO_2) and other greenhouse gases (GHG), which are the main causes of climate change.

The construction sector, as the largest energy consumer, accounts for between 30% and 40% of total global energy consumption. Energy consumption varies by region, with Hong Kong and Switzerland recording high percentages - 60% and 47% respectively (Figure 2). In the European Union, residential buildings consume more energy compared to non-residential ones (26% versus 11%) (Figure 3).

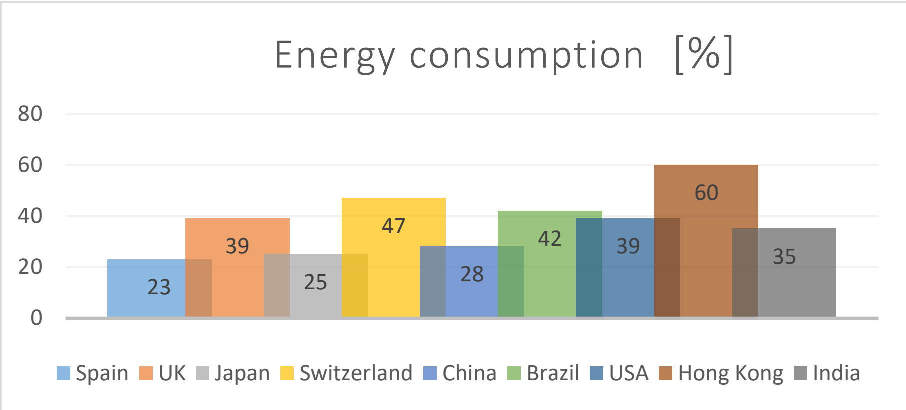

Figure 2. Energy consumption in construction sector in different regions of the world

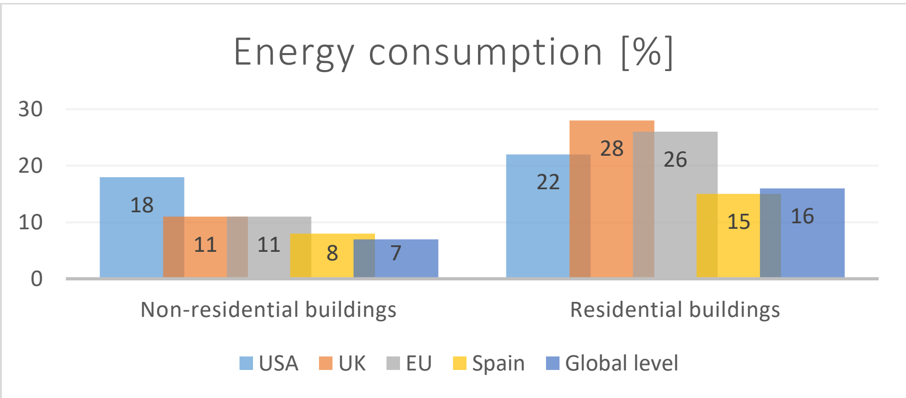

Figure 3: Energy consumption in residential and non-residential buildings

Heating and cooling have a dominant share in total energy consumption, currently accounting for around 20% of total consumption, with an expected increase to 50% by 2050. [1]

There are two main groups of factors with the greatest influence on energy consumption:

1. physical factor or environmental factors (solar radiation, air temperature, wind speed, etc.); and
2. artificially created factors (building orientation, thermo-physical properties of construction materials, etc.).

The European Union sets standards for energy efficiency, such as the Energy Performance of Buildings Directive (EPBD), within the "Clean Energy for All Europeans" package and the Renovation Wave initiative, which encourage renovations aimed at reducing greenhouse gas (GHG) emissions and improving energy efficiency. Sustainable construction aims to reduce greenhouse gas emissions (GHG) through the use of renewable energy sources, recycled materials, and energy-efficient solutions, including zero-energy buildings.

The energy efficiency of a buildings can be defined as "the actual or estimated amount of energy consumed within the building, which is subject to rationalization and savings measures, and encompasses a wide range of activities: heating, hot water preparation, cooling, ventilation, and lighting" [2].

2 BACKGROUND AND METHODS

2.1 METHODS FOR REDUCING ENERGY CONSUMPTION IN BUILDINGS

Methods of energy saving encompass various strategies and techniques that enable the reduction of energy consumption while simultaneously preserving or improving performance and comfort. Dominant methods for saving energy, reducing costs, and decreasing environmental impact can be realized through the following steps:

- Energy efficiency of buildings - optimal design, using advanced insulation materials, enables minimization of energy consumption and maximum exploitation of sunlight,
- Passive solar design - relies on the orientation of windows towards the south and utilizes natural energy sources for heating and lighting,
- Smart buildings – through the use of smart technology, automation and management of energy consumption is enabled,
- Optimization of air conditioning and heating - adjustment of the system to weather conditions,
- Energy-efficient equipment - LED lighting and devices with high energy efficiency,
- Sustainable materials - reduce the ecological footprint of buildings, including, among other things, recycled materials;
- Use of natural ventilation and lighting - reduces the need for artificial energy sources,
- Energy-saving methods during construction works – application of various measures depending on air temperature to accelerate or slow down the corresponding phases of work,
- Reconstruction and rehabilitation - improvement of the energy efficiency of existing buildings through insulation upgrades and replacement of old windows and doors, and
- Active energy-saving systems - include solar panels as well as geothermal systems for heating and cooling.

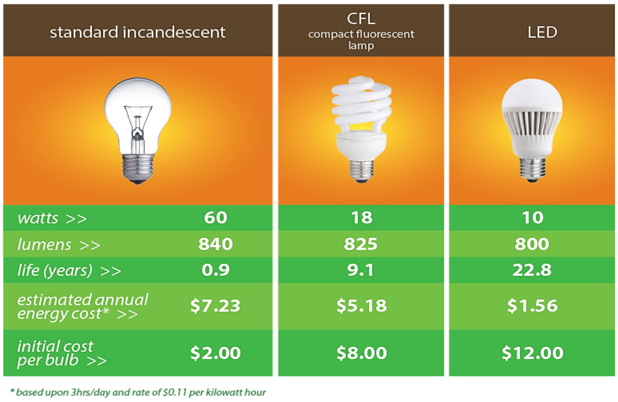

Figure 4. Comparison of Standard and LED Light Bulbs [4]

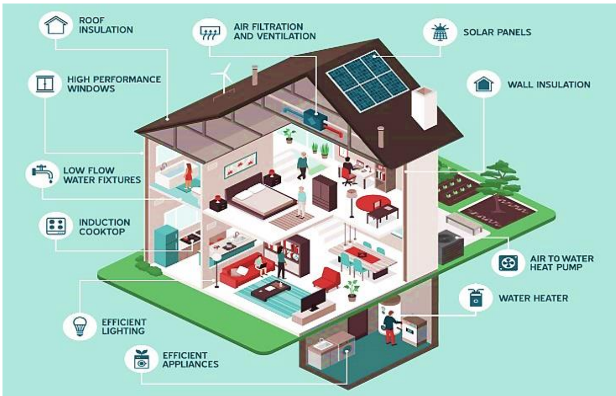

Figure 5: Smart house [3]

Figure 6: Replacement of old window and door frames [5]

The parameters that affect the energy performance of buildings include location and climatic conditions, the position of the building in relation to obstacles, orientation that affects exposure to sunlight and wind, the shape of the building, which can reduce heat loss, as well as the building envelope, which is crucial for thermal characteristics and the efficiency of the materials used.

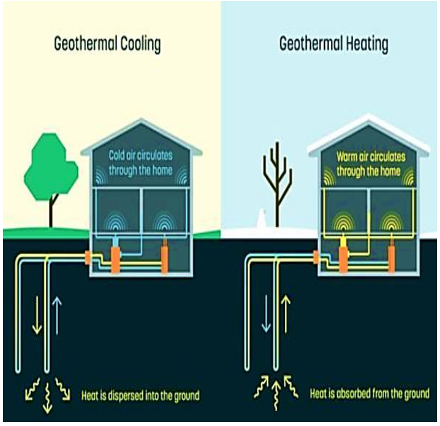

Figure 7: Geothermal heating and cooling systems [6]

Figure 8: Solar panels on the roof of a family house [7]

2.2 ANALYSIS OF WEATHER CONDITIONS AS A KEY FACTOR IN ENERGY CONSUMPTION IN BUILDINGS

With the aim of achieving energy sustainability in all phases of planning and designing a building, efforts are made to align the building as much as possible with its surroundings. Climatic factors play a key role in the planning and design of buildings, and modern approaches integrate traditional methods with technologies for energy sustainability.

The first phase of the analysis includes the analysis of the terrain and soil of the given location, through determining the altitude, average annual temperature, and the duration of low and high temperatures. Additionally, collecting data on insolation, precipitation, and snow cover is essential for understanding the energy needs of the building. The dominant factors in choosing a location are microclimate, topography, solar impact, presence of greenery and wind, as well as bioclimatic conditions. Local climate characteristics significantly affect energy efficiency, leading to the need for maximizing the use of all the advantages of the location to optimize energy consumption and minimize negative impacts. Greenery, for example, can improve the microclimate by reducing the need for heating and cooling.

Microclimate can significantly affect the energy efficiency of buildings in several ways: temperature, air humidity, wind, light, amount of precipitation, soil type, and vegetation. Southern slopes are especially favourable due to greater exposure to sunlight (10-30% more than the northern side during winter), which increases the potential for using solar energy. Insolation (solar radiation) not only improves the energy efficiency of buildings through solar heating and natural lighting, but also reduces the need for artificial lighting.

In order for a residential building to be as energy efficient as possible, it is necessary to have an optimal ratio between the total surface area of the building envelope and its volume, to be properly oriented towards the Sun, to have adequate thermal insulation, to have installed elements for passive solar gain on the south facade (windows, glass veranda, etc.), and to be protected from cold winds [8].

On the other hand, strong wind can increase or decrease energy consumption, especially in combination with rain, which lowers the temperature of the area and increases energy consumption, or it can contribute to ventilation in the summer and reduce energy consumption. Therefore, it is important to consider the direction and intensity of the wind during the planning process. During the location selection process, it is important to meet environmental standards, such as the distance from pollution sources, land safety, and flood protection.

It is recommended to choose locations with favourable bioclimatic conditions in order to achieve significant energy savings and increase comfort. Additionally, it is also important to avoid locations with unfavourable climatic conditions, as they can significantly affect the overall energy efficiency of the building.

Depending on the terrain category and urban planning conditions, examples illustrate how to position structures in relation to the site:

1. On flat terrain, multi-storey buildings should be positioned on the northern side, and lower buildings on the southern side of the site (Figure 9) [9]. It is necessary to correctly determine the mutual distance between the buildings in order to avoid the unwanted shadowing effect from the buildings located on the southern side in onto the lower buildings on the northern side.
2. The most suitable position of the terrain intended for construction, when it comes to the southern side, is on the lower side of the street. Therefore, buildings located on the upper side of the street, on the southern slope, have a less favourable position in terms of sunlight exposure. On flat terrain, multi-storey buildings should be positioned on the northern side, while lower buildings should be placed on the southern side of the site (Figure 10).
3. When a building is positioned on the northern side, there is a problem of insufficient sunlight, especially pronounced during the winter period. From this perspective, in multi-storey residential buildings, living on the lower floors is unfavourable, while the upper floors offer more favourable conditions (Figure 11).
4. The shape of the terrain significantly affects the microclimate, especially temperature, wind direction, and wind speed (Figure 12). When planning urban areas, it is important to align the orientation with the prevailing winds to ensure protection during winter and natural cooling during summer.

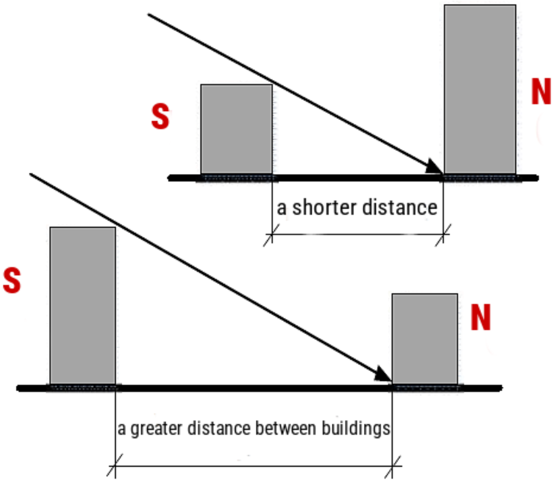

Figure 9: Optimal building orientation on flat terrain [9]

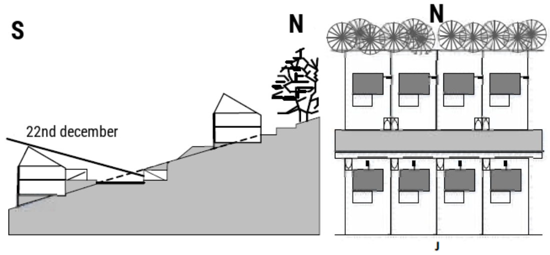

Figure 10: Buildings located on plots on a southern slope [9]

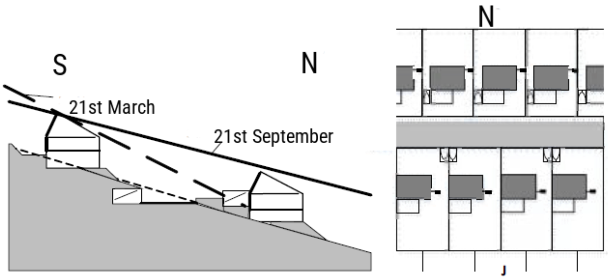

Figure 11: Buildings located on plots on a northern slope [9]

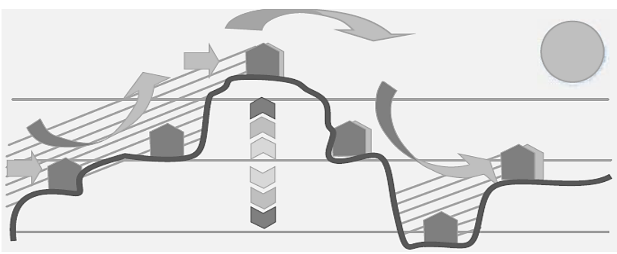

Figure 12: The impact of wind on buildings located at sites with varying elevations [9]

3 RESULTS AND DISCUSSION

3.1 OPTIMIZATION OF HEATING AND AIR CONDITIONING: SEASONAL ADJUSTMENT STRATEGIES FOR ENERGY EFFICIENCY

Energy efficiency in buildings has become a priority in many countries, especially due to the increase in energy consumption in the construction industry, particularly in building construction.

Research within the European Union from 2004 showed that the share of energy consumption in buildings compared to total consumption was as follows [10]:

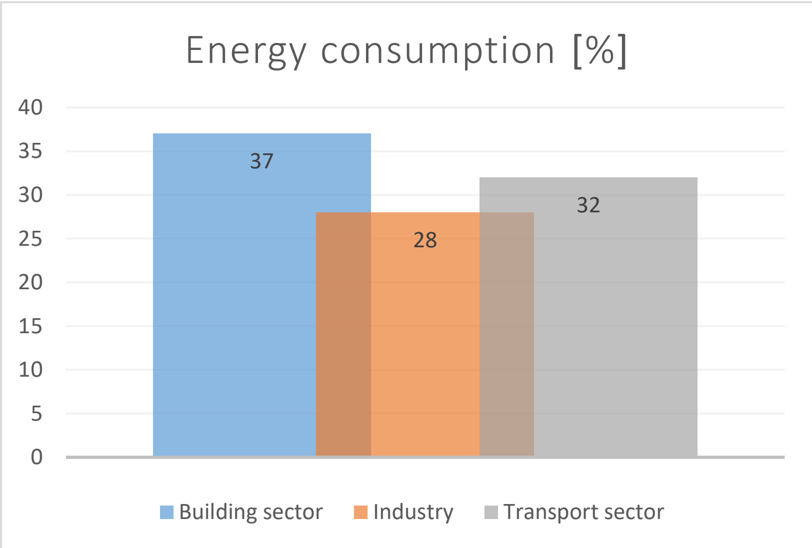

Figure 13: Energy consumption by sectors

When we talk about the share of energy consumption in residential buildings in relation to total energy consumption, the data is as follows [11]:

Table 1: The contribution of the building sector to overall energy consumption

European Union	37%
United Kingdom	39%
United States of America	>40%

Studies on energy consumption in Belgrade and other cities in Serbia have shown that thermal demands, such as heating, air conditioning, and domestic hot water preparation, account for as much as 38% of the total energy needs for all types of buildings, including residential, public, and industrial structures. Key methods for reducing energy consumption in buildings include improving thermal insulation, the use of highly efficient heating, cooling, and ventilation systems, as well as the implementation of renewable energy sources.

3.1.1 Building thermal envelope

The building thermal envelope has the greatest impact on the processes of air conditioning and ventilation processes, depending on the season.

- During the winter period, it reduces heat loss through windows, the roof, and walls, thereby reducing the energy required for heating.
- During the summer period, it prevents heat from entering the outside environment, reduces the load on air conditioning units, and improves cooling efficiency.
- In spring and autumn, it helps maintain a balance between the need for heating and cooling.

3.1.2 Heating, ventilation and air conditioning (HVAC) systems

Heating, ventilation and air conditioning systems significantly have a significant impact on energy consumption in buildings, accounting for approximately 48% of total energy consumption in the building sector [10].

In continental climatic conditions, the energy costs of air conditioning are distributed as follows:

- heating the air 40%,
- air conditioning fan and pump operation 38%,
- cooling and drying 20%,
- humidifying the air 2% [12].

Optimization of the HVAC systems can be achieved in two ways:

(1) by reducing the operating time of the system components: Setting the minimum operating time for air conditioning system components is one of the easiest and most cost-effective ways to achieve significant energy savings. The main goal of these systems in commercial, public, and residential buildings is to provide satisfactory thermal comfort during working hours, but not before or after that period. According to the EN 15251 standard, which defines three levels of thermal comfort (Table 2), a deviation from the prescribed temperature limits is allowed in the range of 3-5% of the daily working time.

(2) by improving the control program: From the perspective of the air conditioning system management, three main operating modes can be distinguished: heating, cooling, and the transitional period, when both modes are needed within a single day.

Table 2: Recommended temperature values according to EN 15251 [13]

Type of space	Category	Temperature range for heating (winter season) [°C]	Temperature range for cooling (summer season) [°C]
Offices and spaces with similar purpose	I	21,0 – 23,0	23,5 – 25,5
	II	20,0 - 24,0	23,0 – 26,0
	III	19,0 - 25,0	22,0 - 27,0

As external conditions change, the duration and components of the air conditioning system are adjusted accordingly. Modern control systems often use programs that optimize the startup and shutdown of the system. These programs analyse internal and external temperatures, as well as data on the average operating time in previous days, in order to calculate the minimum time required to achieve the desired temperature conditions in the rooms at the beginning of working hours. The efficiency of the control system can be improved through several measures:

- Increasing the temperature of the working medium: During non-intensive periods, increasing the temperature of the working fluid by a few degrees reduces energy consumption without compromising indoor comfort. Depending on the method of opening the working fluid valves in air handling units, it has been found that, in addition to the initial algorithm, even a small change in the valve opening from 10 to 30% can quickly and significantly affect the temperature of the supplied air [14].
- Expanding the boundaries of thermal comfort: By increasing the permissible temperature limits, significant savings can be achieved.
- Nighttime temperature setback: Reducing the temperature when the space is not in use (during the night or outside working hours) decreases the need for heating. However, it is necessary to consider the amount of energy that will be consumed during the reheating of the space, as energy is saved during the night, but consumption may increase when returning the temperature to the working level.
- Economical operation: Optimizing of operation with air recirculation reduces energy consumption. This is achieved by using indoor air (recirculation) during winter and by using outdoor air during summer.
- Night ventilation: This method reduces the system load during the day. It is implemented during transitional periods (spring and autumn) and during summer when the outdoor temperature is lower than the indoor temperature. In this way, energy consumption for cooling can be reduced by more than 30%.
- Use of CO_2 sensors: Adjusting ventilation according to the number of users can contribute to greater energy savings. Based on measurements of CO_2 concentration in the space, ventilation can be automatically adjusted, which leads to significant energy savings- up to 40% [15].

The benefits of these measures, besides financial savings, include extended lifespan of air conditioning system components, reduced emission of harmful gas, and consequently, reduces environmental pollution and preservation of energy resources.

It is an important to note that even small changes in work can lead to significant savings. For example, reducing the operation time of heating and cooling systems by just half an hour a day can decrease their operation by 180 hours annually and thereby contribute to substantial energy savings [14].

3.2 NATURAL VENTILATION AS AN EFFICIENT METHOD FOR REDUCING ENERGY CONSUMPTION

Natural ventilation is highlighted as an efficient method for reducing energy consumption, as it decreases the need for mechanical ventilation. It is based on natural processes, such as airflow through windows or ventilation openings. The potential of natural ventilation refers to the ability to achieve adequate indoor air quality using only natural ventilation methods at a given location, assuming that the building is properly designed. Within the framework of the Urban Ventilation Assessment Project (URBVENT) [16], a methodology for multicriteria assessment of this potential was developed.

Natural ventilation is initiated by wind action and buoyancy, which depends on the temperature difference between the indoor and outdoor environments.

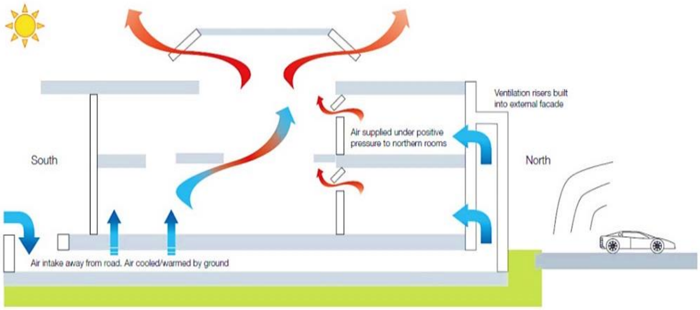

Figure 14: Air circulation of warm and cool air within building [17]

In urban areas, certain challenges related to natural ventilation arise. Winds often have reduced intensity due to high-rise buildings, making the use of complex algorithms necessary. The urban heat island effect leads to significantly higher outside temperatures, which can reduce buoyancy efficiencies. Additionally, air pollution and noise present a major problem, which can be quantified by measuring pollution and noise levels (quantitatively), as well as through user perspectives (qualitatively).

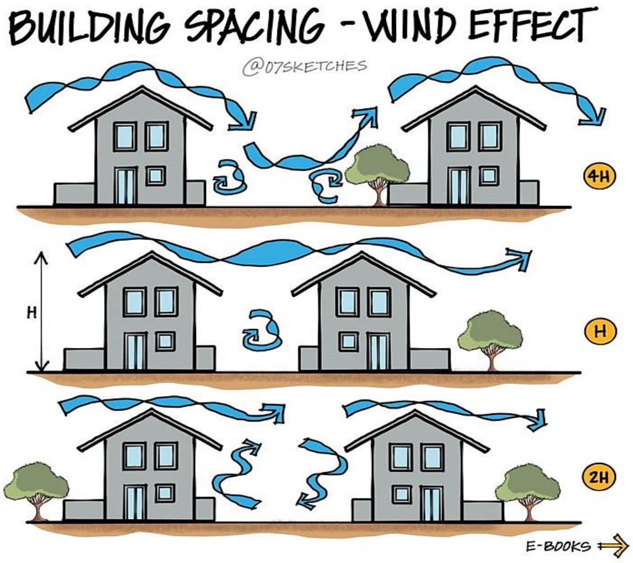

Figure 15: The impact of building spacing on airflow

Natural ventilation through windows and openings works by utilizing the difference in pressure and temperature between the inside and outside of the building. When the indoor air is warmer and lighter than the outdoor air, it rises and exits through openings at higher levels, while cooler, heavier air enters through lower openings. The arrangement of windows and doors significantly impacts this type of ventilation. The highest efficiency is achieved when windows and openings are placed on opposite sides of the space, allowing for airflow throughout the entire area, improving circulation and ensuring an even air exchange.

In cases where natural ventilation occurs due to pressure differences caused by wind, the direction of the wind plays a dominant role. The efficiency of ventilation increases when the wind direction is oriented towards the openings on the building, as windows and openings can be designed to capture the wind and utilize its strength to improve airflow. On the other hand, in areas with strong winds, windows and openings should be oriented to reduce noise and moisture, while still allowing effective ventilation.

In addition to the mentioned process, there is also a stack effect that allows warm air to rise and exit through high-level openings, while cold air enters through lower openings.

By properly positioning openings and using fresh air and the external environment, control and reduction of humidity is achieved, ensuring better indoor air quality. Depending on the time of year, natural ventilation varies: in winter, windows are usually opened for a shorter period to allow controlled ventilation, while in summer, they are opened wide to allow for maximum refreshment.

The advantages of this type of ventilation are multiple:

- It is environmentally friendly because it does not require additional energy to operate fans or heating and cooling systems, which contributes to reduced energy consumption and emissions of harmful gases;
- It is economical, considering the low cost of implementation and maintenance, making it affordable for various budgets;
- It improves air quality by efficiently removing pollutants and increasing the freshness of air in the room.

Disadvantages of this way of ventilation:

- Sensitivity to weather conditions, as efficiency depends on external factors and can be significantly limited in extreme temperatures or areas with little wind;
- Difficulties in precisely controlling the amount of air and temperature in the room, which can affect comfort and the quality of the indoor climate.

Despite all the advantages, natural ventilation is usually combined with other ventilation methods in order to achieve optimal efficiency.

3.3 ENERGY EFFICIENCY THROUGH NATURAL DAYLIGHTING

Due to increasingly severe ecological and energy-related problems, as well as the rise in carbon dioxide emissions, greater emphasis is placed on the use of clean and renewable energy sources. In this context, the Sun stands out as one of the most important sources. However, the use of sunlight for illuminating indoor spaces is still often neglected. Its efficient use in architectural and construction planning has multiple advantages - from reducing energy consumption to improving the quality of indoor living spaces.

There are devices for optimizing the use of daylight through light openings [18]. These devices are designed to efficiently direct light from the sky to the bottom of the opening, and then distribute it into the desired space. This method represents a comprehensive and standardized solution that can be applied at different geographical latitudes. The introduction of light openings in floors, along with light windows, additionally improves the distribution of natural light.

Research shows that the geometric characteristics of light openings affect light distribution and energy efficiency. Combinations of size, height, orientation, and the vertical angle of the walls can enable the stack (chimney) effect in natural ventilation and optimize daylighting.

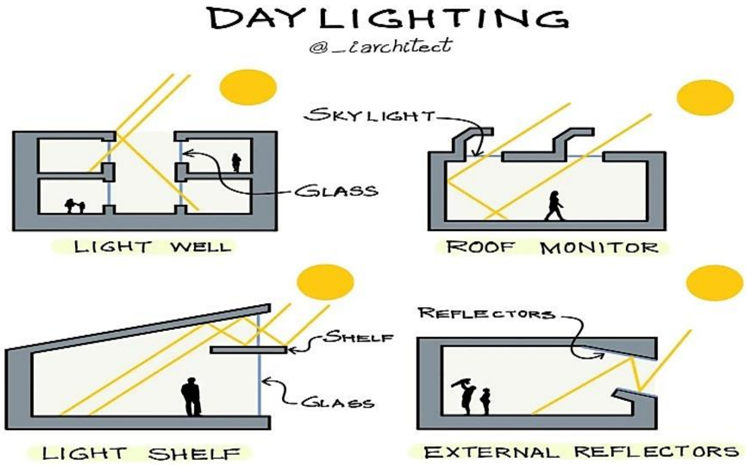

Figure 16: Various combinations of the sizes and positions of light openings [19]

Natural light planning goes through various phases of building design, starting from conceptual planning, project development, and the construction phase, all the way to commissioning.

Actually, everything begins with the selection of the location and continues throughout the entire operational life of the building. In high latitudes, with low levels of daylight during winter days, designers strive to maximize the penetration of natural light into the rooms of the building. Redirecting light from the brightest parts of the sky represents an efficient approach. On the other hand, in tropical areas, where daylight levels are consistently high throughout the year, the emphasis in design is on preventing overheating. This is achieved by reducing the amount of light entering the buildings.

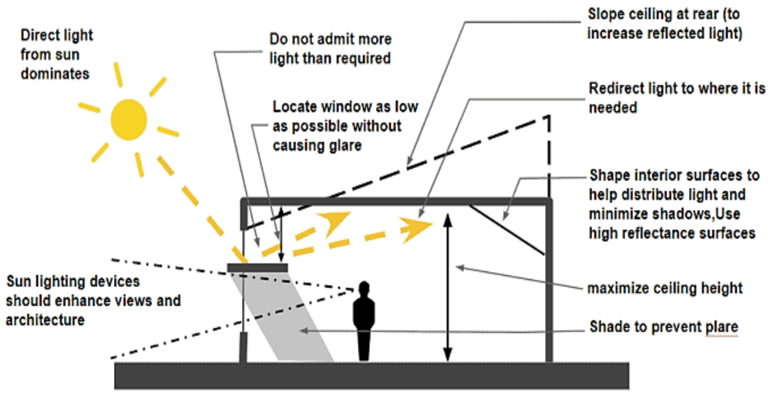

Figure 17: Building design aimed at maximizing natural light use [20]

The most important parameters of the daylight utilization system are highlighted:

- Conditions of daylight at the location – geographical latitude, cloudiness, obstacles
- Goals of utilizing daylight
- Daylight strategies implied by architectural design
- Window schemes and their functions
- Goals for energy reduction and maximum consumption
- Operational constraints – fixed openings, maintenance considerations
- Integration constraints – architectural/construction integration
- Economic constraints

Additionally, it is important to focus on the main objectives of implementing natural lighting systems [21]:

- Redirecting daylight to poorly lit zones
- Improving lighting in rooms designated for work tasks
- Enhancing visual comfort and controlling glare
- Achieving solar shading and heat control

According to [21], two systems for the use of daylight are defined, depending on the presence or absence of shading.

3.3.1 Daylight utilization systems with shading

There are two basic types of systems for utilizing daylight with shading control:

- The first type uses diffuse light from the sky while simultaneously eliminating direct sunlight.
- The second type directs predominantly direct sunlight toward the ceiling or above eye level, achieving pleasant and uniform illumination of the space.

3.3.2 Daylight utilizing system without shading

Systems for utilizing daylight without shading are primarily designed to redirect light to areas distant from windows or light openings.

a) Diffuse light redirection systems: These systems redirect daylight from specific parts of the sky into the interior of the room, which is very useful in cloudy conditions and urban environments, when the upper part of the sky is the only source of light.

b) Direct light guidance systems: These systems direct direct sunlight into the room, minimizing secondary effects such as glare and overheating, which contributes to comfort and the quality of light within the space.

Table 3: Systems for daylight utilization

Category	Systems with shading	Systems without shading
Function	Control of direct sunlight	Maximization of diffuse light
Examples	Roller blinds, pergolas, louvered façades	Skylights, light tubes
Advantages	Glare reduction, improved comfort	Increased natural illumination
Disadvantages	Need for additional equipment and maintenance	Possible excessive illumination
Climatic conditions	Efficient in sunny and warm climates	Suitable for temperature and cloudy climates

3.4 IMPACT OF TEMPERATURE VARIATIONS ON CONSTRUCTION WORK

The construction sector is particularly exposed to extreme weather conditions due to the fact that most work activities are carried out outdoors with the presence of workers. Heatwaves pose a particular risk for construction work compared to other extreme weather conditions such as floods and heavy snowfall. While floods and snow physically disrupt work, high temperatures present a different kind of challenge.

It is necessary to separately analyse the problems that arise at high and low temperatures. The greatest impact is observed in the decrease in worker productivity. Adapting construction work to weather conditions can lead to extended project durations, which not only delay completion but also increases costs. There is also an inevitable negative impact on the quality of construction materials, which require additional treatment and specialised processes, further complicating planning and execution.

It is crucial to plan in advance and prepare equipment for work under these conditions in order to minimize problems and ensure efficiency on the construction site. Taking these factors into account can help contractors manage resources more effectively and reduce the risk of delays and financial losses.

4 CONCLUSION

Within this research, key energy-saving methods adapted to changing climatic conditions were analysed, emphasizing the importance of parameters that affect the energy performance of buildings. It has been determined that location, orientation, shape, and the building envelope directly define its energy efficiency. The analysis of weather conditions proved to be a crucial factor in understanding energy consumption, with harmonization with seasonal periods being essential for the optimizing heating and cooling. Proper use of air conditioning systems, even a minimal reduction in their operating time, can lead to significant savings. Natural ventilation stands out as an efficient method of reducing energy consumption, while proper use of natural lighting significantly contributes to the energy efficiency of buildings. Additionally, the research pointed out the impact of extreme weather conditions on the execution of construction work.

These insights indicate the need for an integrated approach in planning and designing buildings to ensure sustainability and energy efficiency in accordance with climate change. Further research could be directed toward the development of specific recommendations for the implementation of these methods in different climatic conditions, as well as evaluating of their long-term impact on energy consumption and costs.

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