MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

O. M. BEKETOV NATIONAL UNIVERSITY OF URBAN ECONOMY IN KHARKIV

Tetiana Apatenko

BUILDING PHYSICS

A SYNOPSIS OF THE LECTURES

(It is intended for students of Specialty 191 – Architecture and urban planning)

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Author

senior lectures Tetiana Apatenko

Reviewer:

O. Tkachuk, Ph.D., a Doctor of Technical Sciences, Professor, Head of the Department of Urban Construction end Economy of the National University of Water Management and Nature Management.

O. Singaivska, Ph.D., a Doctor of Technical Sciences, Professor of the Department of Urban Development KNUBA.

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The lecture notes consider the theoretical foundations of the formation of thermal, light-color and acoustic environment, which serve as a basis for the rational design of buildings, structures and their complexes, the creation of comfortable living conditions. Methods of standardization, calculation and design of lighting, acoustics, sound insulation of buildings and basics of architectural climatology and thermophysical are stated.

The syllabus of lectures Building Physics fully corresponds to the curriculum of this discipline and can be used during the theoretical substantiation and practical work of students it is intended for students of Specialty 191 – Architecture and urban planning.

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INTRODUCTION

The great masters of architecture (Vitruvius, Alberti, Le Corbusier, Ivan Zholtovsky, Alvar Aalto) determined the influence of climatic factors and physical phenomena on the formation of the most important categories of architectural quality, namely - composition, style, image, plastic. Thus, knowledge of building physics and climatology has a direct and interrelated connection with architectural design, architectural theory, form the creative method of the architect and prevent him from making gross errors in aesthetic, environmental, functional and technical and economic terms.

Components of natural and artificial environment (solar radiation, air (its temperature, humidity, wind speed and direction), precipitation, color, and sound play an important role in the formation of architectural solutions. Achieving rational solutions is possible through comprehensive consideration of physical parameters (lighting, heating and acoustic) at the initial stage of architectural design.

Modern architecture is most closely connected with the natural and climatic environment and social living conditions. Compositional techniques and building density, orientation of buildings on the sides of the horizon, size and filling of light slots, plastic facades, as well as thermal inertia and sound insulation of fences - factors that largely affect the comfort and expressiveness of buildings the most pressing issue of today, the main economic and socio-philosophical problems, which is dictated by life itself for both modern and future architecture. The solution to this problem is possible only through the synthesis of art, technology and science, which are lifelong interconnected, mutually enriched by the categories of architecture.

1 Content Module 1.1 CLIMATOLOGY AND BUILDING THERMOPHYSICAL

Theme 1: The purpose and place of the discipline Building Physics

Basic concepts and definitions of the discipline Building Physics. Negative and positive examples of urban planning and architecture from the point of view of a comfortable human environment. The need for a comprehensive accounting of climatic, light, thermal, acoustic factors in architectural practice at all stages of design.

1.1 Basic concepts and definitions of the discipline Building Physics

Building physics –is a scientific discipline (applied section of general physics) that studies the processes associated with the operation of buildings and structures, load-bearing and enclosing structures.

Considers the issues of ensuring thermal, light, acoustic and environmental comfort in premises for various purposes.

The purpose of the discipline: to study the theoretical foundations and practical methods of forming the internal environment under the influence of sunlight and artificial light, color, heat, air and sound movement, as well as the nature of their perception by a person with an assessment of psychological, hygienic and environmental factors.

Architectural physics - scientific discipline (section of building physics), studies the influence of physical factors on the architectural and urban planning environment.

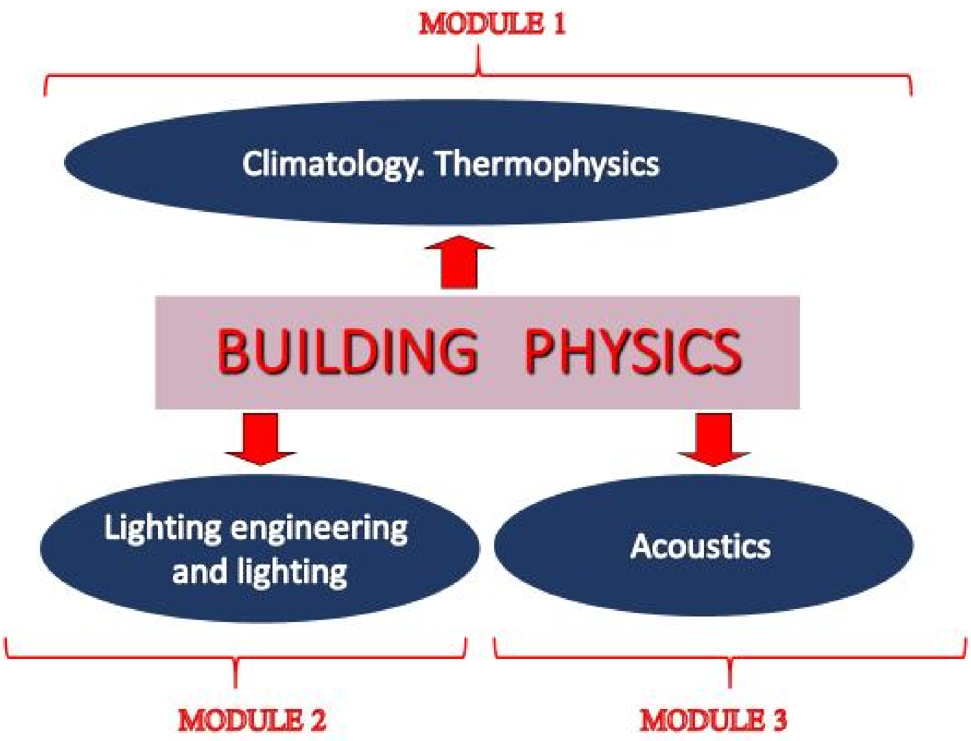


Figure 1.1 – Structure of the discipline Building Physics

Climatology is the science of climate, its types, the conditionality of distribution in different latitudes, its formation in a certain place.

Building thermal physics is a section of building physics that considers the processes of transferring heat, humidity and air in buildings and enclosing structures, establishes methods for calculating these processes.

Lighting engineering – studies the optical laws and characteristics of the propagation and distribution of light energy in open and closed spaces, practical methods of using lighting for a utilitarian, aesthetic and artistic purpose.

Acoustics – studies the laws of propagation of sound wave formations in buildings and urban planning spaces, the acoustic mode of premises, the acoustic characteristics of building and finishing materials and products, load-bearing and enclosing structures, the conditions for planning and building in settlements.

1.2 Negative and positive examples of urban planning and architecture from the point of view of a comfortable human environment

Buildings greatly influence their surroundings, and careful consideration should be given to the manner in which a building meets its surroundings and affects the local area.

Development of the built environment may equally concern its effect on the non-built environment. Thus, in the meeting of building and context, an outward orientation is necessary along with a local perspective. The areas that surround housing developments are often overlooked. These areas should be integrated in the planning, development and actual design of an area.

Organic architecture - the connection with nature is a positive example of urban planning and architecture.

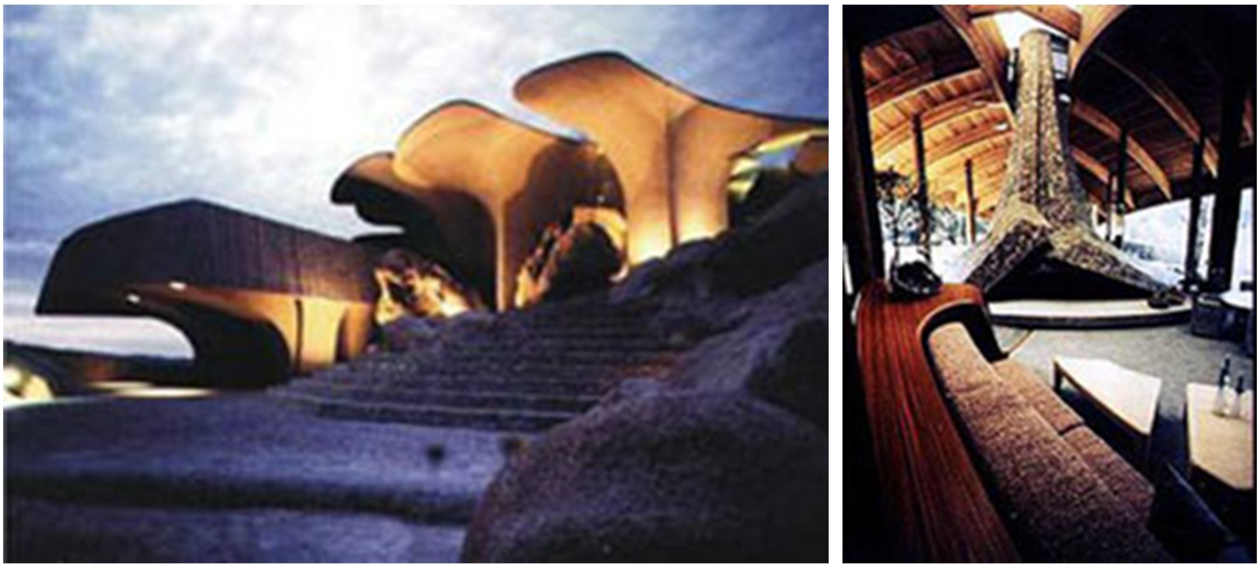


Figure 1.2 – House of Ian, California (USA). Arch. Kellogg

House of Ian, California is almost one hundred percent isolated from the noises of the outside world thanks to an effective soundproofing system. The interior is finished with high quality wood (fig.1.2).

Figure 1.3 – Villa Flap San Diego, California (USA). Arch. K. Kellogg

Villa Flap San Diego is energy efficient and can withstand earthquakes above all maximum existing standards by 30 percent (fig.1.3).

Figure 1.4 – Energy Efficiency – Powerhouse Brattørkaia, Trondheim, Norway

The current function of open areas as gaps between built elements can be transformed into a more positive one by letting them become an active part of the area.

Energy consumption has been a big challenge for most urban conglomerates in the current times. There is a constant battle to create energy-efficient buildings and sustainable technologies all over the world. Trondheim has an interesting situation wherein it receives 5 hrs. daylight in winter 20 hrs. in summer.

Taking advantage of the unique location of the building, the sunlight access, and the weather conditions of the region, Powerhouse (fig.1.4) is an excellent example of a building that proposes to produce double the amount of energy that it will use in its life span inclusive of construction and demolition. Therefore, being able to supply leftover electricity to its neighboring buildings and activities. This is a huge step in the direction of energy-efficient technologies.

Today, most houses, specially, in warm climates are dependent on air-conditioning systems with using of different kind of energy such as electricity. Looking for some technologies with clean energy and efficient is very important in energy strategies. Learning principles and some lessons of traditional sustainable architecture in warm climate can help us to find ways to reduce energy consumption. Integrating those principles by decision makers will be useful in sustainable and clean energy strategies.

The historical architectural heritage of the world is the clearest example of man's ability to use nature to his advantage. Thus, the creation of special ventilation systems – badgirs in Iran is just such an example. Thanks to improved air circulation, Badgirs cool the building. The towers produce air intake, which is sent through the mine to the foundation of the building, which has a reservoir with cold water that cools the air.

Badgir is the traditional and ancestral feature of Persian architecture. Literally, badgir means windcatcher in the Persian language, and is also sometimes referred to as *windtower*. Built since the antiquity, this creative system is meant to create passive ventilation inside the buildings (fig.1.5).

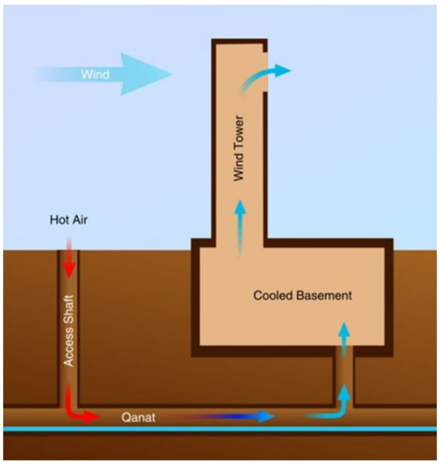


Figure 1.5 – Badgir, the Tower which Tempts the Wind, Iran

They consist of a tall, chimney-like structure, rising up from a corner of the roofs. It somehow looks like a small tower, but with tiny vertical openings on one or several sides. From these openings enters the wind, which is directed downward to refresh the interior of the house. With the pressure difference inside the column, the hot airflow naturally goes up, while the cold one gets down.

High building density prevents normal insolation of areas, which is typical for many cities in the world, which is typical for many European cities and is typical for many cities in the world (fig.1.6).

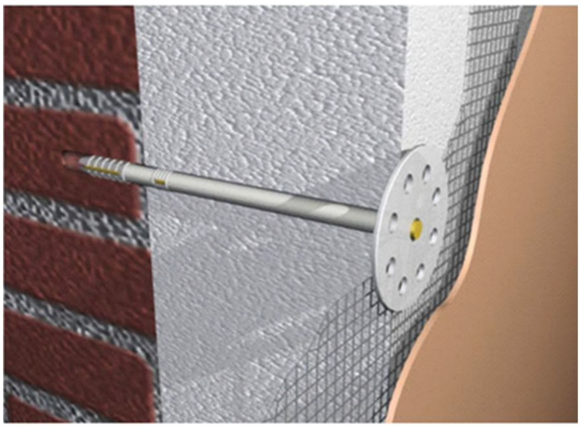
Building density. Cairo, Imbaba

Building density. Paris, France

Figure 1.6 – High building density is typical for many cities in the world

The high concentrations of people and economic activities in urban areas can lead to ‘economies’ of scale, proximity and agglomeration that can have a positive impact on energy use and associated emissions; whilst the proximity of homes and businesses can encourage walking, cycling and the use of mass transport in place of private motor vehicles. The use of environmentally friendly building materials with the introduction of modern methods of using the energy of nature. Wall breathing is the regulation of indoor relative humidity through appropriate finishing of interior surfaces: walls, floor and ceiling (fig.1.7).

Ekodom with solar heating



Warming of external walls: ‘wet façade’

Figure 1.7 – Comprehensive accounting of natural facts

The most common mistake of designers is that in the design process the basic provisions of building physics are not considered, which leads to unproductive loss of time and labor, as the finished project is additionally checked for compliance with the requirements of building physics. Changes identified after such an inspection can radically change the concept of the project. Therefore, only the joint solution of problems of building physics and problems of design should be rational. If you need maximum savings of both design and other means, especially during the implementation of large projects, for the production of accurate calculations it is necessary to involve a specialist engineer in construction physics.

1.3 The need for a comprehensive accounting of climatic, light, thermal, acoustic factors in architectural practice at all stages of design

The social aspects of climate have been studied for centuries, too. For instance, one of the most celebrated doctrines of Montesquieu is that of the political influence of climate and natural circumstances on the organization of states and organs of government. The effect of climate – primarily thinking of heat and cold – on the physical frame of the individual, and as a consequence, on the intellectual outlook of society.

Climate-conscious design is no autonomous principle, but the method to be developed has to match existing design practices. Most architects have in their use a number of practical working methods and beliefs regarding architecture, which may have resulted from a method of stubbornness, authority, intuition or science.

Many architects prefer the use of the word concept to theory and consider intuition to be the solving factor in the end. However, in project reports and criticism of architecture especially, there is an attempt to present things more systematically and some researchers.

Even primitive people sought each other's company when looking for shelter against nature or other tribes, and thus formed densely populated communities. Such opposites as warm and cold countries, inland and coast, mountains and plain produce different goods, which made the origin of trading and towns possible. Besides, one precondition for the origin of towns has been a favorable climate and other natural conditions. A climate favorable for grain-cultivating was important; we can talk about wheat, rye, corn and rice towns and the climate is also reflected at our dining table. In fact, town is a way of eliminating climatic factors and making life independent of topographic matters, but still urban culture developed differently in different climatic zones.

In antique and medieval towns, walls built for defensive reasons bordered a micro-climatic area sheltered against wind. Winding streets weakened the power of wind and archways gave shelter against rain and heat of the sun. Shelter against the open air was important, because most trading and other life took place outdoors. Life in a medieval urban house is described by poor ventilation conditions and lack of light. Since the Baroque period, broad avenues brought light, greenness and wind to towns of the new era. On the other hand, working-class quarters are described by lack of light, hygiene, fresh air and water. In general, the 19th-century town plans did not pay any attention to the directions of prevailing winds, locations of factory areas, healthfulness of soil or terrain shapes.

Research and calculation methods associated with building physics allow us to assess the quality of construction (at all stages of design and construction of buildings). Data of building physics must be considered during the development of projects of district planning, planning and construction of populated cities, justification when choosing a construction site for all types of construction, design of building complexes, buildings and structures.

Test questions on the topic:

1. What are the main methods and significance of Building Physics and Climatology?
2. Name the main negative and positive examples (samples) of Building Physics and Climatology.
3. Expand the essence of the question: the subject and methods of Building Physics.
4. Prove the relationship between the specifics of climate and its role in determining the shape of the structure.

Theme 2: Objective significance of climatology

Basic concepts of science Climatology. The main elements of the climate. Principles of zoning of the Earth's territory.

2.1 Basic concepts of science Climatology

Climatology (from Greek κλίμα, klima, "place, zone"; and -λογία, -logia) or climate science is the scientific study of the origin of the climate and its formation mechanisms, describes and classifies the climates of various areas of the earth, examines the climate of the past and predicts future climate change (fig. 2.1). It is based on data obtained by special (climatological) treatment of meteorological observations.

Meteorology is a science that studies the Earth's atmosphere.

Physical climatology - the study of the genesis of the climate, its physical condition, based primarily on the idea of the thermal and water balance of the earth's surface and the atmosphere and their climate-forming role.

A special branch of *physical climatology* is *dynamic climatology*, which considers climates and their distribution on the Earth depending on the processes of the general circulation of the atmosphere.

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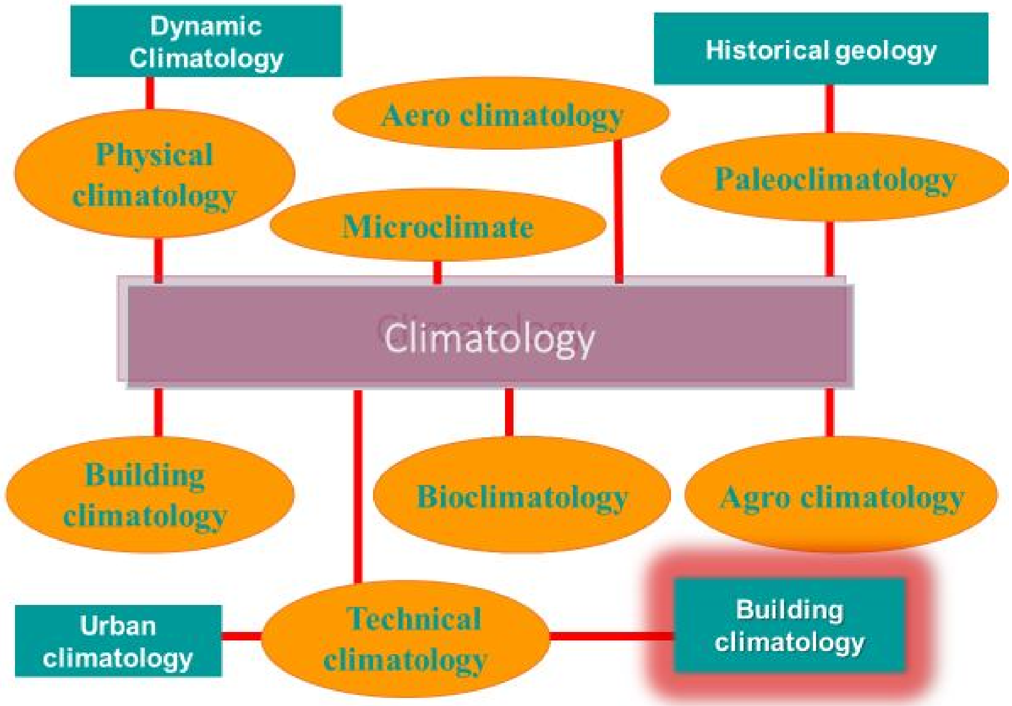


Figure 2.1 – Structure of the discipline climatology

Urban climatology refers to a specific branch of climatology that is concerned with interactions between urban areas and the atmosphere, the effects they have on one another, and the varying spatial and temporal scales at which these processes (and responses) occur.

Integrated climatology is a direction in climatology in which the weather means a complex of interconnected and interdependent meteorological elements and phenomena; the influence of weather on a person, on many objects of his activity, and also on the animal world is considered.

The study of the climate of high layers of the atmosphere is highlighted in *aero climatology.*

The climate of the surface layer of air is the subject of *microclimate*.

Bio climatology study of the influence of climate on living organisms. Ecology closely interacts with bio climatology, especially at the out-ecological level.

Paleo climatology is the study of origin of the climate and its formation mechanisms, describes and classifies the climates of various areas of the earth, examines the climate of the past and predicts future climate change. It is based on data obtained by special (climatological) treatment of meteorological observations.

Agroclimatology - the doctrine of the influence of climate on agriculture.

Medical climatology the study of the relation between climate and disease.

The study of building climate is to reach a healthy and comfortable climate suitable for the individual inside the building.

2.2 The main elements of the climate

All the materials and all the equipment's that take part of the building should meet the purpose to save energy both during its construction and during the *life* of the building.

It is fundamental to the utilization of natural resources and renewable energies: daylight, natural ventilation, solar and geothermic energy, using the power of nature.

Climatology consider all the conditions of a building:

- exposure to sunlight,
- regional climate,
- wind conditions
- and external noise.

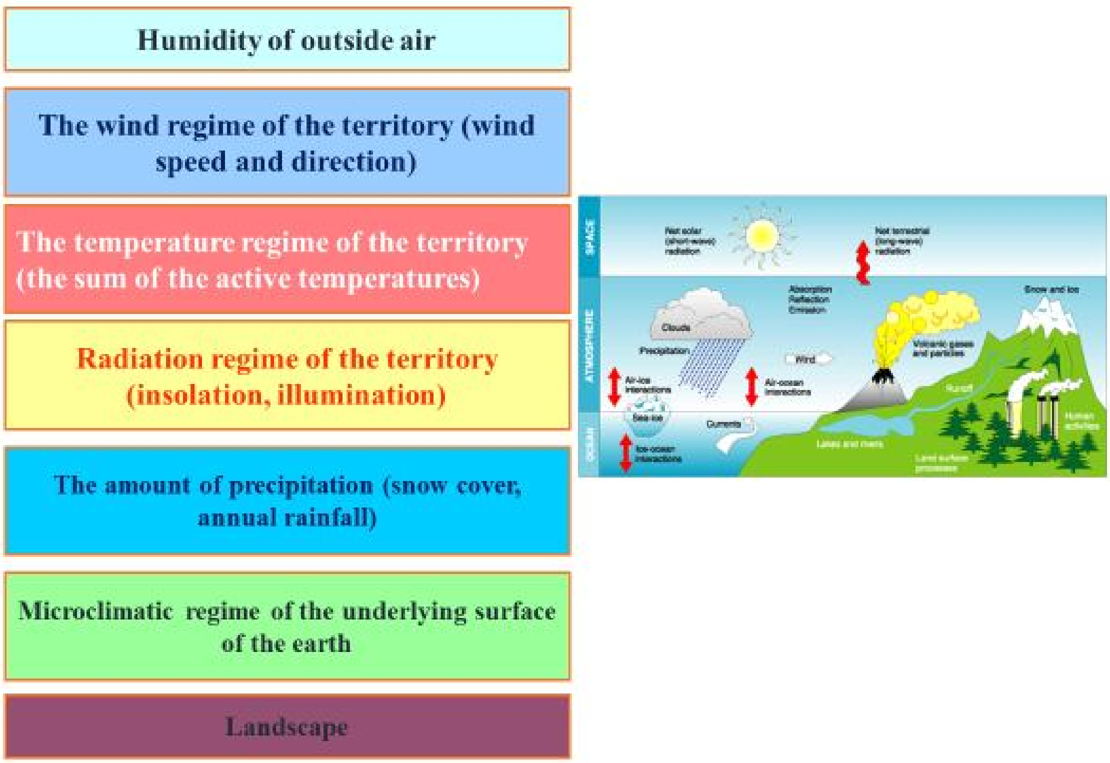


Figure 2.2 – Elements of Climate

The climate is a long-term weather regime, characteristic for this locality due to its geographical location.

Macroclimate is the climate of a large area of the earth's surface. This may be an entire geographic area.

The mesoclimate is the climate of a more or less homogeneous and fairly large territory, for example, the Black Sea or the Sea of Azov.

Microclimate – a complex of physical factors of the environment in the local space, which affects the human heat exchange.

The main factors of climate - the microclimate and landscape that make up natural and climatic complex.

1. Air Temperatures. The max, min, and mean temperatures for each month are entered into this table.

2. Humidity, Precipitation, and Wind. The max, min, and mean figures for each month are entered into this table, and the conditions for each month classified into a humidity group.

3. Comparison of Comfort Conditions and Climate. The desired max/min temperatures are entered, and compared to the climatic values. A note is made if the conditions create heat stress or cold stress (i.e. the building will be too hot or cold).

4. Indicators (of humid or arid conditions). Rules are provided for combining the stress and humidity groups to check a box classifying the humidity and aridity for each month. For each of six possible indicators, the number of months when that indicator was checked are added up, giving a yearly total.

The main content of climate analysis is:

– Wind.

– Temperatures.

– Humidity, precipitation.

– Sun, shadow

Radiation

Solar radiation that reaches the earth is mostly short wave, visible light, while the radiation emitted by the earth’s surface is infrared or thermal radiation.

When solar radiation hits the atmosphere, part of it is reflected back into space, some of it is absorbed by gases in the atmosphere, and some is scattered by molecules in the atmosphere. Thus, solar radiation is divided into direct radiation and diffused radiation.

The amount of direct radiation depends on the angle of inclination of the surface. In other words, a surface perpendicular to the incoming radiation receives the most solar radiation. The sun’s angle of altitude varies with the time of day and the season. In addition, the amount of direct solar radiation depends on the degree of cloudiness.

In practice, the amount of radiation received by different surfaces can be assessed with the help of calculated solar path diagrams.

As solar radiation decreases with the setting of the sun, the radiation equilibrium becomes negative, because the long wave thermal radiation of the earth's surface remains. In cloudy weather the clouds reflect nearly all the thermal radiation back to the earth's surface, but in clear weather the long wave thermal radiation of the earth's surface disappears into space.

Temperature

The temperatures of an area are dominated by the macro and micro-climates, and there are only very limited possibilities to affect the outdoor temperatures of a built environment. But in a defined micro-climate area it is possible to raise or lower the temperatures. During cold seasons temperatures can be raised locally by making the micro-climate of the site better. During warm seasons or in warm regions temperatures can be lowered with shading, vegetation, evaporative cooling and air movement.

Formation of temperature differences

As the thermal energy of a reflecting surface disappears into space, the temperature of the surface begins to decrease. The drop in the temperature is compensated for by heat flow from the earth, and therefore the rate of the temperature drop depends on the thermal properties of the earth or the structures. In clear weather the temperature of the air in the layer close to the ground drops quickly, causing a surface inversion layer, where the temperature near the surface is lower than it is in the higher layers of air.

Humidity

The humidity of an area is affected by the climate, vegetation, soil conditions and handling of surface water. Too high humidity, which often manifests itself as fog, rain, snow and frost, can cause many troubles in everyday life and especially in traffic. There are no possibilities to give numeric levels for the outdoor humidity conditions caused by climate, but some practical criteria are possible. It can be said that the humidity of an area can changes dramatically in different seasons, especially in such climates as monsoon or Mediterranean.

Wind speed is composed of three vector components: the longitudinal, transversal and vertical components of speed. However, in meteorological measurements it is more common to use vertical axle cup anemometers, which measure the resultant horizontal speed. The ratio of the gustiness of wind to average speeds has been found to be in the range of 1.3, and the dependence on wind speed is relatively small.

Wind

The most important factor in macro-climate is the winds.

Climate statistics that are suitable for use as initial data for planners are published both country-specifically and internationally. Rural site observations are generally done according to the recommendations of the World Meteorological Organization (WMO) at a height of 10 m in an open environment. The measurement points in a city are situated on masts placed above the roof level to avoid the wakes from neighboring buildings.

However, observation stations are often not located near the area being planned, in which case it is necessary to calculate the average values of data from nearby climatically representative stations. Sometimes the data of even one climatically representative observation point is sufficient for initial data. Special care should be taken when using statistics near coasts; the average wind speeds can be reduced 25–35% during the first 5 km inland. When mapping out climate conditions, it is sometimes possible to use research reports published by meteorological institutes, which often take into account the effect of terrain in the distribution of climate factors. Besides wind, other climatic parameters that affect buildings and human comfort include temperature, humidity, rain/snow, fog, sun, and in some regions, windborne sand or dust. The combination of these parameters with wind modifies the effects of each single parameter. The most important combination from the planning point of view is wind and temperature.

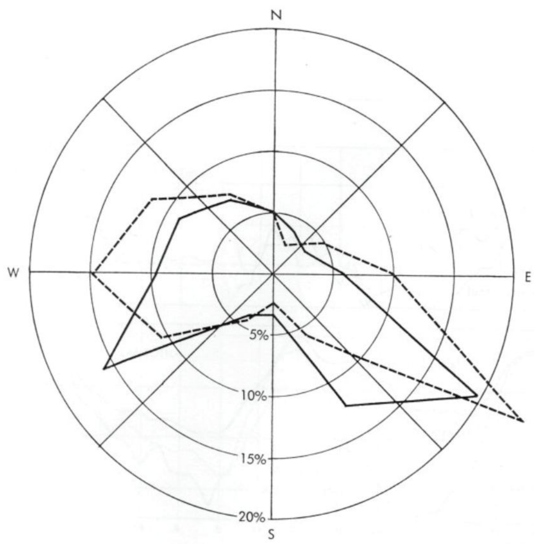


Figure 2.2 – Wind rose

Average wind speeds are not always very successful parameters for describing the effect of wind conditions and wind in terms of planning. Instead, the distribution of moderate and strong winds during the entire year must be determined. The year should be divided into at least four periods, spring, summer, autumn and winter. This indicates the direction from which the wind most often blows. Based on this distribution it is possible to specify the places in the terrain where it is most often windy and the valleys into which winds are channeled.

2.3 Principles of zoning of the Earths territory

The climate maps represent the spatial dispersion of the systematic climatic ratio on earth. Therefore, they provide a good overview of the key climate characteristics of a region. For reasons of content and didactic reduction, only a few climate parameters are considered. It is only possible to typify and classify, despite the continuous changes of the climatic conditions on Earth abstractly affected by the climate. As a result, climate classifications are an important basis of geographical special analysis.

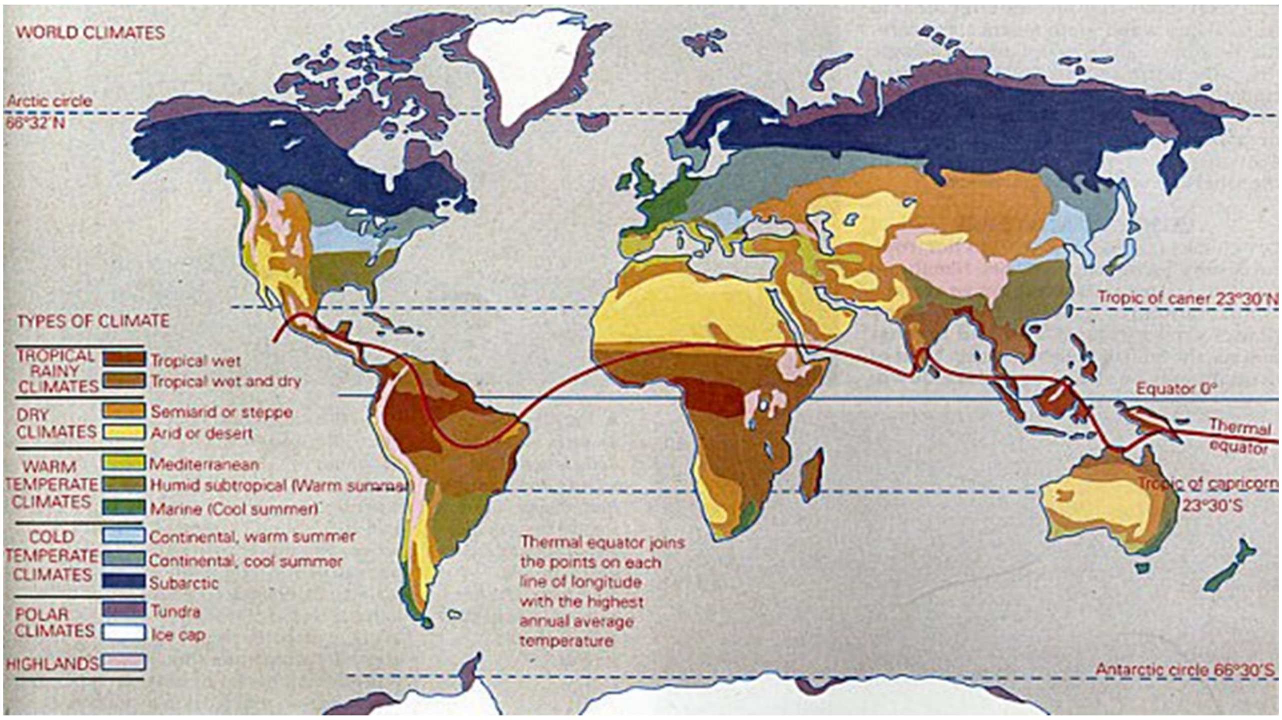


Figure 2.3 – Principles of zoning of the Earth`s territory

Climatic accounting of meteorological data of the district is laid in weather type catalog system. These data are classified according to the actual repetition, which ultimately creates a climatic zoning (fig.2.3). The basis of climatic zoning of the Earth is distribution territories on belts, zones and areas with more – less homogeneous conditions climate. The boundaries of climatic zones and zones not only do not coincide with latitudinal circles, but not always cover the globe (zones in such cases fragmented into separate areas).

Climatic zoning is the classification of the meteorological data of the region, laid down in the catalog of weather types, considering their actual repetition.

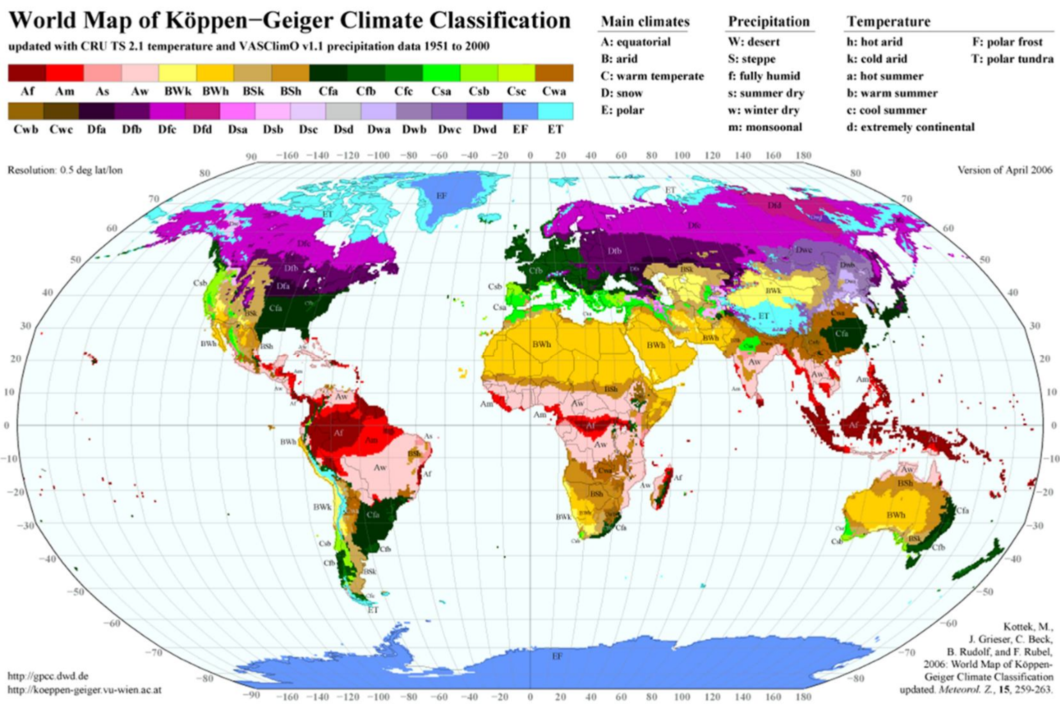


Figure 2.4 – Classification of the Earth's climate according to V. Keppen

Zoning can be done either on climatic signs (for example, on distribution of average temperatures air and precipitation in V. Keppen (fig. 2.4) – allocation of climatic zones by the ratio of annual regimes of surface air temperature and precipitation), or others complexes of climatic characteristics, as well as the features of the general atmospheric circulation, or by the nature of the geographical landscapes identified climate (classification of LS Berg – the allocation of climatic zones by the nature of the geographical landscapes. (fig. 2.4 b).

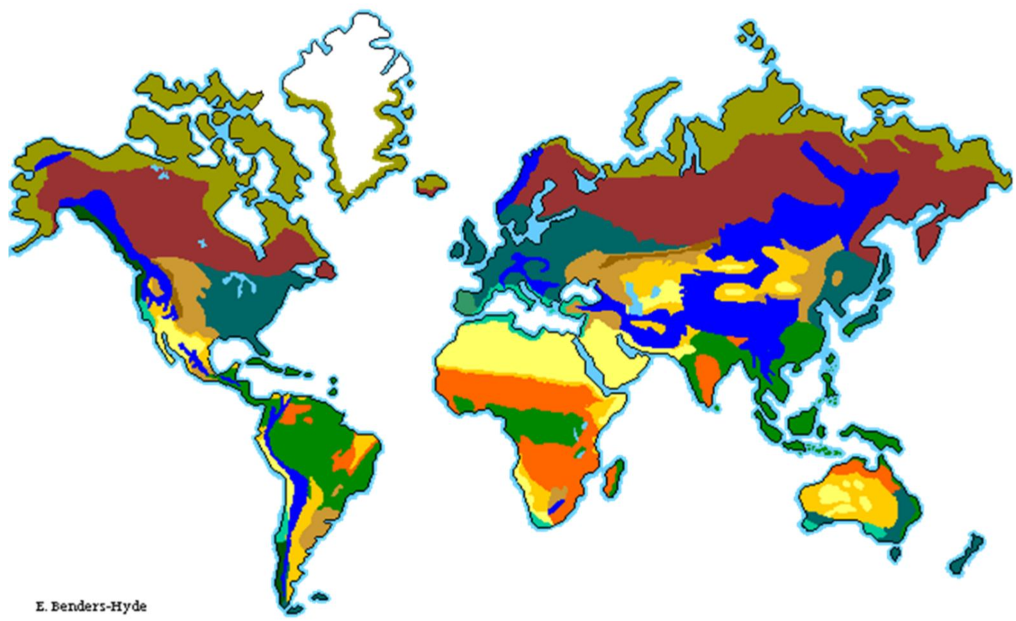


Figure 2.5 – Classification of the Earth's climate according to LS Berg

Equatorial climate. Uniform temperature regime +24 °C – +28 °C; high air humidity – 1-6 thousand mm / year precipitation falls in the form of showers. Landscape-moist equatorial forests.

Climate of tropical deserts. Extremely hot temperatures in the summer up to 40 ° C absolute maximum +58 °C (North Africa, California, Australia), winter temperatures – from +10 °C to +15 °C Low air humidity – up to 100 mm / year precipitation.

Climate of the Tropics. Hot temperatures in summer are higher than 30 °C (Equatorial Africa, Southeast Asia, North Australia); winter temperatures range from + 25 °C to + 3 °C (Madras). High air humidity is up to 1630 mm / year (North-East India-Cherapunji – maximum precipitation on Earth – 12 thousand mm / year) Landscape-humid rainforest. *Trade winds* are winds that blow in the same direction all year due to the general circulation of the atmosphere. *Monsoon* - winds that change the direction 2 times a year under the influence of the difference in heating and cooling of continents and oceans.

The climate of the subtropics. Hot temperatures in summer are above 30 °C (Mediterranean climate); · winter temperatures – from +5 °C to + 10 °C (Crimea, West California, Southern Africa) – hot little cloudy summer, cool rainy winter. Annual precipitation - up to 600 mm / year.

Climate of temperate latitudes. They are characterized by intense cyclonic activity due to frequent changes in air temperature and pressure. Average temperatures are + 12 ° C – + 17 °C – (July), from + 2 °C (Paris) to – 20 ° C (Novosibirsk) - in winter, average air humidity - up to 540 mm / year precipitation falls (Stockholm). The north-eastern regions of Eurasia are more continental.

The climate of the Subarctic. Average temperatures – + 12 °C (July); up to – 40 °C – in winter; Low humidity – up to 300 mm / year precipitation falls. Northeast Siberia – up to 100 mm / year.

The climate of the Arctic. Average temperatures are 0 °C (in summer); up to – 40 °C in winter, the absolute minimum is close to –70 °C. Low air humidity – up to 100 mm / year precipitation falls. Atlantic areas (European territory) – the climate is softer.

The climate of Antarctica. Coast (in Mirny) Average temperatures – 2 °C (in January); Intra-interior: summer temperatures range from –30 °C, in winter –70 °C, low air humidity – up to 100 mm / year.

Test questions on the topic:

1. What are the branches of Climatology?
2. Name the main concepts of climate and its elements.
3. What are the basic principles of zoning of the Earth. The main climates of the Earth?
4. List the main elements of climate.

Theme 3: Landscape: hydro geological conditions, hydro geography conditions, wildlife

Hydro geological conditions. Analysis of natural conditions and resources. Types of landscape.

3.1 Hydro geological conditions

Geomorphological structure of the Earth. Hydro geological rhythm leads to the fact that after certain long periods of time (lasting hundreds of millions of years) on the earth there were cycles of mountain building: the Caledonian, Herzen, Alpine periods lasting 200-240 million years each.

The Earth's crust and the surface of the mantle together make up the lithosphere of the Earth. Due to the interaction of the lithosphere, hydrosphere, atmosphere and the biosphere, modern landscapes of the earth's surface were formed. An important role in their formation belongs to the rocks and the nature of their occurrence.

Natural conditions

Climate conditions – long-term climate characteristics: meteorological data and seasonal climate change data;

Hydro geological conditions – the presence of water spaces their hydrographic and regime features of surface waters;

Engineering geological conditions – information on the study of the territory for engineering training and assessment of the cost of works for development. Determine the degree of suitability of territories;

Hydrothermal conditions – provision of territory with heat and moisture, assessment of the degree of comfort of the territory;

Biogen group natural conditions – soils, vegetation, fauna Information for assessing the territory by type of use.

Natural resources

Territorial (land) resources – information on the availability of urbanized, agricultural areas to maintain the ecological balance;

Air Resources basin – information for the sanitary-hygienic analysis of the air basin for carrying out measures to preserve the ecology;

Biological resources – assessment of the degree of balance and changes in the areas of arable, haymaking and fodder lands, conservation of the flora and fauna population;

Mineral and raw materials resources – strategic tasks of development, exploitation and conservation of deposits, considering the types of raw materials and quality;

Water resources – assessment and accounting for economic or industrial water supply, their operation, protection and replenishment.

3.2 Analysis of natural conditions and resources

Natural resources (fig. 3.1) are derived from the environment. Some resources are essential to survival, while others merely satisfy societal wants. Every man-made product in an economy is composed of natural resources to some degree. There are numerous ways to classify the types of natural resources, they include the source of origin, the state of development, and the renewal ability of the resources.

Biotic: these resources come from living and organic material, such as forests and animals, and include the materials that can be obtained them. Biotic natural resources also include fossil fuels such as coal and petroleum which are formed from organic matter that has decayed.

Abiotic: these resources come from non-living and non-organic material. Examples of these resources include land, fresh water, air, and heavy metals (gold, iron, copper, silver, etc.).

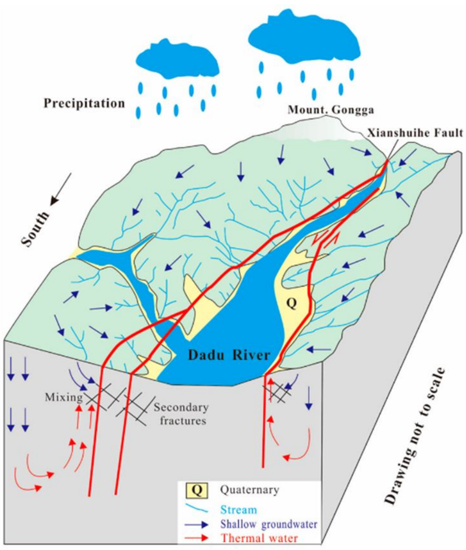
Natural resources can also be categorized based on their stage of development including:

Potential resources: these are resources that exist in a region and may be used in the future. For example, if a country has petroleum in sedimentary rocks, it is a potential resource until it is actually drilled out of the rock and put to use.

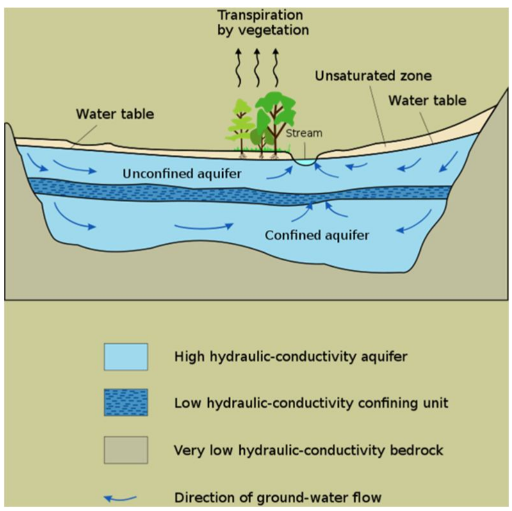
Actual resources: these are resources that have been surveyed, their quantity and quality has been determined, and they are currently being used. The development of actual resources is dependent on technology.

Reserve resources: this is the part of an actual resource that can be developed profitably in the future.

Stock resources: these are resources that have been surveyed, but cannot be used due a lack of technology. An example of a stock resource is hydrogen.



Potential water resources



Groundwater resources

Figure 3.1 – Types of Natural Water Resources

Natural resources are also classified based on their renewal ability:

Renewable natural resources: these are resources that can be replenished. Examples of renewable resources include sunlight, air, and wind. They are available continuously and their quantity is not noticeably affected by human consumption. However, renewable resources do not have a rapid recovery rate and are susceptible to depletion if they are overused.

Non-renewable natural resources: these resources form extremely slow and do not naturally form in the environment. A resource is considered to be non-renewable when their rate of consumption exceeds the rate of recovery. Examples of non-renewable natural resources are minerals and fossil fuels.

There is constant worldwide debate regarding the allocation of natural resources. The discussions are centered around the issues of increased scarcity (resource depletion) and the exportation of natural resources as a basis for many economies (especially developed nations). The vast majority of natural resources are exhaustible which means they are available in a limited quantity and can be used up if they are not managed correctly. Natural resource economics aims to study resources in order to prevent depletion.

Estimation of the territory by natural conditions:

Analysis of natural and anthropogenic conditions of the territory reveals the degree of suitability of the relief for construction;

Analysis of engineering-geological conditions determines the load-bearing capacity of soils, reveals disturbed areas in view of natural processes and anthropogenic impact;

Analysis of hydro geological conditions reveals the degree of use and conservation of water resources, the degree of influence of water spaces on the microclimate of the territory.

Criteria for assessing hydro geological conditions:

Assessment of the microclimate of the territory (wind, temperature and humidity regime-weather conditions);

Assessment of water resources - the nature of the bottom, the high-water content, the presence of tides, undercurrents, current velocity, etc.;

Assessment of the possibility of using water resources for the development of the city.

Conservation measures;

Forecasts of natural destructive phenomena.

Criteria for assessing engineering and geological conditions:

Assessment of physical and geological phenomena (physical and mechanical properties and soil groups);

Assessment of the nature of the occurrence of groundwater;

Forecasts of natural destructive phenomena: karsts; landslips; mud flows; loess like soils; gully-ravine education and so on.

The criteria of territory are presented in the table 3.1

Table 3.1 – Criteria for assessing of territory

Natural conditions	Degree of territory suitability		
	Suitable	Limited suitability	Unsuitable
Relief a) residential building б) industrial building	With slope from 3 to 10 %	With a slope less than 3% and more 10 –20%	Without slopes and with slopes more than 5% more 20% less than 30% in the mountains
	from 0,3 to 5 %	With a slope less than 0,3% from 3 to 5 %	Without slopes and with slopes more than 5%
Quad	Without quad	Specials of work by drain	Quad large areas territory's
Floods	None	Above 0.5 m (Once a year)	Above 0.5 m (1 time in 100 years)
Landslides, karsts and ravines	None	Inactivity landslides, requiring uncomplicated engineering activities	They have significant Spread
Note: Complexity of relief is defined in percent (% for urban-planning assessing) or a thousand (ppm - for tracing streets and roads, laying main networks – extended sites). Slope in 1% - fall marks, when on 100 m distance there is a difference in 1 m.			

The analysis of the territory is a complex of studies aimed at identifying the features of the territory that determine the directions of its long-term use for efficient exploitation of natural resources, the rational allocation of all sectors of the economy and environmental protection.

The analysis of the territory is based on the complex of research that is used in the exploration of natural resources, the rational allocation of all sectors of the economy and environmental protection.

Sanitary protection zones and other projects – impose restrictions, particularly on accommodation of residential development and social facilities (hospitals, health centers, dispensaries, preschool institutions, schools, sports facilities, etc.).

Specially protected natural territories are the most important elements of the natural and ecological framework of the territory, which have special regulations for environmental and economic activities aimed at protecting.

Water protection and coastal zones – have regulatory regulations for the use of economic activities.

Protective zones of engineering structures (pipelines, roads and railways, etc.) – ecological and technical corridors, excluded from development, with regulatory requirements for operation.

Areas unfit for construction and excluded from development - sites with the development of unfavorable engineering and construction conditions, including potentially flooded by catastrophic floods; deposits of minerals, etc.

A differentiated analysis of the territory is the basis for an integrated urban planning assessment

Natural and climatic studies with integrated hygienic assessment of insolation, temperature and humidity regime and wind regime of the territory, considering the forms of the landscape and relief, conditions of soils and vegetation (forests and water spaces).

Detailed topographical surveys and engineering and construction assessment of the territory with specification of relief forms, hydro geological state, geological structure (flooded, flooded areas, ravine formation of river banks, etc.).

Architectural and landscape study of the territory.

3.3 Types of landscape

A landscape includes the physical elements of geophysical defined landforms such as (ice-capped) mountains, hills, water bodies such as rivers, lakes, ponds and the sea, living elements of land cover including indigenous vegetation, human elements including different forms of land use, buildings, and structures, and transitory elements such as lighting and weather conditions. Combining both their physical origins and the cultural overlay of human presence, often created over millennia, landscapes reflect a living synthesis of people and place that is vital to local and national identity.

The character of a landscape helps define the self-image of the people who inhabit it and a sense of place that differentiates one region from other regions. It is the dynamic backdrop to people's lives. Landscape can be as varied as farmland, a landscape park or wilderness. The Earth has a vast range of landscapes, including the icy landscapes of polar regions, mountainous landscapes, vast arid desert landscapes, islands, and coastal landscapes, densely forested or wooded landscapes including past boreal forests and tropical rainforests, and agricultural landscapes of temperate and tropical regions. The activity of modifying the visible features of an area of land is referred to as landscaping.

Types of landscape (tabl. 3.2):

The plain landscape is characterized by a small difference in altitude marks of elevated and lowered places, the absence of hills and ravines.

The average landscape is a combination of watersheds of valleys, hills, hollows, small ravines.

The mountainous landscape is characterized by pronounced steep slopes, deep valleys and ravines, mountains.

Table 3.2 – Influence of the relief on urban planning

Types of landscape	Ensamples of landscape	Advantages	Limitations
The plain landscape		The use of architectural techniques - low-key classics; The cost of earthworks for the preparation of the territory for construction is reduced	The relief is inexpressible, which prevents the creation of town-planning dominants, gives monotony to the urban landscape; It is difficult to arrange gravity and storm sewage
The average landscape	 	Architectural expressiveness of cities; The most optimal for the rational allocation of all elements of the city; Ease of solving the tracing of streets and roads, laying the networks of gravity and storm sewage	Measures for earthworks are becoming more complicated; The cost of earthworks for the preparation of the territory for construction is increasing
The mountainou s landscape	 	A complex relief favors the creation of picturesque architectural ensembles and urban prospects.	It is difficult the layout of the city - actively affects the placement of all elements of the city; It is difficult decisions on the route of streets and roads, rising construction costs; Complicating the solution of water and sewer networks

Test questions on the topic:

1. What are the hydro geological conditions?
2. Name the main concepts of analysis of natural conditions and resources.
3. What are the basic principles of zoning of the Earth. The main climates of the Earth?
4. List the main elements of climate.

Theme 4: Formation of the urban environment based on the components of the natural and climatic complex

The influence of climatic factors on the formation of urban and suburban areas. Measures to improve the microclimate of urban areas. The influence of climatic factors on weather formation.

4.1 The influence of climatic factors on the formation of urban and suburban areas

Regulation of climatic parameters of residential environment with the purpose of formation of a favorable microclimate can occur due to:

– the choice of the optimal location for each functional area of the city;

maximum preservation of elements of the natural complex (landscape, relief, green plantations);

– regulation of climatic parameters with appropriate urban planning, architectural planning and constructive techniques;

– providing visual comfort in the territory (landscaping, use of small architectural forms and features of territories, landscape design and landscaping);

– application of modern engineering equipment of houses.

Factors affecting the climate of urban development (tabl. 4.1)**:**

– direct heat releases and changes in the solar radiation regime;

– dust emissions of industrial enterprises and transport;

– the change in the heat balance due to a change in evaporation, a small permeability of the underlying surface, which contributes to a rapid flow of water and a significant thermal conductivity of the coating.

Climate information needed in planning

When deciding on the placement of buildings in town planning, it is usually not possible to limit construction to areas that are advantageous in terms of the microclimate; (outdoor) functions also have to be situated in disadvantageous locations. In addition, the fact that construction in itself changes the area's micro-climate also needs to be considered. The more disadvantageous the construction site is, the more microclimate factors need to be taken into consideration in detail in the planning phase and the more effort needs to be placed on assessing the impact of the micro-climate on the buildings and areas in subsequent work. Building placement affects the formation of the thermal island phenomenon, the detrimental wind effects of buildings on outdoor areas or elimination of those effects, snow accumulation, moisture conditions, air pollutants etc. Thus, the pleasantness of residential areas can be improved by means of the size, shape, and relative placement of the buildings, plants, and mechanical wind barriers.

Table 4. 1 – Differences in climate in large cities and adjacent rural areas in the middle latitudes

Meteorological factors	In a city in comparison with a suburban territory
Radiation total	15-20% lower
Ultraviolet radiation in winter	30% lower
Ultraviolet radiation in summer	5% lower
The duration of sunshine	5 to 15% lower
Average temperature	0.5 to 1.0 ° C higher
average winter	At 1 - 2 ° C above
Duration of the heating season	10% less
Average wind speed	10 to 30% lower
Stormy	10 to 20% lower
Styles	On 5 - 20% more often
Precipitation total	5 to 10% more
in the form of snow	5% less
Number of days with precipitation less than 5	10% more
mm	5 to 10% more
Number of clouds	100% more
Repeatability of fogs in winter	30% more
in summer	2% less
Relative humidity in winter	10 to 30% lower
in summer	11 to 20% less
sometimes	1,5 - 2 times less often
Thunderstorm frequency	

Radiation regime of the city (fig. 4.1)

The city center is the '*apex of the heat island*', where the maximum temperature of the megapolis is observed.

Most part of the city – 'tableland' – warm air, rising temperature to the center.

A significant horizontal temperature gradient (up to 4 ° C / km) appears on the 'city-countryside' boundary-the 'island of heat'

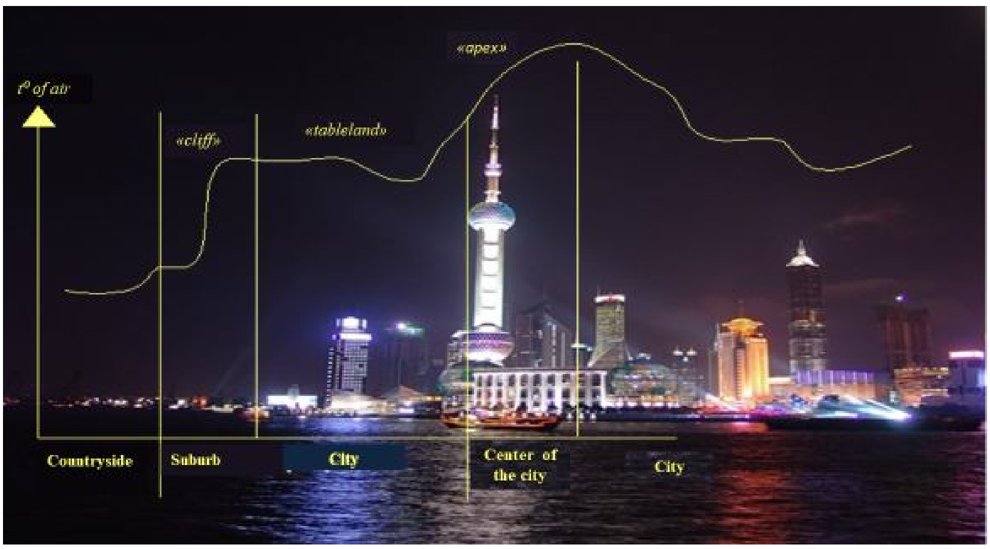


Figure 4.1 – Cross-section of 'island of heat over the city'

Humidity regime of the city

At high humidity, convective instability and air pollution are observed, which causes clouds.

Precipitation falls, mainly in the lee of the city and beyond.

The largest indicator of the nebula of the sky is observed with a decrease in wind speed (air pollution).

Insufficient moisture and an increase in air temperature causes fewer fogs.

Wind regime of the city

Wind is created by pressure differences, as air tends to flow from an area of higher pressure to one of lower pressure. The wind in the free atmosphere is in the direction of the isobars (constant-pressure lines). As air flows over the base, the friction of the base retards wind speeds and turns surface wind about 30 0 to the left toward a lower pressure area.

From the standpoint of wind behavior, the lower part of the atmosphere can be divided into three layers; the surface layer, the friction layer, and the free atmosphere. The surface layer extends from the earth's surface to an altitude of a few tens of meters. The height of the friction layer is hundreds of meters. The free atmosphere begins at the upper boundary of the friction layer.

The characteristics of the air-flow at low levels in the urban environment (Canopy Layer) are quite different from, and to some extent independent of, the characteristics of the flow in the upper part of the Urban Boundary Layer. In the Canopy Layer, in fact, the flow is influenced more by the local street geometry and building height distribution, than by a homogenous energy transfer between horizontal layers.

At weak winds of 2-3 m / s – at a surface of the earth there is a cold stream of air which is directed to 'island of heat'.

Ascending flow – is formed above the surface of heated buildings.

The descending stream – is formed over the shaded walls of buildings, over streets, yards.

4.2 Measures to improve the microclimate of urban areas

Regulation of wind speed and aeration of the city – urban planning and architectural and planning activities;

Reduction of heat losses by buildings – constructive and town-planning measures;

Regulation of relative humidity of air – planning and sanitary-hygienic measures;

Fighting air pollution – eco-urban planning activities

Regulation of the receipt of solar radiation – town planning measures.

For protection from snow and rain, urban planning, planning and constructive techniques are envisaged:

– waterproofing structures and reliable drainage from the roof;

– external drainage from the building, use of natural slopes of the territory and arrangements for vertical planning;

– snow protection of external surfaces of buildings with the device of facing and painting by special persistent colorful compositions;

– intermediate cornices, sandaracs and ventilated air interlayers in the walls.

4.3 The influence of climatic factors on weather formation

The duration of weather types for the year is determined by considering climatic factors: the average monthly temperature; relative humidity; wind speed.

Weather – the state of metrological processes in a short period of time (day, several hours), serves as a criterion for studying and comparing the climate of different regions of the Earth.

Weather classes – depending on the combination of outdoor temperature, humidity and wind speed, the following weather classes are distinguished: severe, cold, cool, comfortable, warm, hot dry, hot. On the territory of Ukraine - 4 classes of weather: cold, cool, comfortable and warm.

Figure 4.2 – Basic weather classes

Types of weather are determined on the basis of the following elements of climate: temperature (average monthly); humidity and wind (average wind speed in warm and cold periods). These data are reduced to tables, based on which determine the type of weather (fig. 4.2, tabl. 4.2). It should be noted that in the warm period the main indicators for determining the type of weather are air temperature and relative humidity, and in the cold period - air temperature and wind speed.

Table 4.2 – Nomogram for determining whether classes

Temperature, ° C

Warm period					
Upper border	Lower limit	Relative humidity,%			
		24 and below	25–49	50–74	75 and more
47,9	44,0				
43,9	40,0		H – hot		
39,9	36,0	H_d			
35,9	32,0	hot dry			
31,9	28,0	W – warm			
27,9	24,0			W	
23,9	20,0				W
19,9	16,0			C – comfortable	
15,9	12,0				
Cold period					
Upper border	Lower limit	Wind speed, m / s			
		1,9 and below	2,0–4,9	5,0–9,9	10 and more
11,9	8,0		Cl – cool		
7,9	4,0				
3,9	0,0				
-0,1	-3,9				
-4,0	-11,9		Cd – cold		
-12,0	-19,9				
-20,0	-27,9				
-28,0	-35,9				
-36,0	-47,9			S – severe	
-48,0	-59,9				
-60,0	-71,9				

Classification of types of weather and modes of operation of housing

1. Open mode – a comfortable type of weather.

The building is protected from the sun, but it is opened to the outside environment and practically does not have a climate-protective function. It is desirable to use balconies, loggias verandas.

2. Half-open mode cool type of weather:

The relationship of housing with the environment is limited; airflow through the ventilator – exhaust ventilation, irregular heating; warm weather type: sun protection; through ventilation, orientation of facades in the S and S, galleries, loggias, verandas.

3. Closed mode cold weather type:

Insulation of housing from the external environment: double glazing of windows, natural airflow, exhaust ventilation, regular heating;
dry hot weather type: Isolation of housing from the external environment, full sun protection, landscaping and watering of areas adjacent to the building; air intake natural exhaust ventilation; it is recommended to use artificial measures to improve the microclimate of the premises.

4. Isolated mode severe type of weather:

Full insulation of housing from the external environment: closed completely windows triple-glazed windows; mechanical supply and exhaust ventilation with heating and humidification of air, heating regular, active;

hot weather with normal and high humidity: complete isolation of housing from the external environment, you need full sun protection; air conditioning; it is recommended to use artificial measures to improve the microclimate of the premises.

Test questions on the topic:

1. What are the hydro geological conditions?
2. Name the main concepts of analysis of natural conditions and resources.
3. What is the difference between the concepts of differential analysis of the territory and differential study of the territory?
4. Prime the relationship between outdoor temperatures and wind parameters, their influence on the formation of the weather regime.

Theme 5: Thermophysical bases of design

Subject and methods of building thermophysics. Determination of heat transfer. Criteria for determining the microclimate of the premises.

5.1 Subject and methods of building thermophysical

Building thermophysical – a branch of building physics, which considers the processes of heat transfer, humidity and air in buildings and structures, establishes methods for calculating these processes.

• Ensuring the required level of thermal protection of external enclosing structures in winter.

• Providing a temperature level on the inner surface of the enclosure that prevents condensation.

• Ensuring the heat resistance of the fence in the summer months.

• Creation of the optimum humidity mode of external protections with a possibility of their fast drying in case of humidification.

• Restriction of air permeability of enclosing structures.

All objects absorb and emit thermal radiation (aka infrared electromagnetic radiation).

• Heat energy is transferred via waves, not particles.

• The Earth is heated through thermal radiation from the Sun.

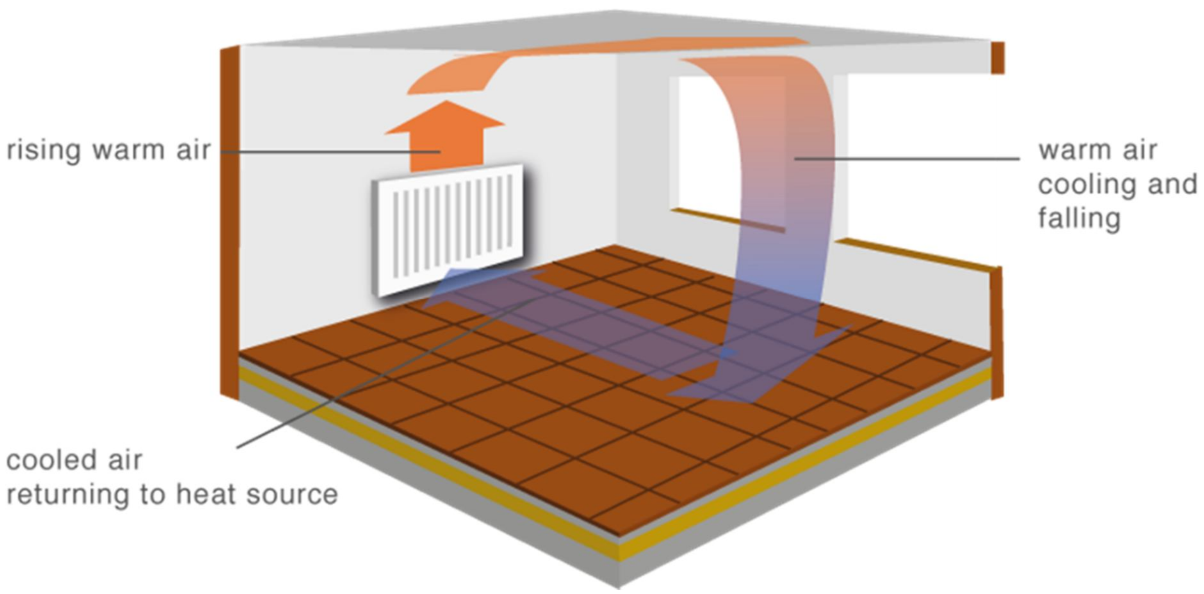


Figure 5.1 – Factors of the indoor climate.

Typical example of convection used to warm space

Thermal inertia (heat resistance) of the building – the main thermal characteristic, which depends on the degree of transfer of enclosing structures (walls, floors, windows, lights) heat, air and moisture.

Thermal inertia (*or thermal diffusivity*) is a term commonly used for modelling heat transfers. It is a bulk material property related to thermal conductivity and volumetric heat capacity. For example, 'this material has a high thermal inertia', or 'thermal inertia plays an important role in this system', mean that dynamic effects are prevalent in a model, so that a steady-state calculation will yield inaccurate results.

The term is a scientific analogy, and is not directly related to the mass-and-velocity term used in mechanics, where inertia is that which limits the acceleration of an object. In similar way, thermal inertia is a measure of the thermal mass and the velocity of the thermal wave which controls the surface temperature of a material. In heat transfer, a higher value of the volumetric heat capacity means a longer time for the system to reach equilibrium.

The thermal inertia of a material is defined as the square root of the product of the material's bulk thermal conductivity and volumetric heat capacity, where the latter is the product of density and specific heat capacity.

Thermal conductivity – heat exchange between body particles that are in contact with each other.

Thermal conductivity – heat exchange between body particles that are in contact with each other.

5.2 Determination of heat transfer

Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity. For instance, metals typically have high thermal conductivity and are very efficient at conducting heat, while the opposite is true for insulating materials like Styrofoam. Correspondingly, materials of high thermal conductivity are widely used in heat sink applications, and materials of low thermal conductivity are used as thermal insulation. The reciprocal of thermal conductivity is called thermal resistivity.

There are three types of heat transfer: thermal conductivity, convection and radiation (fig. 5.2).

Heat transfer – heat transfer, which includes all types of heat transfer from one heated gaseous medium to another through their separating wall (solid).

Heat transfer – the process of heat exchange between a solid wall and its surrounding gaseous or liquid medium is sometimes called.

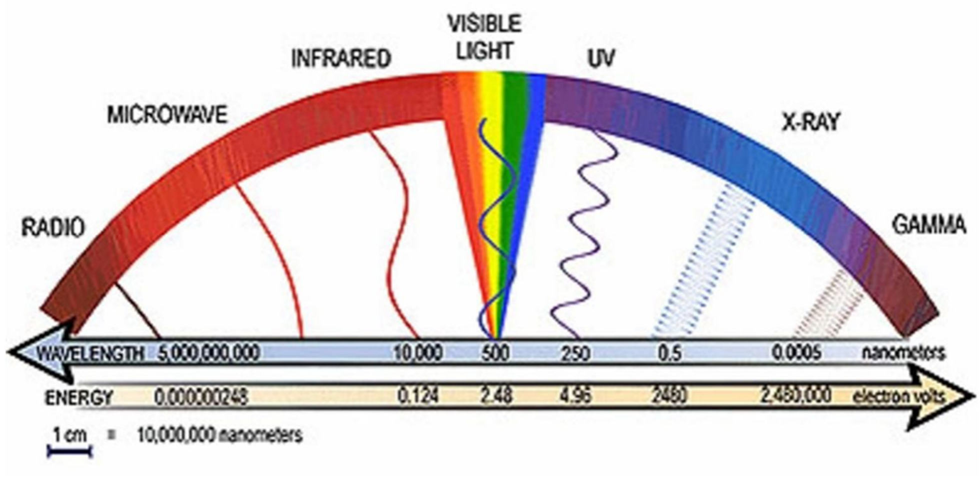


Figure 5.2 – Electromagnetic Radiation & Electromagnetic Spectrum

The heat transfer process includes:

a) heat exchange between the surface of the fence and the heated air in which the fence is – called *heat perception*; such heat exchange is observed, for example, in the heated rooms at collision of an internal surface of a wall with internal air;

b) heat exchange between the surface of the fence and the cooled air in which the fence is located; such heat exchange is observed when the wall (its outer surface) comes into contact with outside air.

5.3 Criteria for determining the microclimate of the premises

As the temperature of the air drops below a person's skin temperature (32° C), that person begins to lose heat to the surroundings. Heat is lost through both conduction and sweating. Metabolizing in the muscles strives to compensate for the loss of heat. At temperatures over 20° C, both temperature and relative humidity affect heat loss. Growing wind speed increases the removal of heat released by conduction and the evaporation of sweat. As the temperature decreases below 20 degrees, the significance of heat released through evaporation begins to diminish, and at temperatures below 10 degrees, relative humidity no longer has any significance. Heat loss can be prevented with clothing. At low temperatures the significance of wind speed increases, and at very low freezing temperatures wind speed has a much more significant impact on heat loss than changes in temperature. Solar radiation also has a significant increasing impact on the sensed temperature.

A number of indices that take into consideration air temperature, relative humidity, wind speed, and solar radiation have been developed to depict people's feeling of comfort. However, none of them can be applied to the entire range of temperatures, +/– 50° C, in which people live and function.

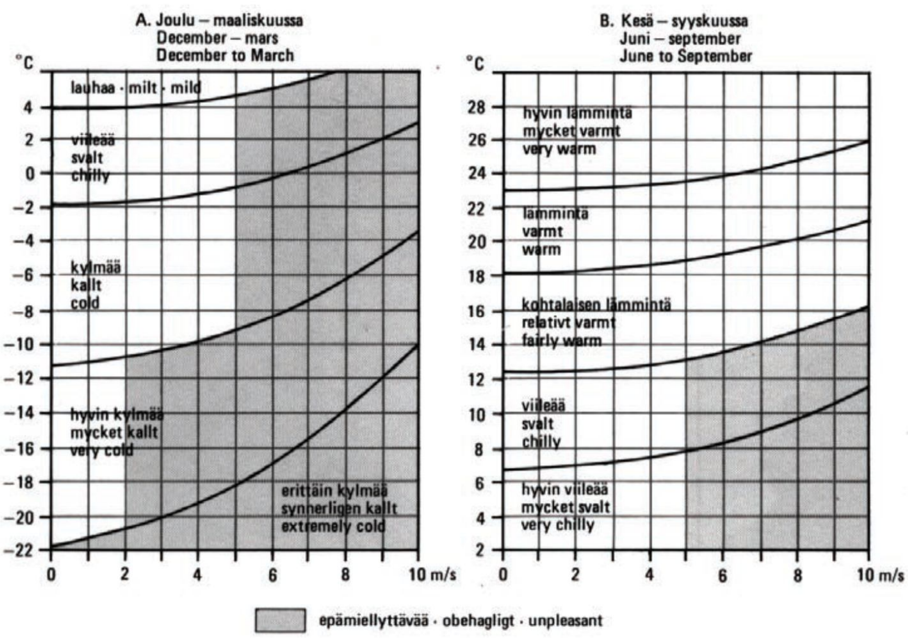


Figure 5.3 – Comfort experienced by people in winter and summer in a cold climate

Figure 5.3 presents a set of comfort curves that depicts comfort experienced by people in winter and summer. The shaded area indicates temperature and wind speed ranges that people experience as uncomfortable. At low temperatures, wind has a major cooling effect, and the cooling effect of wind is emphasized at freezing temperatures.

The range of thermal comfort is especially limited indoors. Also, the temperature difference between two surfaces situated near to each other (e.g. a wall and a window) should not be over 5–10 °C. The radiation temperature difference between the roof and the floor should not be higher than 2–5 °C. The vertical temperature difference indoors should not be over 3 °C. The effect of the surrounding surfaces is presented in figure 5.4.

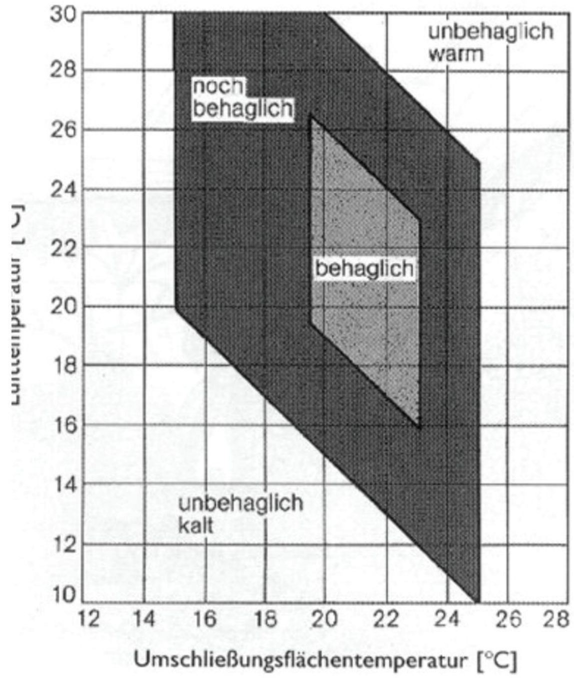


Figure 5.4 – The human range of thermal comfort indoors.
Air temperature is on the vertical axis and the temperature of the surrounding surfaces is on the horizontal axis. Behaglich indicates the range of thermal comfort.

People have only a limited capacity to adjust to the surrounding circumstances.

The human body tries to maintain a core temperature of 37 °C; in hot conditions perspiration increases to maximize heat flow through evaporative cooling of the skin, and in cold air the reverse happens. Relative humidity also greatly affects the range of thermal comfort.

Test questions on the topic:

1. What does the Thermophysical study? Expand the concept subject and methods of thermophysical.
2. List the main factors that determine the thermal comfort of the room
3. What are the Indices of Thermal Comfort?

2 Content Module 1.2 LIGHTING AND ILLUMINATION

Theme 6: Fundamentals of lighting engineering

Basic concepts and laws of light energy propagation. The Lambert's laws of light energy. Vision functions. Optical illusions. Architectural daylighting. The main tasks of creating a light image of the surrounding space.

6.1 Basic concepts and laws of light energy propagation

Light is electromagnetic radiation with wave and corpuscular (quantum) properties that propagate in space with a limited speed of up to 300,000 km / sec.

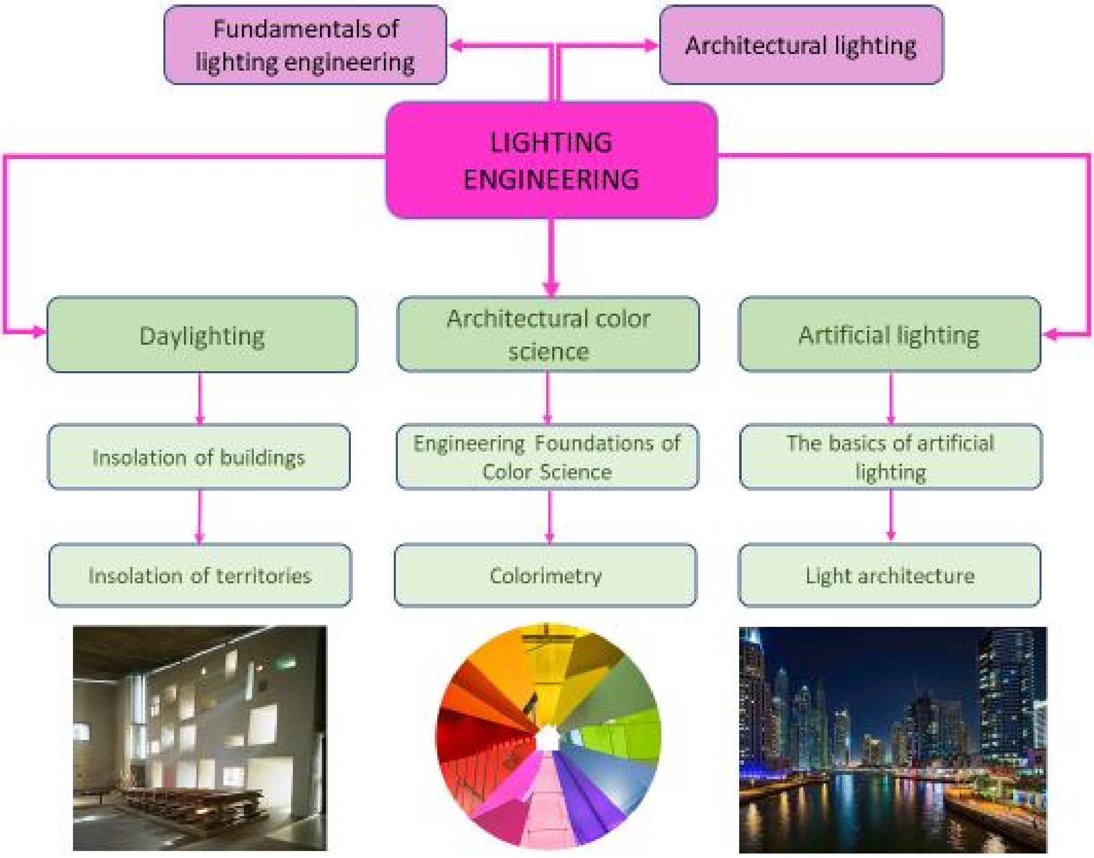


Figure 6.1 – The structure of lighting engineering

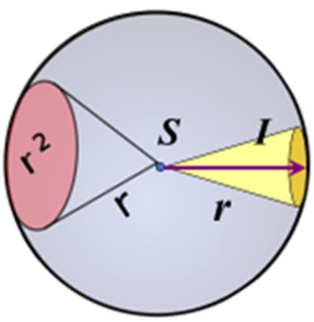


Figure 6.2 – Model of the lighting space

Luminous Flux – lighting power, energy emitted in 1 second.

Luminous Intensity (I) – spatial power (density) of the luminous flux, equal to the ratio of the luminous flux to the value of solid angle in which uniformly radiation is distributed.

The bodily angle is a part of space, which is the union of all the rays emanating from a given point (apex of the angle) and crossing a certain surface. The solid angle is a conical surface (fig. 6.2).

is a light quantity that is directly determined by the eye. It represents the surface density of the luminous intensity in a given direction, and is determined by the ratio of the luminous intensity to the projected area of the mirror surface to the area perpendicular in the same direction.

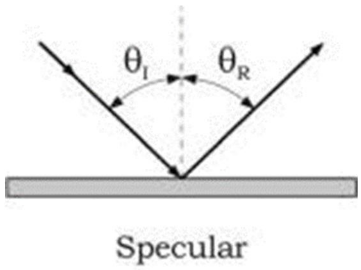
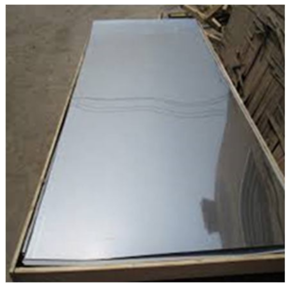
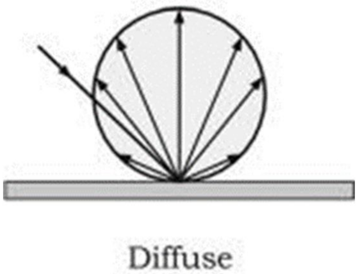
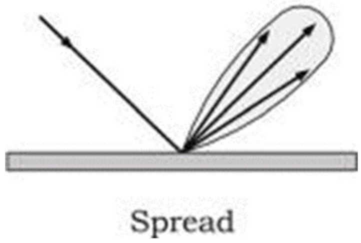
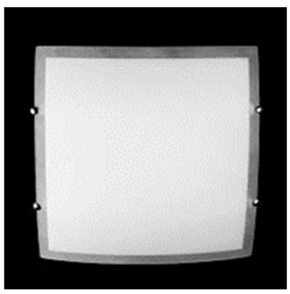
Illumination is a luminous quantity, which is determined by the ratio of the luminous flux to the area over which this flux is evenly distributed.

Flat illumination arises from the action of light directed horizontally or obliquely.

Cylindrical illumination is an indicator of the saturation of a room with light from many dispersed sources.

Luminosity is the surface density of the luminous flux that is emitted by this surface, and is determined by the ratio of the luminous flux that a surface element emits to the area of this element.

Table 6.1 – The kids of reflection

Scheme of reflection	Explanations of reflection	Examples of reflection
	When light obeys the law of reflection, it is termed a specular reflection. Most hard polished (shiny) surfaces are primarily specular in nature. Even transparent glass secularly reflects a portion of incoming light.	
	Diffuse reflection is typical of particulate substances like powders. If you shine a light on baking flour, for example, you will not see a directionally shiny component. The powder will appear uniformly bright from every direction	
	Many reflections are a combination of both diffuse and specular components. One manifestation of this is a spread reflection, which has a dominant directional component that is partially diffused by surface irregularities.	

The criterion for evaluating variable Illumination in natural light is the coefficient of natural light (*CNL*).

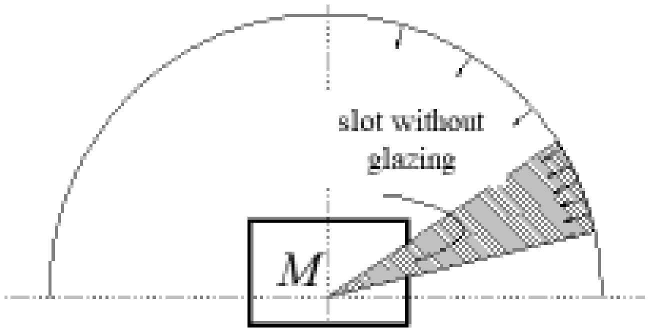


Figure 6.3 – Model for calculations of natural lighting

CNL (e_n) – the ratio of natural illumination created at some point (***M***, fig. 6.3) of a given plane inside the room by the light of the sky ($\boldsymbol{E_m}$) (directly or inside the reflection) to the simultaneous value of the external horizontal illumination under the open sky ($\boldsymbol{E_n}$).

$$e_n = \frac{E_m}{E_n} 100\ (\%)$$

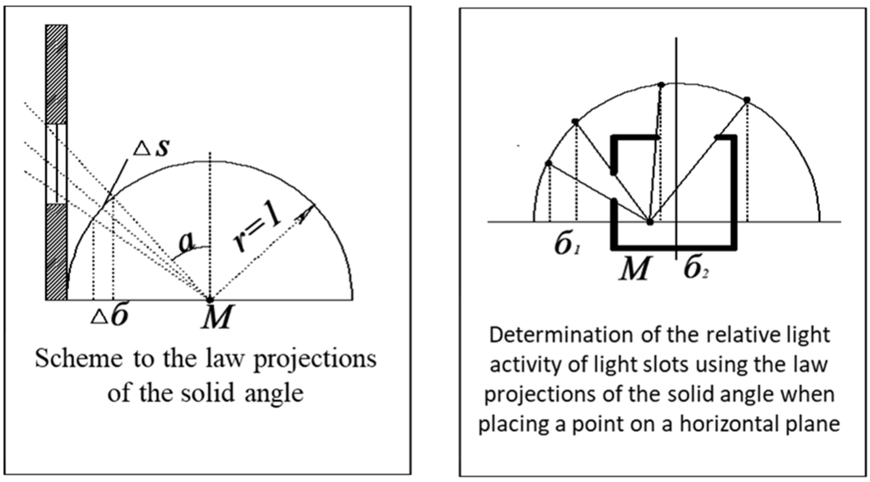
For calculations of natural lighting, it is used geometric coefficient of natural light.

6.2 The Lambert's laws of light energy

Lambert's laws, projections of the solid angle and lighting engineering similarity and application of these laws in architectural lighting engineering.

First law – law projections of the solid angle

The essence of the law: illumination, at any point on the surface of the room, is created by a uniformly luminous surface of the sky, is directly proportional to the brightness of the sky and the area of the projection onto the illuminated surface of the solid angle at which a section of the sky is visible from this point.



Scheme to the law projections of the solid angle

Determination of the relative light activity of light slots using the law projections of the solid angle when placing a point on a horizontal plane

Figure 6.4 – Model for calculations of natural lighting

The second law of lighting engineering similarity

The essence of this law is determined from the diagram. Illumination in the room M is created through the windows, which are characterized by the brightness L1, L2. With different sizes of windows (I and П), the illumination at point M is created precisely by the solid angle, the vertex of which coincides with point M (fig. 6.5).

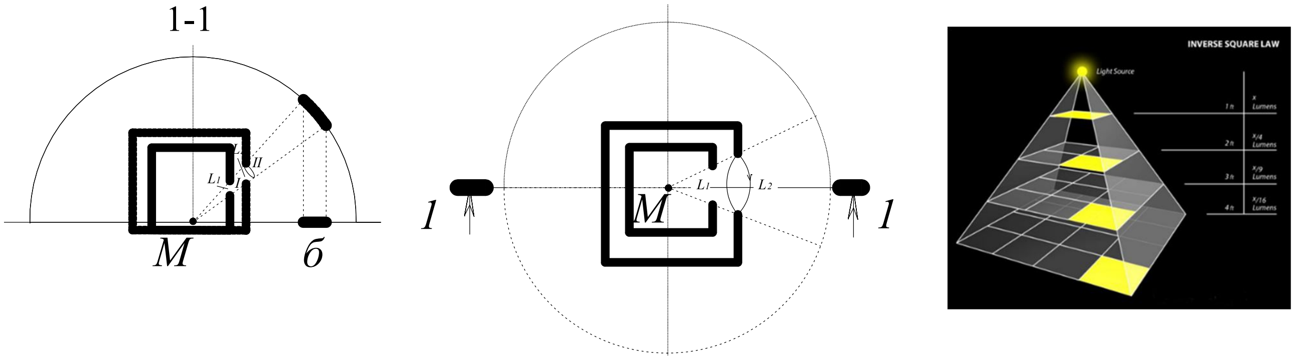


Figure 6.5 – Scheme to the law of lighting similarity

It follows from the solid angle projection law that the illumination at point M remains constant with the condition that $L_1 = L_2 = L_n = const$.

Illumination at any point in the room depends on the relative size of the room. (application of the law – modeling techniques).

6.3 Vision functions. Optical illusions

Vision is a function of the organ of vision and the visual analyzer, which is inherent in the perception and redistribution of the energy of light emitted and reflected by various objects, and the information received about the world around us.

Visual acuity is the ability of the eye to detect, distinguish and identify objects in the surrounding background.

One of the physiological characteristics of the visual analyzer is the ability to adapt to lighting conditions.

In low light, visual perception is provided by receptors located on the retina-rods.

Night, or scotopic vision (gr. Skotos – darkness);

Twilight or mesopic vision (gr. Mesos – medium, intermediate);

Daytime or photopic vision (gr. photos – light).

Monocular and binocular vision.

Looking at objects by a person with one eye of the surrounding space is called monocular vision. With this vision, the actual perception of the environment is difficult.

Full, correct and accurate perception of space gives vision with both eyes – binocular vision.

Optical illusions it is an optical illusion of the brain.

The eye sees the image of one object, but the brain understands this object in its own way.

When the organ of vision receives a picture, many processes in the brain are turned on.

The brain analyzes this process like a computer. An analysis of the location of major edges and corners, color patterns, or light positions begins.

In many cases, this analysis is unconsciously inaccurate – there is a correction of visual images.

The Greek Parthenon is the most typical example of a huge illusion. Slightly thicker are the corner columns, the pylons bent inward, the floor, which is 6 cm higher in the center than the other planes are the all elements work to create the greatness and immortal beauty of the Parthenon (fig. 6.6).

Figure 6.6 – The Greek Parthenon

6.4 Architectural daylighting

The light-color environment is formed by a radiant energy of natural and artificial radiation sources within its optical spectrum and predetermines visibility, perception and comfort in architectural forms and spaces.

The main tasks of creating a light image of the surrounding space:

Functional – ensuring the level and quality of lighting required for specific conditions of visual work.

Aesthetic – creating an architectural light image, giving artistic expression to the surrounding space.

Economic – the choice of the best option at the minimum spent costs, considering the functional and architectural requirements.

Daylight: direct – (sunbeams) daylight; diffuse (diffuse) – (light of the firmament) daylight.

Optimal light conditions:

a) the correct choice of the light climate of the geographic location (where the construction of the projected facility is planned);

b) the correct choice of sizes, shapes and colors of the room;

c) placement of light openings;

d) correct placement and choice of power of artificial light sources.

Brightness of natural illumination – the luminous quantity, determined by the eye, is the power of the intensity of light in a given direction and has the following illumination indicators:

- distribution of brightness in the surrounding space;
- uneven lighting;
- direction and properties of light for the formation of shadows;
- spectral composition of light.

6.5 The main tasks of creating a light image of the surrounding space

Based on the initial data (type and shape of windows, skylights; their design, decoration of premises), the dimensions of windows and skylights are determined, which is expressed in the standard values of the coefficient of natural illumination: average – with overhead lighting and minimum – with side lighting.

The architectural light image of an interior is determined by the main characteristics of the quality of lighting:

The distribution of brightness in the room (the ratio of the brightness of the walls, ceiling and floor).

Elimination of the phenomenon of dazzle created in the room by direct sunlight or bright sky.

Creation of uneven lighting in the room (ratio of maximum and minimum illumination).

Illumination contrast (the ratio of total illumination and illumination created by diffused light (creates as a result of multiple reflections from the surfaces of walls, ceiling and floor)).

Test questions on the topic:

1. What does the Lighting Engineering study? Expand the concept of Lighting Engineering.
2. Define the essence and justify the practical application of Lambert's laws.
3. What are the main objectives of lighting architecture?

Theme 7: Insolation of buildings and territories

Insolation design basics. Methods for determining the insolation of buildings. The main characteristics of sun-protection devices and methods for their design.

7.1 Insolation design basics

Insolation (*from Latin in solo – I put it in the sun*) The term insolation is derived from the words "incoming solar radiation". Insolation is specifically applied to radiation which is arriving at earth's atmosphere first and then earth surface.

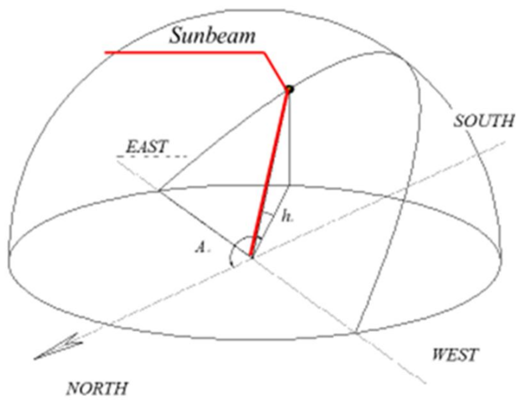


Figure 7.1 – Scheme of sun coordinates

The azimuth of the sun's rays (A_o) is the angle in the horizontal plane formed by the horizontal projection of the sun's ray and the direction of the meridian. Sunbeam height (standing height

Sun h_o) – the angle formed by the sunbeam and its horizontal projection; measured in the vertical plane.

The angle of incidence of the sunbeam on the ground, found for the point under study, is determined by: latitude of a given point solar radiation on the day of the study moment of research, which is expressed in sundials.

The main tasks of insolation calculations:

Determination of the duration of insolation (shading) of the object;

Determination of the shape, size and area of the insulated (shaded) area indoors or on the territory;

Calculation of sun protection devices.

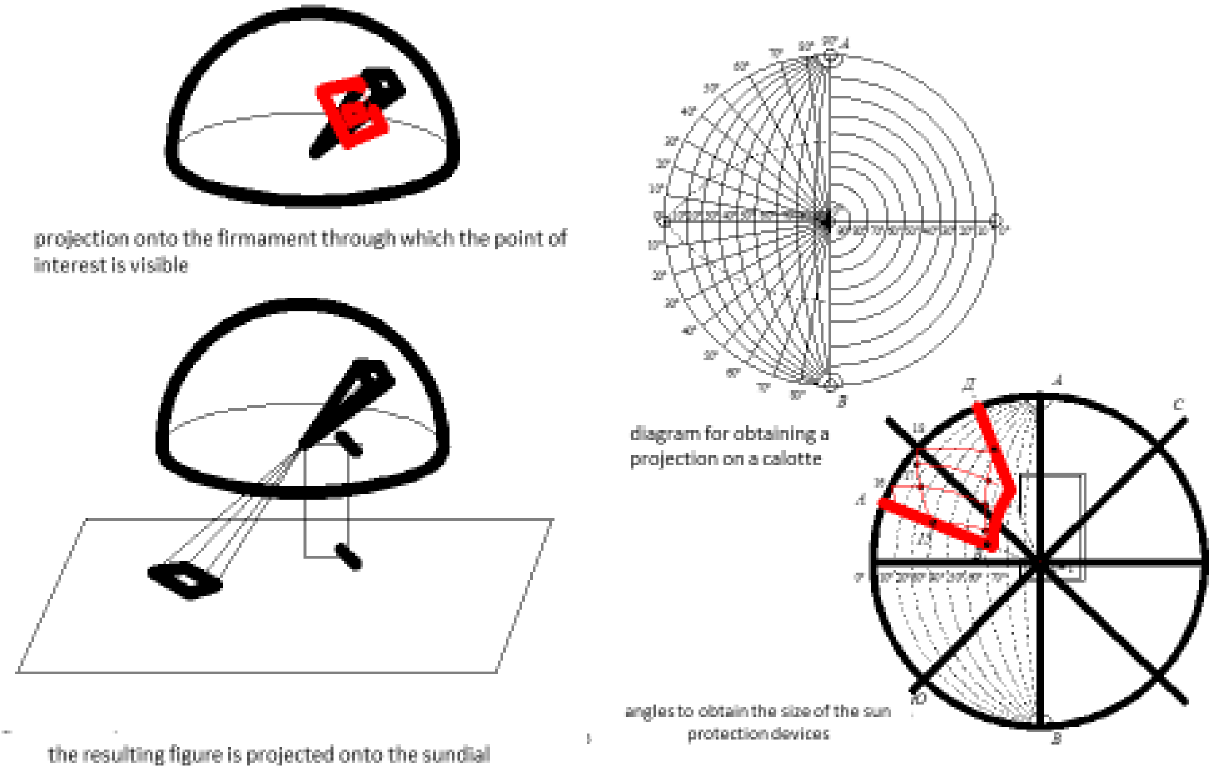
To perform the calculation of insolation, it is necessary to:

- specify the geometric characteristics of the design object (room or area) and the system of shading objects;
- consider the directions of the cardinal points and the latitude of the area.

The result of the calculation of the insolation time is the values characterizing the insolation (insolation time in hours and minutes, the number of insolation intervals, the percentage of the insulated area).

7.2 Methods for determining the insolation of buildings

The method of oblique projection onto the studied surface of shading objects in the direction of the sun's rays (constructing the contours of the shadow at regular intervals).



a) b)

Figure 7.2 – Methods for determining building insolation:
a) Double projection method; b) Calotte projection method

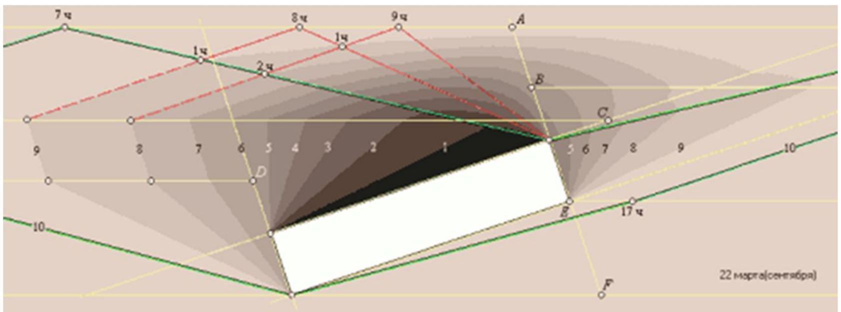


Figure 7.3 – Method for constructing a daily shadow envelope

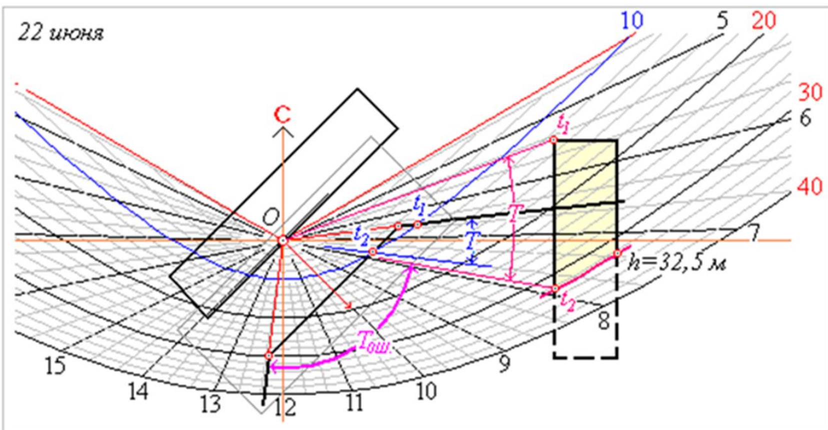


Figure 7.4 – Calculation of insolation of a room with a loggia on the day of the summer solstice by the method of orthogonal projection

7.3 The main characteristics of sun-protection devices and methods for their design

Shading devices are equipment's that are used externally or internally or in between the building spaces to protect from direct sunlight.

Table 7.1 – Main characteristics of the sun protection devises

Sun protection devises	Location in building	The nature of the action	Sun protection effect	Region application
Horizontal or inclined one-piece visors	Over the windows outside facade	Limiting or excluding insolation	At high solstice	Walls of South orientation
Horizontal or tilted louvered louvers	Over the windows outside facade	Limiting or excluding insolation, aeration	At high solstice	Walls of South orientation
Vertical edge screens, normal or at an angle to the wall	Close to window openings on one side	Limiting or excluding insolation, aeration	At low solstice	Walls of west and east orientation
Remote walls	Above window openings on both sides	Limiting or excluding insolation, aeration and protection of walls from overheating	No limits	No limits
Louver grilles horizontal or vertical	In front of or inside lights openings	Limiting or excluding insolation	No limits	No limits predominantly western orientation; predominantly eastern orientation
Mobile blinds, awnings, visors	Behind or inside lights openings	Limiting or excluding insolation	No limits	South, southeast, southwest
Light diffusers	Over the entire area of the facade	Limiting or excluding insolation, ventilation is provided worse	No limits	No limits
Special types of glazing	Filling light openings	Light scattering, reflection or absorption	No limits	South, southeast, southwest

The main functions of sun protection devises:

1) protection against overheating of premises in the summer months;

2) limitation of direct and reflected brilliance, which is accompanied by blinding of workers;

3) replacing the distribution of luminous fluxes.

Types of the sun protection devises: a set of architectural and planning activities;

Sun protection devices:

a) stationary: visors (solid or lattice), screens (horizontal and vertical, solid or lattice), bowl-like spatial forms;

b) adjustable (mobile): blinds (horizontal or vertical), shutters, awnings, curtains, etc .;

constructive means: (use of heat-reflecting, light-scattering, etc. glass, heat-insulating materials, air spaces, etc.);

technical means – air conditioning of premises.

Test questions on the topic:

1. What does the Insolation study? Identify the main methods for determining the insolation of buildings.
2. Describe the meaning of the radiation mode of the territory (insolation of the building).
3. What are the main methods for determining the insolation of buildings?

Theme 8: Fundamentals of Architectural Color science

Basic physical characteristics of color. The main types of color contrasts. Color in the interior

8.1 Basic physical characteristics of color

Color science – the science of color, systematization of general data on physics, physiology, psychology and other sciences that consider human perception of color, the impact of color on humans, systematization and measurement of color (colorimetry).

Colorimetry – a set of methods for mathematical description of colors and methods for measuring them (quantitative measurement).

Color tone determines the place of color in the spectrum – the main characteristic of color (Red – green – yellow – blue).

In the physical sense, *color tone* depends on the wavelength of light.

Long waves are the red part of the spectrum. Short – shifts to the blue-violet side. The average wavelength is yellow and green, they are the most optimal for the eye.

Achromatic colors: black, white, and intermediate – the whole scale of gray.

Differ in the lack of tone. Black – no color. White – a mixture of all colors.

Grays are usually obtained by mixing two or more colors. Everything else is chromatic colors.

Chrominance – which is often called 'juiciness' is the amount of color in a color. The color without color is achromatic and is perceived as gray.

Value or Brightness – the degree of relative brightness and shading of the color - depends on the amount of light emitted by the color.

Luminance – this is the position of the color on the scale from white to black. It is characterized by the definitions of dark, light.

8.2 The main types of color contrasts

The ratio of colors is the main factor that determines the nature and influence of the composition. It is subject to the laws of color combinations, among which one of the most important - color contrast, which controls the relationship of colors with each other for all basic parameters and many associations of perception (fig. 8.1).

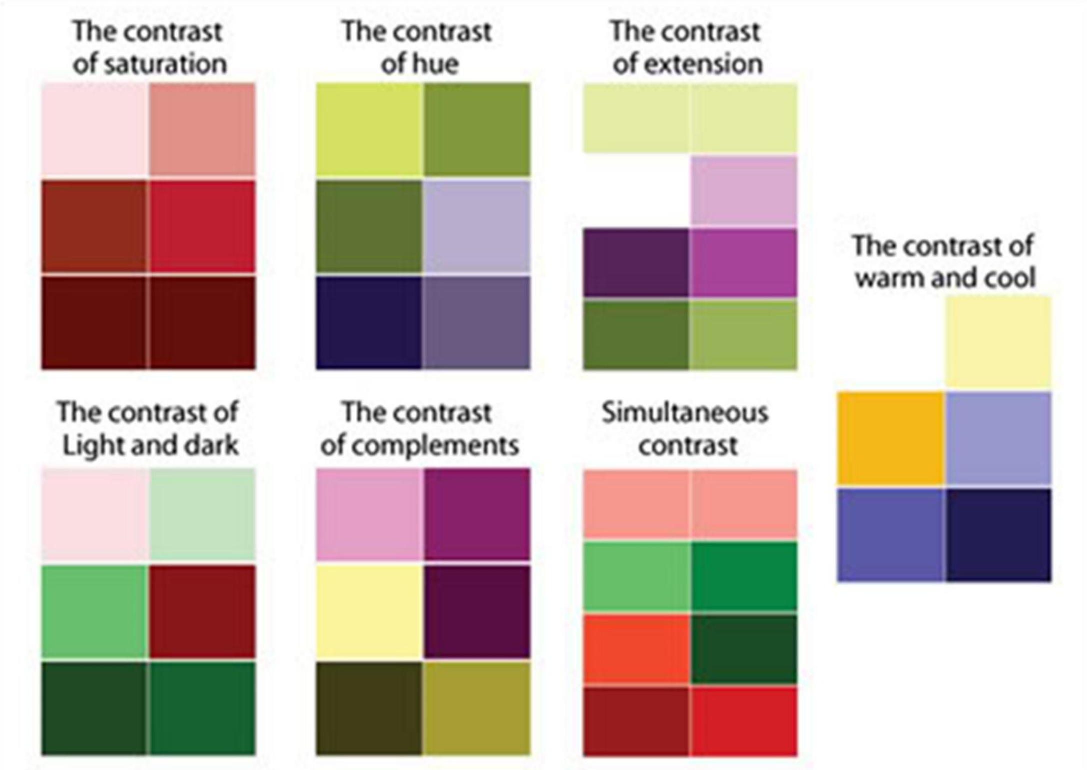


Figure 8.1 – Types of contrasts

Color contrast – controls the ratio of colors among themselves by basic parameters and many associations of perception (speakers – retreating; warm – cold).

High color contrast – allows high contrast in color tone with medium and high contrast in photos (yellow-blue); average contrast in color tone with high contrast in photos (yellow and dark green) (more than 0,5).

Medium color contrast – determines the average contrast in color tone at the average contrast in the photos (yellow and green); low contrast in color tone with high contrast in photos (yellow and dark orange) (0.5 – 0,2).

Low color contrast assumes small contrast on color tone at average and small contrasts on photos (yellow and light green); high contrast in color tone with low contrast in photos (orange and blue) (less than 0,2).

Types of contrasts and their range:

In the light – light – dark (achromatic, chromatic, mixed);

By color tone – the main color and it's additional;

By saturation – saturated chromatic and achromatic;

For cleanliness – optimal dark – series;

By texture – matte – shiny;

By associations – spatial: protruding – retreating; temperature: warm – light; weight: light – heavy;

By activity of influence: passive – active, arousing – calming and depressing.

8.3 Color in the interior

To solve color problems in the interior, you need to know the features of the emotional impact of colors on a person.

Emotional perception of color is determined by its direct physiological influence, exciting or suppressed by its nature, associations caused by color (tabl. 8.1). The general trend is the regularity of this effect of color on a person in the case of increasing the wavelength of radiation from the minimum in the blue-violet part of the spectrum to the maximum – in red.

The characteristics of the spectral and achromatic colors by associations for all major surfaces are shown in table 8.1, but the data presented are subjective and may change with changing color purity or lighting conditions.

With the spatial qualities of colors, you can influence the perception of three-dimensional shapes and create a color composition using the basic qualities of colors (color tone, brightness, saturation, texture), or some features of color perception.

Speaking about interior design, the colors are those through which a house can get personality, are those that create different optical illusions and have also a strong influence on our psychological level as we told you in a previous article the psychology of color for interior design. Using green in interior design with appropriate other shades of green or with other colors with a well contoured destination may have special effects. Use this color especially when you want to inspire a fresh and natural atmosphere.

Table 8.1 – Psychological functions of color

Colors	Characteristics of colors								
	Warm	Cold	Easy	Heavy	Retreating	Impending	Exciting	Depressing	Sedative
Spectral (chromatic) colors									
Red	+	+	+	+	+	+	+		+
Orange	+	+	+	+	+	+	+	+	+
Yellow	+	+	+	+	+	+	+		+
Yellow-green	+	+	+	+	+	+	+		+
Green	+	+			+				+
Green-blue									
Blue									
Blue									
Violet									
Purple									
Achromatic colors									
White			+	+				+	
Light gray			+	+				+	
Dark grey									
Black									

Test questions on the topic:

1. Justify what is studying architectural color science?
2. What are the main characteristics of the color?
3. What is the principle of colorimetry?
4. What is contrast in color theory?
5. Name the main properties of colors that determine their psychological impact on humans.

Theme 9: Standardization and design of color solutions

Basic color measurement systems. Atlases of colors. Color systematization. Retrospective of scientific systematization of colors. Coloristic of the city

9.1 Basic color measurement systems. Atlases of colors

Atlases of colors – systematized set of various samples – color standards; is designed to determine the color shades of objects by visually comparing their color with the reference from the Atlas of colors in the same lighting. Estimation of color and shade of an object is reduced to selection in the atlas of the sample close to it.

Color metrology – the science of color measurement, or colorimetry. Along with the actual measurement of color, colorimetry studies the issues of its systematization and mathematical description.

Basic color measurement systems:

Colorimetry is to determine the color coordinates, in numerical characteristics, which can not only describe the color, but also to reproduce it. An example of its implementation can be a variety of color models.

The system of specifications is a set of colors (atlas), in which a color identical to the reproducible (measured) is selected. In most modern graphics programs, it is matched by a variety of palettes and color matching systems such as Pantone and Trumatch.

9.2 Color systematization. Retrospective of scientific systematization of colors

In today's world, when the range of colors is constantly expanding means, especially the need for a single system that disciplines difficult to manage color abundance. This system must correspond exactly as technical and aesthetic requirements.

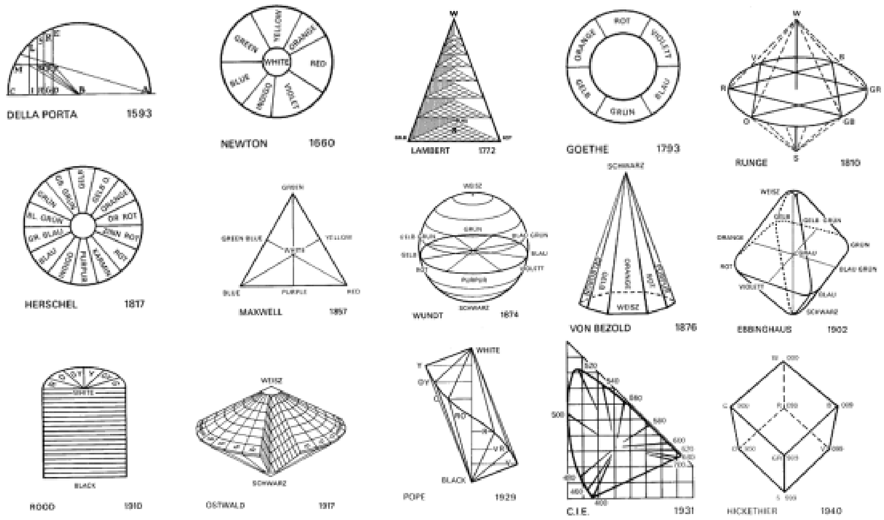


Figure 9.1 – Retrospective of color models

The color wheel is the first colorimetric system. The main characteristics of colors: color tone; conditional purity or color saturation; relative lightness or brightness of color.

Philippe Otto Runge developed his color classification system using the principle of a globe or sphere. Optimally saturated colors of the spectrum are located along the equator of the sphere, to the pole along the meridians the colors change in lightness, to the center of the axis each modification in lightness changes in saturation.

Color circles. It is accepted to allocate two groups of color circles: physical (based on Newton's 7-step color wheel) physiological (based on the color wheel 6-step Goethe's circle) (fig. 9.1).

Philippe Otto Runge developed his color classification system using the principle of a globe or sphere. Optimally saturated colors of the spectrum are located along the equator of the sphere, to the pole along the meridians the colors change in lightness, to the center of the axis each modification in lightness changes in saturation.

Oswald perfected the Runge sphere system. He takes a circle, divides it into 24 parts, paints each spectrum in a certain color.

Main characteristics of the study of color models:

Newton - for the first time proposed a real range of colors for the convenience of radiating their relationship in the form of a color wheel.

Goethe arranged the main colors on different sides of the triangle. The theory of color mixing does not correspond to the three-component Helmholtz system, is not optical - mixing of light rays.

Runge is the first color three-dimensional model, but it is primitive and bulky.

The Oswald's color three-dimensional model is based on the definition of colors by color tone, purity and relative brightness. Oswald compiled an atlas containing 2,500 colors. The disadvantage of his theory is the excessive mathematization of the principles of color combination.

Maxwell's Atlas consists of ten tables, and each of them has one color tone, modified by lightness and saturation, shows in the color range the color of 100 shades of color tones (combination of color tone and saturation).

9.3 Coloristic of the cities

The main factors of the concept of color of the city: Project idea climatic features; the color scheme of the natural landscape; city structure; historical architectural polychrome; color culture of society; symbolism of color and tradition.

Main tasks of city coloristic

1. Analysis of the existing color situation of the region and natural factors influencing the color characteristics of the city.

2. Selection of the palette of local building materials and setting priorities in the color scheme of the city depending on the color and seasonal changes.

3. Creation of the concept of coloristic in the form of parameters of the general plan of the city: search of microculture, search of the basic palette of coloristic of the city, definition of degree of variability of polychrome of building zones.

Psychophysical patterns:

individual features of perception; color preference; the duration of the depicted, short-term and long-term (constantly formed) color memory; color contrast.

Color modeling in urban planning

Long – historical epochs the development of the sense of color in the process of evolution.

Periodic – change of natural rhythms and occupations of the person;

Contact – daily dynamics of the environment, human movement, daily biorhythms.

Test questions on the topic:

1. Justify what is studying architectural color science?
2. What are the main characteristics of the color?
3. What are the main types of color contrasts?
4. Name the main properties of colors that determine their psychological impact on humans.

Theme 10: Artificial lighting of urban spaces and buildings quantitative and qualitative characteristics

Quantitative and qualitative characteristics of artificial lighting. Standardization and design of artificial lighting. Means of architectural lighting of urban spaces. Light panorama of the city, light ensembles and dominants.

10.1 Quantitative and qualitative characteristics of artificial lighting

Artificial lighting has transformed the outdoor nighttime environment over large areas, modifying natural cycles of light in terms of timing, wavelength, and distribution. This has had widespread benefits and costs to humankind, impacting on health and wellbeing, vehicle accidents, crime, energy consumption and carbon emissions, aesthetics, and wildlife and ecosystems.

Artificial lighting – lighting created by lamps, lighting installations, projectors and other artificial light sources.

Artificial light is human-made and can emanate from sources including fire, candlelight, gaslight, electric lamps and so on. Today however, the term artificial lighting' generally refers to lighting that emanates from electric lamps.

Artificial light is generally easily manipulated to achieve the required lighting outcome. The light can be increased or decreased, directed, focused and colored. This allows lighting to create a range of effects according to the requirements of a space.

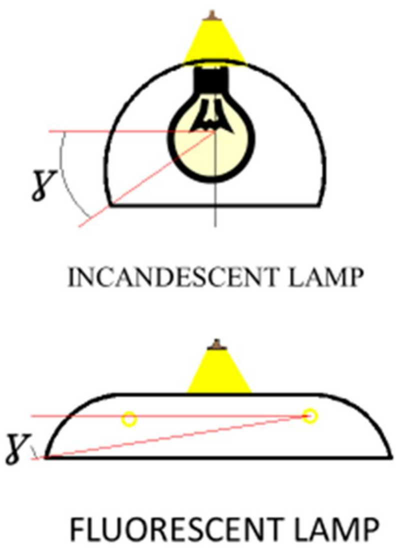


Figure 10.1 – Protective angle γ

Depending on the value of the protective angle (γ), it is standardized suspension height of the luminaires above the horizontal level working surface or from the floor of the room (fig. 10.1).

Basic parameters used in lighting:

Luminous flux – Luminous intensity – Illuminance – Luminance

Luminous flux (φ) is the light emitted by a source and is measured in lumens (fig. 10.2).

Luminous intensity is the power of light from the source measured in candela (fig. 10.2).

Illuminance is a measure of the density of luminous flux at a surface measured in lux (lumens per square meter) (fig. 10.2, from eq. 1).

$$E\ (lx) = \frac{luminous\ flux\ (lm)}{area\ (m^2)}, \quad (1)$$

Luminance is a measure of the light reflected from a surface measured in candela per m^2.

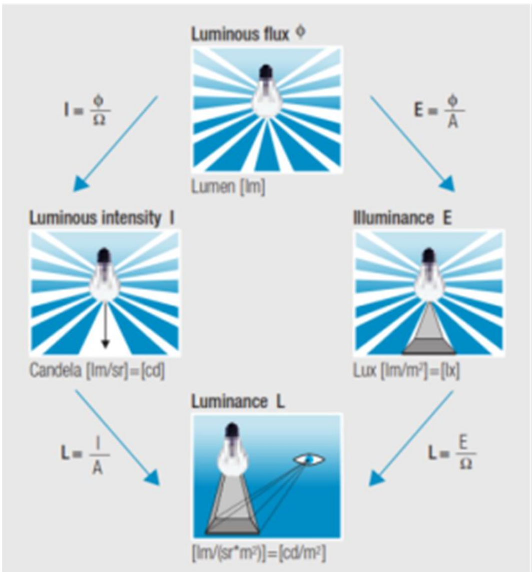


Figure 10.2 – Basic parameters used in lighting

The luminous efficiency is the ratio of the luminous flux to the electrical power consumed (lm / W). It is a measure of a lamp's economic efficiency (fig. 10.2).

Luminous efficacy is the ratio of the luminous flux emitted by a lamp to the power the lamp consumes this is measured in lumens per watt (W).

A light fixture (US English), light fitting (UK English), or luminaire is a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

All luminaires have a fixture body and a light socket to hold the lamp and allow for its replacement. Also, they may a have a switch to control the light. Typical luminaires are shown in figure10.3.

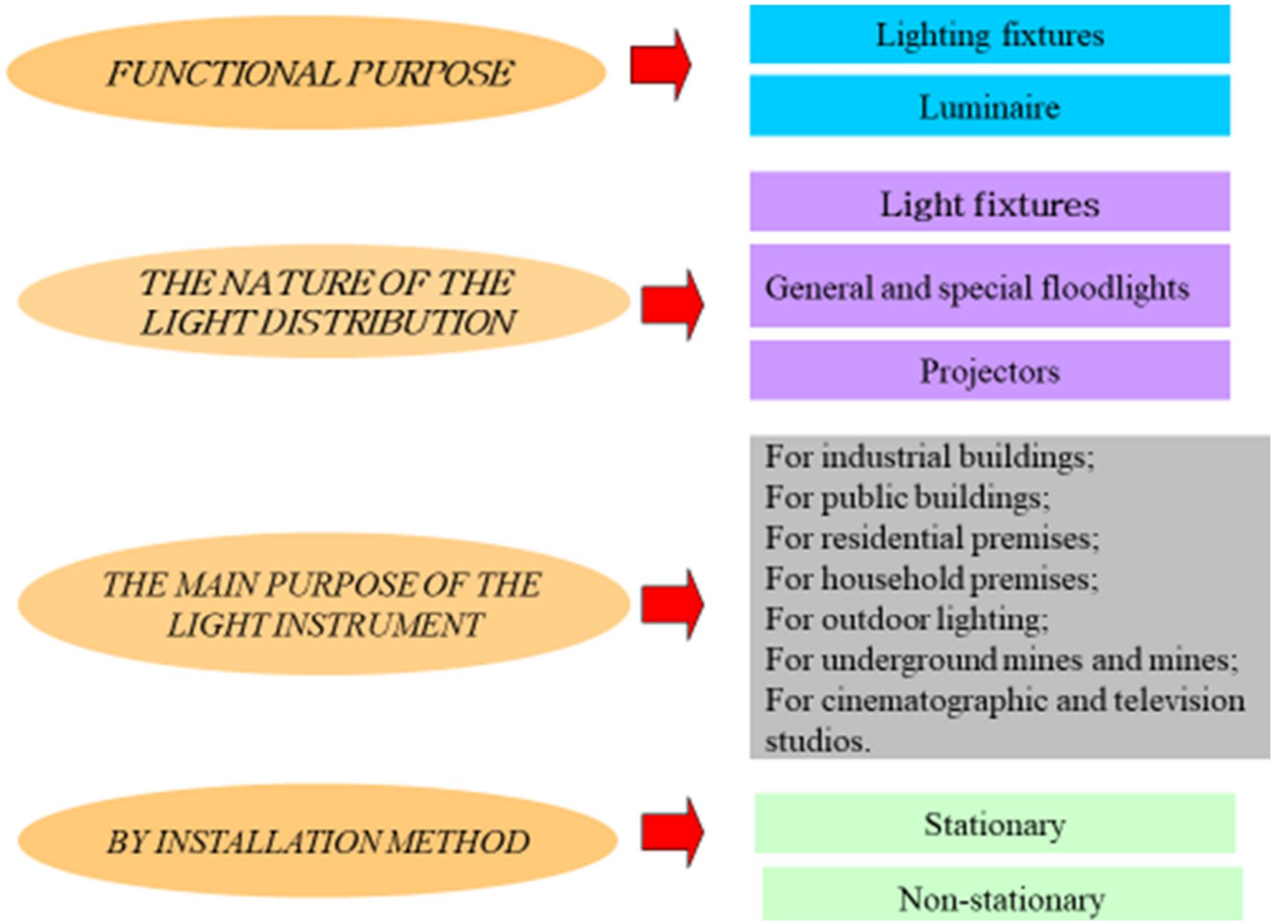


Figure 10.3 – Lighting devices classification

Recent years have seen a huge shift away from traditional incandescent filament-type light bulbs to more energy-efficient alternatives. The following are some lamps currently available.

Incandescent – the traditional bulb-type lamp with a glowing filament, once commonly used in residential applications. They are generally considered to be the least energy-efficient choice of electric lamp but are inexpensive, turn on instantly and come in a range of sizes and shapes.

Fluorescent – compact fluorescent lights (CFLs) are available in various sizes and fittings and can be used in place of incandescent lamps without changing light fixtures. They are generally more energy efficient than incandescent bulbs. Some are dimmable and are compatible with other lighting controls. CFLs come in globe, spiral, floodlight and reflector variants.

Light-emitting diode (LED) – are a rapidly developing lighting technology and one of the most energy-efficient lamps available. Compared to incandescent lamps, they can use around 75% less energy and can last 25 times, longer although they can be more expensive. They are generally highly regarded for their comparable or better-quality light output compared to other lighting types.

10.2 Standardization and design of artificial lighting

The type of artificial light source chosen will depend on the type of space the lighting is for (office, living room, bathroom etc.); the quality and type of light required for the space, and the energy consumption of the light fitting (fig. 10.4).

Types of artificial lighting

Ambient lighting – this is the general artificial lighting and overall illumination in a room. It can provide an even spread of light to give a comfortable level of brightness for most people to be able to see reasonably well and navigate safely around the room. Typically, it can be provided by a pendant fitting or ceiling downlights.

Task lighting – this allows the completion of tasks such as reading, studying and way-finding. It is used where ambient light levels are insufficient for the task in hand. A reading lamp is an example, as are under-cabinet lights.

Accent lighting – this type of lighting imparts drama and character and allows certain features regarded of interest to be highlighted. The idea is to draw the viewer's attention to the item that is lit, whether a feature wall, an ornamental pool or an expensive vase.

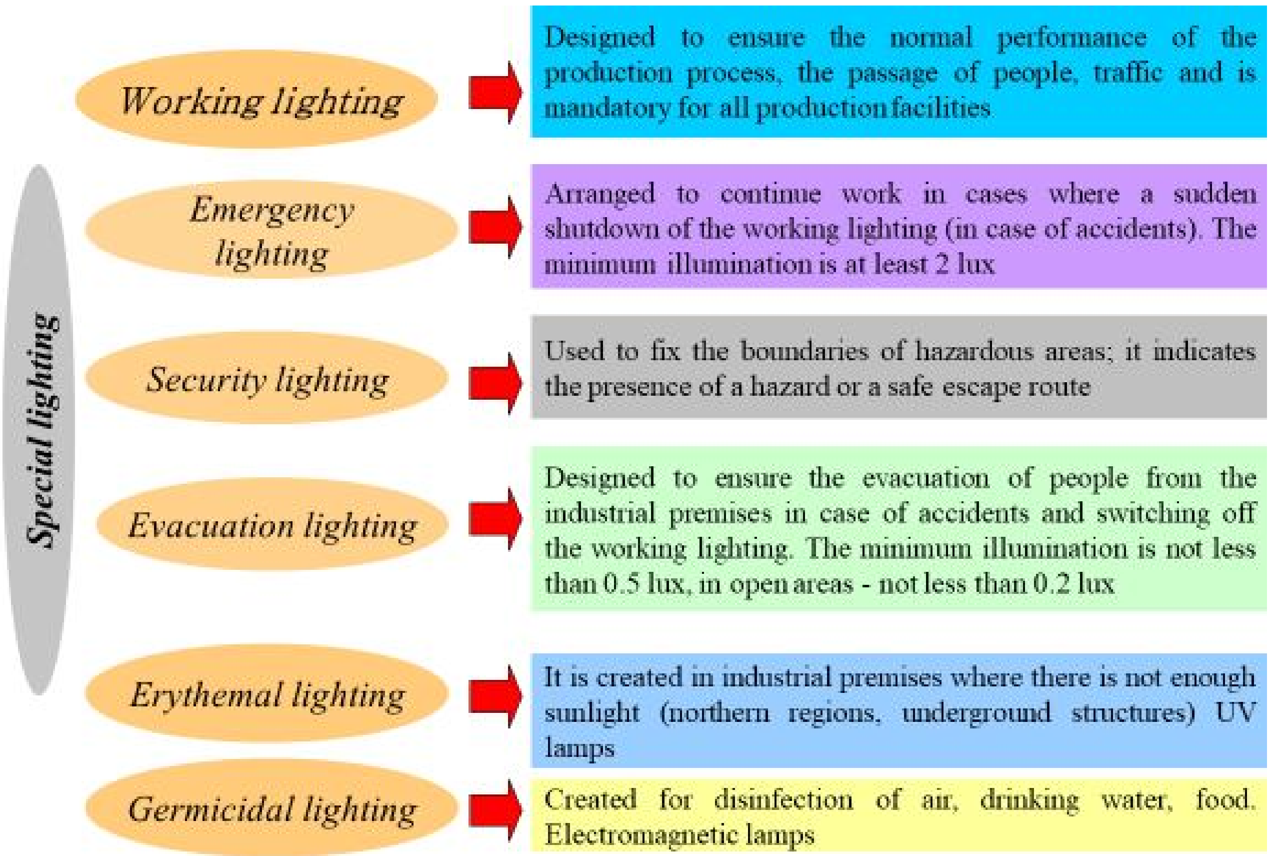


Figure 10.4 – Classification of lighting devices by functional purpose

10.3 Means of architectural lighting of urban spaces

Architectural lighting design is a field of work or study that is concerned with the design of lighting systems within the built environment, both interior and exterior. It can include manipulation and design of both daylight and electric light or both, to serve human needs.

Lighting design is based in both science and the visual arts. The basic aim of lighting within the built environment is to enable occupants to see clearly and without discomfort. The objective of architectural lighting design is to balance the art and the science of lighting to create mood, visual interest and enhance the experience of a space or place whilst still meeting the technical and safety requirements (fig. 10.5).

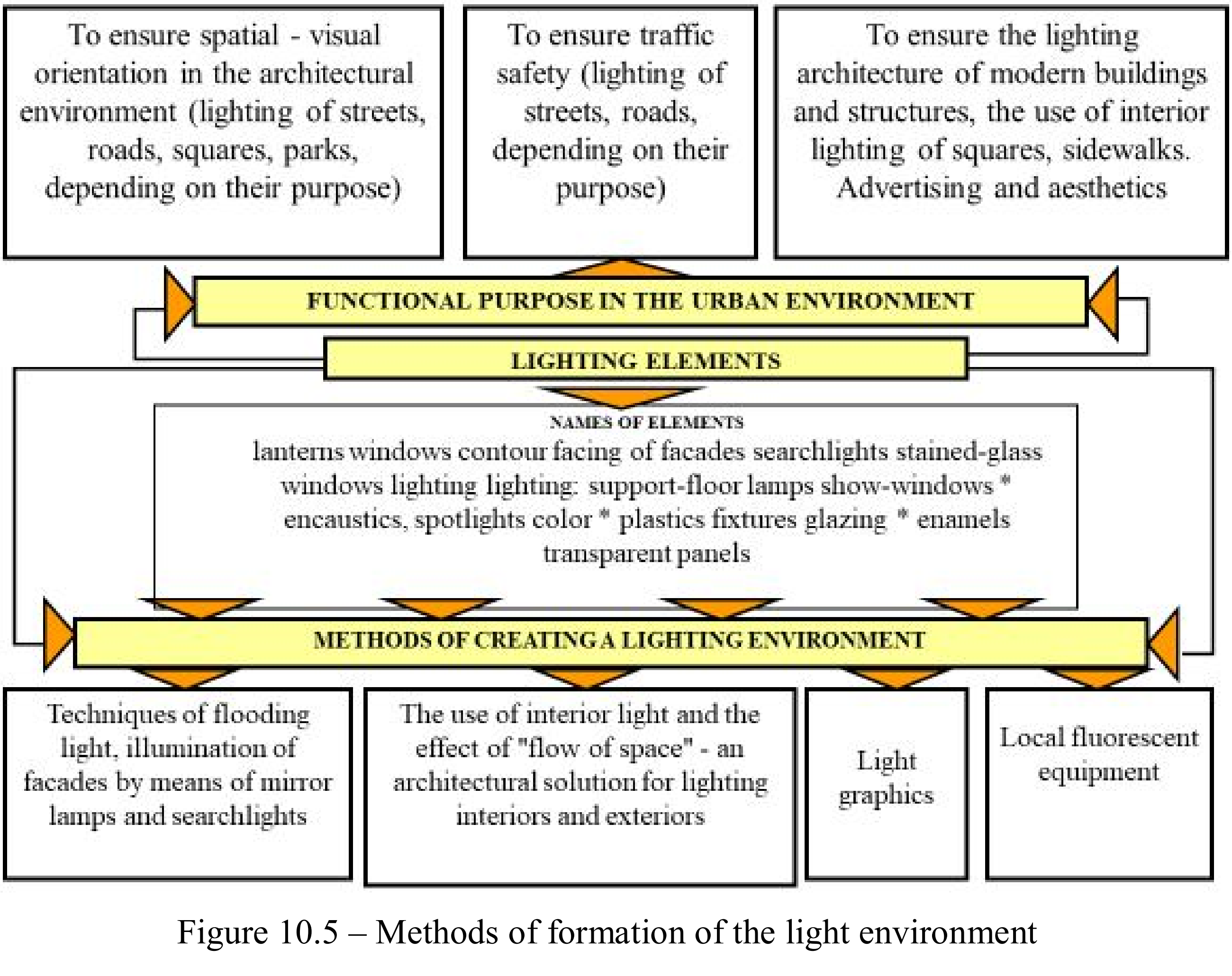


Figure 10.5 – Methods of formation of the light environment

The purpose of architectural lighting design is to balance the characteristics of light within a space to optimize the technical, the visual and, most recently, the non-visual components of ergonomics with respect to illumination of buildings or spaces (fig. 10.6).

The technical requirements include the amount of light needed to perform a task, the energy consumed by the lighting within the space and the relative distribution and direction of travel for the light so as not to cause unnecessary glare and discomfort. The visual aspects of the light are those that are concerned with the aesthetics and the narrative of the space (e.g. the mood of a restaurant, the experience of an exhibition within a museum, the promotion of goods within a retail space, the reinforcement of a corporate brand) and the non-visual aspects are those concerned with human health and well-being.

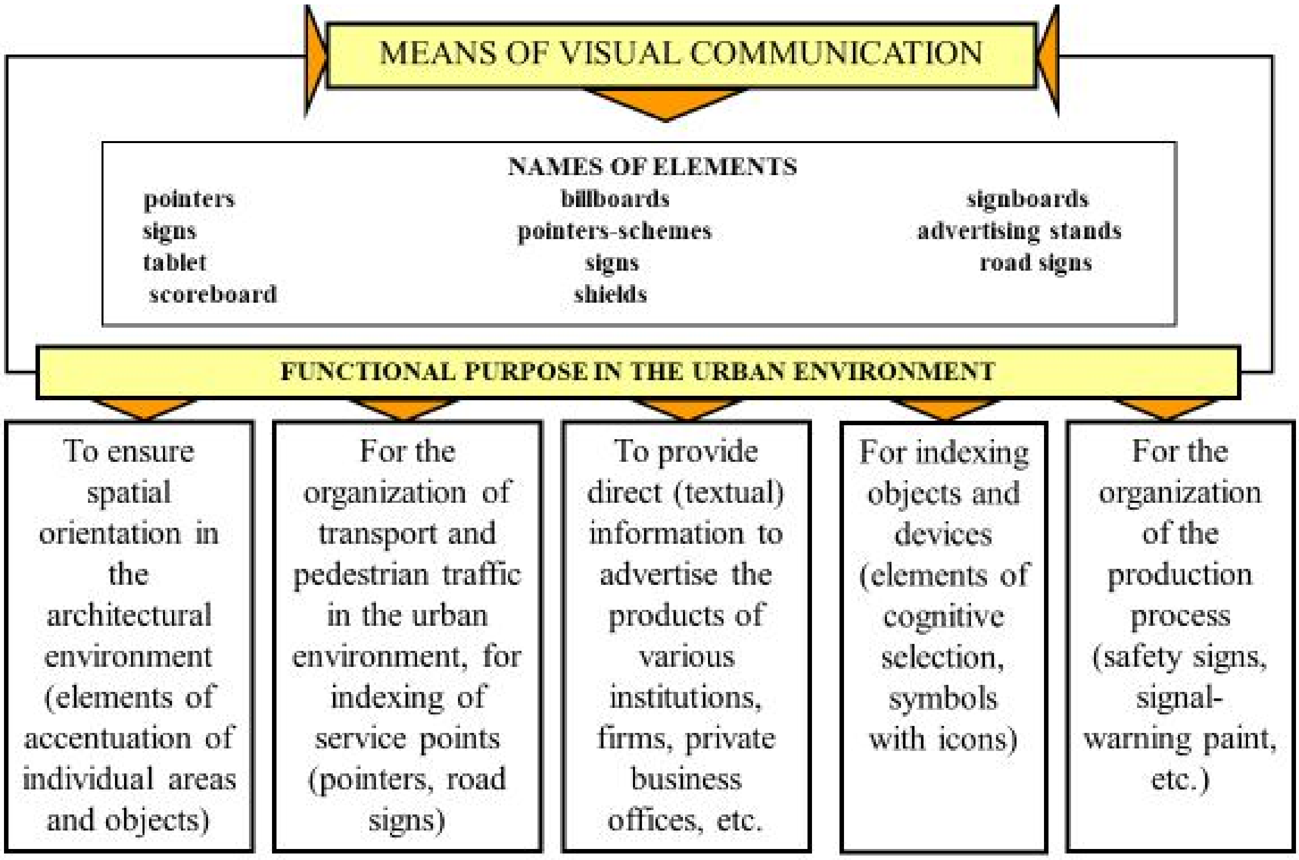


Figure 10.6 – Means of visual communication as part of the light environment

As part of the lighting design process both cultural and contextual factors also need to be considered. For example, bright lighting was a mark of wealth through much of Chinese history, but if uncontrolled bright lights are known to be detrimental to the effect of insects, bird and the view of stars.

10.4 Light panorama of the city, light ensembles and dominants

Light architecture – an alternative to the lighting design of the city, the main purpose of lighting architecture - saturation of the main streets and the city center with advertising and showcase lighting.

Light panorama of the city – expediency of use of artificial light for architectural expressiveness of the city in the evening.

The main task of light architecture – creation by means of light and color of a holistic artistic image at transition from day to night.

The main provisions for solving this problem:

- preservation of spatial solutions of the city and its architectural ensembles;
- selection of buildings and structures, which are characterized by high architectural quality;
- preservation of the colorimetric image of construction of various parts of the city;
- inclusion in the light architecture of the city of utilitarian, advertising and showcase lighting,
- inclusion in the light architecture of the city of small architectural forms, solved in a single key with the artistic light image of the street or square.

Lighting Landscape scale – is created by the spatial elements of the city, viewed from great distances (areas of the focal type, avenues crossed by streets, squares, canals and ending with tall buildings and structures.

Intimate scale – is created by a composition of buildings, their plastic decoration, viewed from short distances, buildings of the kurdoner type.

Test questions on the topic:

1. Justify what is studying artificial lighting?
2. What are the main characteristics of the lighting fixtures?
3. List the means methods of formation of the light environment and of visual communication as part of the light environment.
4. Expand the concept of Light panorama of the city. Define the main objectives of lighting architecture.

3 Content Module 1.3 ACOUSTIC

Theme 11: Architectural acoustics

Fundamentals of acoustics. Unity of architectural and acoustic solutions. Basic principles of acoustics.

11.1 Fundamentals of acoustics

Acoustics (*akustikos gr. - hearing*) – is a branch of physics that deals with the study of mechanical waves in gases, liquids, and solids including topics such as vibration, sound, ultrasound and infrasound. A scientist who works in the field of acoustics is an acoustician while someone working in the field of acoustics technology may be called an acoustical engineer. The application of acoustics is present in almost all aspects of modern society with the most obvious being the audio and noise control industries.

Architectural acoustics investigates the laws of propagation, absorption of sound in closed rooms, solves the problem of creating favorable conditions for the full perception of sounds.

The purpose of architectural acoustics is to create design techniques for halls (theater, concert, lecture, radio studios, etc.) with in advance good hearing conditions.

Architectural acoustics studies:

- Wave theory.
- Geometric theory for the study of the directions of propagation and the establishment of the boundaries of the main part of the flow of sound energy carried by direct and reflected sound waves.
- Acoustic modeling of halls.
- The theory of sound absorption and methods of its measurement.

Building acoustics solves the problem of suppressing, attenuating and limiting the propagation of unwanted sounds - noises. Studies the issues of noise protection of premises, buildings and urban planning spaces.

The purpose of building acoustics is to protect the human life environment from negative noise effects and create a favorable acoustic regime, eliminate noise sources.

Building acoustics studies:

- Acoustic mode of premises for various purposes.
- Acoustic characteristics of building materials and products, load-bearing and protective structures.
- Conditions for planning and building up settlements to create a favorable acoustic climate.
- Noise control measures.

Acoustic climate is a combination of some natural, climatic and acoustic characteristics of the environment (wind direction, type of underlying surface and level of transport and industrial noise).

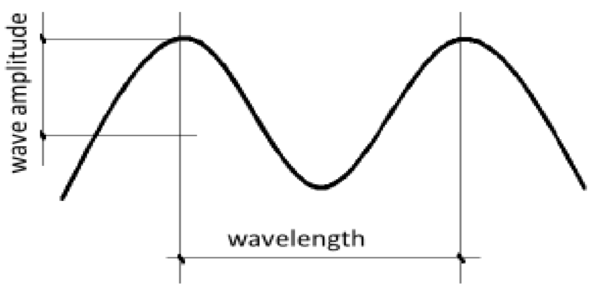


Figure 11.1 – Basic characteristics of wave motion

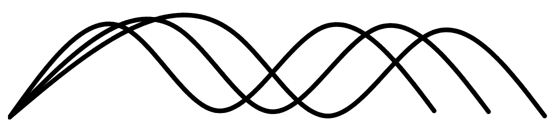


Figure 11.2 – Scheme to the process of interference of a sound wave

Sound waves are characterized by wavelength, vibration frequency, and speed of propagation (fig. 11.1).

The phenomenon of amplification or destruction of oscillations in wave motion is called i*nterference*. This phenomenon occurs when the following conditions are met: when the frequency ratio of the two sources is 1: 1; 1: 2; 2: 3, etc., with a constant phase shift (fig. 11.2).

In acoustics, the type of interference is the formation of standing waves during reflection. Increase or decrease the sound volume.

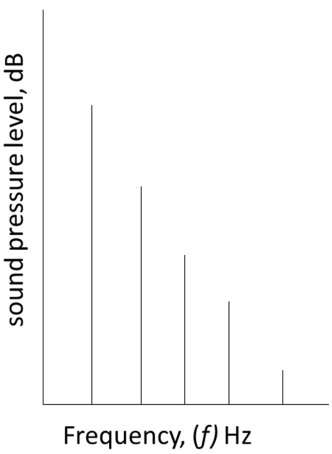
Diffraction of sound waves – the ability to bend around oncoming obstacles during propagation. The dimensions of the obstacles should be comparable to the wavelength or be less than it – an indispensable condition for diffraction.

11.2 Objective and subjective characteristics of sound

The response of the human ear to sound or noise depends both on the sound frequency and the sound pressure level. Given sufficient sound pressure level, a healthy, young, normal human ear is able to detect sounds with frequencies from 20 Hz to 20,000 Hz. Sound characterized by frequencies between 1 and 20 Hz is called infrasound and is not considered damaging at levels below 120 dB. Sound characterized by frequencies in excess of 20,000 Hz is called ultrasound and is not considered damaging at levels below 105 dB. Sound which is most damaging to the range of hearing necessary to understand speech is between 500 Hz and 2000 Hz.

The frequency of sound waves perceived by the normal human ear ranges from 20 Hz to 20,000 Hz. Sound vibrations with a frequency of less than 20 Hz – *infrasound*, more than 20,000 Hz – *ultrasound*.

Sound characteristics that can be quantified: sound frequency, sound pressure, sound intensity. The energy measured by the sound source is distributed over frequencies.



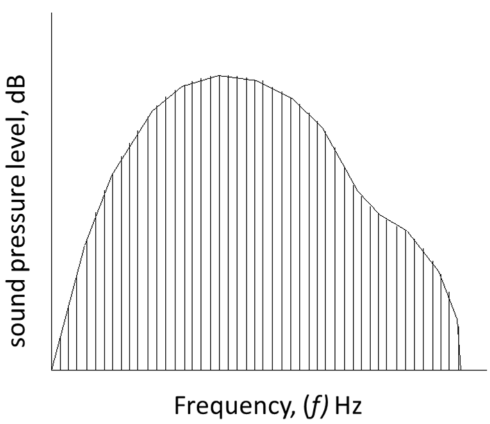


Figure 11.3 – Types of the sound spectrum: ruled (discontinuous) solid (continuous)

Sound waves propagate in all directions from the point of propagation, the spaces formed by sound waves is called the sound field.

With a continuous spectrum of a sound source, the concept of a spectrum level is introduced – the level of sound intensity in the frequency band = 1 Hz.

Pure tone – sounds in which pressure fluctuations are harmonious.

Sound level

– due to practical reasons the sound pressure level measured in the whole frequency range using A–weighting is usually given as a single number.

– this single number quantity is called sound level and denoted as LA.

Physiological characteristics of sound:

- The subjective quality of the auditory experience is loudness.
- The volume depends on the sound pressure, the frequency and shape of the sound wave, the duration of the sound and the conditions of its perception.
- The main physiological criteria for assessing sound – the pitch and volume of the sound.

Pitch is the quality of the auditory experience that determines the position of the sound in the musical row.

The reference sound is a sinusoidal tone with a frequency of 1000 Hz in the form of a plane wave.

11.3 Admissibility of the use of radiant reflections

Geometric (radiation) theory of acoustic processes in premises is based on the laws of geometric optics. The motion of sound waves is considered similar to the motion of light rays.

According to the laws of geometric optics, when reflected from mirror surfaces, the angle of reflection is equal to the angle of incidence, and the incident and reflected rays lie in the same plane.

However, excessive reverberation sound causes a loss of clarity.

The optimum reverberation time for an auditorium or room of course depends upon its intended use.

Around 2 seconds is desirable for a medium-sized, general purpose auditorium that is to be used for both speech and music.

A classroom should be much shorter, less than a second. A recording studio should minimize reverberation time in most cases for clarity of recording.

Concert halls:

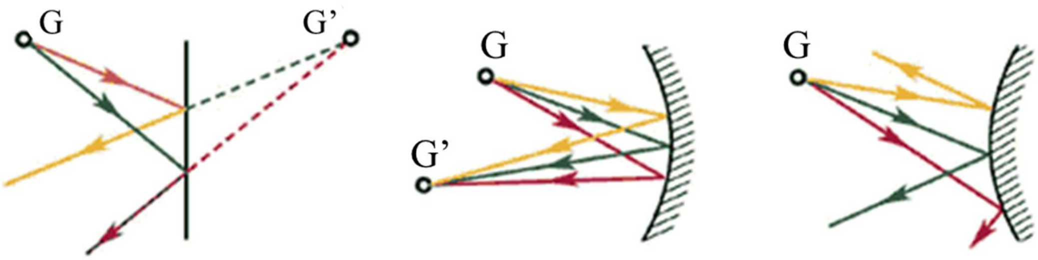
A concert hall is considered '*intimate*' if the delay time between direct and first reflected sounds is less than 20 m/s.

Sometimes reflecting surfaces are suspended from the ceiling.

A study has shown listeners prefer concert halls in which ceilings are sufficiently high so that the first lateral reflection reaches the listener before the first overhead reflection (fig. 11.5).

Other studies have shown that if the total energy of the lateral reflections is greater than that of the overhead reflections, the hall has a '*spatial responsiveness*' or '*spatial impression'*.

The reverberation time is strongly influenced by the absorption coefficients of the surfaces, but it also depends upon the volume of the room as shown in the Sabine formula. You won't get a long reverberation time with a small room.



a) b) c)

Figure 11.5 – The scheme of reflection of sound from a surface of various form: a) direct; b) bent; c) convex

Specific air volume per one spectator seat (m^3):

– in the halls of drama theaters, auditoriums and in conference halls: 4 – 5 m^3;
– in the halls of music and drama theaters (operetta): 5 – 7 m^3;
– in the halls of opera and ballet theaters: 6 – 8 m^3;
– in concert halls of chamber music: 6 – 8 m^3;
– in concert halls of symphonic music: 8 – 10 m^3;
– in halls for choral and organ concerts: 10 – 12 m^3;
– in multipurpose halls: 4 – 6 m^3;
– in concert halls of modern pop music (in cinema and concert halls): 4 – 6 m^3.

Complete refusal from a rectangular shape of a room. A ceiling with dispersing elements is recommended for a better acoustic ambience.

Capacity of a hall must be a concern in choosing a form. Small rooms must have a shape of rectangular parallelepiped. Being narrow, amount of sound reflections, that fall on the audience, grows so fast in the beginning and end of a reverberation process, that has a large impact on sounds spreading in the enclosed space.

Test questions on the topic:

1. What does the acoustics study? What are the principles of acoustics?
2. Expand the concept of the structure of early reflections and to prove the need to use this phenomenon in solving problems of acoustics.
3. What are the characteristics of sound?
4. Identify and describe the processes of absorption, reflection and diffraction of sound.

Theme 12: Acoustics of closed and open spaces

Basic principles of acoustic design of halls for different purposes. Acoustic design. Summer theaters acoustics. Methodology of using soundproofing and sound-absorbing materials.

12.1 Basic principles of acoustic design of halls for different purposes

Good acoustic design requires knowledge of the physics of sound, the engineering qualities of materials, and the unique attributes of music and then applying this knowledge to building construction to create a facility that allows listeners to have an outstanding aural experience (tabl. 12.1).

Table 12.1 – Differentiation of halls according to acoustic requirements

	Division of halls into groups according to acoustic requirements	Perception of sounds by the viewer	
	Halls with natural (natural) sound of music, vocals, speech. *Chamber opera houses, music and drama theaters, philharmonic societies, organ halls, religious buildings*	Directly from performers or instruments	On the architectural, structural and acoustic solutions of the hall
	Chamber opera houses, music and drama theaters, philharmonic societies, organ halls, religious buildings	Much attention is paid to the quality of reproduction, naturalness and clarity of sound	The architectural solution of the halls and the working conditions of acoustic equipment
	Halls for musical purposes: concert halls, opera houses, music and drama, stage theaters; *Theater halls for performances of different genres;* *Speech halls - congresses halls*	Halls in which, along with natural sound, electro-acoustic means are provided for enriching and reproducing a variety of sound effects	The greatest difficulty in solving the acoustics of large-capacity halls: fullness and clarity of sound, good articulation, expressive timbre, balanced sound of all musical instruments throughout the hall

Taking the primary function of auditorium into account, high speech intelligibility (articulation of speech) was judged to be the most desirable parameter through the audience area in the hall. When articulating, move the sound, the hour of reverberation, the background noise in the primitive, the form of the primitive. The efforts of the parameters to rotate in the form of performance, such as the process itself.

Music should be optimally heard (including an excellent ‘ring’) throughout the entire performing venues.

The process of gradual fading of the sound in a room after the cessation of the sound source is called reverberation.

The phenomenon of *reverberation* – the process of formation and attenuation of sound after cessation of the sound source as a result of repeated reflection from enclosing surfaces. This process is characterized by three main one’s periods (fig. 11.4):

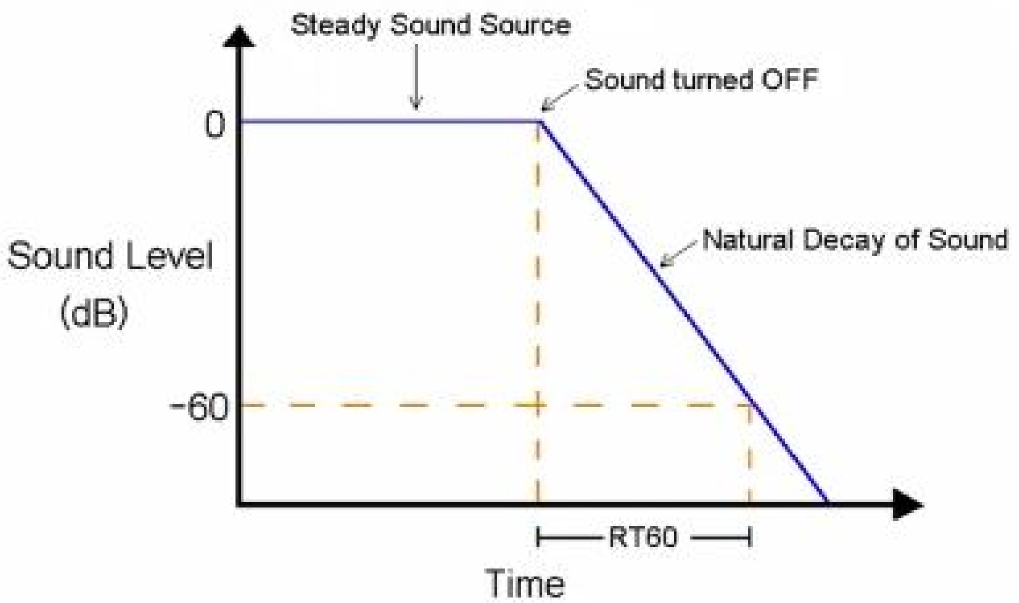


Figure 11.4 – Reverberation time diagram

1. The increase in the density of sound energy, due to the summation of the reflected energy with the original.
2. A period of dynamic equilibrium between sound energy gain and sound absorption.
3. Decay period due to the attenuation of sound energy during multiple reflections.

Reverberation sound in low levels reinforces the direct sound.

The process of decay of sound energy observed after the sound source stops sounding is a reverberation process, and the decay time of a sound is the reverberation time.

A great concert hall has both sound isolation and reverberation. These two qualities received special attention in designing the Music Center.

When a sound is produced in a concert venue, the reverberation of the hall (often called ‘ring’) can be timed until that sound has completely disappeared. Longer reverberation is desirable for a music space as opposed to a theatrical space, where clarity and intelligibility of speech is more important than ring.

Longer reverberation is difficult to achieve. To be successful, planners must create adequate cubic volume and limit sound absorbing material. An additional consideration when building is to have adequate mass (weight) in all exposed surfaces; it is important to have hard surfaces with no hollow spaces beneath.

The result. Many of the great halls in the United States have reverberation time of two seconds, such as the Kennedy Center in Washington, D.C. Some concert halls, such as Carnegie Hall in New York City, ring for nearly three seconds.

Adjustability of the "ring' is possible throughout the facility by deploying sound-absorbing curtains and panels, offering endless possibilities for various types of music (i.e. full reverberation for choral music and some orchestral music; less reverberation for jazz and Contemporary Christian music).

12.2 Acoustic hall design. Open (Summer) theater acoustics

The open antique theatre signifies the initial meeting point between architecture, acoustics and the theatrical act. This simple structure consists of the large truncated-cone shaped stepped audience area, (the amphitheatrical "*koilon*" in Greek or "*cavea*" in Latin), the flat stage area for the chorus (the "orchestra") and the stage building (the "*skene*") with the raised stage ("*proskenion*") for the actors (Figure 11.5 a).

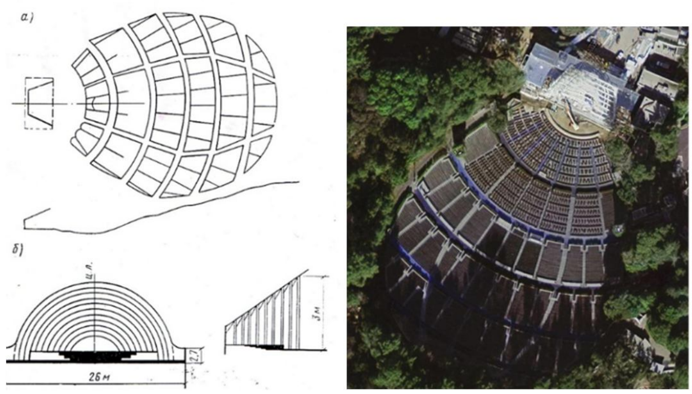
The theaters contained three main parts:

a stage (*shena*) 3,5 – 4 m deep in Greece and 6 – 8 m in Rome, on which the theatrical action was performed;

a platform in front of the stage - an orchestra (*orhestra – dance place*), where the choir was located and the dancers performed;

spectator seats rising in steps around the orchestra, forming the so-called *amphitheater* (from the Greek words *amphi* – on both sides, around and *theatron* – place of spectacles) (fig. 11.5).

a) Ancient open amphitheater's



b) Opera House 'Hollywood Bowl' USA, capacity 22500 people

Figure 11.5 – The structure of the Hellenistic period open theatre

It is now clear that the "good acoustics" of these amphitheater's and especially of Epidaurus, is due to a number of parameters: sufficient amplification of stage sound, uniform spatial acoustic coverage, low reverberation, enhancement of voice timbre, all contributing to perfect intelligibility even at seats 60 meters away, provided that environmental noise is low. These acoustically important functions are largely a result of the unique amphitheatrical shape: for any sound produced in the stage or the orchestra, the geometric shape and hard materials of the theatre's surfaces generate sufficient reflected and scattered sound energy which comes first from the stage building (when this exists), then the orchestra floor and finally from the surfaces at the top and back of seat rows adjacent each listener position and which is uniformly spread to the audience area (figure 11.5 b).

12.3 Methodology of using soundproofing and sound-absorbing materials

Noise is random vibrations of various physical nature, characterized by the complexity of the temporal and spectral structure. Initially, the word noise referred exclusively to sound vibrations, but in modern science it has been extended to other types of vibrations (radio, electricity) (fig. 12.1).

1 – airborne noise
2 – impact noise (forward movement of transmission noise)
3 ; 4 – bypass noise
4 – structure-borne noise

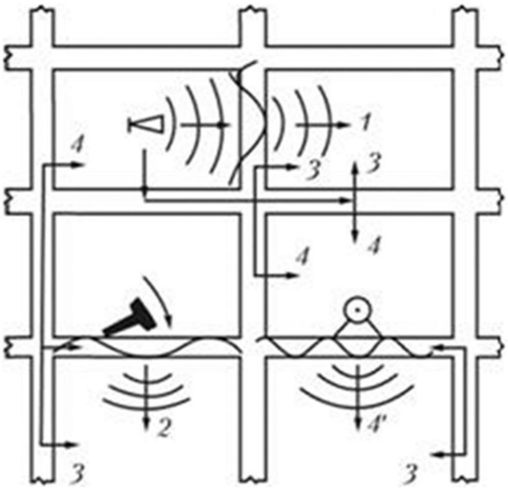


Fig. 12.1 – Classification of the considered insulation materials.

If a screen-barrier is located between the source and the observation point, then a sound shadow zone is formed behind it. However, in this area, noise is not completely excluded due to the phenomenon of diffraction (sound bending around obstacles).

Natural and artificial elements of the terrain, various walls, buildings and other obstacles – acoustic or noise protection screens – have a significant impact on the propagation of noise.

Sound Absorption

Controlling noise through sound absorption can be an extremely effective method of lessening the echo and noise within a space. Products that are designed to absorb sound are made with soft materials that can soak up the sound as it hits its surfaces. Our huge product catalogue features lots of sound absorbing products ranging from acoustic wall panels and stretched fabric systems to acoustic ceiling systems and acoustic baffles. All of these products are built specifically with absorption in mind. Whether it's excessive noise in an office, poor speech intelligibility in a classroom or a disturbing echo in a village hall – a selection of cleverly placed sound absorbing materials on the walls and/or ceiling will help to resolve an array of noise issues. Whilst the term 'sound absorption' is less frequently heard, it's probably the method we undertake the majority of the time – even if we are approached to provide a 'soundproofing' solution.

Traditional Materials for Thermal Insulation of Buildings

Previous studies proposed different classifications to describe insulating materials. The considered materials were categorized based on form, composition, or heat exchange properties (i.e., whether they provide mass insulation or reflective insulation) (fig. 12.2).

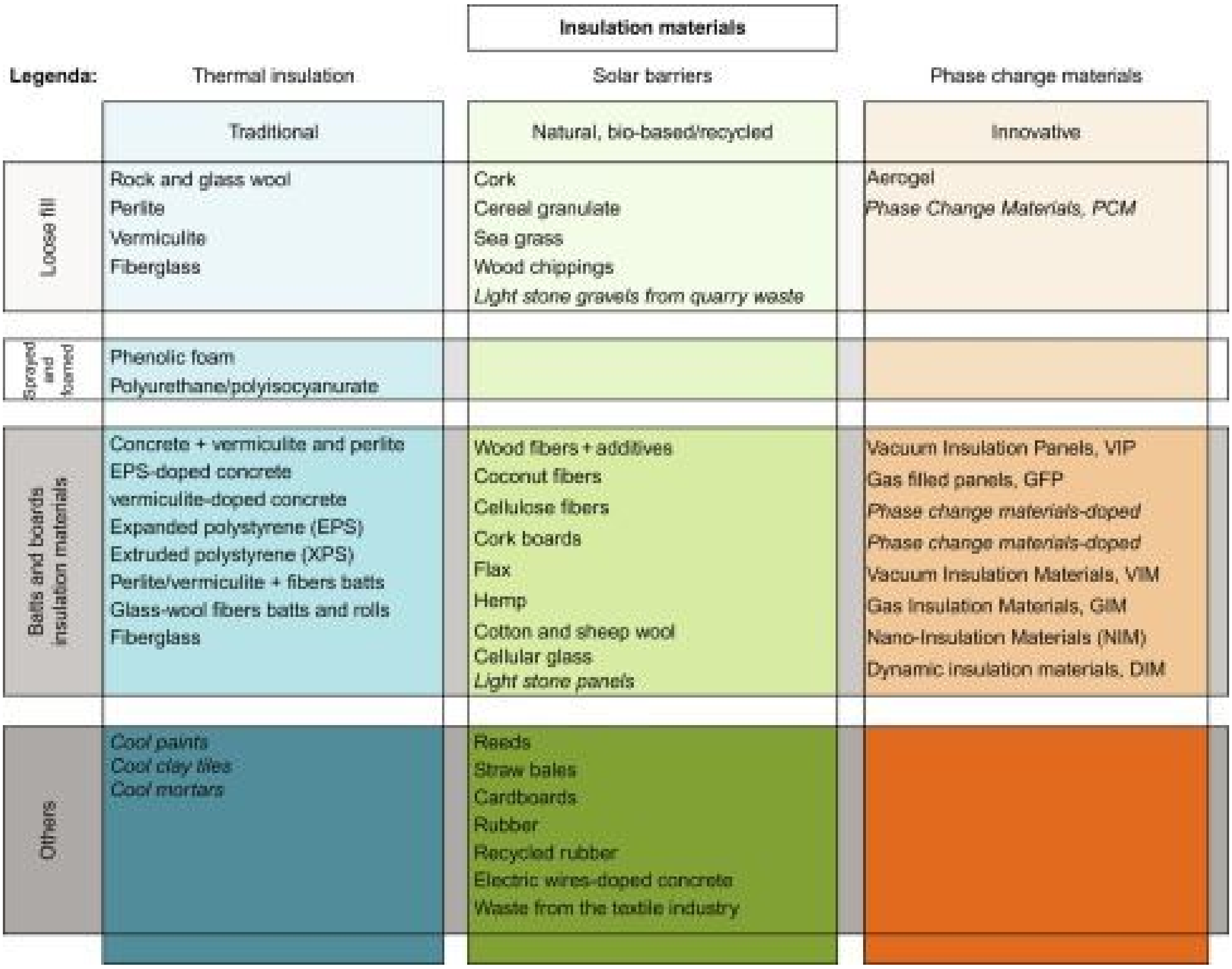


Fig. 12.2 – Classification of the considered insulation materials.

Soundproofing or sound blocking with sound insulating material stops sound from entering or leaving a room. Soundproofing materials are mostly solid and heavy – the action of physically blocking sound requires it to be dense enough to reflect sound and keep it enclosed in one space. Soundproofing isn't always the go-to solution when someone has a problem with noise, but there are definitely circumstances where soundproofing is the most suitable method. Theatres, cinemas and TV/Radio studios often need to use soundproofing to resolve issues of unwanted sound entering or leaving a room.

Test questions on the topic:

1. What are the basic principles of acoustic design of halls? Identify and describe the process that characterizes the acoustics of a room (reverberation, speech articulation).
2. What are the characteristics of sound?
3. Identify, using historical examples, the main architectural and urban planning measures to meet the acoustic requirements of open theaters.
4. Prove with specific examples the need for the unity of the architectural and acoustic solutions of theaters, concert halls, entertainment facilities.
5. Identify the methodology of using soundproofing and sound-absorbing materials

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Електронна адреса: rectorat@kname.edu.ua
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