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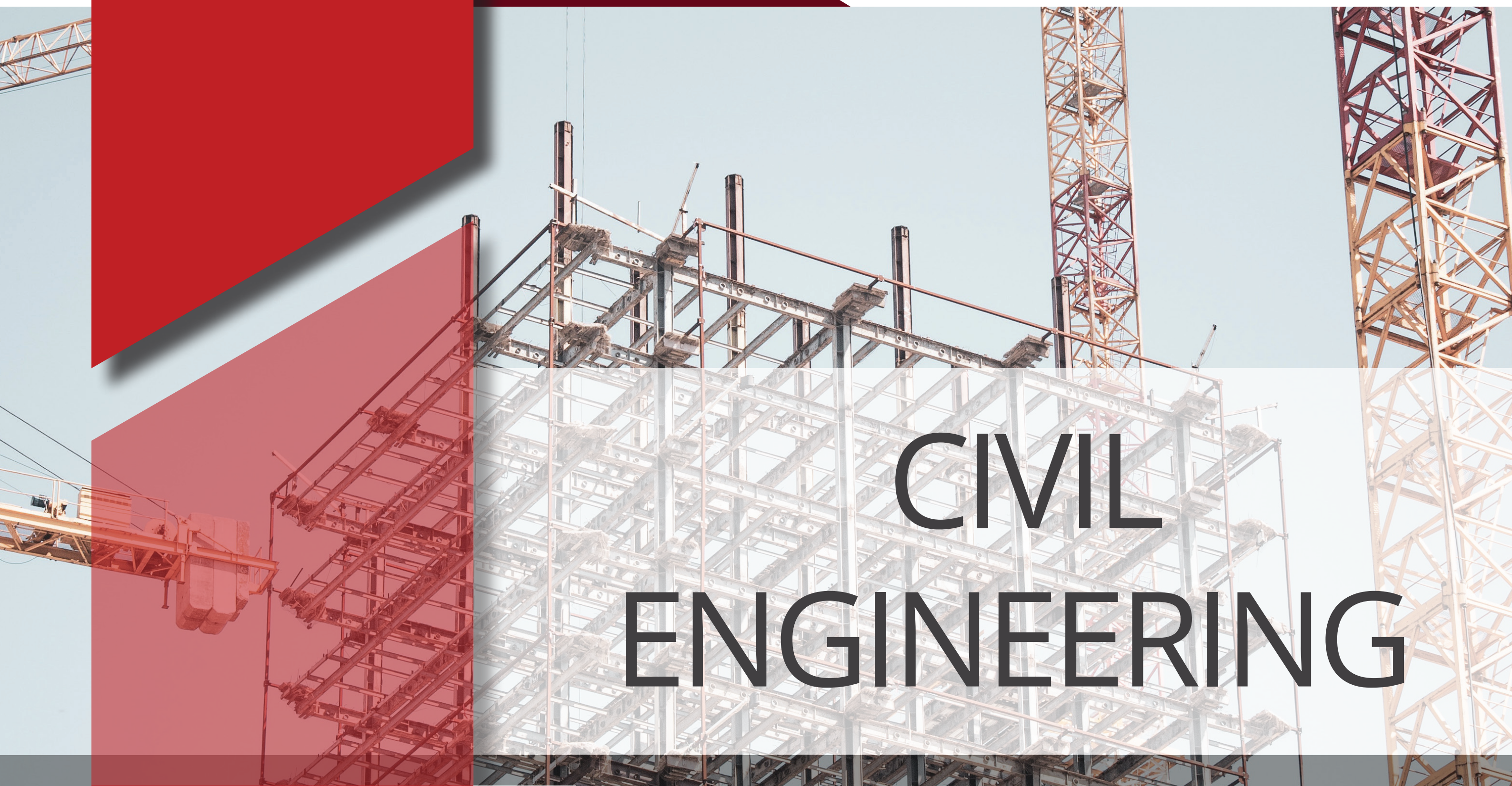

CIVIL ENGINEERING

Building physics

UNIVERSITY
OF APPLIED SCIENCES
UPPER AUSTRIA

VŠTE

EUROPEAN UNION

CONTENTS

1. BASIC TERMS, AIMS AND TASKS OF BUILDING PHYSICS I, LEGISLATION

Stable temperature state – a state, when the temperature distribution in the body does not change over time.

Two-dimensional temperature field - a place where two structures (eg wall and roof, wall and balcony slab, etc.) come together to produce two-dimensional (2D) heat conduction due to deformation of the temperature field.

Three-dimensional heat conduction - a place where three flat structures (eg, two walls and a roof in the corner of the room under the roof) come together, may occur three-dimensional (3D) heat conduction.

1.1. The aims of the building physics I

The aim of the subject Building Physics I is to acquaint the student with thermo-technical standards. To be able evaluate the basic requirements of the thermo-technical standards.

Standards:

- CTS 73 0540-1: 2005 Thermal protection of buildings. Part 1: Terminology
- CTS 73 0540-2: 2011 Thermal protection of buildings. Part 2: Requirements
- CTS 73 0540-3: 2005 Thermal protection of buildings. Part 3: Design values for quantities
- CTS 73 0540-4: 2005 Thermal protection of buildings. Part 4: Calculation methods
- CTS ES ISO 6946: 2009 Building elements and building structures - thermal resistance and heat transfer coefficient - calculation method
- CTS ES ISO 13789: 2009 Thermal behavior of buildings - Specific thermal flows through heat and ventilation - Calculation method

- CTS ES ISO 10211: Thermal bridges in building structures - Calculation of thermal flows and surface temperatures - Detailed calculations
- CTS ES ISO 13790: 2009 Thermal behavior of buildings - Calculating the energy demand for heating
- CTS ES ISO 13789: 2009 Thermal behavior of buildings - Specific thermal flows through heat and ventilation - Calculation method

2. BOUNDARY CONDITIONS FOR THE THERMO-TECHNICAL CALCULATIONS

2.1. Outdoor environment

It is important to specify the parameters of outdoor environment in the area under consideration to design the elements of the building envelope structures and energy assessment of a building. The basic climatic elements are temperature and humidity.

Temperature

Design temperature of outdoor air in winter. It depends on the geographic location and altitude of the object under consideration. The territory division into the four basic temperature areas is shown in Fig.1.

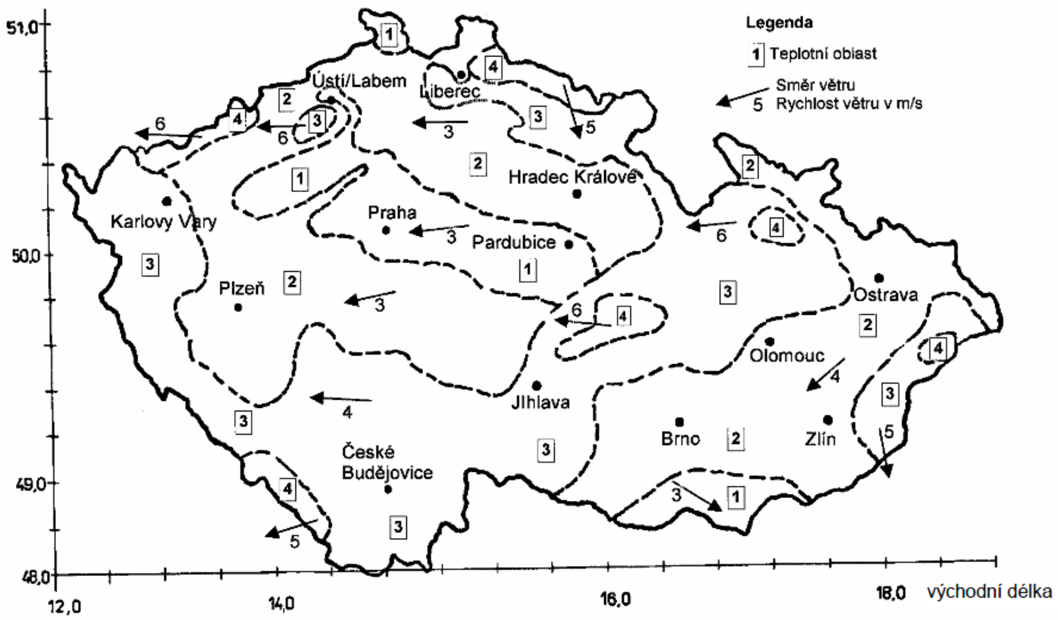

Fig. 1: Temperature areas in winter

Source: CTS 73 0540-3: 2005 Thermal protection of buildings. Part 3: Design values for quantities

Relative humidity

The design relative humidity of the outdoor air can be determined according to CTS 73 0540-3:

$\varphi_e=(93.\theta_e-3153,5)/(\theta_e-39,17)$ [%]

$$\varphi_e = \frac{93.\theta_e - 3153{,}5}{\theta_e - 39{,}17}\ [\%]\varphi_e = \frac{93.\theta_e - 3153{,}5}{\theta_e - 39{,}17}\ [\%]\varphi_e = \frac{93.\theta_e - 3153{,}5}{\theta_e - 39{,}17}\ [\%]$$

2.2. Indoor environment

The calculation values of indoor temperature and relative humidity of the indoor air depend primarily on the purpose of the object use.

Design indoor temperature:

It corresponds to the resulting operating temperature in the room. It is therefore a value including the effect of air temperature and influence of surface temperatures on boundary structures. It is used in calculations related to the heat losses and heat demand for heating.

Design indoor air temperature:

It is necessary in the assessment of building structures and details. It is the temperature of the indoor air without the influence of radiation from surrounding surfaces.

Relative humidity:

In calculations, the most common is using the table design relative humidity of indoor air, which is shown in Tab. I. 1 in CTS 73 0540-3 according to the type of room. Typically the value of relative humidity is 50 % and this value is used for all common areas, except for dry, moist and wet premises.

3. THERMO-TECHNICAL PROPERTIES OF BUILDING MATERIALS

3.1. Thermal conductivity λ

It characterizes the substance´s ability to conduct heat.

Is is defined as the amount of heat that must pass through the body per unit of time so that to the unit length is unitary tepmperature gradient. It is assumed that the heat is transmitted only in one direction.

Declared value λD:

It is the expected value of thermal conductivity coefficient of the building material or product. It is determined from measured data under reference conditions of temperature and humidity (these are determined by special relations).

The manufacturer demonstrate the guaranteed quality of his products. The conditions in which the material will be build in are not taken into account. They can´t be used to calculate the heat transfer coefficient.

Declared value of thermal conductivity coefficient is stated in the ES Certificate of Conformity, ES Declaration of Conformity, on the CE label affixed to the materialor on the packaging of the material and usually in technical data sheets issued by the manufacturer or distributor.

Characteristic value λk:

It is the value of the thermal conductivity coefficient derived for the characteristic mass moisture (air temperature 23°C, relative humidity 80%). It is default value for the determination of design value.

Design value λU:

Is the value of the termal conductivity coefficient of the building material or product that can be considered typical for behavior of the material or product in the building structure. For external structures, it is always necessary to use design values (approx. higher by 10%).

Thermal conductivity coefficient depends on a number of influences:

- specific and bulk density, porosity (increasing the bulk density increases thermal conductivity)

- moisture (increasing the moisture increases thermal conductivity)

- the direction of heat flow of non-isotropic substances (in the case of anisotropic substances the total thermal conductivity depends on the direction of the heat flow, in different directions it is different);
- chemical composition (complexity of structure, less complex - higher λ, metals)

- temperature (increasing temperature of the substance increases thermal conductivity - increasing the kinetic energy of molecules in the base substance).

3.2. Diffusion resistance factor μ

It is a dimensionless quantity indicating how many times the respective water vapor material is less permeable than air.

4. HEAT DISSIPATION

4.1. Basic ways of heat dissipation

Heat is energy that dissipates in any arbitrary environment, where there are places with different temperatures in this environment. Due to the attempt to equalization of the temperature state of the body or space, the heat dissipates from places with higher temperature to places with lower temperature.

3 Basic ways of heat dissipation:

- conduction
- convection
- radiation

4.2. Heat dissipation through conduction

Heat dissipation through conduction occurs mainly in solids. From the standpoint of building technology, this is the most common way of heat dissipation, it is applied to all building structures. Heat conduction is essentialy a gradual give in of kinetic energy to body molecules upon their contact.

Heat conduction is described by Fourier´s laws (first and second).

The first Fourrier´s law defines the heat flow dependence on the temperature gradient. This law is based on the assumption of a stable temperature field, which is a condition when the temperature distribution in the body does not change over time. Another assumption is the homogeneity and the isotropicity of the body. The heat flow direction is a contradictory temperature gradient as the heat dissipates from places with higher temperature to places with lower temperature.

The second Furier´s law describes the relationship between temporal and local temperature change (a constant temperature field in three-dimensional space).

4.3. Heat dissipation through convection

In liquid and gaseous substances. Particles of substances move and transfer heat.

We distinguished the natural convection that results from the displacement of particles of different weight when the substance is heated and forced convection where the convection is caused by external influences – in technical practice usually by a pump or fan.

Newton´s law – describes the density of the heat flow through the convection

4.4. Heat dissipation through radiation

It is basically the electromagnetic radiation transmission, especially infrared radiation transmission. This radiation is emitted by every body with a temperature higher than 0 K. Such a body not only emits the radiation, but partly absorbs, reflects and dissipates it.

5. THERMAL RESISTANCE, HEAT TRANSFER COEFFICIENT

Thermal resistance, heat transfer coefficient are the basic quantities characterizing the thermal insulation properties of building structures.

5.1. Thermal resistance of the structure R

$R = d / \lambda$ [(m2·K)/W]

Resistance to heat transfer Rsi , Rse:

- heat exchange on the structure surface between the structure and the surrounding environment
- on the basis of air flow on the structure surface and the radiation between the structure surface and surrounding bodies

Thermal resistance of the structure during heat transfer RT

$RT = Rsi + \sum R + Rse$ [(m2·K)/W]

5.2. Heat transfer coefficient U

Revers value of the thermal resistance:

$U = 1 / RT$ [W/(m2·K)]

Requirements for the heat transfer coefficient are given in CTS 730540-2:

- For each building structure, the condition $U \leq UN$ must be met
- U is a structure heat transfer coefficient
- UN is a value of heat transfer coefficient required by standard

Required and recommended value:

- Required value = the max. permissible value, which ensures all the basic requirements for the indoor microclimate quality, but with regard to the heat demands for the building heating is a purely standard value without the possibility of achieving significant savings.

- Recommended value = gives the prerequisites for a very rational use of thermal energy, and by using this value, we can directly influence the quality of outdoor environment by reducing demands for energy sources. From this point of view, the design of structure in the area of recommended heat transfer coefficient values seems optional.

6. LINEAR HEAT TRANSFER COEFFICIENT

Linear heat transfer coefficient characterizes thermo-technical properties of two-dimensional thermal bridges and bonds.

It expresses the amount of a heat in W that passes at the unit temperature difference through the unit length of thermal bridge.

For building structures, it affects the quality of indoor microclimate in buildings and therefore also has an impact on user comfort of a building facility.

Requirements are stated in CTS 730540-2:

$\square_k \leq \square_{k,N}$ [W/(m·K)]

$\square_k$ is the linear heat transfer coefficient of the heat bond between the structures

$\square_{k,N}$ is the value required by standard

In a place, where two structures come together (eg wall and roof, wall and balcony plate, etc.), it occurs the two-dimensional (2D) heat conduction due to deformation of the temperature fields.

In a place, where three flat structures come together (eg two walls and the roof in the corner of the room under the roof), it occurs the three-dimensional (3D) heat conduction.

Deformation of the thermal field always means a change in the thermal permeability (hence these places are reffered to as thermal bridges).

6.1. Construction thermal bridge

It occurs where materials with higher thermal conductivity pass through or enter thermal insulation, interruption or thinnest insulation (balcony brackets, wall heels, foundations, fastening system in the thermal insulation system, wooden column in a lightweight structure, ...).

Geometric TB – thermal bonds:

They always occur where the insulation plane changes direction or changes its thickness (corners of the outer walls, plinths, gutters, crest, shield face, window lining,...).

Direct impacts of TB:

- change of the heat flow with generally higher heat losses

- reduced surface temperature in the thermal bridge area compared to other flat outer surfaces.

The impacts of TB occur:

- higher heating load, higher heat demands for heating, higher specific energy consumption
- reduce comfort with low inner surface temperatures
- risk of condensation and mold formation on the inner surfaces
- increased dust deposition with higher humidity and structure moisture near the TB area

7.INNER SURFACE TEMPERATURE

Inner surface temperature of the building structures affects the quality of the indoor microclimate in the buildings and thus also affects the user´s comfort of the building facility.

It is used to assess the risk of water vapor condensation and the occurrence of mold on the inner surface of the building structure.

Since 2007, the indoor temperature factor has been used to assess the indoor surface temperature requirements. It is a proportional quantity which is, unlike the inner surface temperature, the property of structure and does not depend on the operating temperatures.

For non-transparent structures, it is the criterion to exclude the mold formation, for windows, it is the criterion to exclude the water vapor surface condensation:

- exclusion of mold formation = relative humidity up to 80 %.
- exclusion of surface condensation = relative humidity 100 %.

Requirements are stated in CTS 730540-2.

Building structures in common areas with a relative humidity up to 60 % must meet the following conditions at all points of their internal surfaces:

$f_{Rsi} \geq f_{Rsi,N}$

$f_{Rsi,N} = f_{Rsi,cr}$

f_{Rsi} *the lowest temperature factorofthe inner structure surface*

$f_{Rsi,cr}$ *the critical temperature factor of the inner surface, determining by calculation or tables*

8. DIFFUSION AND CONDENSATION OF WATER VAPOR

Water vapor transmission and moisture transfer through building structures

The occurrence of moisture cases defects, affects the structure service life and hygienic conditions. All building structures contain moisture.

Moisture sources in building structures:

- Technological: when the construction is carried out by wet processes
- Earth: from the earth surrounding the parts of the structures that are in contact with it
- Rainfall: rain, snow, frost
- Sorption: materials accept the humidity from the air due to hygroscopic properties, depending on fluctuations in relative humidity
- Condensed water: precipitates on the surface or inside the structure from water vapor contained in the air and from water vapor passing through the structures of the envelope constructions
- Operating: where wet processes (washing, cooking, baths, washrooms, ...), , protecting the construction against the humidity by well-made waterproof wall finishes and waterproof floor insulation

8.1. Humidity

The air that surrounds us is amixture of dry air and water vapor.

- Partial pressure consists of partial dry air pressures and of partial water vapor pressures [Pa], according to the Dalton´s law.
- Absolute humidity expresses the amount of water vapor in the air [g/m3].
- Relative humidity expresses the degree of air saturation by the water vapor [%].
- Dew point temperature is temperature at which the air without a condensation is saturated by water vapor cooling.

Methods of moisture transmitting in building structures:

- moisture sorption (water vapor adsorption, absorption, chemisorption)
- water vapor diffusion
- conductivity of humidity

Diffusion and condensation of water vapor

Assuming the structure separates two environments with different partial water vapor pressures.

As a result of this gradient of partial water vapor pressures, moisture movement occurs in macrocapillaries of building materials whose dimension is greater than the mean free water molecule path (2,78.10-10 = 27,8 nm), according to the diffusion laws from the places with higher partial water vapor pressure to the places with a lower pressure.

8.2. Basic quantities

Water vapor diffusion coefficient δp (sometimes called the diffusion conductivity coefficient):

It characterizes the diffusion capacity of the material, from the previous relationship, it follows that this coefficient is a constant of proportionality between the diffusion flow density and the gradient of partial water vapor pressure.

Diffusion resistance factor μ (currently more used):

It is a dimensionless quantity indicating how many times the relevant material is less water vapor permeable than the air.

Equivalent diffusion thickness of layer sd:

It indicates what should be the thickness of the air layer to have the same diffusion resistance as the layer of investigated material.

Detection of water vapor condensation presence inside the structure:

- The methodology of detection of water vapor condensation presence inside the structure is based on a comparison of the values of partial watervapor pressures – actual partial water vaper pressure and partial pressure of saturated water vapor in the structure.

- Detection of water vapor condensation presence inside the structure is carried out for the boundary conditions corresponding to the greatest differential of partial water vapor pressures in internal and external environment, which corresponds simultaneously with the greatest temperature differential, thus the calculation is performed for winter conditions.

- Water vapor condensation occurs when the actual partial water vapor pressure in any cross section of the structure reaches at least the saturated pressure value.

8.3. Annual balance of condensation and evaporation of water vapor

Active (positive) – all moisture condensed during the annual cycle evaporates during the same cycle

Passive (negative) – moisture is not able to evaporate completely during the annual cycle and there is a long-term accumulation inside the structure.

Standard requirements:

Standard CTS 73 0540 recommends designing building structures in such a way to avoid the water vapor condensation.

If condensation occurs:

- water vapor condensation must not compromise the function of the structure
- annual balance of condensation and evaporation must be active
- annual condensed quantity of water vapor must not exceed a normative limit, which is:
    - For sandwich structures 0,1 kg/m2, but simultaneously not more than 3 % by weight for structures with a bulk density exceeding 100 kg/m3 or max. 6 % by weight for structures with a bulk density up to 100 kg/m3.
    - For single-layered structures 0,5 kg/m2, but simultaneously not more than 5 % by weight for structures with a bulk density exceeding 100 kg/m3 or max. 10 % by weight for structures with a bulk density up to 100 kg/m3.

- Simultaneously, the moisture can´t exceed 18 % if there is a wood or a wood-based material in the structure.

Principles for the building structures design in terms of diffusion and condensation of water vapor:

- The right sorting of single layers in terms of diffusion resistance (optimal to drop from inner and outer surface).

- In case there is a need to design a structure with a high diffusion resistance cheek layer (glass, sheet metal, etc.):

    - place the ventilated air layer in front of the outer vapor barrier and treat the structures double-skinned

    - also design a inner face structure layer with the same or higher diffusion resistance than the outer face (to ensure that the materials insed of the composition have minimal moisture content at the time of installation, are vapor-tight)

9. DECREASE IN TOUCH TEMPERATURE OF THE STRUCTURE´S FLOOR

Assessment of the floor in terms of heat removability, it means in terms of the contact cooling effect on the human organism.

Thermal receptivity of the floor is determined:

- in winter, assuming a constant temperature condition
- initial foor surface temperature θk = 33 °C
- contact time of foot with floor structure t = 600 sekund

2 basic stages:

- initial: after a short initial delay the contact temperature of the foot decreases

- reaction: the thermoregulatory system of the human body starts to apply, the heat is coming from the body to the contact surface

Depending on the heat removal capacity of the floor, it occurs:

- decrease (slowing) contact temperatures (cold floor)
- increase of contact temperature (worm floor)

Calculation of touch temperature decrease:

- Calculation procedure according to CTS 730540-4.

- The value of the touch temperature decrease of the floor structure Δθ10 is determined on the basis of the inner surface temperature θsi and the thermal receptivity of the floor structure B, which is equal to the thermal receptivity of the upper surface of the floor walking layer.

- The thermal receptivity of the upper surface is determined by the gradual calculation of the thermal receptivity of the upper surface of the single layers of the floor structure, from the lowest layer to the uppermost laid floor layer

The lowest layer of flooring is considered to be:

- layer over waterproofing insulation (floor on the ground);
- supporting layer of the ceiling structure.

Requirements are stated in CTS 730540-2

Touch temperature decrease may not be assess for floors:

- with a durable walk all-surface layer of textile flooring
- with a surface temperature permanently higher than 26 ° C

For floors with underfloor heating, the floor touch temperature decrease is determined and assessed for the floor surface temperature determined without the influence of heating, at the design temperature of the adjacent environment corresponding to the design air temperature at the beginning or end of the heating period (θe = 13 ° C).

10. THERMAL STABILITY IN SUMMER PERIOD

The thermal stability of the room during the summer period examines the behavior (increase in indoor air temperature) of the sunny interior space during the summer.

An ever more current problem (danger of overheating on glass surfaces).

The computational assessment is performed for a critical room:

- a space with the highest heat load;
- a room with the largest direct sunlit glazed areas oriented to the W, SW, S, SE, E in relation to the floor area of the adjacent space.

CTS 730540-2 uses the highest daily room temperature for the assessment.

10.1. Design principles

Translucent structures: surface, orientation, screening:

- Contradictory requirements, minimizing heat gains in the summer and getting the most solar energy in winter.
- Usually prefer solar gains in winter and to suggest adequate screening in summer (louvers, blinds, awnings, ledges, roof overhangs).
- Design of shielding elements with regard to orientation towards the world directions, daylight quality and use of solar gains in the winter.

Heat flow reduction with opaque envelope structures with a suitable color and structure of the outer surface (light color).

Double-skinned ventilated structure (outer sheath = radiation curtain, reduces energy permeation into the interior).

Design of envelope structures with increased accumulation capacity (layers of high density on the structure inner face).

Storage elements inside the building (ceiling structure, internal partition structure as a massive construction with increased storage capacity).

11. THERMAL STABILITY IN WINTER PERIOD

The thermal stability of the room during the winter period examines behavior in the winter period, when the room heating is interrupted (heating break, crash, ...).

Constant outdoor air temperature, variable indoor air temperature.

The calculation is based on the energy balance of the space:

- Heat losses of the room by permeation and infiltration.

- Thermal gains from cooled structures, or gains from other internal heat sources (technological equipment, cooled radiators, ...).

The computational assessment is performed for a critical room:

- the room with the highest average heat transfer coefficient by the room structure;
- It is often a corner room under the roof.

The advantage of the winter stability solution is to obtain the cooling time course of the room:

- Optimizing the length of the heating break (in case of accident, in case of storage of certain products, ...).

CTS 730540-2, criterion for assessment:

- for the assessment of winter thermal stability is used
  decrease of the resulting room temperature

11.1. Design principles

- Translucent structures - improvement of thermal insulation properties (glazing, frame, wing, casting into the structure).
- Improving the thermal insulation properties of envelope structures.
- Improving the thermal insulation properties of internal cooled structures.
- Increase of the storage capacity of the inner layers of the envelope structures (layers of high density on the inner face of the structure).
- Storage elements inside the building (ceiling structure, internal partition structure as a massive construction with increased storage capacity).
- Create storage cores inside the object.

12. CONSTRUCTION-ENERGY PROPERTIES OF BUILDING

It is assessed in the winter period using the average heat transfer coefficient Uem [W/(m2.K)]

Calculation procedure according to CTS 73 0540-4.

Requirements for average heat transfer coefficient (CTS 73 0540-2):

- they express the influence of the construction solution on saving energy for heating.
- they don´t take account any uncertaion factors (user behavior, climatic conditions influence).
- must meet the condition Uem ≤ Uem,N

Reference building – a virtual building of the same dimensions and same spatial layout as the building under consideration. Same purpose and location. All envelope surfaces have the required value.

12.1. Energy label

Energy label is a simple assessment of the building according to CTS 73 0540-2, whether it meets the prescribed heat transfer coefficient, ie whether the house in terms of thermal insulation complies with the current requirements.

Each label must be accompanied by an appropriate protocol with identifying and calculated values.

The contents and form of the energy label of the building envelope are given in the appendix to CTS 73 0540-2: 2011.

Building energy intensity according to the Decree No. 148/2007 Coll.

It is a total energy delivered to:

- heating
- cooling
- hot water preparation
- mechanical ventilation
- adjusting the relative humidity of the indoor air
- lighting

Energy requirement x Energy consumption:

- energy consumption: the estimated total energy needs supplied for the purpose, including the impact of the efficiency of all distribution systems and sources.

- energy requirement: the basic energy requirement without the impact of the system efficiency

12.2. Energy performance certificate of the building

Energy performance certificate of the building contains information on the energy performance of the building, calculated according to the method prescribed by the implementing legal regulation. The energy performance of a building is determined by calculation the total annual energy delivered in GJ.

- Energy performance certificate of the building contains a protocol demonstrating the energy performance of the building and a graphic representation of the energy performance of the building.

- Classification of the energy performance of the building is divided into classes from A to G, where their boundaries are also determined.

12.3. Principles for building design in terms of energy

- location of the building
- geometric object solution
- layout solution

The location of the building affects:

- outside air temperature (terrain configuration, density and nature of the surrounding area)

- not suitable to build buildings in closed valleys, on northern slopes

- wind speed (affects heat loss through infiltration)

- inappropriate places - the tops of the hills, open landscape with intense winds

Geometric solution of the building:

- affects heat loss through heat transfer, heat loss increases with increasing surface area of the envelope structures
- optimizing the shape of a building (as small a building factor as possible)

Layout solution of the building:

- orientation to the world directions (translucent areas to the south)