




TREES

Training for Renovated Energy Efficient Social housing

Intelligent Energy  Europe

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Section 2 Tools

2.1 Simplified heating load calculation

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1. Objectives and principles

Objectives and principle

- ▶ Objective : decrease the heating energy consumption and the heat demand
- ▶ Principle : decrease of the transmission and ventilation losses, utilization of the solar gains and optimization of the equipments
- ▶ Example : „passive house labeling“ in Germany, Minergie in Switzerland
- ▶ EPBD: European Energy Performance Directive on Buildings,
 - In force since January 2006
 - Energy certification
 - Regular inspection of boilers and air conditioning systems
- ▶ Tools : simplified energy balance, dynamic simulation tools (see section 2.2)
- ▶ European standards EN 832, EN ISO 13790

Slide 2

Simplified heating energy demand calculation tools are made to estimate the demand with relative small efforts, within short time and acceptable preciseness ($\pm 25\%$). They are applied for estimating fuel consumption or in certification processes (passive house labelling, EPBD, etc.). For higher level of preciseness or in case of complicated buildings simplified tools are not adequate, dynamic simulation tools are recommended.

Heating energy balance of a building

$$\Phi_{tr} + \Phi_{vent} + \Phi_{sol} + \Phi_{int} \pm \frac{\Phi_{stored}}{T} - (\Phi_H - \Phi_{system\ losses}) = 0$$

$$\Phi_H = \Phi_{tr} + \Phi_{vent} - \Phi_{sol} - \Phi_{int} \pm \frac{\Phi_{stored}}{T} + \Phi_{system\ losses} = 0$$

Φ_H	Heating load
Φ_{tr}	Transmission losses
Φ_{vent}	Ventilation losses
Φ_{sol}	Solar gains
Φ_{int}	Internal heat charges
$\frac{\Phi_{stored}}{T}$	Variation of stored heat in function of time
$\Phi_{system\ losses}$	Losses of the heating system (distribution losses)

Slide 3

Heating load is the amount of heat needed in order to maintain a prescribed indoor air temperature during a period (heating season). It can be calculated for a day, a week, a month or for the whole heating season. The equation shows the different heat flows that determine the heating energy balance of a building. The values are in Watts, for a period their integral should be taken into account (heating load is expressed in Joule or MJ, GJ, kWh).

Heating load calculation

With other words
(according to Standard EN ISO 13790)

Heating load =
= heat losses - η · (solar + internal gains) + distribution losses

Slide 4

The detailed method of simplified heating load calculation can be found in the Standard EN ISO 13790.

From the equation of slide 3 the heating load can be expressed as the present formula shows: the heating load is the difference between losses and gains. Only a part of the gains can be utilised depending on the thermal mass and the control of the heating system. It is expressed by the η .

2. Heat losses

Heat losses

- ▶ **Transmission losses through the building envelope**
 - Exposed surfaces: facade walls, roof, ground
 - Openings (windows, doors)
 - Thermal bridges
- ▶ **Ventilation losses:**
 - Opening of windows
 - Losses of mechanical ventilation system
 - In- or exfiltration of air
- ▶ **Depends also on the indoor air temperature (control, zones) and the outdoor conditions (latitude, altitude)**

Slide 5

Usually the bigger part of the heat losses are caused by transmission: heat flowing through the structures of the building envelope. The other major part is the loss caused by ventilation (fresh air is always needed): it can be spontaneous filtration through air leakages or caused by opening the windows or the ventilation system. The losses mainly depend on the climatic conditions, the insulation level of the building, the air tightness and the HVAC system.

2.1 Transmission losses

Transmission through multi-layer structures

Transmission losses: $\Phi_{tr} = U \cdot A \cdot (\vartheta_i - \vartheta_e)$ [W]

- ▶ U-value: Air-to-air conductance (thermal transmittance)
- ▶ R: thermal resistance of a layer
 $U = 1 / \sum R$ [W/m²/K]
- ▶ A: Surface of the exposed elements [m²]
- ▶ ϑ_i : Design indoor air temperature
- ▶ ϑ_e : Design outdoor air temperature

▶ Total heat transfer through a building element is a result of

- conduction.
- convection
- radiation

$$U = \frac{1}{\frac{1}{h_i} + \sum R_j + \frac{1}{h_e}} = \frac{1}{\frac{1}{h_i} + \frac{\lambda_1}{d_1} + \frac{\lambda_2}{d_2} + \frac{\lambda_3}{d_3} + \frac{1}{h_e}}$$

Slide 7

The transmission through a multi-layer structure is the product of the thermal transmittance (U-value), the area and the temperature difference. If a structure is better insulated, the lower the U-value is. U-value depends on the thermal conductance of the layers and the convection in the boundary layers. Simple multi layer structures can be calculated with the formula, for complicated elements (e.g. windows) it is given by the producer.

In many cases thermal resistance (R) is used instead of U-value, because it is more practical to calculate with.

Conductivity of materials

▪ polystyrene $\lambda = 0,04$ W/mK	▪ wood $\lambda = 0,15$ W/mK
▪ reinforced concrete $\lambda = 2,1$ W/mK	▪ glass $\lambda = 1$ W/mK
	▪ steel $\lambda = 50$ W/mK

Slide 8

The thermal quality of a material is expressed by its thermal conductance (λ). The lower the λ is, the better the insulation level is. As the figures show the insulation materials, such as polystyrene are more than 1000 times better than steel.

Convection+linearised radiation

$h = h_c + h_r$ [W / m² / K]
 $\Phi = h \cdot (\vartheta_1 - \vartheta_2)$

h_i and h_e
 $R_i = 1/h_i$
 $R_e = 1/h_e$

Slide 9

Beside of conduction, heat flow through the building envelope is also determined by convection in the boundary layers. It doesn't depend on the material but other stochastic factors: temperature, wind, air movement, etc. Practically the radiation is also expressed in the h-values, although it is a third way of heat flow.

Special cases for determining U-value: Air layers

- ▶ Air gap between two materials
- ▶ Thermal resistance depends on position, width and level of ventilation
- ▶ Thermal resistance in function of the width of air gap

R = 0.11	0.13	0.14	0.15	0.16	m ² .K / W
0.7	0.9	1.1	1.3	width	(cm)

Slide 10

For air layers the formula of the U-value presented in slide 7 doesn't work, because here heat flow is not caused by pure conduction. Depending on the type, thickness and position of the air gap, the U-value can be determined from tables of standards, software tools or books of building physics.

Special cases : Non homogeneous materials

Non homogeneous materials, average R (usually given by the producer)

Examples :

- ▶ brick of 5 cm , R = 0.11 m².K/W
- ▶ insulating masonry blocks (bricks with holes) of 44 cm (« Phorotherm »), R = 2.57 m².K/W

Slide 11

For non homogeneous materials, such as bricks with holes, the formula of the U-value from slide 7 doesn't work, either. Here, product catalogues can help to find the correct U-value.

Walls, floor and roof


- ▶ Facades U_f A_f $U_f \cdot A_f$
- ▶ Floor U_{fl} A_{fl} $U_{fl} \cdot A_{fl}$
- ▶ Roof U_r A_r $U_r \cdot A_r$
- ▶ TOTAL $\Sigma (U \cdot A)$
- ▶ transmission heat losses :

$\Phi_T = \Sigma (U \cdot A) \cdot (\vartheta_i - \vartheta_e) + \text{windows, doors and thermal bridges}$

Slide 12

Doors and windows

- ▶ Single glazing : $U = 5.5 \text{ W/m}^2\text{K}$
- ▶ Double glazing : $U = 3.3 \text{ W/m}^2\text{K}$
- ▶ + low-emissivity coating : $U=1.8 \text{ W/m}^2\text{K}$
- ▶ + argon filling : $U = 1.1 \text{ W/m}^2\text{K}$
- ▶ Wooden frame : $U = 2.4 \text{ W/m}^2\text{K}$
- ▶ PVC frame : $U = 1.7 \text{ W/m}^2\text{K}$
- ▶ Average U-value: mean value weighted with proportion of area, e.g. 75% glazing, 25% frame + losses caused by spacer
- ▶ Door : according to thickness and material (R)



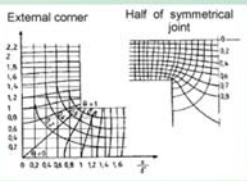
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Slide 13

For doors and windows also the producers should provide the U-value. Today, an average new window has a U-value of 1,1-1,4 $\text{W/m}^2\text{K}$. It is a double glazed window with low-emissivity coating and argon gas filling. With triple glazing and xenon gas filling U-value can be decreased to 0,4 $\text{W/m}^2\text{K}$. In the case of windows not only the glass, but also the frame and the spacer should be taken into account. $U_{\text{glazing}} \neq U_{\text{frame}} \neq U_{\text{window}}!$

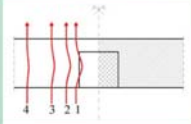
Thermal bridges

External corner Half of symmetrical joint



Ψ [W/mK]: Linear heat loss.
Can be determined using:

- ▶ Thermal bridge catalogues
- ▶ Thermal bridge calculation tools
- ▶ Some producers of complete construction systems publish their usual Ψ -values in catalogues



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Slide 14

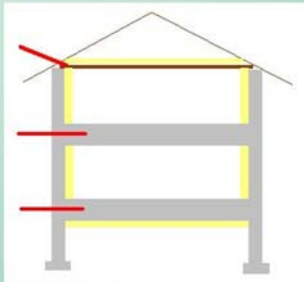
At joints of building elements two- or three-dimensional heat flow develops. In case of good external insulation it increases the heat loss with maximum 5%, but in badly insulated structures it can be 10-200% (the latter is typical for sandwich panels built in the 60s and 70s)! The losses caused by thermal bridges cannot be calculated manually, thermal bridges catalogues or calculation tools are recommended.

Thermal bridges (examples)

$\psi = 0.05$

$\Psi = 0.8$
-> 1

$\Psi = 0.5$
-> 0.7
W/m/K



$\Phi = \psi \cdot L \cdot (T_i - T_e)$ ψ in W/m/K

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Slide 15

Heat loss through thermal bridges is expressed with the "linear thermal transmittance", the so called Ψ -value (dimension: W/mK). Thermal bridges can be caused by geometric reasons or by non-homogenic materials at a junction (e.g. a reinforced steel pillar or a beam).

2.2 Ventilation losses

Calculation of ventilation losses

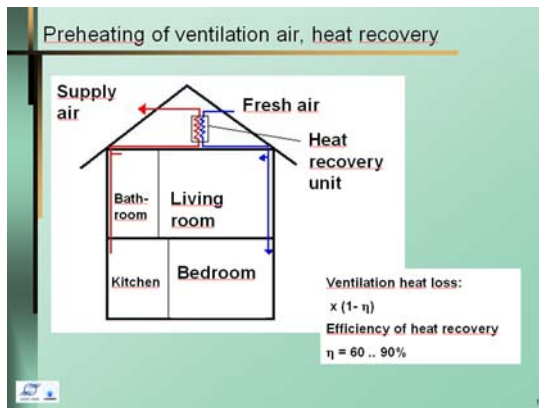
- ▶ Minimum ACH determined by:
 - Biological need (fresh air for breathing)
 - Required ACH for fabric protection
- ▶ 2 ways of determination of ACH:
 - Fresh air required per person : $30 \text{ m}^3/\text{h}\cdot\text{person}$
 - Minimal air change rate: $n_{\text{min}}=0,5 \text{ h}^{-1}$
- ▶ Infiltrations (spontaneous losses through window gaps, joints, shafts...)
- ▶ Ventilation losses : $\text{ACH} \cdot V \cdot \rho \cdot C \cdot (t_i - t_e)$

ACH: Air change rate [h^{-1}]
 ρ : density of air, [m^3/h]
 C : heat capacity of air = $1000 \text{ J/kg}\cdot\text{K}$

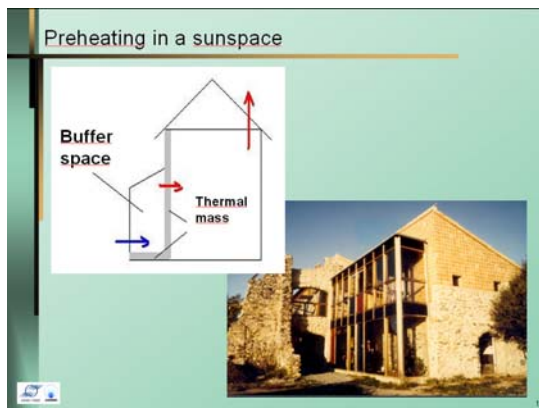
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Slide 17

In all buildings there are ventilation losses, because fresh air is needed and it comes from outside. The ventilation heat loss is determined by the air change rate (ACH) that can be determined two ways: from the number of persons or from pre-defined air-change rates given by standards. Ventilation losses depend on the air tightness of the building envelope, the ventilation habit of the occupants and the type and the control of the mechanical ventilation system (if exists).

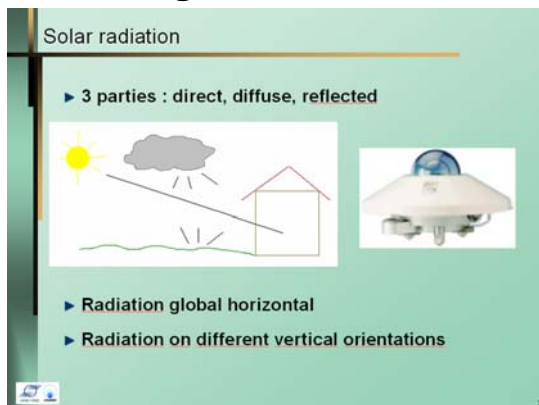
**Slide 18**

The ventilation losses can be significantly decreased by a balanced ventilation system with heat recovery. In such a system the fresh air is preheated by the exhaust air in a heat recovery unit (heat exchanger). The efficiency can be between 60 and 90 % depending on the type of the heat exchanger and the air tightness of the building. Electricity consumption of the fans should be taken into account in the overall energy balance of the building.

**Slide 19**

Another way of decreasing ventilation losses is preheating of fresh air in a sun-space. It is a passive way of use of solar energy. Sun space performs as a buffer zone.

Other passive solar measures can be applied to pre-heat fresh air: trombe wall, air-collectors.

3. Heat gains**3.1 Solar gains****Slide 21**

Already slide 19 has shown that there are not only heat losses, but also gains that can be utilised in a conscious way.

Solar radiation comes from the sun during daytime in two ways: direct (clear sky, sunny weather) and diffuse radiation (cloudy weather). Even diffuse radiation causes solar gains due to the greenhouse effect.

Solar gains

Utilised solar gains depend on:

- ▶ Climate
- ▶ Geographical position of the site
- ▶ Orientation of glazing
- ▶ Shading objects (neighbouring buildings, trees)
- ▶ Shading coefficient of shading devices
- ▶ g-value of the glazing
- ▶ Thermal mass of the building

DESIGN VALUES OF SOLAR RADIATION DEPEND ON THE LOCATION AND ARE GIVEN BY THE STANDARDS

Slide 22

Solar gains depend on the listed factors. Glazing can be characterised by the solar energy transmittance, the so called g-value. It is a figure between 0 and one and represents how many percent of the arriving (perpendicular to the glazing) solar energy can pass through the glazing. Usually a glazing with better (lower) U value has a lower g-value as well, which is a disadvantage in winter. Thermal mass is also an important factor: a heavy building can utilise more solar gain than a lightweight construction.

Shading devices and movable insulation

- ▶ Shading devices and movable insulation are of importance both in winter and summer from the points of view of reducing transmission heat losses and controlling solar penetration.
- ▶ If the shading device is outside, in front of the glazing, the total solar energy transmittance can be as low as 0,1-0,4. For the same device, if it is behind the glazing, the shading coefficient is higher: 0,4-0,7.

Slide 23

The solar gains are welcome in winter, but not in summer, therefore solar protection is often needed. External shading devices are usually more efficient than internal ones.

In winter shading devices can be utilised at night, because they decrease the U-value of the window.

Solar Protections

Shading coefficients

Slide 24

The figure shows the influence of different shading devices on the solar energy transmittance.

Sun path diagram and shadow mask calculator

Sun path diagram and shadow mask calculator are tools to determine the shading effect of the neighbouring objects and shading devices

Slide 25

Before taking into account the solar gains we must check when the window is exposed to the sun and when it is in shadow. For this purpose sun-path diagrams and shadow mask calculator can be utilised either manually or using computer tools. The tools can inform us at which days of the year and in which period of the day our window is in shadow.

3.2 Internal gains

Internal gains

- ▶ Occupants : about 100 W / person (in function of physical activity)
- ▶ Artificial lighting
- ▶ Office equipments (computers, photocopy machines)
- ▶ Cooking
- ▶ A part is lost (e.g. hot water)

Slide 27

Heat gains are also caused by electric devices (lighting, domestic appliances), cooking and the occupants. Their effect can be significant especially in office buildings, large kitchens or in crowded public buildings. Although they cause heat gains it is not recommended to increase them, because they are uncontrollable and most of them use electric energy. Their effect can be estimated using tables from books of building physics.

Energy consumption reduction by solar and internal gains

- ▶ The real reduction is only a part of the internal and solar gains. Expressed with efficiency: η
- ▶ η depends:
 - The proportion of the gains (γ : gains Φ_v / losses Φ_L)
 - The thermal mass and the time constant of the building
 - Heavy building can utilise more gains than light ones

Slide 28

Only a part of the solar and internal gains can be utilised. As they are uncontrollable they can cause overheating even in winter and occupants have to open the window: the gain is lost. If a building has high thermal mass (heavy buildings built with e.g. bricks or concrete) the gains can be store by the structure and released when the losses are higher than the gains (at night). Factors η and γ are explained in the slide.

4. Thermal mass, time constant

Thermal mass

- ▶ The change of the stored heat is proportionate to the change of the temperature, the mass (m) and the specific heat (C):

$$\Delta q = m \cdot C \cdot \Delta T$$

- concrete : C=0.26 Wh/kg/K, 2400 kg/m³
- wood : C= 0.36 Wh/kg/K, 630 kg/m³
- polystyrene : C= 0.34 Wh/kg/K, 25 kg/m³
- glass : C= 0.5 Wh/kg/K, 2500 kg/m³

Slide 30

The change of the stored heat can decrease the heating load at night, when heat is released from the walls. However in case of intermittent heating the heating up period is longer for a heavy building, because the heavy structures warm up slower.

External and internal insulation, time constant

- ▶ Time constant depends on the level of thermal transmittance ($H=A \cdot U$) and heat capacity $\tau = C / H$
 - If external insulation: lower $H \rightarrow$ higher τ
 - If heavy structures: higher $C \rightarrow$ higher τ
 - If internal insulation: lower thermal mass \rightarrow lower τ
- ▶ Maximum 10 cm of the inner part of exposed structures can store heat (for 24 hours). Mass and resistance of this layer is a key issue.
- ▶ Intermittent (programmed) heating can result in energy saving because of thermal mass

Slide 31

A structure can store more heat for a longer period if the thermal mass of the built-in materials (product of density and specific heat, see slide 30) is higher, or if it is better insulated from outside. External insulation keeps the stored heat inside.

Although the warming up period of the intermittent heating is longer in case of higher time constant, it can save energy, because it cools down slower as well.

5. Heating load calculation for a period

Heat losses during a period

- ▶ Heat loss coefficient: losses in case of 1K temperature difference:
 - ▶ $H = H_t + H_v$
 - ▶ $H_t = (\sum (U \cdot A) + \sum (\psi \cdot L))$
 - thermal bridges
 - walls, roof, ground, windows and doors
 - ▶ $H_v = ACH \cdot V \cdot \rho \cdot C$ Prescribed indoor air temperature for example $\vartheta_i = 20^\circ\text{C}$
 - ▶ $\Phi = H \cdot (\vartheta_i - \vartheta_o)$ ϑ_o variable during the heating season
- ▶ Yearly losses = \sum monthly losses = \sum hourly losses
 $\sum H (20 - \vartheta_o) = H \cdot \sum (20 - \vartheta_o)$
 - Degree - hours based on 20°C

Slide 33

The heat loss coefficient (H) is introduced in order to represent the losses of a building in one factor. Thus, it includes transmission and ventilation losses. "H" is constant during the heating season, it doesn't depend on the weather, so it can be used for periodic calculations. The actual heat loss is the product of the "H" and the temperature difference between inside and outside.

Degree - hours

- ▶ Simplification of climatic model
- ▶ $\sum (18 - \vartheta_o) =$ degree hours based on $\vartheta_i = 18^\circ\text{C}$
- ▶ Heating not needed if $T_{b, \text{int}} \geq$ balanced point temperature, depends on climate e.g. 12°C (internal heat gains)
- ▶ Examples for yearly degree hours:
 - Warsaw: 93 000 degree hours
 - Budapest: 72 000 degree hours
 - Paris: 58 000 degree hours
 - Nice: 32 000 degree hours
 - Athens: 34 000 degree hours
 - Copenhagen: 70 000 degree hours

Slide 34

For a period, the product of the "H" and the integral of the temperature difference should be taken into account. This integral is the so called degree-hours that can be determined for each month of the heating season or for the whole season. It strongly depends on the climate as the figures show. Above a certain outdoor temperature (balance point temperature) the gains cover the losses and heating is not needed. These unheated periods are taken out from the degree hours.

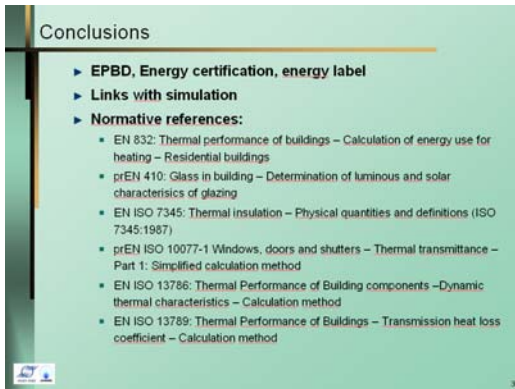
Heating period

- ▶ $\vartheta_{\text{ext}} \leq \vartheta_{\text{int}} - \eta_1 \cdot Q_g / (H \cdot 24)$
- ▶ ϑ_{ext} : daily average outdoor temperature
- ▶ ϑ_{int} : daily average indoor temperature
- ▶ $\eta_1 = a / (a+1)$ (η for $\gamma = 1$)
- ▶ Q_g : daily average gains
- ▶ H = total heat losses in W/K
- ▶ In case of monthly calculations: $a = 1 + \tau / 15$
- ▶ Time constant $\tau = C / H$

Slide 35

A good simplified monthly calculation tool takes the solar gains into account in a right way. It means that the average solar radiation is different in each month, thus not only losses, but also gains are taken into account month by month.

6. Conclusions



Conclusions

- ▶ EPBD, Energy certification, energy label
- ▶ Links with simulation
- ▶ Normative references:
 - EN 832: Thermal performance of buildings – Calculation of energy use for heating – Residential buildings
 - prEN 410: Glass in building – Determination of luminous and solar characteristics of glazing
 - EN ISO 7345: Thermal insulation – Physical quantities and definitions (ISO 7345:1987)
 - prEN ISO 10077-1 Windows, doors and shutters – Thermal transmittance – Part 1: Simplified calculation method
 - EN ISO 13786: Thermal Performance of Building components –Dynamic thermal characteristics – Calculation method
 - EN ISO 13789: Thermal Performance of Buildings – Transmission heat loss coefficient – Calculation method

Slide 36

Simplified heating load calculation tools are usually computer based tools and can be applied with limitations explained in slide 2. However they are easy to deal with and they are recommended in certain certification processes and energy audits.