4. Heat Engineering

4.1. Analytical Part

On January 1, 2003 the construction regulations LCR 002-01 Heat engineering of building envelopes [6] came into force, which harmonise the requirements for heat engineering in Latvia with EU requirements. The main indicator in these construction regulations is the building's heat loss coefficient **(H_T, W/K),** which determines the loss of energy in watts through the building's boundary constructions at 1 degree difference in temperature of their opposed surfaces. The building's heat loss coefficient H_T must not exceed the normative heat loss coefficient (H_{TR}). In order to calculate H_T, at first it is necessary to calculate thermal resistance or heat transfer coefficients U of building envelopes.

Heat flows in building envelopes are usually calculated for stationary (regardless of weather conditions) situation. Heat transfer coefficient U shows the amount of heat passing through one square meter of the construction during a set amount of time, if the temperature difference between the warmer and colder surface is one degree.

In accordance with the standard LVS EN ISO 6946 [1], the heat transfer coefficient U of flat constructions is calculated by using formula, which also includes heat insulation possibilities of the construction

$$U = \frac{1}{R_i + R_e + \sum_{i=1}^{N} \frac{d_i}{\lambda_i}}, \qquad (4.1)$$

where U – heat transfer coefficient, W/($m^2 \cdot$ K);

R_i – thermal resistance for convection heat transfer: construction – interior, $m^2 \cdot$ K/W;

R_e – thermal resistance for convection heat transfer: construction – exterior, $m^2 \cdot$ K/W;

d_i – thickness of i-th construction layer, m;

λ_i – thermal conductivity coefficient of i-th construction layer, W/(m . K);

N – number of layers in the construction.

The following heat transfer resistance Ri and Re values have been set in standard LVS EN ISO 6946:

R_i = 0,10 $m^2 \cdot$ K/W, upward heat flow;

R_i =0,13 $m^2 \cdot$ K/W, horizontal heat flow;

R_i =0,17 $m^2 \cdot$ K/W, downward heat flow;

R_e =0,04 $m^2 \cdot$ K/W .

Thus the heat loss through 1 m^2 of building envelope can be determined by using the formula

$$Q = U\,(T_i - T_e), \qquad (4.2)$$

where Q – heat loss, W/($m^2 \cdot$ K);

T_i - interior temperature, °C;

T_e – average outdoor temperature during the heating season, regulated by construction regulations LCR 003-01 [7], °C.

Construction regulations LCR 002-01 [6] determine requirements for heat transfer coefficient values for building envelopes. In accordance with [6] they should correspond the normative U_{RN} values, but, if it is not possible, they must not exceed maximal U_{RM} values. Normative URN and maximal U_{RM} values are calculated in the following way. Temperature factor k is calculated using formula:

$$k = \frac{19}{T_i - T_e}, \qquad (4.3)$$

where T_i - interior air temperature, °C [LCR 211 – 98];

T_e - average outdoor temperature during the heating season, °C [7];

which is then multiplied with heat transfer coefficient values given in table 4.1

Normative U_{RN} and maximal U_{Rm} heat transfer and Ψ_R coefficient values

Table 4.1

Construction element	U_{RN}, W/(m^2 · K)			U_{RM}, W/(m^2 · K)		
	Dwelling houses	Public buildings	Industrial buildings	Dwelling houses	Public buildings	Industrial buildings
Roofs and coverings, having contact with outdoor air	0,20k	0,25k	0,35k	0,25k	0,35k	0,50k
Floors on the ground	0,25k	0,35k	0,50k	0,35k	0,50k	0,70k
Walls with mass of 100 kg/m^2 and more	0,30k	0,40k	0,50k	0,40k	0,50k	0,60k
Walls with mass lower than 100 kg/m^2	0,25k	0,35k	0,45k	0,30k	0,40k	0,50k
Thermal bridges Ψ_R	0,20k	0,25k	0,35k	0,25k	0,35k	0,50k

4.2. Calculation of Heat Permeability

In correspondence with standard [1] the heat permeability coefficient for panel construction consisting of heat insulating layer covered by two steel sheets is calculated using formula (4.1). In order to do that it is necessary to know the heat conductivity coefficients of the respective panels and thickness of layers. In this case the thermal resistance of steel sheets is very small comparing to the thermal resistance of heat insulation layer and can be practically omitted. The thermal conductivity of heat insulation materials depends on the temperature and humidity content. In standard this dependence is indicated as

$$\lambda = \lambda_{10} \cdot F_T \cdot F_m , \qquad (4.4)$$

where λ_{10} – heat conductivity at 10°C;

F_T – thermal adjustment factor for heat conductivity;

F_m – humidity adjustment factor for heat conductivity.

These factors are calculates as follows

$$F_T = e^{f_t \cdot (T_2 - T_1)}, \quad (4.5a)$$

$$F_m = e^{f_\omega \cdot (\omega_2 - \omega_1)}, \quad (4.5b)$$

where f_t , f_w – temperature and humidity calculation coefficients, K^{-1}; m^3/m^3;

T_1, T_2, ω_1, ω_2 – limit value of temperature and humidity, °C; m^3/m^3.

Temperature and humidity calculation coefficients for temperature interval (0 - +30°C) are tabulated in standard [8]. Directed measurements are necessary for determination of the precise heat conductivity outside this interval.

If exponent indices in formulas (4.5a, 4.5b) are low (<<1), then setting mathematical expressions (4.5a and 4.5b) in a row and placing in formula (4.1) it is possible to get an approximate mathematical expression

$$U = U_{10} + \Delta U_T + \Delta U_m , \quad (4.6)$$

where ΔU_T – thermal adjustment for heat permeability coefficient of building envelopes,

$\Delta U_T = U_{10} \cdot f_t \cdot (T_2 - T_1)$, W/(m · K);

ΔU_m – humidity adjustment for permeability coefficient of building envelopes,

$\Delta U_m = U_{10} \cdot f_\omega \cdot (\omega_2 - \omega_1)$, W/(m · K).

4.3. Calculation of Heat Permeability for Sandwich Panels with Polystyrene Foam Heat Insulation

Heat conductivity coefficient for a dry polystyrene foam layer at 10°C can be calculated according to European standard [6] by using formula

$$\lambda_{10} = 0,027174 + 5,1743 \cdot 10^{-5} \cdot \rho + 0,173606 \cdot \frac{1}{\rho}, \quad (4.7)$$

where ρ – volume mass of polystyrene foam, kg/m^3.

The heat conductivity W/(m · K) of dry polystyrene foam, calculated by using formula (4.7) taking into consideration the low panel thickness adjustment, if λ > 0,038 W/(m · K) [2] is shown in table 4.2.

Polystyrene foam heat conductivity at 10°C, W/(m . K)

Table 4.2

Thickness, m	Polystyrene foam brand			
	EPS 60	EPS 100	EPS 150	EPS 200
0,05	0.0407	0.0373	0.0354	0.0345
0,08	0.0401	0.0369	0.0354	0.0345
0,10	0.0395	0.0369	0.0354	0.0345
0,12	0.0395	0.0369	0.0354	0.0345
0,15	0.0395	0.0369	0.0354	0.0345
0,20	0.0395	0.0369	0.0354	0.0345

Table 4.3 shows the values of sandwich panel (from outside: 0.6 or 0.5 mm steel sheet; polystyrene foam heat insulation; 0.5 mm steel sheet; +/-plasterboard for increased fire protection) heat permeability

coefficients W/($m^2 \cdot K$), calculated by using formula (4.1) and data from table 4.2.
Values R_i =0,13 $m^2 \cdot K/W$; R_e =0,04 m^2 K/W. are used in formula (4.1).

Heat permeability coefficients for sandwich panels with polystyrene foam at temperature of 10°C, W/($m^2 \cdot K$)

Table 4.3

Thickness, m	Polystyrene foam brand			
	EPS 60	EPS 100	EPS 150	EPS 200
0.05	0.715	0.662	0.536	0.524
0.08	0.462	0.428	0.412	0.402
0.10	0.370	0.347	0.334	0.326
0.12	0.312	0.292	0.281	0.274
0.15	0.252	0.236	0.227	0.221
0.20	0.191	0.179	0.172	0.168

As heat conductivity of polystyrene foam depends on temperature* (see reference in the end of the chapter, page 61) and humidity content, it is necessary to calculate the corresponding adjustments using formula (4.6). In accordance with standard [8] the value of temperature adjustment calculation coefficient for insulation layers with thickness of 50-200 mm and λ_{10} variations from 0.035 – 0.040 W/($m \cdot K$) varies within 0.0033 – 0.0036 K^{-1}. An average value f_T=0,0035 K^{-1} can be used for calculations. It should be observed that the given value in standard [8] is guaranteed up to temperature of 30°C. If no experimental measurements have been made, then approximately the same value is used.

4.4. Condensate

The air diffusion equivalent of water steam resistance of sandwich panels: steel sheet + heat insulation + steel sheet + metal coverings, is considered to be infinite [4].
However, from the point of view of the heat engineering insulation layer of panel is in risk zone of condensate evaporation. Using condensate calculation method from standard [5], Latvian construction regulations [6], allowing to use water steam resistance factor μ=10^6 (actually it will be larger) in calculations regarding steel sheets and data of construction regulations [7], it can be gathered that the amount of condensate accumulated during the year in sandwich panels with polystyrene foam insulation is 4 g/m^2. This means that assuming that the panel lifetime is, for example, 50 years, the amount of condensate accumulated in the panel will not exceed 200 g/m^2 (actually it will be smaller, if for steel sheets $\mu \geq 10^6$). Depending on the thickness of panel, such amount of condensate amounts to humidity volume percent within 0.1% – 0.4% (0,004 m^3/m^3) and cannot substantially influence the panel load or its heat conductivity. Humidity adjustment coefficient f_ω = 4 m^3/m^3 for calculation of heat permeability coefficient humidity adjustment. Then the humidity adjustment of heat permeability coefficient can be calculated using formula (4.6)

$$\Delta U_m = U_{10} \cdot 4 \cdot 0,004 = 0,016 \cdot U_{10}. \qquad (4.8)$$

Combining the thermal and humidity impact on sandwich panel with polystyrene core and certain core composition, it is possible to draw up a table for determination of heat permeability coefficient depending on the temperature of middle part of the panel (operational temperature) T, formula (4.9), as shown in table 4.4 for panel core with EPS 100 (FS 20)

$$T = 0,5 \cdot (T_i + T_e). \qquad (4.9)$$

Heat permeability coefficient values of sandwich panels with polystyrene foam EPS 100 core, depending on operational temperature T, with humidity correction, $W/(m^2 . K)$

Table 4.4

Thickness, d, m	U values for sandwich panels with polystyrene foam EPS 100 core, $W/(m^2 . K)$							
	T= -10°C	T=0°C	T=10°C	T=20°C	T=30°C	T=40°C	T=50°C	T=60°C
0.05	0.63	0.65	0.67	0.70	0.72	0.74	0.77	0.79
0.08	0.40	0.42	0.43	0.45	0.46	0.48	0.49	0.51
0.10	0.33	0.34	0.35	0.36	0.38	0.39	0.40	0.41
0.12	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35
0.15	0.22	0.23	0.24	0.25	0.26	0.26	0.27	0.28
0.20	0.17	0.18	0.18	0.19	0.19	0.20	0.21	0.21

Colours of table 4.4 correspond to the requirements of table 4.1 (temperature factor k = 1).

- (white) 0,5 $W/(m^2 \cdot K)$ < does not correspond to requirements
- (blue) 0,45 – 0,50 $W/(m^2 \cdot K)$ – industrial buildings
- (yellow) 0,25 – 0,30 $W/(m^2 \cdot K)$ > dwelling houses
- (green) 0,35 – 0,40 $W/(m^2 \cdot K)$ – public buildings

4.5. Impact of Fixing Screws

Panel fixing screws (steel λ=50 $W/(m \cdot K)$; diameter 6.3 mm) additionally increase the heat permeability coefficient of the panel, depending on the panel area and number of screws. Increase in the heat permeability coefficient of panel, calculated for one screw per m^2 depending on the length of screws is given in table 4.5.

Adjustments to U coefficient for one fixing screw per $1m^2$

Table 4.5

Length, m	0.05	0.08	0.1	0.12	0.15	0.2
ΔU_s, $W/(m^2 \cdot K)$	0.031	0.019	0.016	0.013	0.010	0.008

The total increase of the heat permeability coefficient of panel caused by screws can be calculated using formula

$$\Delta U_{ks} = \frac{N}{A} \Delta U_s , \qquad (4.10)$$

where N – number of screws in a panel;

A – area of the panel, m^2;

ΔU_s – heat permeability coefficient adjustment of one screw (table 4.5), $W/(m^2 . K)$.

Including the adjustments, heat permeability coefficient of sandwich panels can be calculated using formula

$$U = U_{10} + \Delta U_T + \Delta U_m + \Delta U_{ks} \tag{4.11}$$

where U_{10} – panel heat permeability coefficient at 10°C, as shown in table 4.2

ΔU_T, ΔU_m – thermal and humidity adjustment to heat permeability coefficient;

ΔU_{ks} – screw adjustment (4.10) to heat permeability coefficient, W/(m2 . K).

Example for the calculation:

The length of panel is 6m; width 1.2 m; thickness 100 mm; operational temperature T = 40°C. Heat insulation brand Tenapors EPS 100 (FS 20). The panel does not have a plasterboard sheet inside. The panel is fixed with eight screws (U_{10} = 0,347 W/(m^2 · K), in accordance with table 4.3).

According to the explanatory text of the formula

$$\Delta U_T = U_{10} \cdot f_t (T - T_{10}) = 0{,}347 \cdot 0{,}0035 \cdot (40 - 10) = 0{,}036 \ \text{W/(m}^2 \cdot \text{K)} \tag{4.12}$$

we can calculate thermal adjustment to heat permeability coefficient. According to the formula (4.8) we can determine the humidity adjustment

$$\Delta U_m = U_{10} \cdot 4 \cdot 0{,}004 = 0{,}347 \cdot 4 \cdot 0{,}004 = 0{,}006 \ \text{W/(m}^2 \cdot \text{K)} \tag{4.13}$$

According to the formula (4.10) we can calculate the adjustment to heat permeability coefficient caused by screws using data from table 4.5

$$\Delta U_{ks} = \frac{8}{1{,}2 \cdot 6} \cdot 0{,}016 = 0{,}0178 \ \text{W/(m}^2 \cdot \text{K)} \tag{4.14}$$

Thus, using table 4.3 and formula (4.10) the panel heat permeability coefficient shall be calculated as follows:

$$U = 0{,}347 + 0{,}036 + 0{,}006 + 0{,}0178 \approx 0{,}41 \ \text{W/(m}^2 \cdot \text{K)}$$

We shall get identical result by adding screw adjustment to the value 0.39 W/(m^2 · K) (d = 0.1 m, T = 40 °C) given in table 4.4

$$U = 0{,}39 + 0{,}0178 \approx 0{,}41 \ \text{W/(m}^2 \cdot \text{K)}$$

4.6. Heat Permeability Values of Sandwich Panels with Polystyrene Foam or Mineral Wool Core

Combining the calculations presented above, heat permeability values of sandwich panels 1.2 x 6 m with polystyrene foam core with/without fire-resistant plasterboard sheet inside are given in tables 4.6 – 4.12, depending on core brand and operational temperature of the panel, including adjustment due to six fixing screws. In table 4.13 the core of identical sandwich panel is mineral wool. The heat conductivity of mineral wool guaranteed by the producer is λ_{10} = 0,038 W/(m · K). Thermal adjustment f_T=0,0058 K^{-1}. Humidity adjustment is identical to adjustment for panels with polystyrene foam [8].

In cases when:

- the number of screws in panel is not equal with 6,
- dimensions are not 1.2 x 6 m,

it is necessary to re-calculate the screw adjustment to panel heat permeability coefficient. It can be done by deducting screw adjustment for six screws on a 7.2 m^2 area from the heat permeability coefficient values given in tables 4.6 – 4.13, and adding the particular screw adjustment.

Example for calculation:

The length of panel is 2m; width 1.2 m; thickness 100 mm; operational temperature T = 40°C. Mineral wool heat insulation. The panel is fixed with four screws.

According to formula (4.10) we find adjustment coefficient for six screws on 7.2 m2 area, as already shown in (4.13), $U_{ks\,6}$ = 0,0178 W/(m^2 · K). Then according to formula (4.10), using data from table 4.5, we find the respective four-screw adjustment

$$\Delta U_{ks4} = \frac{4}{2 \cdot 1,2} \cdot 0,016 = 0,027\ W/(m^2 \cdot K)$$

From table 4.13 (heat insulation – mineral wool; thickness – 100 mm, operational temperature T = 40°C), we find that U = 0,48 W/(m^2 · K). Thus the final calculation is as follows

$$U = 0,48 - 0,0178 + 0,027 \approx 0,49\ W/(m^2 \cdot K).$$

Colours of tables 4.6 – 4.13 correspond to the requirements of table 1 (temperature factor k = 1).

white	0,5 W/(m^2 · K) < does not correspond to requirements	
blue	0,45 – 0,50 W/(m^2 · K) – industrial buildings	$U_{RN} - U_{RM}$
green	0,35 – 0,40 W/(m^2 · K) – public buildings	U_{RN} – normative value;
yellow	0,25 – 0,30 W/(m^2 · K) > dwelling houses	U_{RM} – maximal value.

Table 4.6

U, W/(m^2 . K) at operational temperature of -10°C				
Thickness d, mm	EPS 60	EPS 100	EPS 150	EPS 200
50	0.70	0.65	0.62	0.61
80	0.45	0.42	0.41	0.40
100	0.36	0.34	0.33	0.32
120	0.31	0.29	0.28	0.27
150	0.25	0.23	0.22	0.22
200	0.19	0.18	0.17	0.17

Table 4.7

U, W/(m^2 . K) at operational temperature of 0°C				
Thickness d, mm	EPS 60	EPS 100	EPS 150	EPS 200
50	0.73	0.68	0.65	0.63
80	0.47	0.44	0.42	0.41
100	0.38	0.35	0.34	0.33
120	0.32	0.30	0.29	0.28
150	0.26	0.24	0.23	0.23
200	0.19	0.18	0.18	0.17

Table 4.8

U, W/(m² . K) at operational temperature of 10°C				
Biezums d, mm	EPS 60	EPS 100	EPS 150	EPS 200
50	0.75	0.70	0.67	0.65
80	0.49	0.45	0.43	0.42
100	0.39	0.37	0.35	0.34
120	0.33	0.31	0.30	0.29
150	0.26	0.25	0.24	0.23
200	0.20	0.19	0.18	0.18

Table 4.9

U, W/(m² . K) at operational temperature of 20°C				
Thickness d, mm	EPS 60	EPS 100	EPS 150	EPS 200
50	0.78	0.72	0.69	0.68
80	0.50	0.47	0.45	0.44
100	0.40	0.38	0.36	0.36
120	0.34	0.32	0.31	0.30
150	0.27	0.26	0.25	0.24
200	0.21	0.19	0.19	0.18

Table 4.10

U, W/(m² . K) at operational temperature of 30°C				
Thickness d, mm	EPS 60	EPS 100	EPS 150	EPS 200
50	0.80	0.74	0.71	0.70
80	0.52	0.48	0.46	0.45
100	0.41	0.39	0.38	0.37
120	0.35	0.33	0.32	0.31
150	0.28	0.27	0.26	0.25
200	0.21	0.20	0.19	0.19

Table 4.11

U, W/(m^2 . K) at operational temperature of 40°C				
Thickness d, mm	EPS 60	EPS 100	EPS 150	EPS 200
50	0.83	0.77	0.73	0.72
80	0.53	0.50	0.48	0.47
100	0.43	0.40	0.39	0.38
120	0.36	0.34	0.33	0.32
150	0.29	0.27	0.26	0.26
200	0.22	0.21	0.20	0.19

Table 4.12

U, W/(m^2 . K) at operational temperature of 50°C				
Thickness d, mm	EPS 60	EPS 100	EPS 150	EPS 200
50	0.85	0.79	0.76	0.74
80	0.55	0.51	0.49	0.48
100	0.44	0.41	0.40	0.39
120	0.37	0.35	0.34	0.33
150	0.30	0.28	0.27	0.26
200	0.23	0.21	0.21	0.20

Table 4.13 Dependence of heat permeability coefficient of sandwich panels with mineral wool core on the operational temperature of the panel

Table 4.13

Thickness d, mm	U, W/(m^2 . K) depending on operational temperature						
	Operational temperature of panel, °C						
	-10	0	10	20	30	40	50
50	0.64	0.68	0.71	0.75	0.78	0.82	0.86
80	0.42	0.44	0.46	0.49	0.51	0.54	0.57
100	0.34	0.36	0.38	0.40	0.42	0.44	0.46
120	0.28	0.30	0.32	0.33	0.35	0.37	0.39
150	0.23	0.24	0.26	0.27	0.28	0.30	0.32
200	0.17	0.18	0.19	0.20	0.22	0.23	0.24

* If heat conductivity of heat insulation material depends on the temperature in accordance with formula (4.5a), then equation

$\frac{\partial}{\partial x}\left(e^{f_T(T-T_{10})}\frac{\partial T}{\partial x}\right)=0$, has to be solved and limiting states $-\lambda\frac{\partial T}{\partial x}\Big|_{x=0}=\frac{1}{R_i}\left(T_i-T\Big|_{x=0}\right)$ and

$-\lambda\frac{\partial T}{\partial x}\Big|_{x=d}=\frac{1}{R_e}\left(T\Big|_{x=d}-T_e\right)$. have to be observed. The solution of the problem is expressed as transcendent equations, and can be solved only numerically. Calculations show that values of heat permeability coefficient obtained in this way do not differ from the data of table 4.4 within rounding-off limits of ±0,01 W/(m^2 . K).

LITERATURE

1. Standarts LVS EN ISO 6946:2000. Ēku daļas un elementi. Termiskā pretestība un siltuma caurlaidība. Aprēķina metode.
2. Standarts EN 13163. Wärmedämmstofe für Gebäude – Werkmäšig hergestellte produkte aus expandiertem Polystyrol (EPS) – Spezifikation.
3. Technische Information. Styropor. TI 0 – 150 d. 47529 Mai 1992.
4. Standarts prEN 14509. Selbsttragende Sandwich-Dämmelemente mit beidseitiger Metalldeckschicht – Vorgefertige Produkte – Festlegungen. Juli 2002.
5. Standarts: LVS EN ISO 13788. Hygrothermal perfomance of buildings components and building elements – Estimation of internal surface temperature to avoid critical surface humidity and assessment of the risk of interstitial condensation.
6. Latvijas būvnormatīvs LBN 002-01 "Ēku norobežojošo konstrukciju siltumtehnika". Apstiprināts ar Ministru kabineta 2001. g. 27. novembra noteikumiem NR 495.
7. Latvijas būvnormatīvs LBN 003-01 "Būvklimatoloģija". Apstiprināts ar Ministru kabineta 2001. g. 23. augusta noteikumiem NR 376.
8. Standarts: LVS EN ISO 10456. Būvmateriāli un to izstrādājumi. Deklarēto un projektēto termisko lielumu noteikšanas procedūras.

5. Construction Acoustics

5.1. General Description

Noise is a factor that has a negative impact on people, lowering their capacity to work and even harming their health. Thus one of the tasks of construction acoustics is not only designing acoustics for various public concert halls and theatres, but also protecting people against everyday noise in different kinds of buildings. The developed European countries have national standards ensuring protection of people against a definite noise. A national standard is currently being developed in Latvia. It is planned that in the future more or less uniformed standards will be developed in the European Union.

Types of noises in the buildings are divided according to their cause and its transmission:

1. If the noise emerges in one of the rooms of a building and is transmitted by air through the wall to adjacent room, then the insulation of transmission of this sound can be described as "airborne sound insulation index" or "weighted sound reduction index" – R'w(measured in dB, decibels). This is a number characterising the sound insulation of internal enclosure of the building, taking into consideration both the transmission of sound through the enclosure, as well as through adjacent structures – flanking transmission. In laboratory conditions, excluding flanking transmission possibilities, the sound insulation of internal enclosure of the building is characterised as "airborne sound insulation index" or "weighted sound reduction index" – Rw(dB)".
2. If the noise emerges in the result of impact of various objects with the enclosure of the building, (impact noise), then the insulation of this noise is characterised as "weighted normalized impact sound pressure level $L'_{n,w}$ (dB)." This amount characterises the impact noise insulation in real conditions, including also flanking sound transmissions. In laboratory conditions, excluding flanking transmission possibilities, we get the "weighted normalized impact sound pressure level$L'_{n,w}$ (dB)."
3. If the noise penetrates the building from outside through the external envelope of the building, then it is characterised as "airborne sound insulation index $R'_{fr,\ s,\ w}$ (dB)", describing the insulation between the room and external area.

The described characteristics of building envelope or enclosure depend largely on the frequency, and these dependencies can be measured experimentally both in a particular building, as well as in laboratory conditions (in cases 1 and 2).