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# Analysis of Heat Losses from Typical Buildings in Riga

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### Abstract

Due to remarkable extent of reconstruction of buildings in Latvia, the analysis of their heat losses should be performed at two stages – the designing and the quality control of thermal insulation and air thickness. Optimised inspection of the heat insulation properties of building structures is ensured by combining thermographic express diagnostics, heat transfer and air exchange measurements in existing buildings and mathematical modelling of their heat balance. A special database of information about typical building structures in Latvia has been created. Basing on the obtained data, the analysis of heat losses in typical buildings is possible with developed software *HeatMod* before and after various reconstructions. This analysis helps to evaluate the economic efficiency of the reconstruction of buildings.

### Introduction

Because of poor insulation of heat and moisture and uncontrollable air exchange in the existing dwelling, public and industrial buildings, there is a sharp increase in their heating costs after the transition to market economy. This is caused by abolishing of subventions and state regulations in the field of energy carrier production, as well as by low efficiency of their production, transportation and consumption. Therefore, the improvement of thermal and moisture insulation of building structures involves remarkable potential for saving energy and basing on this, a decreasing of the amount of $CO_2$ emission.

The following scheme is developed for complex monitoring of heat losses and analysis of energy consumption:

1. Express methods for detection of insulation defects of heat and humidity in building structures with thermography (EN ISO 6781).
2. Automated computer monitoring of climatic characteristics in buildings (temperature, humidity, $CO_2$, etc.) in buildings.
3. Automated computer monitoring of energy (heat, electricity, water, etc.) consumption in buildings and the affiliated trend analysis.
4. Measurement exchange intensity of air in building blocks with over/under pressure tests with the so called Blower-Door equipment (EN ISO 9972)
5. Measurement of heat fluxes in building structures (walls, roofs, windows, etc.) and estimation of heat transfer coefficient $U$ (W/m$^2$K) and thermal time-constant $\tau$ (h):
   - standardised (EN ISO 8990) laboratory tests of finished structures (windows, doors, etc.) ;
   - control-tests in existing old, new and reconstructed buildings in various conditions.
6. Development of databases for $U$ values of typical building structures in Latvia. Their use for designing of the reconstruction of heat insulation and estimation of energy consumption of buildings

7. Mathematical modelling of heat consumption in buildings for optimal design of reconstruction and estimation of economical efficiency of projects in accordance with EN 4108-6.
8. Development of Building-codes (LN-002) and adaption of European standards.

## 1. Practical Estimation of Heat Losses

### *1.2. Estimation of Heat Transfer Coefficient of Existing Building Structures*

Automated measuring equipment has been developed for measuring of heat transfer coefficient in real exploitation conditions of buildings. The equipment allows to collect the temperature data inside and outside as well as the heat flux density at the inner surface of building element during several weeks. One of the possibilities is data collection directly on PC using a highly sensitive (multifunctional) multifunctional measuring card with attached sensors. Special software is designed for this purpose [1]. An alternative possibility is the use of universal hand-type data collector (e.g., ALMEMO 2290-8). This causes a high portability of the measuring equipment and the independence of stationary electrical power supply [2]. In this case, the measured data for calculation of heat transfer coefficient are stored and then transferred to PC by V24 interface after the measurements. The elaborated software *UMeas* allows to measure *U* values even in complicated cases (small, unstationary flux or flux with alternating direction), when traditional cumulative approach gives inaccurate results. The software minimises the difference of heat flux densities in the experiment and in mathematical model of unstationary heat transfer process. The minimisation approach includes the check of precision of the results. Moreover, it allows to determine the thermal time-constant [1,2] simultaneously with heat transfer coefficient. This time constant characterises the thermal inertia of building constructions.

The measured *U* values essentially differ in many cases from results of direct calculations in thermal engineering and values determined by building experts (see Tab. 1). The difference is caused for example by:
- the deviation of material properties (heat conductivity, density) from specified values;
- disregard of technological requirements of building houses;
- change of the properties of low-grade building constructions during prolonged exploitation int. al. influence of moisture.

Tab. 1. Characteristic values of heat transfer coefficient *U* (W/($m^2$K)) of dwelling houses

| Building construction and its brief description | Measu-rement | Calcu-lation |
|---|---|---|
| Panel of outside wall (concrete of ceramsite, 35 cm) | 1,2 | 0,8 |
| Panel of outside wall (concrete of ceramsite, 30 cm) | 2,0 | 1,5 |
| Outside wall (clay bricks, 55 cm) | 1,2 | 0,8 |
| Outside wall (silicate bricks, 45 cm) | 1,8 | 1,3 |
| Ceiling of attic in block house | 1.0 | 0.7 |
| Ceiling of cellar in block house (30 cm) | 0,8 | 0,4 |

In many cases, the calculation of *U* value is impossible at all, because there is lack of information about used materials in building and the structure of outside wall.

The data basis of *U* values has been developed basing on the results of measurement for various building constructions typical for former USSR. The data basis is necessary for modelling of heat consumption of buildings and for elaboration of restructuring projects. Incidentally, the measurements demonstrates that the *U* values of existing building constructions exceed even more than 6 times the recommended values for the elements of outside wall in West-Europe – $U<0.3$.

***1.2. Estimation of Thickness of Air Layer for Buildings***

A special ventilator with continuously adjustable frequency of rotation is used to detect the degree of airtight-ness of the outer building-wrap in correspondence with international standards EN ISO 9972 [5]. The ventilator is combined with measuring instrument for pressure difference and efficiency of ventilator $V'$ ($m^3$/h), as well as with framework and cloth for packing system in one of the openings of considered building (window, door, etc.). The measurements are performed creating such a pressure in the building, which exceeds or goes beyond the outside pressure by 50 Pa (see Fig. 1). The openings and cracks in outer shell of building can be easily detected creating the over/under pressure by so called Blower Door equipment. This equipment should be used also for thermographic inspection of building [6,7].

Such measurements of air exchange coefficient $n_{50}=V'/V_N$ (1/h) at 50 Pa difference of pressures, where $V_N$ – the volume of building, allows to appreciate the air exchange coefficient $n$ in natural conditions: $n = n_{50}{\cdot}e$, where $e$ is coefficient of wind protection ($0.04<e<0.1$). The coefficient $n$ is necessary for modelling of heat losses. Additional standardised properties of packing of building such as $q_{50}=V'/S_H$ ; $n_{p50}=V'/S_F$ can be determined, too, where $S_H$ and $S_F$ are areas of outer shell and cellar, respectively. A correspondig wind load to this difference of pressure (50 Pa) would be caused by a wind hitting the house with a speed of about 9 m/s.

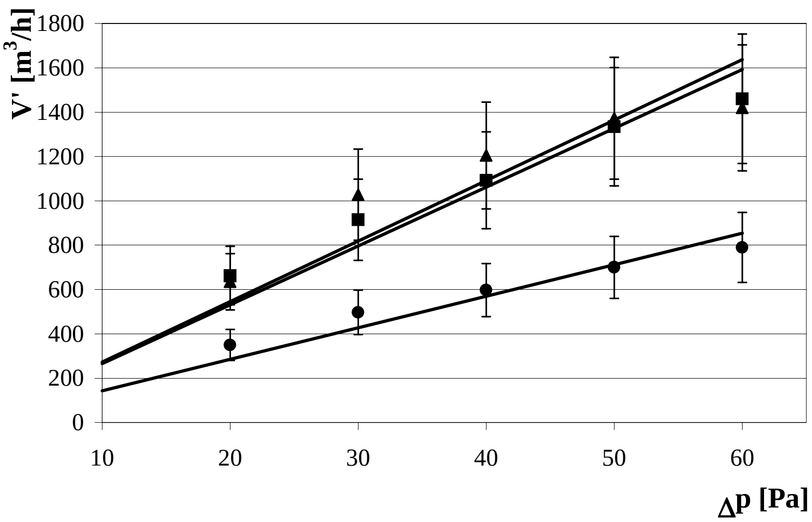


Fig. 1. Air flux vs. pressure difference for buildings with various degrees of packing.

Planed building normatives of Latvia sets that $n_{50}$ must not exceed 3.0 for dwelling houses and normal exchange of air without forced ventilation is achieved at $n$=0.7. Measurements in various existing slab-buildings of Latvia shows existing results of $n_{50}$>8-10 and in staircase $n_{50}$>50, because of poor quality of windows and their packing. The value $n_{50}$ becomes less than 6 only in these buildings, where the residents perform simple packing of windows and doors by themselves. To more regrettably manner, the new-built individual dwelling houses before exploitation has $n_{50}$=3–5. The reason is insufficient packing with isolating material the joint places of building constructions and essential indent from technological requirements building in the windows. Therefore, the heat exchange coefficient frequently reaches 1–2 in real climatic conditions increasing the heat losses by uncontrollable outflow of warm air and invasion of cold air.

### *1.3. Typical Problems*

Summing up, the mass of houses built in times of former USSR has very high heat transfer coefficient (see Tab. 1), nearly uncontrollable intensity of air leakage $n_{50}$>8-10 1/h, and a poor resistance of building constructions to impact of moisture. Whereas, the new-built and reconstructed houses have defects of building technology. These defects cause that

- cold air can get behind the insulating layer by pressure of wind increasing heat losses. For example, the measurements of heat transfer coefficient in reconstructed office showed satisfactory values $U$=0,3-0,4 W/m$^2$K at lull, but the value increased up to 0.8-1.0 performing repeated measurements in windy weather. It results from improper infixing of windbreaking film and unpacked joint places of insulating materials;
- insulating material sags. As a result, the distribution of $U$ values all over the surface of building construction is irregular. Such situation can happen using the rolls of light mineral-cotton for the walls;
- moisture condenses in the layer of heat-insulating material. Consequently, mould develops after some time. The following situation is found, e.g., on the inner side of heat-insulator of building construction, where the temperature of dew point has been reached because the heat-insulating material has not been protected by windbreaking film.

The cheapest PVC windows with double packet of ordinary glass are used continually for building and reconstruction in Latvia. Heat transfer coefficient of them reaches 2.8, while the windows with $U$<1.8 costs only 5-10% more. Such action is short-sighted for saving of energy and avoiding the risk of damage by humidity.

## 2. Mathematical Modelling of Heat Losses and Consumption

### *2.1. Calculation Procedure*

The analysis of heat losses of buildings and heat consumption in correspondence with EN 4108-6 [3] is made by mathematical model of the monthly heat balance in building. The mathematical model includes internal and external heat sources, heat losses by convection and conduction through the outer shell of building, and climate conditions in Latvia. The special elaborated software *HeatMod* is used for this purpose. The software is easy to use usable in Windows environment for data collection and visualisation of results [4].

### *2.2. Example of Analysis for Public Building*

As example for an application of this software, there is the analysis of measurements and results of modelling for the 4-floor building of UL laboratories in Zellu street 8. This building has outer brick wall with $U$=1,3 W/(m$^2$K), total volume – $V$=10192 m$^3$, the area of outer surface of building constructions – A=3573 m² (see Tab. 2). The analysis showed that building initially (I) had very high specific heat consumption – $Q_H$=49,8 kWh/(m$^3a$) (see Fig. 3), where $a$ is year. The constitution of the heated part of outer shell of building is shown in Fig. 2. The measurements of heat losses showed that the most important role belongs to insufficient degree of sealing (especially because of poor windows) which

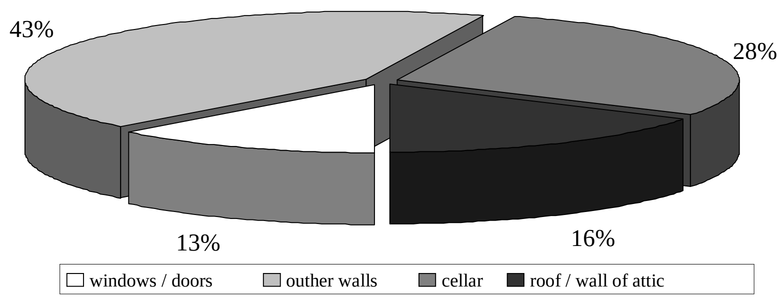


Fig. 2. Constitution of areas of elements in heated part of the outer shell of building

results in – $n$=1,2 1/h. Analysing the possibilities to reduce the heat losses of buildings, the heat consumption has been calculated for three variants of renovation (II, III, IV). The heat transfer coefficient of respective building elements and degree of sealing would change essentially during the proceed of renovation (see Tab. 2):

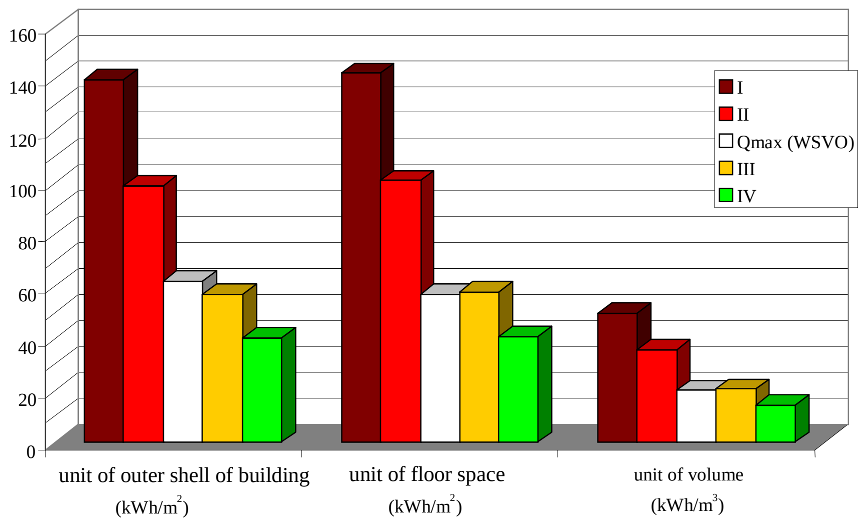


Fig. 3. Comparison of normalised heat consumption with respective marginal values of building normatives in Germany.

Tab. 2. Used data for heat transfer coefficient $U$ and exchange coefficient of air $n$ in various variants of calculations

| Variant | U (W/(m²K)) | | | | $n$ (1/h) |
|---|---|---|---|---|---|
| | *Walls* | *Windows / doors* | *Roof/ceiling of attic** | *Cellar* | |
| I | 1,3 | 3 | 1 | 1,2 | 1,2 |
| II | 1,3 | 2,4 | 1 | 1,2 | 0,7 |
| III | 0,3 | 2,4 | 0.7* | 1,2 | 0,7 |
| IV | 0,25 | 2 | 0.25* | 0,25 | 0,7 |

II. All windows are replaced by packed windows from wood with $U$=2,4 W/(m$^2$K) - $Q$=35,3 kWh/(m$^3$$a$) (Fig. 3).

III. Additionally, heat insulation of outer wall is improved up to $U$=0,3 W/(m$^2$K), and heat insulation of attic is improved, too, and gabled roof has been built – $Q$=20,2 kWh/m$^3$$a$. This renovation project has been carried out.

IV. The windows are replaced by windows with heat insulating packets ($U$=2,0 W/(m$^2$K)), “ideal” heat insulation of outside walls, ceiling of attic, and heated cellar ($U$=0,25 W/(m$^2$K)). In this case, the heat consumption for heating period decreases down to $Q$=14,3 kWh/m$^3$$a$, which would be much better than actual existing building-normatives for saving of heat in Germany for such a house – $Q$=19,9 kWh/(m$^3$$a$) (comparison see in Fig. 3).

The constitution of the windows in outer shell of the building is relatively small – 13 %. Nevertheless, the change of them would decrease the necessary heat consumption by 30 %. It can be explained not only by decreasing of heat transfer coefficient from $U$=3,0 down to $U$=2,4, but principally due to increasing of the degree of the sealing of building from $n$=1,2 down to $n$=0,7 – 9 (Fig. 3-5). The additional heat insulation of outside walls and building of roof decreases the energy consumption to 40 % of the initial (Fig. 3,4).

Figures 4 and 5 demonstrate that part of the losses are covered internal and solar heat sources. In case of good heat insulation (IV), they cover up to half the heat losses of building. The thermal inertia of building changes. It slightly influences the duration of heating season in correspondence with the calculation of marginal heating temperature (Fig. 6). Initially, the building should be heated also in May and September to maintain the optimal thermal conditions ($T$=20ºC). The improving of heat insulation (in correspondence with calculation IV) decreases the heating season, i.e., heating for “ideal” improvement of heat insulation is necessary only from October to March in climatic conditions of Latvia. Despite of the small heat gain through outside walls and windows, they do not worsen substantially make not worse the heat consumption of building (Fig. 7). Gable roof not only decreases the heat losses (Fig. 3 and 4), but also principally protects the building construction from action of moisture and creates an additional usable space. Therefore, the reconstruction efficiency can not be valued only from aspect of saving heat energy. It must be stressed that reconstruction of ventilation system and integration in of forced ventilation (if absent) for such kind of municipal building. Moreover, other factors should be included planning the investments: especially designing and maintaining of the longevity of building constructions, and also social and human aspects.

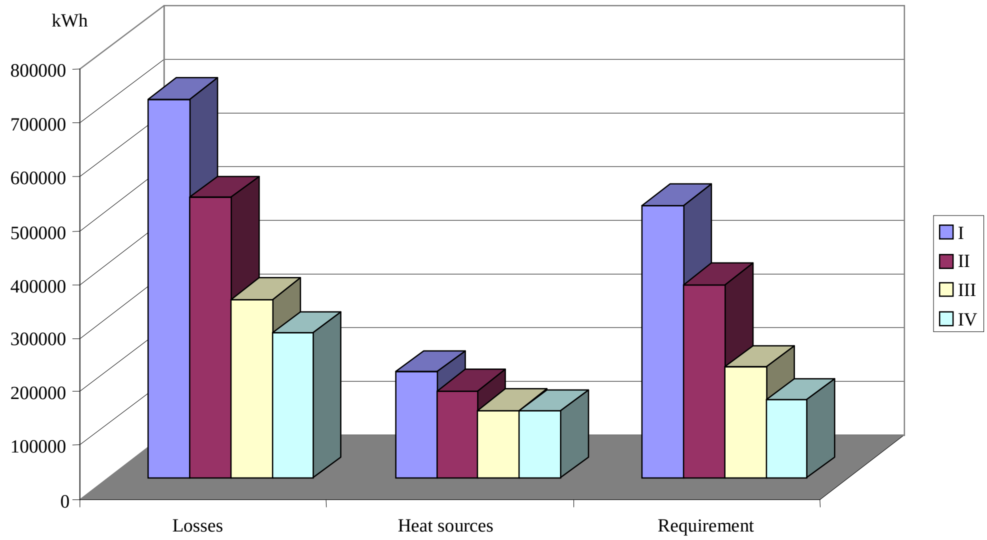


Fig. 4. Normalised annual heat consumption of building in initial state (I) and various variants of renovation (II, III, IV)

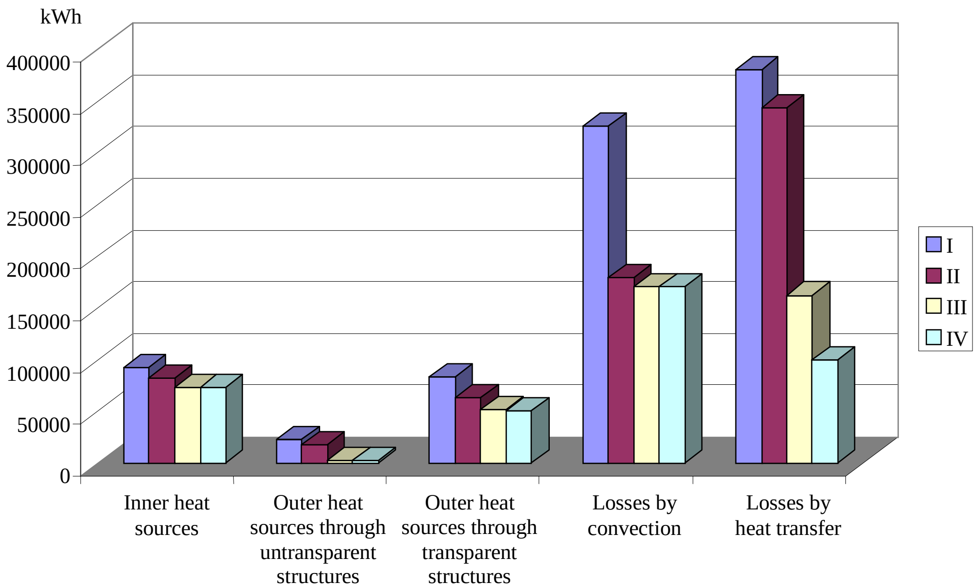


Fig. 5. Annual constitution of heat losses and heat sources

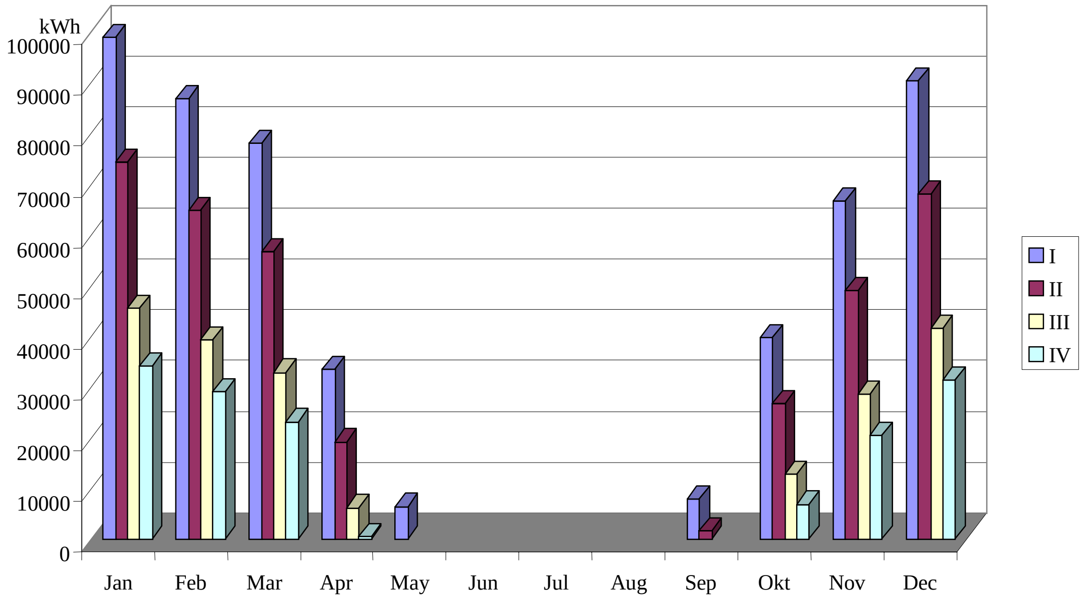


Fig. 6. Monthly heat consumption in heating season

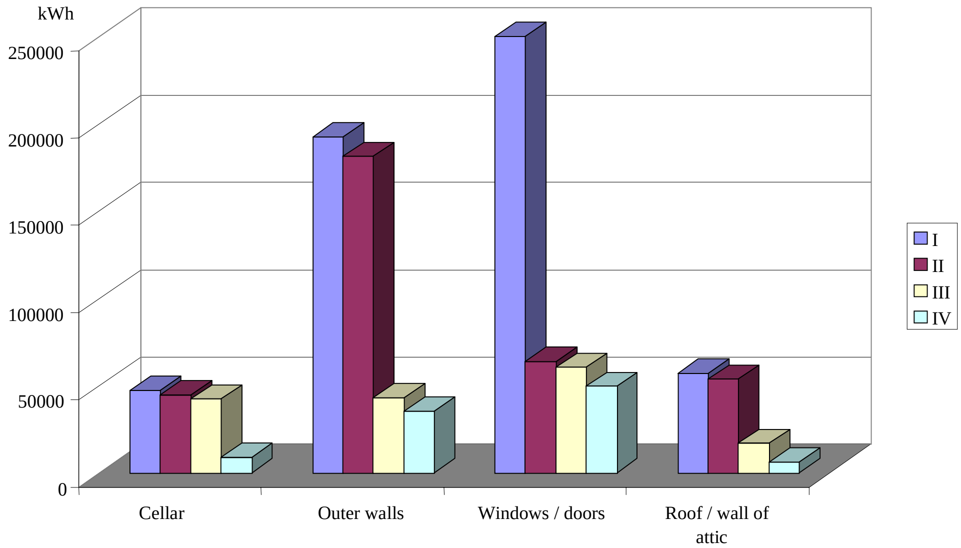


Fig. 7. Annual constitution of heat losses through the elements of the outer shell of building

## Conclusions

Optimal way to check heat and moisture insulation of building structures is combination of thermographic express diagnostics and measurements of heat transfer and characteristic values air thickness. The obtained values represent an essential part of the data, which are collected in data base for modelling of heat losses and heat consumption of buildings basing on monthly heat balance [4]. Public and industrial buildings in Latvia approved the approach of making measurements and calculations for multiform dwelling. The scheme is used for the evaluation of economic efficiency to reconstruct the buildings at the phase of planing. The scheme can also be applied in other countries in Central and Eastern Europe.

## References


[1] Jakovics, A., Jekabsons, N., Mühlbauer, A., Trümmann, H.: *Bestimmung des effektiven* Wärmedurchgangskoeffizienten von Bauelementen unter praxisnahen Bedingungen. Elektrowärme international. - 1997, No A2, pp. 77- 83.

[2] Jakovics, A., Gendelis, S., Krievans, Z.: Determination of the heat transfer coefficient of construction elements for existing buildings. Progress in Engineering Heat Transfer - Gdansk, 1999, pp. 145-152.

[3] DIN V 4108-6. *Wärmeschutz im Hochbau. Berechnung des Jahresheizwärmebedarfs von Gebäuden.* 1995, 37 S.

[4] Jakovics, A., Gendelis, S., Krievans, Z.: Numerical modelling of heat losses and heat requirements for buildings. Latvian journal of physics and technical sciences. – 2000, No. 3, pp. 3-18.

[5] EN ISO 9972: *Thermal insulation. Determination of building airtightness. Fan pressurization method.* 1996, 10 pp.

[6] ISO 6781: *Thermal insulation. Qualitative detection of thermal irregularities in building envelopes. Infrared method.* 1983, 11. pp

[7] Jakovics, A., Trümmann, H., Banga, A., Mühlbauer, A.: *Einsatz der Gebäudethermografie zur Diagnostik der Wärmedämmung an osteuropäischen Hochbauten*. Elektrowärme international. - 1998, No. A3, S. 93-100.


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