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Implementation of Heat Flux Measuring Methods for Heat Transfer Coefficient Determination of In Situ Construction

Marian Flimel [1], Darina Duplakova [2,*] and Enes Sukic [3]

1 Department of Process Engineering, Faculty of Manufacturing Technologies with a Seat in Presov, Technical University of Kosice, Bayerova 1, 080 01 Presov, Slovakia; marian.flimel@tuke.sk
2 Department of Automobile and Manufacturing Technologies, Faculty of Manufacturing Technologies with a Seat in Presov, Technical University of Kosice, Bayerova 1, 080 01 Presov, Slovakia
3 Faculty of Information Technology and Engineering—FITI, University Union—Nikola Tesla, 11070 Belgrade, Serbia; enes.sukic@fiti.edu.rs
* Correspondence: darina.duplakova@tuke.sk

Abstract: Subjectively, to verify the human perception of the state of satisfaction with the environment it is necessary to use objective methods. One of these methods is the heat flux measuring method. This paper points out the risk factors that affect the heat transfer coefficient H through building structures that are necessary to determine the projected heat input of the building. At the operation stage, the aforementioned structures are affected by environmental factors (noise, artificial lighting, heat sources). This changes the suggested value H_c to the real value H_r, which is documented by the measurements. The rate of change of the H value is given by the correction "K". According to the measurements the value obtained can be corrected from 0.08 to 0.25. The final values of the heat transfer coefficient were generalized in the equation and the value of the building energy category within the energy certification of buildings was determined. The result is a methodology for the optimal determination of H values for hazard prevention.

Keywords: heat transfer; heat flux; heat transfer coefficient; built environment

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1. Introduction

The recent literature provides solutions that concern the stratigraphy of windows and walls using phase-change materials [1–3], such as the new silica aerogel-based insulation [4,5] or the use of heat sources, which employ geothermal and solar radiation [6].

In the last decade, there has been no specific regulation in the windows issue. The different insulation materials minimize heat loss through walls, but reduction of window heat loss is complicated. [7] There are several methods to reduce heat loss through windows: optimization of the thickness of the air layer in double pane windows [8], filling the cavity between panes with an inert gas [9], evacuating the cavity [10], coating the pane surface with low emissivity materials [11] or solar selective coatings [12], using multiple pane windows [13,14] or simultaneous applications of some of these methods [15–17].

In windows, the glazing materials provide adequate illumination levels in the interior of buildings receiving the visible part of solar radiation. The solar heat-gain component in summer can be reduced by proper selection of glazing material. The solar heat-gain component can also be reduced by heat loss in winter [18]. For thermal management in building technology and vehicles, heat transport is of great importance [19]. The heating/cooling load calculation requires an accurate evaluation of heat transfer through the envelope components of the building [20]. The determination of the H value (heat transfer coefficient) of the building's construction is required for the following:

- to calculate building heat loss; these losses are necessary to determine the design of central heating,

- to evaluate a building to determine the energy criteria; this is known as the technical assessment. This assessment is used for the determination of the minimum requirements for energy economy in buildings. The design evaluation is based on calculations with the application of project documentation and project values, which are calculated for buildings at the design phase; it is the basis for a building permit. The standardized evaluation works with standardized input data about internal and external climate conditions along with input data about the manufacturing of building constructions [21],
- to create the energy certificate of a building and determine its energy classification category [22].

The calculation of building energy criteria represents the indicators that express the need for heating in buildings. In the new buildings this is not a problem because the construction compositions are stated in the technical drawings and the text parts of project documentation. There can be problems in restored building where the original documentation is not available. In restored buildings it is necessary to determine the composition of the construction and the technical heat properties by several methods. In this case, construction–design diagnostics are required. This manuscript presents a novel description of the influence interaction of internal and external environmental factors on the behavior of heat fluxes in building structures (walls and window glazing). This article points to the change of the H value as a function of time and operating factors (noise, artificial lighting, heat sources, etc.). The key improvement of this method is the determination of the "K" correction, which describes the change of the original design value H due to the action of the above factors after the implementation of the structure and its operation.

2. Materials and Methods

It is possible to use the various methods for calculating the H value, which determines the required value directly or is calculated from measured parameters. The measuring methods are possible to divide into two parts:

- stationary methods—the measurement of heat flux density passing through the construction (sample) and the measurement of surface temperature in the stabilized heat state,
- dynamic methods—the measurement of the variable thermal field and the reading of values is realized continuously (non-stationary conditions).

The advantages and disadvantages (hazards) of these methods are stated in Table 1. The inaccuracies of the heat transfer coefficient value are absolute values of the difference of the real (r—lower index) and calculated values (c—lower index).

Nowadays, the following are the most frequently used non-destructive methods [23]:

- protected heat plate method,
- heat flux measuring method,
- heat isolation on the circular pipeline method,
- contact dynamic methods for measuring thermal–physical parameters,
- calorific wire and calorific belt method,
- needle and planar probe method,
- heat case method, etc.

Table 1. Advantages and disadvantages of the d iagnostic methods related to buildings in the determination of the H value.

Diagnostic Method	Advantages	Disadvantages
Determination from documentation.	Simple and fast.	Possibility of changes.
Visual inspection.	Additional methods.	It is not possible to establish the exact material structure.
Application of experiences.	Fast assumption for the determination of composition.	Possibility of incorrect conclusion.
Destructive methods.	Finding out the exact material structure, the possibility of sample collection for analysis.	Laboriousness, disruption ofconstruction homogeneity, possibility of roof leaking.
Non-destructive methods.	Accuracy of finding out the actual values by measuring or calculation.	Relation to devices, dependence on marginal conditions of measurement and object running.
Combined methods.	Possibility of combination according to real situation	Various degrees of accuracy.

Problem Formulation

For the purpose of the determination of the H value, the diagnostics of the building are focused on all of kinds of bounded construction: perimeter walls, roof, transparent construction, floors, etc., which form the heat-change wrapper of building. The basic diagnostics are primarily focused on the determination of the heat transfer coefficient in the parts of the constructions where there is no deflection of the temperature field, which means the homogeneous parts of the structures. The subsequent diagnostics are focused on heat bridges in the constructions. In restored buildings it is possible to establish the composition of the construction by the following methods [24]:

- from documentation such as the original project documentation, the records,
- the building diary, cards and markings of the construction (insulating glass) etc., which are possible to obtain by contacting the ex-realizer of the building,
- from visual inspection and measurement of the geometrical parameters such as the wall thickness, for example the wall material under the fallen plaster,
- from experiences such as the composition of construction according to building time and technologies,
- from the determination of composition by destructive methods such as by probe into the composition of the building and material sample collection,
- from the measurement of technical heat properties of the construction by devices, e.g., the non-destructive methods (stated in the following part of this article),
- a combination of the aforementioned previous methods.

$$\Delta H = |H_r - H_c| \tag{1}$$

$$H_c = \frac{1}{R_{si} + R + R_{se}} \tag{2}$$

$$H_c = \frac{1}{R_{si} + R_o + R_n + R_{se}} \tag{3}$$

$$R_o = R_n = \frac{\sum d_i}{\lambda_i}, \tag{4}$$

where

H—heat transfer coefficient,

R_{si}—resistance during the heat transfer on the interior surface of the construction [m^2.K/W],

R_o—original heat resistance of the construction [m^2.K/W],

R_n—new heat resistance of the construction [m^2.K/W],
R_{se}—resistance during the heat transfer on the exterior surface of construction [m^2.K/W],
λ_i—thermo–physical property of the materials [W/m.K].

Equation (2) is determined for the contemporary state evaluation of building boundary constructions and Equation (3) is determined for restored buildings—original and new state (with additional thermal insulation). In these equations, the original value of thermal resistance depends on the ratio of homogenous material thickness (d_i) and thermo–physical properties of the materials (λ_i). These two parameters are important in the field of diagnostics.

The risks of determining the heat transfer coefficient by the method of measuring the heat flow can be divided into two main groups:

- the hazards related to the realization of the method and the determination of the H value—these facts are stated in the following part of article,
- the hazards related to the value determination of the time coefficient—the change of H value by operational conditions; it is established that the H value can change due to environmental factors such as the humidity in the construction (condensational zones can impact the thermal conductivity coefficient λ) and the influence of environmental physical factors such as noise [25]. These could result in an error in categorizing the building.

3. Calculation

3.1. Measurement and Calculation of the H Value Using the Heat Flux Measuring Method for Non-Stationary Conditions

The heat transfer coefficient, H, indicates the spread of the heat flux from the internal environment to the external environment through 1 m^2 of construction at a unit difference between the temperature of the internal and external environments. It is a very important quantity in determining the energy properties of a building and it can be determined from measured values (experimental values) according to the following equations [26]:

$$H_c = \frac{q}{\theta_{ai} - \theta_{ae}} \quad (5)$$

$$\Delta = \frac{q}{\theta_{si} - \theta R_{se}} \quad (6)$$

$$H = \frac{1}{\frac{1}{h_i} + \frac{1}{\Lambda} + \frac{1}{h_e}} \quad (7)$$

where

q—heat flux density [W/m^2],
$\theta_{ai} - \theta_{ae}$—quantity of air temperature on the internal and external side of construction [K],
Λ—planar thermal transmittance [W/m^2.K],
h_i, h_e—coefficients of heat transmission on the internal and external side of construction, respectively.

Measurement devices in alternatives:

- The plate for measuring the heat flux density is situated on the inner side of the building construction in the line of heat flux and consists of two probes for temperature measuring—it is used for the calculation of Equation (5).
- The plate for measuring the heat flux density is situated on the inner side of the building construction in the line of heat flux and consists of two probes for surface temperature measuring on the internal and external side of the building construction—Equations (6) and (7).
- The plate for measuring the heat flux density consists of four probes for measuring temperature according to the above-mentioned points.

3.2. *Example of Value Determination at the Transparent and Non-Transparent Construction (Measurement and Calculation According to the Alternative, No. 1)*

The ALMENO 2290-8 system was used for taking measurements with the application of Equation (5). This system provides the continuous writing of measured values. The measurements were realized for the glazing of plastic windows and peripheral wall of the panel building system BA NKS—Figure 1 (the realization of the building was in the 1980s). The course of measured values is presented by graph for the selected measuring cycle—every 10 min (Figure 2). The total recording time was 14 h, and the calculated values are presented in Table 2.

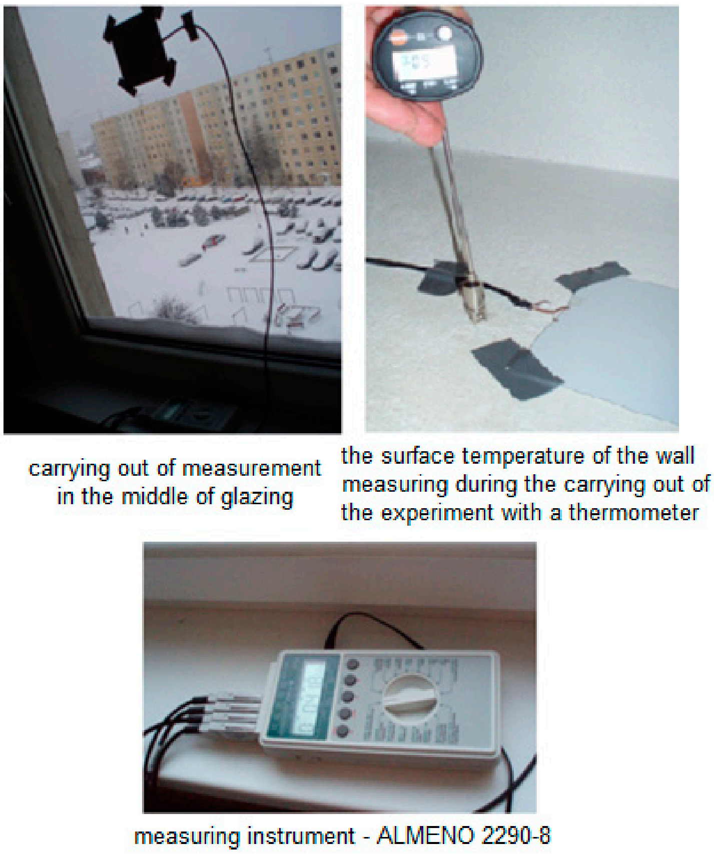

Figure 1. Measuring system of surface temperature with control gauge.

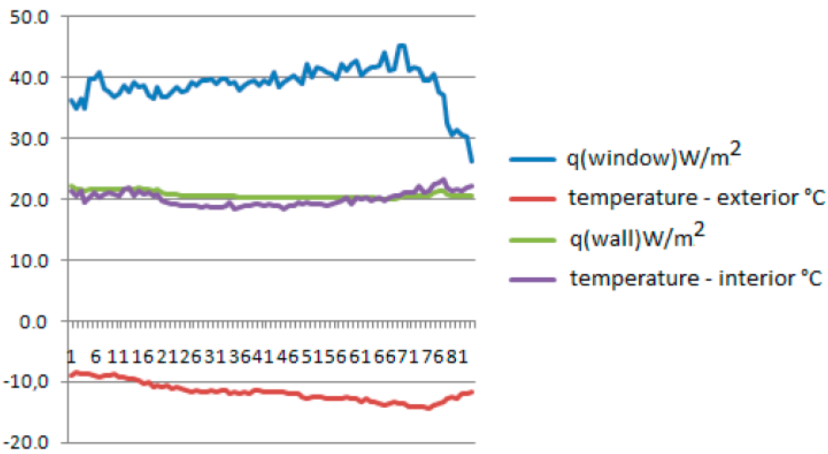

Figure 2. Graphical representation of heat flux density course and temperatures on the window glazing of peripheral wall BA NKS.

Table 2. Final values from the measurements—calculated by Excel for alternative No. 1.

		Building Construction H Value	
	Calculated Values	**Insulated Sealed Unit**	**BA NKS Panel**
Total measurement.	Maximal value of H.	1.33	0.76
	Minimal value of H.	0.93	0.56
	Arithmetic mean.	**1.2**	**0.65**
	Median.	1.21	0.66
	Standard deviation.	0.081	0.046
	Variation coefficient %.	6.78	7.61
Measuring during the night.	Arithmetic mean.	**1.12**	**0.67**
Measuring during the day.	Arithmetic mean.	**1.22**	**0.59**

The graph (Figure 2) presents the nonlinear course of interior and exterior temperature. Based on the realized measurements, supported by graphical interpretation, it is possible to state a stable behavior of the wall temperature with high storage capacity and inertia, while a dynamic course of heat flux on the glazing (decrease) is recorded that is associated with changes in said temperatures and changes of the sky component.

Measuring results:

- Value changes of heat flux density are more dynamic at the sealed unit of the window as opposed to at the panel BA NKS. This state is related to higher accumulation capability of the wall in response to temperature fluctuations in the exterior (for a given measured time it was the temperature fluctuations from −8.67 °C to −14.29 °C).
- Measuring during the night was more reliable—the calculated values approximate to reality (projected values) much more as during the day there is an impact of several environment several that affected the accuracy of the measured values.

3.3. Example of Value Determination at the Transparent Construction by the Two Methods (Measurement and Calculation According to the Alternatives, No. 1, 2)

The ALMENO 2290-8 system was also used for measuring with the application of Equations (6) and (7). This system provides the continuous writing of measured values. The measurement was realized for the glazing of plastic windows—Figure 3. It measured not only air temperatures but also the surface temperatures on both sides of the construction. The course of calculated values was presented in the following table (Table 3). It measured 16 273 data points from 8:20 PM to 11:21 PM (with a measuring cycle of 1 s).

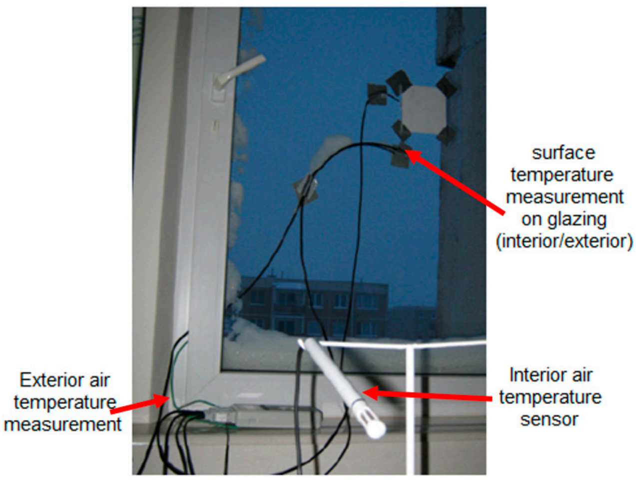

Figure 3. Measurement of heat flux density and temperatures on the glazing of the window.

Table 3. Final values from measurements—calculated by Excel for alternatives No. 1, 2.

		Insulated Sealed Unit	
No.	Calculated values.	H	Λ
Total measurement	Maximal value of H.	1.73	2.26
	Minimal value of H.	1.07	1.40
	Arithmetic mean.	**1.18**	1.54
	Standard deviation.	0.049	0.067
	Variation coefficient %.	4.2	4.35
	H calculation according to Equations (6) and (7).		**1.22**

3.4. Experimental Determination of the Value H_g by the Method of Heat Flow Measurement In Situ

Experimental measurement of heat flow density was carried out on the window glazing in a block of flats in quasi-stationary conditions by the method of heat flow measurement with the help of the measuring system Almeno (see Figure 4). Under the same boundary conditions, the influence of the environmental conditions were assessed—the effects from the indoor environment. These outputs were selected from several outputs, there was a documented measurement in the evening when the influence of environmental factors in the background was eliminated.

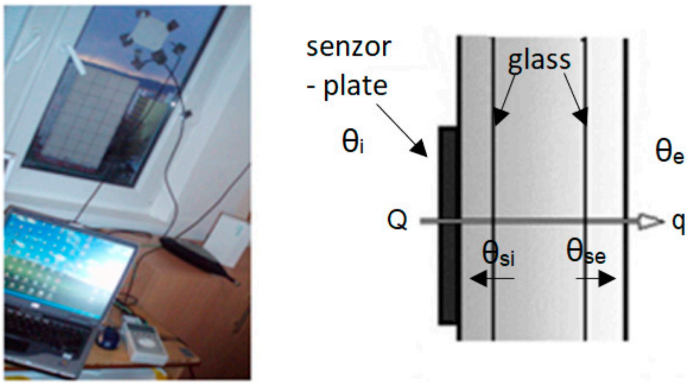

Figure 4. View of the used disc (type of disc was FQ A018C + ZA 9007-FS) in the measuring system ALMEMO 2290-8 of the company Ahlborn and the sound analyzer Investigator 2260 of the company B&K.

Legend to Figure 4:
θ_i—air temperature, inside [°C],
θ_e—air temperature, outside [°C],
θ_{si}—wall temperature, inside surface [°C],
θ_{se}—wall temperature, outside surface [°C],
q—heat flow density [W/m^2],
Q—heat [J].

Outputs from the individual measurements taken in situ during the heating season are listed in Table 4. The influence of sound effects (source—vacuum cleaner) and artificial lighting (reflector, energy saving bulb) on the window glazing from the distance of 1 m was continuously recorded and subsequently evaluated by the software AMR WinControl [27]. Each measurement was spread to 3 min of the initial measurement without any environmental factor effects (noise source) and to 5 min with its effect along with the final 3 min of decay of a change in the heat flow density q. The results from the measurements are presented in the following figures (Figures 5 and 6).

Table 4. Outputs from measurements and determination of the value H_g [28].

Number of Measurement	Description of Influence of Environmental Factors	Determined Value H_g	
		Min H_g	Max H_g
42	Without the influences of environmental factors—middle of the window glazing 0.6 × 1.5 m, insulating double glass.	1.135	1.26
34	With the influence of noise (vacuum cleaner L = 76 dB).	1.27	1.49
40	With the influence of artificial lighting—reflector.	1.15	1.26
37	With the influence of noise and lighting (vacuum cleaner + reflector).	1.17	1.45
41	With the influence of artificial lighting (60W bulb).	1.155	1.22
36	With the influence of noise and lighting (vacuum cleaner + 60 W bulb).	1.18	1.33

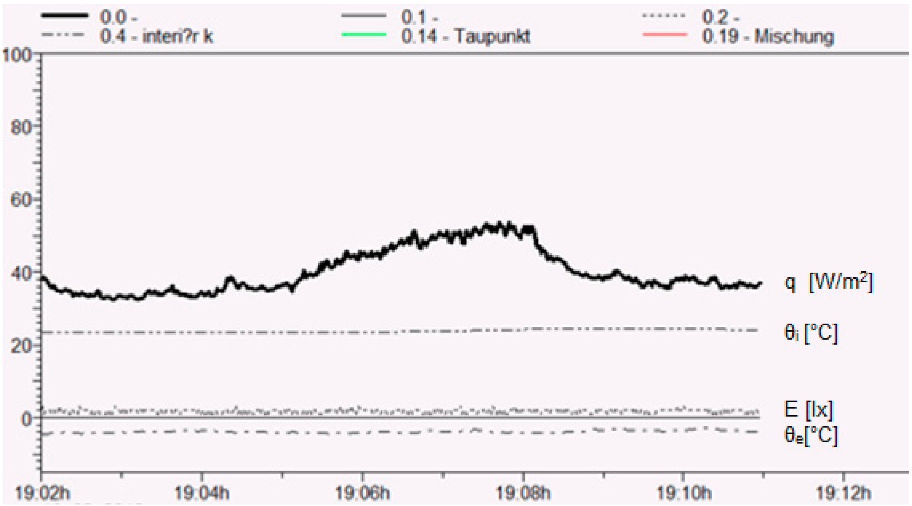

Figure 5. Outputs from the measurement of parameters on the glazing when exposed to the noise source.

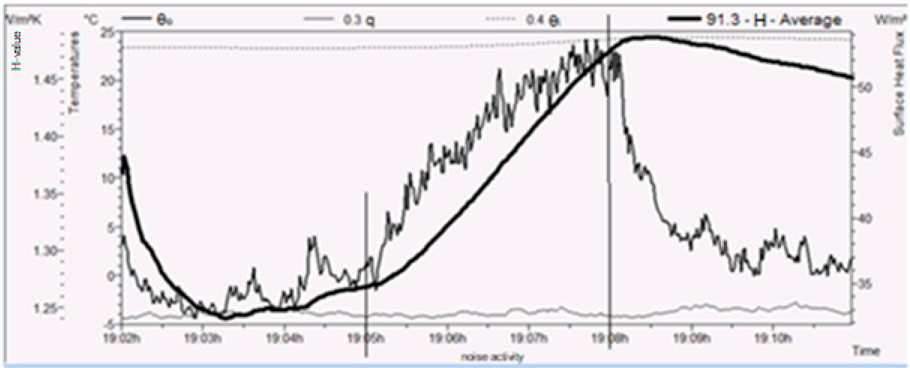

Figure 6. Outputs from the evaluation of the value H_g on the glazing (hick line) when exposed to the noise source.

The measurements showed that the heat flow density on the glazing of the window was influenced by the action of the environmental factors—noise and artificial lighting. The individual factors affected the added value of the heat flow density through the construction of glazing depending on the intensity of the flow transforming the heat, flow characteristics (spectrum composition), the distance of the source of the agents from the construction, location of sources in space and their directional characteristics and duration of the effect from the heat flow interactions with the construction of the glazing.

The heat flow density can be expressed as follows:

$$q = \frac{d\Phi}{dA} = \frac{\frac{dQ}{d\tau}}{dA} \quad (8)$$

After adjustment, we can write Equation (1) in the form:

$$q = \frac{1}{dA} \cdot \left(\frac{dQ_1}{d\tau_1} + \frac{dQ_2}{d\tau_2} + \frac{dQ_3}{d\tau_3} \right) \quad (9)$$

where

q—heat flow density [W/m^2],

Φ—heat flow rate [W = J/s],

A—area [m^2],

Q—transferred heat [J],

τ—time [s],

1—index for transferred heat Q_1 by difference of environmental temperatures between the interior and the exterior,

2—index for transferred heat Q_2 added by transformation of sound energy to heat energy in the window glazing,

3—index for transferred heat Q_3 added by radiant thermal component from artificial light on the window glazing,

4—other added heat flows from the interior or exterior.

4. Recommended Measuring Method

From the previous measurements, it is evident that inaccuracies can emerge during the determination of the real value of the heat transfer coefficient by the heat flux method. These hazards are influenced by the following:

- Measuring system—devices (accuracy, calibration).
- Subject—human (manipulation technique with devices, evaluation of measured values, measuring conditions).
- Environment—the right selection of measuring position (without the environment influences such as radiant heat, sound, artificial illumination).
- Measuring time, length of measurement and measuring cycles during the continuous measurement.

Recommended measuring rules to the heat flux measuring method are as follows:

- Preparation of measurement—study of the assessed building, room and types of constructions when the measurements are taken. This is to ensure the stabilization of the temperature of the internal spaces, accessibility to the measuring surfaces and the possibility of the placing of sensors for taking measurements in the exterior of the building.
- Realization of measurement—the measurements were realized in accordance with required marginal conditions; the temperature differences between the exterior and interior were twenty Kelvins minimum. The determination of the H parameter was problematic in the construction where there was not a heated room (it was not the heat flux between the two environments).
- After the analysis of the building construction types, suitable positions needed to be determined where the measurements would be taken. The suitability of positions was ascertained because the construction should be homogeneous without any thermal or form bridges (Figure 7). It was possible to determine this using a thermal imaging camera.
- It was advisable to carry out the measuring when the heat fluxes were stabilized without the external and internal effects in the constructions. It was suitable to measure during the night or early morning. It was necessary to eliminate the impacts of the environment which could influence the concrete measurement—Figure 8.
- Provision of suitable cooperation between the construction and the sensors.

- Drawing up of the data file of the measurements followed by statistical evaluation.

Figure 7. Checking the correctness of measured fragments using a thermal imaging camera—hidden thermal bridges for construction.

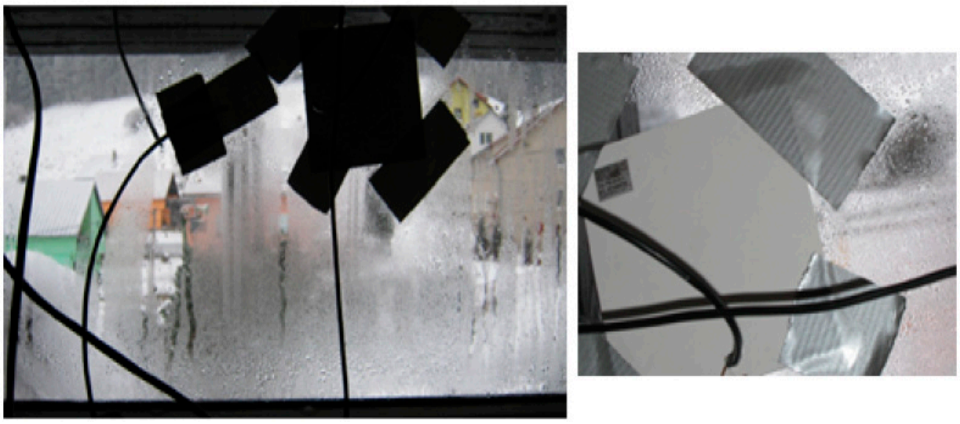

Figure 8. Influence of the surface condensation on the window glazing during the measurement of heat flow.

5. Results and Discussion

The application substance of the heat flow measuring method consists of the possibility of determinating the real values of the heat transfer coefficient through the building construction, which are necessary for the energy evaluation of buildings and the creation of energy certificates.

Differences between the measurements in situ were ascertained with the determination of the heat transfer coefficient values on the glazing H_g (Table 4). These differences are presented in the following table (Table 5), according to Equation (1). These results are based on the condition—H_g = 1.1, which was declared by the maker of the insulation glazing. This condition was stated on the internal side of the distance frame between the two panels of glazing. The type of insulation glazing was PLU 4-16-4 mm with argon glazing panel. In addition the mentioned value was the calculated value. This value is stated in the standard STN 73 0540-3.

Table 5. Determination of the difference between the real value (H_g) from the measurements and the calculated value H_g = 1.1.

Operating Conditions	Min. Value of ΔH	Max. Value of ΔH	Scatter of ΔH Residuum Growth [%]	Average of ΔH Residuum Values [%]
Regular without effect of outside influences (measurement No. 42).	0.035	0.16	3.18–14.54	8.86
Noise effect on glazing (L = 76 dB) (measurement No. 34).	0.17	0.39	15.45–35.45	25.45
Noise effect on glazing (L = 76 dB) (measurement No. 34).	0.05	0.16	4.54–14.54	9.54
With the influence of noise and lighting (vacuum cleaner + reflector) (measurement No. 37).	0.07	0.35	6.36–31.81	19.08
With the influence of artificial lighting (60W bulb) (measurement No. 41).	0.05	0.12	4.54–10.9	7.72
With the influence of noise and lighting (vacuum cleaner + 60 W bulb) (measurement No. 36).	0.08	0.13	7.27–11.81	9.54

Results from Table 5:

- The real values of the heat transfer coefficient H_g on the window glazing are higher (by around 8.8%) than the declared values under the optimal conditions (without the influence of the environment factors—e.g., noise, light sources). This fact is influenced by degradation processes such as commission time of the window (the measured sample was eight years old) and the other climatic factors. In addition, the design and the join stress quality of the glass, along with the distance of the frame, were important. These can cause argon leakage and a decrease in the insulation qualities of the glazing.
- The increase in H_g (from 9.54% to 19.08% against the calculated value on average) wats caused by the effect of the infrared element from the sources of artificial light. The increase in H_g was dependent on the type of artificial light source and the distance between the source and the glazing.
- The increase in H_g (from 25.45% on average) was caused by the effect of the sound pressure level on the front of the glazing (L = 75 dB).
- The increase in H_g (by 9.54% on average) was caused by the collective influence, which was lower during the insulation effects of the sources.

The selection from many measurements (which were realized in the presented experiment) points out the fact that the H_g value increased due to the influence of internal factors (artificial light and noise). This fact was disadvantageous for the insulation properties of the construction—window glazing. The factors from the exterior also had an impact on the H_g value [29].

It was necessary to anticipate the mentioned hazards that could influence the final parameters. The presented method was not applicable during the whole year because it was not possible to ensure the measuring conditions for the measurements stated in the recommended rules. It was necessary to determine the H value of the floor constructions. In this case it was necessary to proceed by other methods [30]. The aim of the presented method was to allow the measurement of conditions such as detect changes in the value of the heat transfer coefficient at a specific time (e.g., annual measurement) or to verify the parameters of building structures in their failure [31]. The following were established during the long-term measurement of the heat transfer coefficient through the building constructions:

- changes of values occur during the time of the experiment, e.g., the H value was worse in the window glazing due to the wear of window (deformation, wind actions). The H value of the solid walls and roof may have been aggravated by the internal condensation of the structures,
- the H value has an influence on other environmental factors (radiations, noise) thus it was suitable to realize the measurements according to the recommended rules which are presented in this article.

6. Conclusions

The optimal determination of the real H value has economic meaning—the minimization of differences between the values and needs of the actual consumption of heat in the building and to qualitatively determinatine the building energy category, which affects its market value [32–35]. The consequence of heat transfer values and their dependence from different factors are necessary to correct the calculated values by correction "K", which takes into consideration the following influences:

- the influence on the building construction amortization and its operation and the possible changes of thermal insulation properties
- the influence of the environmental factors (noise, radiation—artificial light, etc.)
- the influence of measurement errors such as systematic error—during the violation of the measuring method, the measuring instrument was not calibrated; random error—instantaneous conditions of measurement and gross errors are caused by human mistakes.

The final real values of the heat transfer coefficient were possible to determine using the following equation:

$$H_r = H_c + K \quad (10)$$

where

H_c—determined by values according to STN 73 0540

K—total correction

$$K = P \cdot H_c \quad (11)$$

where:

P—one hundred percent of calculated values increased depending on the effect of individual influences; this parameter takes into consideration the different influences and it is dependent on the type of construction, environmental factors and their time exposition.

According to the measurements, corrected values can be obtained from 0.08 to 0.25. The exact value determination of the total correction will be the next research direction in this field.

It is determined that the value of the building energy category lies within the energy certification of buildings. It needs to be able to upgrade the real values of the heat transfer coefficient by upgrading the energy audit within the life cycle of buildings. The value upgrade relates to the changes of the H values in time. The recommended measuring method enables the measuring optimization of heat flux values and the calculation of H values in situ without the disturbing environment effects.

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References

1. Sevostianov, I.; Kachanov, M. On discontinuities of thermal, electric and diffusion fluxes at interfaces of different materials. *Int. J. Eng. Sci.* **2016**, *102*, 1–3. [CrossRef]
2. Thakur, A.K.S. Periodic heat flux through extended structures and projections of buildings. *Build. Environ.* **1985**, *20*, 43–46. [CrossRef]
3. Lee, K.O.; Medina, M.A.; Raith, E.; Sun, X. Assessing the integration of a thin phase change material (PCM) layer in a residential building wall for heat transfer reduction and management. *Appl. Energy* **2015**, *137*, 699–706. [CrossRef]
4. Goia, F.; Perino, M.; Haase, M. A numerical model to evaluate the thermal behaviour of PCM glazing system configurations. *Energy Build.* **2012**, *54*, 141–153. [CrossRef]
5. Ibrahim, M.; Biwole, P.H.; Achard, P.; Wurtz, E.; Ansart, G. Building envelope with a new aerogel-based insulating rendering: Experimental and numerical study, cost analysis, and thickness optimization. *Appl. Energy* **2015**, *159*, 490–501. [CrossRef]
6. Pérez, G.; Coma, J.; Martorell, I.; Cabeza, L.F. Vertical Greenery Systems (VGS) for energy saving in buildings: A review. *Renew. Sustain. Energy Rev.* **2014**, *39*, 139–165. [CrossRef]
7. Mazzeo, D.; Oliveti, G.; Arcuri, N. Influence of internal and external boundary conditions on the decrement factor and time lag heat flux of building walls in steady periodic regime. *Appl. Energy* **2016**, *164*, 509–531. [CrossRef]
8. Arıcı, M.; Karabay, H.; Kan, M. Flow and heat transfer in double, triple and quadruple pane windows. *Energy Build.* **2015**, *86*, 394–402. [CrossRef]
9. Arıcı, M.; Karabay, H. Determination of optimum thickness of double-glazed windows for the climatic regions of Turkey. *Energy Build.* **2010**, *42*, 1773–1778. [CrossRef]
10. Reim, M.; Beck, A.; Körner, W.; Petricevic, R.; Glora, M.; Weth, M.; Pötter, F.J. Highly insulating aerogel glazing for solar energy usage. *Sol. Energy* **2002**, *72*, 21–29. [CrossRef]
11. Collins, R.E.; Simko, T.M. Current status of the science and technology of vacuum glazing. *Sol. Energy* **1998**, *62*, 189–213. [CrossRef]
12. Bahaj, A.S.; James, P.A.; Jentsch, M.F. Potential of emerging glazing technologies for highly glazed buildings in hot arid climates. *Energy Build.* **2008**, *40*, 720–731. [CrossRef]
13. Oelhafen, P. Optimized spectral transmittance of sun protection glasses. *Sol. Energy* **2007**, *81*, 1191–1195. [CrossRef]
14. Karabay, H.; Arıcı, M. Multiple pane window applications in various climatic regions of Turkey. *Energy Build.* **2012**, *45*, 67–71. [CrossRef]
15. Gorla, R.S.R. Unsteady heat transfer characteristics of a two-dimensional laminar wall jet. *Int. J. Eng. Sci.* **1973**, *11*, 841–851. [CrossRef]
16. Siegel, R. Transient effects of radiative transfer in semitransparent materials. *Int. J. Eng. Sci.* **1998**, *36*, 1701–1739. [CrossRef]
17. Horikiri, K.; Yao, Y.; Yao, J. Modelling conjugate flow and heat transfer in a ventilated room for indoor thermal comfort assessment. *Build. Environ.* **2014**, *77*, 135–147. [CrossRef]
18. Roos, A.; Karlsson, B. Optical and thermal characterization of multiple glazed windows with low U-values. *Sol. Energy* **1994**, *52*, 315–325. [CrossRef]
19. Hammond, G.P. Thermal performance of advanced glazing systems. *J. Inst. Energy* **2001**, *74*, 2–10.
20. Pal, S.; Roy, B.; Neogi, S. Heat transfer modelling on windows and glazing under the exposure of solar radiation. *Energy Build.* **2009**, *41*, 654–661. [CrossRef]
21. Gałązka, K.; Populoh, S.; Xie, W.; Hulliger, J.; Weidenkaff, A. Radiative heat losses in thermal conductivity measurements: A correction for linear temperature gradients. *Measurement* **2016**, *90*, 187–191. [CrossRef]
22. Khoukhi, M.; Fezzioui, N.; Draoui, B.; Salah, L. The impact of changes in thermal conductivity of polystyrene insulation material under different operating temperatures on the heat transfer through the building envelope. *Appl. Therm. Eng.* **2016**, *105*, 669–674. [CrossRef]
23. Chmurny, I. *Comments and Suggestions for Calculating the Energy Certification of Buildings*; MVaRR SR, SKSI: Bratislava, Slovakia, 2007.
24. Flimel, M.; Dupláková, D. *Vibro-Acoustical Certification Management of Residential Houses*; LAP Lambert Academic Publishing: Saarbrücken, Germany, 2016.
25. Vaverka, J. *Building Thermal Technology and Energy Buildings*; VUTIUM: Brno, Czech Republic, 2006.
26. Flimel, M. *Riziká pri Určovaní Súčiniteľa Prechodu Tepla pri Projektovom Hodnotení Budov, Budova a Energia, Proceeding from Conference*; Vysoké Tatry: Štrbské Pleso, Slovakia, 2009; pp. 135–138.
27. *Almemo Manual 2290-8*; AHLBORN Mess- und Regelungs Technik GmbH: Holzkirchen, Germany, 1999.
28. AMR WinControl. Available online: http://amrwincontrol.software.informer.com (accessed on 7 May 2020).
29. Flimel, M. The effect of light on the value of heat transfer coefficient Ug-glazed windows. In Proceedings of the Lighting Conference of the Visegrad Countries (Lumen V4), Bratislava, Slovakia, 26–28 September 2012.
30. Flimel, M. Interaction of environmental noise and building construction. In Proceedings of the CESB 10: Central Europe towards Sustainable Building, Prague, Czech Republic, 30 June–2 July 2010; pp. 1–4.
31. Vilčeková, S.; Sedlakova, A.; Turcsanyi, P.; Mečiarová, L.; Burdová, E.K.; Varga, J.; Rošková, P. Ultra-low-energy house and indoor environmental quality: A case study. *Int. J. Energy Environ.* **2016**, *10*, 171–180.
32. Rimar, M.; Fedak, M.; Hatala, M.; Smeringai, P. The synergistic effect of thermal collectors rotation in relation to their energy efficiency and stagnation compared with the static thermal system in the conditions of central Europe. *Int. J. Photoenergy* **2015**, *2015*, 1–19. [CrossRef] [PubMed]

33. Matisková, D. The methodology of economics costs influential on automation of component production. *Am. J. Econ.* **2012**, *7*, 164–170. [CrossRef]
34. Variny, M.; Jediná, D.; Kizek, J.; Illés, P.; Lukáč, L.; Janošovský, J.; Lesný, M. An investigation of the techno-economic and environmental aspects of process heat source change in a refinery. *Processes* **2019**, *7*, 776. [CrossRef]
35. Katunský, D.; Bagoňa, M.; Katunská, J.; Lopušniak, M.; Rudišin, R.; Tóth, S.; Vertal', M. Measurements of physical parameters of envelope structures in real conditions in situ. *Visn. Nac. Univ. L'vivska Politech. Teor. I Prakt. Budivn.* **2012**, *737*, 259–264.