Use of heat mirrors on field of renovation of window structures

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Abstract. The paper presents the results of the analysis of several variants of glass systems using low emissivity heat mirror films. The subject of the paper is the determination of the thermal-optical parameters of the structure as well as the analysis of surface temperatures of the considered glass systems, which were obtained by calculation. The result is optimization of the structure which will be the subject of further research.

1. Introduction
For a longer time, the current topic of renovation of existing buildings may vary in scope. It may be a complex design or, conversely, only minimal changes, depending on investor’s requirements and source options. Building renovation also addresses the issue of replacement of window structures.

After the millennium, the first three-chamber plastic windows (frames) with insulating double glass unit experienced a great boom. Year-to-year, progress has been made and improved frames and glass systems have been introduced to the market. Improvement happened in case of thermal insulating and optical properties of glass systems. A huge trend was the replacement of the original windows as the household heat consumption was observed as well as the users noticed a significant outflow of heat through the windows, up to 47% [1,2] approximately 10% of total energy consumption [3]. Conventional double glass systems will no longer be able to meet the standards, the use of a triple insulating unit will therefore be necessary. The main drawbacks of this solution are increased system weight and impaired light transmission [4]. The solution could be a glass system consisting of two 4mm thick glass panes and additional foils.

However, the normative system of the Slovak Republic in relation to energy saving is still intensifying. The current requirement (recommended value) for U value through windows up to year 2020 is \( U_{W,1} = 1.0 \text{ W/(m}^2\text{K)} \), the normalized value being \( U_{W,N} = 1.4 \text{ W/(m}^2\text{K)} \). Since 2020, the target U value has been approved so far \( U_{W,2} = 0.6 \text{ W/(m}^2\text{K)} \). The requirements laid down by the standard are binding on new buildings, but if they are functionally, technically and financially feasible, renewed buildings should also meet them [5].

However, the values obtained by the calculation declared by the window manufacturers may not coincide with the real values obtained by in-situ measurements [6]. Any errors or deviations in production and installation into existing perimeter structure may not be taken into account. For this reason, certain reserves are in place and therefore improved thermal insulation properties should be considered in the design.

In case of renovation of existing buildings, their partial designs are considered as a cost-effective solution, the replacement of the glass system in the existing frame. This alternative is based on the fact that the windows (frames) installed after 2000 have at least the adequate thermal insulation features and, if they do not show any defects, their replacement would be unprofitable. It is also important to note that
the ratio of the frame surface is significantly lower in relation to the area of the glass system, which logically implies that it is necessary to draw attention mainly to the thermal-optical parameters of the glass system.

2. Progressive glass system - heat mirror film
The heat mirror films work on the principle of reflection of long-range infrared radiation emitted by surrounding surface while being highly transparent [7]. The glass system with the use of the heat mirror is significantly lower in comparison to a conventional triple glass system of the same thickness as the intermediate glass sheet is replaced by one or more heat mirror films. The original gap between in the glass system is thus divided into two or more parts that can be filled with different gases.

![Figure 1. U-value performance comparison (6mm glass.)][10]

Low emissivity heat mirror films were in 1958 discovered as a material applicable to the glass system, have since been used primarily as space thermal insulators [7]. Designed for the patent, 1976 John C. C. Fan and Frank Bachner of the institute of Technology, 1982 [8] under number 4337990 [9].
At the same time, since 1978, Stephen E. Selkowitz and colleagues [7,10] form the University of California, Berkley, also studied the possibilities of using heat mirrors. Films can be applied to glass or plastic element and, depending on application, can reduce thermal losses by 25-57% [7]. Effectively eliminate UV radiation (x<99%). In the form of monolayer coatings, In$_2$O$_3$: Sn, doped SnO$_2$, Cd$_x$SnO$_{4}$; as the two layers are applied: ZnS/metal/ZnS, Bi$_2$O$_3$ and TiO$_2$/Ag/TiO$_2$ [11].

| Name                | Emissivity ε [%] | Solar heat gain coefficient g [%] | $T_{sol}$ [%] | $R_{sol}$ [%] | $T_{vis}$ [%] | $R_{vis}$ [%] | $T_{UV}$ [%] |
|---------------------|-----------------|----------------------------------|--------------|--------------|--------------|--------------|--------------|
| Heat Mirror 88      | 12,2            | 69                               | 65           | 23           | 88           | 6            | 1,6          |
| Heat Mirror TC 88   | 10,9            | 56                               | 52           | 25           | 80           | 2            | 2,0          |
| Heat Mirror 77      | 7,0             | 51                               | 48           | 41           | 79           | 13           | 1,6          |
| Heat Mirror SC 75   | 5,5             | 40                               | 37           | 46           | 76           | 11           | 1,4          |
| Heat Mirror 66      | 4,3             | 38                               | 35           | 55           | 65           | 26           | 1,3          |
| Heat Mirror 55      | 3,4             | 32                               | 29           | 62           | 54           | 36           | 1,1          |
| Heat Mirror 44      | 3,1             | 25                               | 23           | 70           | 44           | 48           | 0,8          |
In the introduction there is an outline of the possibility of replacing the glass system as an alternative to replacing the entire window. Three variations were chores for the glass system of the original thickness of 4mm; each of which has several alternatives. They differ in number of heat mirror layers used (2-6pcs/44mm) and at the same time in the thickness of chamber between the gas filled glasses (Krypton, Argon): 12-5mm/44mm. The most effective gas layer thickness for Krypton is 8, in the case of Argon 12 mm [13]. The different variations differ in the type of heat mirror used, which significantly influences the resulting thermal-optical properties of the glass system. In the table 2 there are compositions of original (commonly available) and newly designed glass systems.

Figure 2. Original and substitutitional glass systems; thickness 44mm.

The boundary conditions of the calculation model were chosen according to [5,14,15]. The required normalized value of the internal surface temperature to avoid condensation is determined by considering the average outdoor temperature of the coldest month in the year (January) for the building location according to STN EN ISO 13790/NA [15]. Kosice is for the month of January in region III. and therefore has a regression formula for the monthly average outside temperature:

\[ y = -0.004x - 2.5 \]  

where \( y \) is average monthly outdoor temperature in °C, \( x \) height above sea level of town in m [15].

\[ y = -0.004 \times 230 - 2.5 \]
\[ y = -3.42°C (Kosice, region III.) \]

Internal design temperature is \( \theta_i = +20°C \). The results are obtained using the Window 7.4.14 [16] software according to the NFRC standard with external design temperature changed. For more accurate results, it would be useful to use dynamic simulation model and the thermal reference year [17,18].
Table 2. Input parameters- compositions of selected glass systems; thickness 44mm.

3. Results and discussion

The resulting values of the evaluated parameters for glass systems of thickness 44 mm. In the case of commonly used glass systems (see table 2) of 44 mm thickness, after taking into account the boundary conditions, the surface temperatures on the external glass pane surface range form -2.4°C ~ -3.5°C; on the inner surface in the range of +14.7 ~ +17.3°C. A summary of the results of the comparison glass systems can be found in table 3. From the point of view of the thermal insulation ability of the original glass system (X1, X2, X3), the most advantageous system is X1 with \( U_{COG} = 0.889 \text{ W/(m}^2\text{.K)} \) with acceptable solar factor \( g = 51.3\% \) and visible transmittance \( \tau_{vis} = 73.5\% \), but more than 37\% of the ultraviolet radiation is released into the interior. System with the most unacceptable \( U \) value is system X3 with \( U_{COG} = 1.619 \text{ W/(m}^2\text{.K)} \), resulting in a solar factor higher by 21.7\%, the transmittance of the visible part of spectrum by this glass system is at approximately the same level (2.1\% difference) and the ultraviolet radiation transmittance is nearly 53\%. In case of glass system X1, it can be said that its parameters, and in particular the calculated temperatures of the inner surface of the glass, meet the actual requirements, and there is no risk of condensation on the surface in the middle of the glass system surface under normal outdoor temperatures. If there are an increased number of people in the considered room where the glass system is located and hence increased temperature and relative humidity there is a risk of condensation on the inner glass. If the outdoor temperature drops below -10°C (in Kosice there are several such days during the winter), the relative humidity of indoor air is approx. 70\% and the indoor temperature is 20°C, the dew point temperature under the given conditions would was \( \theta_{dp;20°C;70%} = 14.36°C \). With these parameters, the condensation on the inner surface of the glass would be more than likely for the glass systems X2 a X3 [19]. The temperature over the circumference of the glass system is further aggravated by the influence of the spacer and therefore its linear thermal transmittance need to be taken into account. However, the risk of condensation (and icing) is also threatened on the outside of the glass systems where \( U_{COG} \) is in the range of 0.4 ~ 1.0 W/(m².K) [20]. An adverse phenomenon can be avoided by using a low emissivity coating with a maximum emissivity 0.2 at position #1.
The proposed progressive glass systems are designed using three types of heat mirror films, each of which includes five alternatives that vary in the number of heat mirror films used. For HMGS 1 ~ 3, that U-value is in the range of 0.282 ~ 0.368 W/(m².K). Interestingly, due to the use of the heat mirror, the ultraviolet transmittance coefficient value dropped to zero, this effect can be observed for all 15 chosen glass systems. The temperature in the middle of the inner surface of the glass pane is in the range of +19.3 ~ +19.6°C. These values are significantly closer to indoor air temperature (+20°C), which not only eliminates the possibility of condensation on the glass surface but eliminates the thermal discomfort of occupants due to the unpleasant coldness radiation from the indoor glass pane.

4. Conclusion
As a result of the increasing heat protection of buildings, replacement of windows is an often solution to a high heat leakage through them. Since the glass system forms the majority of the area of the structure, it is worth considering, exchanging only the glass system itself. The selected progressive glass systems were evaluated in terms of thermal-optical parameters and their surface temperature calculations. The results indicate the possibility of profitable replacement of the original glass system as progressive, which could be put into the original e.g. plastic frame. The heat insulating properties of heat mirror system is 60 ~ 75% better than the original glass systems. In the vast majority of cases, they
exclude the risk of condensation of water vapour on the inner surface of the glass, which is the most observable problem in the winter period; during summer period effectively prevent undesired overheating of interior. The choice of the most appropriate system from analyzed depends on the conditions in which heat mirror insulating unit will be installed.

5. References

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