Influence of Contamination of Snow Deposits on Roof Skylights on Levels of Internal Natural Illumination in Rooms with an Upper Natural Light System

K O Larionova 1, S V Stetsyk 2
1 Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
2 Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: larionova_k_o@mail.ru

Abstract. The article considers the problems of required levels of natural illumination in premises with a natural light system in the form of roof skylights. The influence of snow deposits on roofs and skylights on light penetration through the glazing of these elements with respect to snow pollution is being considered. The latter factor, due to general pollution of air masses becomes very important and characteristic to the large conditions of cities in our country. This makes the problem in question very actual. The results of field studies, general conclusions and recommendations are being quoted. A great influence of snow covering on the roof skylights in general and the degree of the snow pollution in particular on the levels of the natural lighting of interiors is being shown.

1. Introduction
Designing energy-efficient buildings is a topical issue, considered by many authors [1-8], an important role in this is played by the level of natural illumination [9-20]. Snow cover on the roof of buildings in the winter conditions of most regions of the Russian Federation, accumulates a significant amount of pollutants present in the airspace of large cities. This is to a much greater extent than the pure snow deposits on the roof skylights, worsens the light in the premises with the system of upper natural light. Hence, one can say, that problems with the effect of clean or dirt snow covers on glazing of roof skylights on level of natural lighting of interiors have not been solved up to date. That’s why case with contamination of snow cover on skylights were, considered in a series of full-scale experiments and are presented in this article.

2. Method of experimental studies
Experimental studies were conducted in accordance with the following main stages:
1. Determination of the daylight factor (D.F.) and the light transmission coefficient of glazing (τ1) with a clean glass surface 4 mm thick;
2. The same, with a small layer of snow cover on the glazing, 10 mm thick;
3. The same, with a large layer of snow cover, 25 mm thick;
4. The same, with a small or large layer of snow on the glazing with contamination of the snow cover in small, medium or large extent. Note that as a general principle, for large tables font sizes can be reduced to make the table fit on a page or fit to the width of the text.

As practice shows, snow cover on roof skylights of any shape usually does not exceed 25 mm with its uniform layer. A more powerful layer of snow is usually blown away by the wind, either completely or partially. In the latter case, the thickness of the snow cover changes chaotically and is less predictable, which, naturally, can not be used as a constant indicator in calculating the D.F. In premises with roof skylights when snow covered with a clean or contaminated layer of snow. Uniform thickness of the snow layer on the glazing in the actual conditions of the experiment was formed artificially, i.e. manually.

When determining the extent of snow cover contamination, its maximum value was not considered, which is explained by the following reasons:

1. The maximum degree of snow cover contamination on the glazing is reached at the end of winter or at the beginning of spring, when the duration of sunshine significantly increases and the snow cover on the buildings roof, leaving accumulated dirt on the glazing of the roof skylights. The field measurements of the lighting parameters of the elements of the upper natural light systems were carried out in Moscow, from December 2017. – to February 2018, with a continuous of cloud sky with of 8-10 points, of low cloudness which allows us to accept the conditions of outdoor natural lighting as appropriate to the «International Standard Sky» of the International Commission on Illumination (Commission internationale de l'éclairage (CIE)). To simplify the experiment, it was not a specific glazing of the zenith, but elements of a 4 mm thick window glass, on which layers of clean and contaminated snow of different thicknesses were applied. This made it possible to easily determine the partial light transmittance of glazing τ1. In future, depending on the number of glazing layers, this allows the results to be extrapolated for various specific cases. Measurements of natural illumination were carried out with the help of modified «Ecolight-01».

2. The increase in the duration of sunshine during this period makes it difficult to correctly determine the values of the D.F. according to the normative method of the "Standard Overcast Sky of CIE " and requires a transition to the "Clear Sky" methodology, which was not considered in this paper. The general scheme of the experiment is shown in Figure 1. To obtain the most reliable statistics, each stage of measurements was carried out five times. We considered both a basic version of a clean non-snow-covered glass, and a layer of snow on it with a thickness of 10 and 25 mm for small, medium or heavy contamination. The coefficient of natural illumination "e" (in percent) was determined as a result from the division of the illumination under the glass "E1,u" into the illumination above the glass "E1,a." After that, the light transmittance of glass τ1 was determined by dividing the values of medium E.F (eMED) by 100.

**Figure 1.** General scheme of the experiment: a) Measurements of "e" with clean glazing; b) measurements of "e" in the case of glazing with a layer of snow. On the diagram: 1- The position of the photo-head 1 of the luximeter; 2- Position of the photo-head 2 of the luximeter; 3- Glass thickness of 4 mm; 4- A layer of snow 10 and 25 mm thick. with different degrees of pollution (12.5, 25, 50%). 5 - lights flows.

3. Results of experimental studies
The results of field observations are presented in Tables 1-9.

Table 1. The values of the lighting parameters of a clear window glass 4mm thick.

| № № | Of takes | $\varepsilon$, % | $\varepsilon_{MED}$, % | $\frac{\tau_1 = \varepsilon_{MED}}{100}$ |
|-----|----------|------------------|------------------------|---------------------------------|
| 1   |          | 90,806           |                        |                                 |
| 2   |          | 91,478           |                        |                                 |
| 3   |          | 91,478           | 91,132                 | 0,91                            |
| 4   |          | 91,091           |                        |                                 |
| 5   |          | 90,806           |                        |                                 |

Table 2. The value of the lighting parameters of the examined window glass covered with a layer of pure snow thickness = 10 mm.

| № № | Of takes | $\varepsilon$, % | $\varepsilon_{MED}$, % | $\frac{\tau_1 = \varepsilon_{MED}}{100}$ |
|-----|----------|------------------|------------------------|---------------------------------|
| 1   |          | 18,680           |                        |                                 |
| 2   |          | 18,000           |                        |                                 |
| 3   |          | 18,816           | 18,8042                | 0,19                            |
| 4   |          | 18,895           |                        |                                 |
| 5   |          | 18,824           |                        |                                 |

Table 3. The value of the lighting parameters of the investigated window glass covered with a layer of pure snow with a thickness of 25 mm.

| № № | Of takes | $\varepsilon$, % | $\varepsilon_{MED}$, % | $\frac{\tau_1 = \varepsilon_{MED}}{100}$ |
|-----|----------|------------------|------------------------|---------------------------------|
| 1   |          | 6,636            |                        |                                 |
| 2   |          | 6,738            |                        |                                 |
| 3   |          | 6,759            | 6,7302                 | 0,067                           |
| 4   |          | 6,759            |                        |                                 |
| 5   |          | 6,636            |                        |                                 |

Table 4. The value of the lighting parameters of the investigated window glass covered with a layer of pure snow with a thickness of 25 mm.

| № № | Of takes | $\varepsilon$, % | $\varepsilon_{MED}$, % | $\frac{\tau_1 = \varepsilon_{MED}}{100}$ |
|-----|----------|------------------|------------------------|---------------------------------|
| 1   |          | 5,356            |                        |                                 |
| 2   |          | 7,979            |                        |                                 |
| 3   |          | 5,952            | 6,1602                 | 0,0616                          |
| 4   |          | 6,007            |                        |                                 |
| 5   |          | 6,007            |                        |                                 |
Table 5. The value of the lighting parameters of the window glass under investigation, covered with a layer of snow with a thickness of 25 mm with a contamination of 12.5%.

| № № Of takes |  |  |  |
|---------------|---------------|---------------|---------------|
|               | $e = \frac{E_v}{E_d} \times 100$ | $e_{MED}$, % | $\tau_1 = \frac{e_{MED}}{100}$ |
| 1             | 2.111         |               |               |
| 2             | 2.111         |               |               |
| 3             | 2.134         | 2.1264        | 0.021         |
| 4             | 2.126         |               |               |
| 5             | 2.150         |               |               |

Table 6. The value of the lighting parameters of the investigated window glass covered with a snow layer of thickness = 10 mm with a contamination of 25%.

| № № Of takes |  |  |  |
|---------------|---------------|---------------|---------------|
|               | $e = \frac{E_v}{E_d} \times 100$ | $e_{MED}$, % | $\tau_1 = \frac{e_{MED}}{100}$ |
| 1             | 3.535         |               |               |
| 2             | 3.535         |               |               |
| 3             | 3.535         | 3.5486        | 0.0355        |
| 4             | 3.569         |               |               |
| 5             | 3.569         |               |               |

Table 7. The value of the lighting parameters of the investigated window glass covered with a layer of snow with a thickness of 25 mm with a contamination of 25%.

| № № Of takes |  |  |  |
|---------------|---------------|---------------|---------------|
|               | $e = \frac{E_v}{E_d} \times 100$ | $e_{MED}$, % | $\tau_1 = \frac{e_{MED}}{100}$ |
| 1             | 0.918         |               |               |
| 2             | 0.925         |               |               |
| 3             | 0.925         | 0.919         | 0.0092        |
| 4             | 0.925         |               |               |
| 5             | 0.902         |               |               |

Table 8. The value of the lighting parameters of the examined window glass covered with a snow layer of thickness = 10 mm with a pollution of 50%.

| № № Of takes |  |  |  |
|---------------|---------------|---------------|---------------|
|               | $e = \frac{E_v}{E_d} \times 100$ | $e_{MED}$, % | $\tau_1 = \frac{e_{MED}}{100}$ |
| 1             | 0.455         |               |               |
| 2             | 0.472         |               |               |
| 3             | 0.476         | 0.4709        | 0.0047        |
| 4             | 0.471         |               |               |
| 5             | 0.478         |               |               |
Table 9. The value of the lighting parameters of the investigated glass pane covered with a layer of snow with a thickness of 25 mm with a contamination of 50%.

| № of takes | $E = \frac{E_0}{E_A} \times 100$, % | $e_{MED}$, % | $\tau_1 = \frac{\theta_{MED}}{100}$ |
|------------|---------------------------------|-------------|-----------------|
| 1          | 0.044                           |             | 0.0438          |
| 2          | 0.044                           |             | 0.00044         |
| 3          | 0.043                           |             |                 |
| 4          | 0.044                           |             |                 |
| 5          | 0.044                           |             |                 |

The carried out experimental studies made it possible to obtain a number of data that illustrate the regularity of the change in the specific transmission coefficient of glazing depending on both the thickness of the layer of pure snow on it and the degree of contamination of this layer. The graphs illustrating such dependencies are presented in Figures 2 and 3.

Figure 2. Dependence of the value of $\tau_1$, due to the thickness of the layer of pure snow on the glazing.

Figure 3. Dependence of the value of $\tau_1$, due to the degree of contamination of the snow layer with a thickness of 10 and 25 mm on the investigated glazing.

4. Conclusions.

1. Analysis of the results of studies showed that snow deposits on building covers and, in particular, on roof skylights seriously affect the light transmission of the glazing of these elements of the system of top natural lighting. For example, the partial light transmission cofactor of the glazing of skylights openings is reduced by a thickness of the snow layer at 10 mm on it, depending on the degree of snow cover contamination (from 0% to 50%) by almost 40 times (from 0.19 to 0.0047). With similar conditions and thickness of the snow cover at 25 mm almost 153 times (from 0.067 to 0.00044). Thus, even a small layer of pure snow on the glazing deprives the premises with the system of upper natural light of normalized levels of top illumination, not to mention the situations when the snow cover to some extent is contaminated.

2. In accordance with the results of the conducted studies, it is also possible to give recommendations on the procedure for cleaning the light fixtures of the upper light. As follows from the normative documents, the required amount of cleaning of the glazing of the lanterns of the upper light, depending on the position of the glazing relative to the horizon, the functional purpose of the building and the degree of air pollution varies from 1 to 4 times a year. The conducted studies convincingly showed that in winter conditions for large cities of the Russian Federation, especially those located in the central and northern climatic zones, the number of cleanings should not be limited, but should be made as necessary to eliminate the permanent snow deposits formed on the glazing. In other words, such cleaning should be carried out regularly in winter conditions.
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