Operation of Building Envelopes in Humid and Wet Environment in the North of Krasnoyarsk Krai

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Abstract. The paper dwells upon the relevance of comprehensive analysis into the durability and frost resistance of stone envelopes for industrial buildings operating in extreme cold. The inner environment of a facility and the climate directly affect the lifespan of the industrial building in the North of Krasnoyarsk Krai. The paper analyzes the primary causes and consequences of frost deterioration of building envelopes operated in humid or wet environment. It presents the attributes that indicate the condition of outer building walls of varying age; such attributes point to the deviation from the normal condition. The condition of supports was categorized by examination. The paper further summarizes the results of processing the obtained data on the temperature and humidity the buildings and their envelopes are operated at. It presents the results of testing the efficiency of brick, fly-ash autoclaved aerated concrete, and ceramsite concrete as envelope materials.

1. Introduction
Norilsk urban district is located in the north of Krasnoyarsk Krai above the Arctic Circle [1,2]. Zapolyarny District that Norilsk is in features harsh climate. Low outdoor temperatures, snowdrifts, strong wings (sometimes classifiable as hurricanes), Polar nights, insufficient UV exposure, severe weather, and permafrost are extreme not only for humans, but also for the construction and operation of buildings [3, 4].

Production facilities in the Far North have extremely humid air indoors, which gradually deteriorates the envelopes. The major industrial facilities in Norilsky District, the production cycles of which imply high humidity [5], have been in operation for 40 to 65 years by now. Their outer walls are made of standard-sized red brick with a 2-2.5x brickwork, or of brick blocks filled with a weak solution. Wall brickwork is complicated, as there are multiple ledges framing the windows in addition to heavy brick eaves [6]. The walls are mainly 510 mm thick. The assess the general condition of envelopes, the research team sampled data on walls of several buildings [7]: an enrichment plant, a filtering facility, a concentrate condensation facility, a reinforced concrete factory.

2. Condition of Building Envelopes in Humid and Wet Environment
Envelope condition data was sampled [8] from a large surface area totaling 10,000 m². Defect statements indicated that the most frequent types of damage were frost, icing, and wall flowing down the walls, see Figure 1. Less frequent were cavernous masonry destruction, collapsing or exfoliating plaster, and end-to-end vertical and horizontal cracks [9].
Survey results indicated that surficial destruction of walls was most likely caused by high water saturation of the bricks. Water saturation does deteriorate the thermal properties of envelopes. At low negative outdoor temperatures, moisture in brick pores and capillaries freezes almost completely, which is what deteriorates the thermal properties [10]. When repairing or reconstructing such facilities, they’d often dismantle the destroyed brick walls and construct new ones instead; alternatively, fly-ash autoclaved aerated concrete (FAAAC) could be used. Despite most of the brickwork having been renewed, newly done brickwork is not safe from moisture-induced destruction either. Replacing bricks with FAAAC cannot be considered a reliable solution, as these were destroyed in three to four years of operation to be finally replaced with ceramsite concrete panels [11]. Fluctuations in the outdoor temperature displace the zero temperature point within the wall. Migration of the zero isotherm results in repeated thawing of the brickwork, which gradually destroys it, see Figure 2. Humidity was (and is) high indoors at 90% to 100%; lack of vapor insulation resulted in excessive moisturization of the brickwork. The walls were thus well below standard heat transfer resistance [12]. Thus, sampled data showed the brick envelopes were either only partially suitable or totally unsuitable for that environment all due to the frost deterioration of the brickwork [13].
Figure 3. Brick wall condition after removing shotcrete.

Shotcrete has been a popular solution in Norilsk for better waterproofness of brickwork since mid-1980s [14]. The outer surface would form a ‘coat’ of cured concrete with moisture accumulating under it; brick deterioration was only visible after removing the shotcrete, see Figure 3.

3. Envelope Quality Study Plan
To find out patterns in the frost deterioration of walls and to make guidelines on how to improve their lifespan, the research team analyzed the temperature and humidity buildings were operated at, studied the forces the envelopes were exposed to, devised various options to provide thermal and physical protection for the envelopes, and redesigned the building supports to sustain extra envelope. Temperature and humidity levels were measured by an aspirational psychrometer [15]. To measure the temperature inside the wall, there were bored 16-mm holes for the placement of thermometers. Temperatures were then measured by mercury thermometers calibrated for \(-30^\circ\text{C} to +30^\circ\text{C}\) with 0.1°C increments [16]. Thermometers were further fitted with copper tips for better wall-to-thermometer heat transfer. To prevent outdoor temperatures from corrupting the temperature readings, the holes were not made end-to-end; rather, each of them ended 5 cm to the outer surface. The wall temperature was measured at points spaced at 10 cm through the wall. Temperature readings were time-stamped and synchronized with humidity readings. The wall material strength and humidity were measured on specially selected samples [17]. Sampling points were located at temperature-measurement cuts.

4. Patterns of Frost Deterioration of Envelopes
Table 1 shows the inner air temperature and humidity readings. Apparently, the humidity varied from 83% to 100% and averaged at 91% to 94%. Humidity did not correlate with the time and location of measurement. In summer, air humidity at \(+1.8\) m was 91%, in winter, 94%. At \(+8.0\) m, 93% and 92%, respectively.

| #/p/p | Altitude, m | When measured | Humidity, W, % | Temperature, T, deg. |
|-------|-------------|---------------|----------------|---------------------|
|       |             |               | Minimum | Average | Maximum | Coefficient of variation, % | Minimum | Average | Maximum | Coefficient of variation, % |
| 1     | 1.8         | June to October | 84     | 91      | 100     | 11 | 9 | 15 | 25 | 24 |
| 2     |             | October to July | 85     | 94      | 100     | 10 | –2 | 2  | 6  | 21 |
| 3     | 8.0         | June to July   | 83     | 93      | 100     | 12 | 13 | 24 | 30 | 25 |
| 4     |             | October to July | 86     | 92      | 100     | 13 | 9  | 11 | 12 | 18 |
Whether the difference in readings was significant was tested by Kruskal-Wallis H-test [18]. Testing showed that at 5% significance, it was safe to accept the hypothesis of the homogeneity of sampled data; the humidity could be generalized as $W_{\text{mean}} = 98\%$ with the coefficient of variation $V = 12\%$.

Situation was different, however, with the indoor air temperature. As shown in Table 1, both the measurement site and the season had significant effects on this reading. The indoor air temperature was 10 to 12°C higher in summer than in winter. Temperature was 9-10°C on average at +8.0 m than at +1.8 m. The annual average temperature was approximately 6°C for the latter, 15°C for the former. Annual average outdoor air temperature is approximately −10°C according to long-term observations. Thus, the annual average difference between outdoor and indoor air temperatures was far more significant at +8 m than at +1.8 m: −25°C vs −16°C.

The operating humidity of envelopes was assessed by analyzing the samples taken from different parts of the wall at +1.8 m and +8.0 m. The analysis showed the operating humidity was 10% to 22%, averaged at 14% to 15%, 7 to 8 times the standard. Figure 4 shows the typical wintertime temperature distribution in a 510 mm/380 mm thick brick wall as well as in a 400 mm thick ceramsite concrete wall. Notably, the curves that show how the temperature changed through the wall at +8 m are steeper than their +1.8 m counterparts.

While at +1.8 m, the wall was frozen practically throughout the winter and would be exposed to a very low number of freezing/thawing cycles, at +8.0 m, a part of the wall (thickness-wise) was freezing and thawing continually throughout the winter. Patterns like that caused a more profound frost deterioration of envelopes at +8.0 m compared to +1.8 m.

![Figure 4. Wintertime temperature curves: brick walls versus ceramsite concrete panels.](image)

The research design included an assessment of defects in walls of different ages in order to identify how time could affect those [19]. This produced the curves of the outer wall condition $\Omega$ as a function
of the building operation time $T$. Condition of outer brick walls as a function of time was exponential and can be described by the equation:

$$\Omega = A e^{-bT},$$

where $A = 6$; $b$ is an empirical coefficient based on humidity, temperature, and wall material properties.

This is in line with the earlier hypothesis of frost deterioration of brickwork. While the building is still new, the general wall condition is deemed appropriate and defines the domain of structural stability. After 5 to 11 years in operation, while $T$ is only slightly higher, the condition $\Omega$ deteriorates considerably. After five years in operation, the wall starts collapsing. In 11 years, the structure may collapse entirely all of a sudden.

5. Conclusions

This research identified that the outer walls of most industrial buildings operated in the humid and wet environments of the northern Krasnoyarsk Krai are either only partially suitable or totally unsuitable for such use [20]. Bricks, fly-ash autoclaved aerated concrete, and ceramsite concrete have all been found impractical for making the envelopes for such buildings. An outer brick wall may only be used for up to 11 years in a humid or wet environment before it needs overhaul.

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