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Airtightness of High-Rises in the North

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Abstract: For the Republic of Sakha (Yakutia), effective thermal insulation of buildings is imperative for human comfort and for reducing the leakage of heat through the envelope. To design such insulation, one needs to duly consider the microclimatic specifics in the context of an extreme continental climate. Climate-induced leakage of heat through the envelope results in heat and electricity waste; such leakage is non-acceptable by modern standards. Demand for energy-efficient housing is rising. Thus, improving the thermal insulation of structures is a relevant issue.

1. Introduction

Yakutia has an extreme continental climate; estimated temperatures are low, winds are slow, and temperature fluctuations are immense. Annual temperature range varies from 50°C to 127°C; the coldest five days have outdoor air temperatures from -50 to -65 degrees, cf. -25°C to -41°C in the rest of Russia—the difference exceeds 20 degrees. The heating season is long, permafrost is present, the infrastructure is underwhelming, and human settlements (mostly quite underpopulated) are distanced substantially from each other. All of this makes construction and living in the north a challenging undertaking [1, 2, 3]. The climate of Yakutsk has some specific features that are most striking when compared against the climate of Central Russian cities, see Figure 1.



Figure 1. Distribution of monthly average temperatures.



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Yakutsk is the world's most contrastive city temperature-wise, with an annual range of 102.8°C; it is also the world's largest city on permafrost. The basic architectural principles behind energy-efficient buildings are well-known; they are intended to reduce energy costs by using heat-insulated envelope in conjunction with optimized architecture and layout, state-of-the-art heating, water heating, and ventilation, as well as alternative energy. As of today, testing the feasibility of energy-saving measures, in particular with regard to using advanced engineering solutions, is mandatory [4-5]. It has always been relevant to research ways to make buildings more energy-efficient by reducing heat leakage through the envelope in the cold climate of Russia's Northeast [6, 7]. This paper analyzes the air permeability indicators of the envelope in high-rises. In the 1930s, research into the air permeability of construction materials and envelope was carried out by P.A. Bryantsev, B.F. Vasilyev, S.I. Vetoshkin, D.D. Galanin, S.I. Idashkin, M.I. Subbotkin, P.S. Filosofov. Raisch was a prominent researcher abroad. In 1936–37, R.E. Briling ran the most comprehensive and systematic experimental research in construction, which sought to determine the airtightness and the filtering laws applicable to construction materials and envelopes. This research was performed at the Infiltration Laboratory of the Central Institute of Industrial Construction (CIIC, Rus: ЦНИПС) [8].

2. Methods

Today's residential construction industry uses effective multilayer envelopes. Three buildings in Yakutsk were selected to be tested for air permeability; these are cast-in-place concrete residential high-rises featuring multilayer envelopes:

Building 1. 5/1 Gubina ul., a 9-storey building consisting of two L-shaped blocks. The load-bearing parts of walls, foundations, slabs, and staircases are made of cast-in-place reinforced concrete. The windows are triple-pane windows per GOST 30674-99. The walling is heat-insulated by ventilated facades. The building occupies an area of 867.18 m² (porches included), has a construction volume of 21,820.08 m³, a total floorspace of 6120.09 m², and a total apartment space of 4499.51 m².

Building 2. A 16-storey building at 45 Chepalova ul.; the load-bearing parts of walls, foundations, slabs, and staircases are made of cast-in-place reinforced concrete. The windows are triple-pane windows per GOST 30674-99. The walling is heat-insulated by ventilated facades; the building occupies an area of 2325.50 m² and has a total volume of 11,562 m².

Building 3. A 16-storey building at 4/2-A Avtodorozhnaya ul.; the load-bearing parts of walls, foundations, slabs, and staircases are made of cast-in-place reinforced concrete. The windows are triple-pane windows per GOST 30674-99. The walling is heat-insulated by ventilated facades. The building occupies a total of 2571.39 m² and has a total floorspace of 21,837 m².

Experiments were carried out in situ per GOST 31167-2009 Buildings and structures. Methods for determination of air permeability of building envelopes in field conditions [9]. The requirements to the air permeability and air changes/hour (ACH) values of the envelopes are listed in SP 50.13330.2012 *Thermal insulation of buildings* [10]. Test procedure is described in GOST 31167-2009 as well as in the user manual of the envelope air permeability test unit. The method essentially consists in pumping air by means of a fan into residential premises and then vacuuming the indoor air out. Step 1 is to use an airtight panel and a sliding frame to install a fan in the doorway of the tested room. Then turn the fan on to induce a stable pressure difference between the tested room and the space outside it. During the test, change the airflow gradually to adjust the indoor/outdoor air pressure difference in increments. Maintain a specific air pressure difference between the indoor space and the outdoor space, and measure the fan airflow. Use the measurements to calculate the generalized indicators of air permeability for the tested space. To find the air permeability of the envelopes, the ventilation system performance, and the filtration volumes, the research team used the following instrumentation and equipment: a RETROTEC 5000 envelope air permeability testing unit, a Testo 435-4 air temperature and humidity instrument, a Satir Hy-G90 thermographic camera, and an HP laptop. Tests were carried out from November 2019 to February 2020. For the tests, air ducts were sealed, and so were the maintenance holes in walls and floor slabs. The SatirHY-G90 unit was used to perform thermal imaging, which revealed the following:

1. There were no openings, rifts, or cracks at window mount points nor wall-to-roof transition points.

2. The walls did filter the air flow.

Figure 2 shows the blower door mounted in the entrance doorway; for measurements, all the windows were shut tight, and so were all the exhaust vent grills. During the tests, the experimentation team inspected ventilation channels and flue-gas stacks, measured their cross-section areas, and checked their general condition. The team measured the airflow and air velocity in the ventilation exhausts. These measurements were used to calculate the actual airflow and ACH of the ventilation ductwork.

Figure 2 shows how the test unit was mounted.



Figure 2. Retrotec 5000 blower door mounted in the doorway.

The ventilation system was inspected and the indoor air transfer parameters were calculated per SP 60.13330.2016 [11] GOST 12.3.018-79 Ventilation systems. Aerodynamic test methods [12] to monitor the effectiveness of the ventilation system.

3. Results

During a blower door test, a fan induces a pressure difference between the indoor and outdoor air. By controlling the air flow Q = var, induce incremental change in pressure $\Delta P = var$. Maintain a specific air pressure difference between the indoor space and the outdoor space, and measure the fan airflow.

Table 1 shows the results of tests with the pressure difference of 50 Pa. Figure 3 shows experimental data curves.

Test name	Airflow at pressure difference $\Delta P = 50 Pa$		ACH at ΔP = 50 Pa, n50		Maximum acceptable value per SP 50.13330.2012, n50
	m ³ /hour	error	hour-1	error	hour-1
Decrease in pressure	283.75	+/- 0.65 %	1.16	+/- 0.65	%
Increase in pressure	285.64	+/- 0.65 %	1.163	+/- 0.65	%<2
Average	284.69	+/- 0.65 %	1.165	+/- 0.65	%

Table 1. Air transfer, indoor/outdoor air pressure difference of 50 Pa A first-floor room, Building 1.



Figure 3. Volumetric airflow through the envelope as a function of the pressure difference between the tested indoor space and the outer wall. A first-floor room, Building 1.

Experimental data revealed that:

1. Building 1, the average air permeability of the envelope with sealed ductwork sufficed to reach an ACH of n50 = 0.69-2.85 h¹. The air permeability of structures and the ACH value were found standard-compliant on Floors 1, 3, 4, 5, 6, 7; the equipment malfunctioned on Floors 2 and 8; ACH was outside the standard limits on Floor 9.

2. Building 2, the average air permeability of the envelope with sealed ductwork sufficed to reach an ACH of $n50 = 0.675-11.76 \text{ h}^1$. The air permeability of structures and the ACH value were found standard-compliant on Floors 2, 5, 6, 7, 8, 9; the equipment malfunctioned on Floors 1,3,4,10,12,13, and 14; ACH was outside the standard limits on Floor 11.

3. Building 3, the average air permeability of the envelope with sealed ductwork sufficed to reach an ACH of n50 = 0.85-6.15 h¹. The air permeability of structures and the ACH value were found standard-compliant on Floors 3,8,7; the equipment malfunctioned on Floors 4, 6, 9, 12, 15; ACH was outside the standard limits on Floors 5, 10, 11, 13, 14, and 16.

4. The air permeability of the envelope with sealed ductwork sufficed to reach an ACH of $n50 = 11.76-67.15 \text{ h}^1$ at an indoor/outdoor air pressure difference of 50 Pa.

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5. The air permeability of the structures and the air changes per hour in the tested rooms were mostly outside the acceptable standard limits; besides, the measurements were not totally accurate due to the windows and the outer walling being non-airtight.

6. The effective resistance coefficient of the experimentally tested structures would decrease gradually the higher we went.

7. In some rooms, outdoor air infiltrating through the window openings and the outer envelope as well as due to opening the elevator shaft doors would cause the equipment to malfunction.

4. Conclusions

Thickening the thermal insulation of buildings beyond standard-mandated values will increase the capital costs of the building; heating the indoor air to keep the temperatures comfortable will carry additional loss of heat to heating. Air is filtered through the envelope due to the difference in air pressure between the opposite surfaces of the structure. This air pressure difference may arise from the natural draft head due to p Its value depends on the temperature difference as well as on the altitude / height of the building.

Lower in the building, heavier cold outdoor air can infiltrate into the indoor space through any opening in the envelope or wherever it is not tight enough; higher in the building or even within the room, warmer air is exfiltrated. These two phenomena induce natural air change, which is especially noticeable when it is very cold outside, as the air temperature difference between the outdoors and the heated indoor space will be significant. This is why lower floors are more susceptible to cooling down in winter as the wind pressure and the temperature difference induce the most profound infiltration. As the indoor/outdoor air temperature difference increases, and one moves higher up in the building, the pressure difference due to natural draft head is increasing as well.

Therefore, to reduce the heat loss and to improve the airtightness of the envelope, one must:

1. Seal the outer entrance doors and install door closers.

2. Make the envelope thermally homogeneous by sealing the seams between panels and eliminating the cold passage-throughs, including the wall-window joints.

3. Improve the thermal insulation of windows and balcony doors to meet the existing requirements.

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IOP Conf. Series: Materials Science and Engineering	1079 (2021) 032082	doi:10.1088/1757-899X/1079/3/032082
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