Autonomous Air Shutoff Valves and How They Work in Northern Climate

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Abstract. For the Republic of Sakha (Yakutia), effective and reliable ventilation of buildings is imperative for human comfort and for appropriate air change. Demand for wall vents is rising in mass housing construction. However, practical experience has shown that neither domestically made nor imported vents are suitable for the Republic’s cold climate. At the same time, improving the airtightness of building envelopes remains indeed a relevant undertaking in the context of providing a comfortable indoor microclimate.

1. Introduction
Yakutia’s coldest month is January, and the hottest month is July. Gentle breezes and calms are typical of the cold season [1]. Temperatures can drop below -60°C nearly anywhere in the Republic during the coldest days. Record minima were observed in Oymyakon at -71°C and Verkhoyansk at -68°C. When it is warm, daily average temperatures are quickly rising in spring and falling as quickly in fall. The coldest five days have temperatures (reliability equals 0.92 for estimated outdoor temperatures in Yakutia’s settlements) ranging in \( t = -42...-60°C \), c.f. -24...-41°C elsewhere in the Russian North, a difference of 10...15°C. Maximum average wind speed by rhumb lines falls within \( v_a = 1.4...8.7 \text{ m/s} \) in January. Yakutia’s climate has an outstandingly broad annual temperature range of 50...127°C; thus, the Republic’s extremely continental climate pertains to low estimated temperatures, slow winds, and excessive temperature ranges [2]. Heat required to heat and ventilate a room depends on the climate in the region. As of today, testing the feasibility of energy-saving measures, in particular with regard to using advanced engineering solutions, is mandatory [3-4].

A standalone ventilation system comprises specialized equipment intended to provide optimal microclimate for work or rest depending on the intended use of the room. Such systems can be fully automated by utilizing a set of environmental sensors; or manually controlled by a person. A state-of-the-art standalone ventilation system provides air change by feeding fresh air and removing contaminated air.

It is needed in two cases:

1. If for technical or other reasons, only one ventilation systems must be installed.
2. If the existing ventilation systems does not comply with sanitary, technical, environmental, or other standards.

Housing is the most important type of buildings, as people spend up to 70% of their time at home. Indoor air is also prone to contamination from human activity, chemicals released from the construction materials, radon released from the ground under the building, etc., making it 4-5 times...
more polluted than the ambient air outdoors. Despite the continuous advancement of engineering, residential high-rises still rely on natural ventilation. The reason is the desire to minimize the construction and operating costs. In such systems, air is set into motion by the difference in density: outdoor air is heavier than the warm air inside. Such air change systems are inherently flawed: circulation is weak and prone to reversal, smells travel from apartment to apartment. As a result, mold and fungi flourish, toxins from plastics and furniture accumulate, and the air becomes too humid [5].

This is why it is relevant to research the patterns of air change in mass-constructed residential housing as affected by apartment layouts and climate parameters.

2. Methods

Natural air change is only possible where there is natural draft head and wind pressure [6, 7, 8]. Natural draft head is induced when the outdoor air and the indoor air differ in density. At any distance \( x \) off the neutral zone, the air pressure difference induced by natural draft head can be found by the formula (1):

\[
\Delta P_t = x g (\rho_n - \rho_i)
\]

where \( \rho_n \) is the outdoor air density (kg/m\(^3\));
\( \rho_i \) is the indoor air density (kg/m\(^3\)); it depends on what the room is used for and can be found from the reference documentation;
\( x \) is the distance from the neutral zone (m).

Natural air change is also induced by wind. Dynamic wind pressure can be found by the formula (2):

\[
\Delta P_v = \frac{\rho_n v^2}{2}
\]

where \( \rho_n \) is the outdoor air density;
\( v \) is the wind speed (m/s).

Wind pressure can alter air change significantly, as it affects the airflow and the trajectories of air flows [9]. Calculations show that the wind pressure induced at most probable wind speeds and the natural draft head are on the same order [10]. It should also be borne in mind that wind pressure is a vector quantity whose value will depend on many factors: wind speed, wind direction, building orientation, apartment layouts, etc. Analysis of reference standards that calculate similar heat and air exchange processes in buildings proves the need to take into account the effects of outdoor air temperature and wind speeds in building design. Reference books [11, 12] also confirm that outdoor air temperature tends to fluctuate substantially over 24 hours and over a year. For instance, temperature in Yakutsk may vary from 7.4 to 17.2 degrees Celsius depending on the month. Monthly average temperatures vary from \(-39.6\)ºC in January to \(+19.1\)ºC in July. Climate statistics can help derive natural draft head values for each month. Analysis of the outside air temperature and available natural draft head as a function of this temperature shows that such head needs to be calculated on a monthly basis using the monthly average outdoor air temperatures. Since natural draft head depends on how high a building is and which floor is under analysis, this paper presents the estimates of natural draft head for the 1st, 5th, and 9th floors in a 9-storey building; the values are to be used in further calculations. \( p_i \) is the indoor air density at the reference temperature of 20 ºC; \( g(\rho_o - \rho_i) \) is the excess pressure (Pa) at 1 m of the column height \( H \).

Figure 1 shows the annual fluctuations in natural draft head calculated by this method vs. reference values at \(+5\)ºC.
Figure 1 shows that natural draft head differs by a factor of >10 from the first floor to the ninth floor, while the difference between July and January is nearly 40-fold. This once again proves that a single reference natural draft head calculated at $t_0 = +5^\circ$C for the whole year is far from the actual air change patterns.

Today’s construction industry offers a multitude of solutions that vary from using additional air admittance devices mounted in the envelope to structural changes in the envelopes themselves, intended to enable controllable inflow. These include envelope-mounted or window-mounted devices; some feature heat recovery, others do not; some can heat the inflowing air, others cannot; some are automated, others are fully manual; some can adjust air inflow, others cannot; finally, noise reduction may vary as well. These units are intended to boost air inflow. Airflow capacity is the decisive factor when selecting a vent for natural air draft in an apartment. However, it alone cannot be a sole factor if sanitary and hygienic requirements are to be complied with. SP 60.13330.2012 states that each person in residential space needs ~30 m$^3$ of fresh air an hour; thus, for the total indoor space of an apartment, air change rate must be at least 0.35/h. To ensure sufficient, standard-specified air change in rooms only equipped with natural draft ventilation, the envelope must contain controllable inflow devices. The need to make a hole in the wall to mount a wall vent is apparently a drawback. Besides, shall such a vent be mounted inadequately, the wall will freeze in winter, or some portion of the air duct will be frosted. It should also be borne in mind that fanless models usually only provide 30 m$^3$ of air per hour, which the currently applicable standards say [13] only suffices for a single person.

Natural ventilation analysis considers the available draft head, ductwork resistance, and volume of air to be removed. Natural ventilation estimation methods do not make adjustments for apartment layout, use no data of the trajectories and velocities of air flows, do not take into account how air stagnation pockets are distributed in the apartment, and ignore the statistics of air change over the year as attributed to change in climate. Thus, natural ventilation is in fact unable to create an indoor air environment of sufficient sanitary and hygienic quality.

3. Results
Studies in kind were carried out from October 15 to December 25, 2019 in Yakutsk, where the reason team picked three buildings for analysis. Vents of different design were mounted in each building: Air-Box, Winzel Comfo RB1-50, and KIV-125. During the observations, the research team measured
the temperature and humidity of air indoors and outdoors. The velocity of air passing through the vents was measured with Testo-405-V1 and Testo-423 units in the outlet section of the converging nozzle. When air vents are used during the heating season, surfaces near them may cool down. To find out how temperature changed in the vicinity of these vents, the team used a FLIR C3 thermographic camera, see Figure 2 for some of the images. For tests, the researchers picked a first-floor room with a floor space of 12m². A Winzel Comfo RB1-50 heat recovery unit was mounted in the envelope.

![Infrared image of the exhaust vent: first velocity (a), second velocity (b), and third velocity (c).](image)

Then the team plotted inflow and outflow air temperatures as a function of the outdoor air temperature. The curves are shown in Figure 3.

![Inflow air temperature as a function of the outdoor air temperature.](image)

Further tests found out that the mean airflow was 51 m³/h for the KIV vent at a pressure difference of 30 Pa with the outer blade open. Closing the outer blade would reduce the airflow by an average of 16%. Mean airflow was 7.4 m³/h for the Air-Box vent at a pressure difference of 10 Pa with the outer blade open. Closing the outer blade would reduce the airflow by an average of 13%. Mean airflow was 32 m³/h for the Winzel Comfo RB1-50 unit with a pressure difference of 30 Pa at the maximum velocity. Switching to the 1st velocity reduced the airflow by an average of 16%. Table 1 summarizes the test results.
Table 1. Vent test results.

| Vent model     | Δp, Pa | Q, m³/h | Q_{certificate}, m³/hour |
|----------------|--------|---------|--------------------------|
| Air-Box        | 10     | 7.4     | 31                       |
| Winzel Comfo RB1-50 | 30  | 36      | 51                       |
| KIV-125        | 30     | 51      | 65                       |

4. Conclusions
1. Visual inspection of the Air-Box unit at -23.1°C outdoors revealed the vent was fully closed for inflow due to a strong draft. At -32.7°C and lower, the surface of the KIV-125 unit would partially freeze. The Winzel Comfo heat recovery unit had condensation on the lid bottom at -39.0°C, causing the device to malfunction.
2. The finding is that novel guidelines need to be made on which apartment design solutions must be in place to improve air change in residential housing.
3. Wall vent performance does depend on the outdoor air temperature and on the wind pressure as well as on the vent design. Such vents can provide sufficient air change for the indoor space thanks to their design and improve natural ventilation while keeping the envelope airtight.
4. Thermal insulation and architecture of buildings do affect the performance of such vents, too [14, 15]. Using envelopes and engineering systems to reduce the actual loss of heat is an important approach for the Far North.
5. Experiments show that infiltration vents for naturally induced ventilation systems are usable in Yakutia’s climate. These systems can partially handle air change and comfort of residence where the engineering infrastructure is underdeveloped, in particular where mechanical ventilation and heat recovery systems are absent.

5. References
[1] Quality of indoor air 2007 AVOK 6 pp 28-30
[2] Catlyar O K 1962 Natural microclimatic observations in the people's housing of Khiva Research on the microclimate of populated areas and buildings and on building physics Collection number 2 pp 110-123
[3] Gagarin V G, Kozlov V V 2011 Requirements for thermal protection and energy efficiency in the draft of the updated SNiP "Thermal protection of buildings" Construction materials 8 pp 2–6
[4] Gagarin V G 2010 Macroeconomic aspects of substantiation of energy-saving measures when increasing the thermal protection of building envelopes Stroitelnye materialy 3 pp 8–16
[5] Zhilina T S 2017 Efficiency of natural ventilation systems in residential buildings Fundamental research 7 pp 25-29
[6] Ananiev V A 2000 Ventilation and air conditioning systems Theory and practice: textbook 2nd edition (Moscow: Euroclimate) 416 p
[7] Bogoslovsky V N 2006 Building thermal physics (SPb : Publishing house "AVOK North-West") 400 p
[8] Korchago I G 1998 Ensuring environmental safety in housing construction Housing construction 12 pp 21-23
[9] Kinash O V 2007 Air exchange in the premises of residential buildings and its influence on the microclimate: author. dis. ... Cand. tech. Sciences: 05.23.03 (Makeevka) 21 p
[10] Kupriyanov V N 2007 Construction climatology and physics of the environment: textbook (Kazan: KG ASU) 114 p
[11] Gubernskiy Yu D 1978 Hygienic principles of microclimate conditioning of residential and public buildings (M.: Medicine) 192 p
[12] Conclusion based on the results of a survey of vertical ventilation systems in apartments 141, 145 in a residential building on the street. Dekabristov, 85 (Kazan: Central Analytical Laboratory for Energy Saving in the TsALESK building complex) 10 p
[13] Grudzinsky M M 1982 Heating and ventilation systems of high-rise buildings (M.: Stroyizdat) 256 p
[14] Feist V 2011 Basic provisions for the design of passive houses. 2nd edition (Moscow: ASV Publishing House) pp 162-163
[15] Sapozhnik K R, Bashkov O V, Borisenko M D, Solovev D B 2020 Modelling of Ultrasonic Concentrators for Processing of Volume Nanostructured Materials *Materials Science Forum* 992 940-946. [Online]. Available: https://doi.org/10.4028/www.scientific.net/MSF.992.940