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Case studies of energy consumption in residential buildings in Russia's middle belt area

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Abstract

This paper describes the analytical results of heating energy consumption monitoring and the determination of heat protection levels for both single-family and multi-family buildings in Russia. Experiments have been jointly conducted by Russian and American researchers from the Research Institute for Building Physics, Gosstroy of Russia, and the Natural Resources Defense Council. The paper describes qualimetric methods which provide a quantitative estimation of thermal and energy performance by using instrumental facilities and non-destructive methods.

The first Section gives a brief methodological summary for determining on-site building energy and thermal performance. The second part reviews the field results of energy monitoring to determine techniques that may result in the highest energy conservation effect for standard single-family houses in Russia. The third Section presents a comparative energy analysis of the use of highly insulating windows in a multi-family apartment building in field conditions. The experiments conducted prove that it is possible to ensure a 20–25% reduction in energy consumption for residential buildings under actual conditions existing in Russia. Finally, a methodology for assessing whole-building energy consumption for multi-family buildings is described.

Introduction

It should be emphasized that tests of existing buildings in Russia primarily aim at determining the computed thermal properties of the envelope in order to establish whether they meet the design and code-stipulated values. Unlike those studies, the investigations made in this paper aim at finding out a building's actual energy-relevant properties and developing a methodology and techniques for carrying out field studies to determine both a building's thermal properties and its energy consumption.

To understand achievable energy savings potential, buildings must be tested under field conditions to compare actual performance with predicted performance. Field performance of buildings is ascertained using quantitative measurements of building envelope performance and various qualitative assessments of indoor environmental conditions.

The Research Institute for Buildings Physics (NIISF) of Gosstroy of Russia and the US-based Natural Resources Defense Council (NRDC) established collaboration on energy efficiency in building in 1988. To date, several joint projects have been carried out.

As Russia moves toward a market economy, it will become increasingly important to understand the energy use characteristics of buildings because of fuel supply conditions and price fluctuations. It is known that the rural wooden panel houses of Russia consume twice the heating energy of multistory buildings in urban areas. For example, single-family houses in the middle zone of Russia consume about 600–800 kWh/(m^2 yr) of primary energy, whereas in Germany average single-family houses consume 250 kWh/(m^2 yr) [1]. In Sweden, the figure is 135 kWh/(m^2 yr). It is also known that highly efficient single-family houses in Germany consume from 90 to 120 kWh/(m^2 yr) and experimental German houses 50–70 kWh/(m^2 yr).

The main goal of the NIISF/NRDC experiments was to develop and test a methodology for determining insulation levels and other energy-relevant properties of existing and newly built single-family

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houses, in order to assess their energy consumption. Tests of a new highly insulating window technology in a real apartment building were also conducted. In 1988 we conducted the first such experiments to study energy consumption and thermal state performance of a single-family house near Moscow as a result of cooperation between NIISF and the Center for Energy and Environmental Studies in Princeton [2].

Methods of determining the energy performance of buildings

Two main parameters of the building shell [3] have been chosen to determine energy consumption: overall heat transfer coefficient of the entire building envelope, k_m^{ef}, measured in W/(m^2 °C) and air permeability of the building G_m, measured in kg/(m^2 h), at 10 Pa (in compliance with national codes and standards). The overall envelope heat transfer coefficient k_m^{ef} is derived and the specific annual space heating consumption of the building is based on the following equation:

$$k_m^{ef} = \frac{(Q_2 - Q_1) \times 10^3}{(t_2 - t_1) \times \Delta T} \times A_{ext} \tag{1}$$

where Q_1, Q_2 = the space heating energy consumption (kWh) and t_2, t_1 are the corresponding internal and outdoor air temperatures (°C) for interval ΔT; ΔT = the time interval for measuring (h); A = the enclosing area of the building shell (walls, windows, ceiling, floor in m^2).

The effective overall heat transfer coefficient k_m^{ef} incorporates transmission losses k_t and infiltration losses k_{inf}, which can be analyzed separately using either measured or calculated infiltration rates. Expected overall heat transfer is calculated based on design standards [4] for comparison to measured results. The overall heat transfer coefficient is calculated in this case by equation:

$$k_t^r = \sum_{i=1}^{n} A_i \Big/ \frac{R_{0i}^{exp}}{A_{ext}} \tag{2}$$

where A_i and R_{0i}^{exp} are the area and the experimental value of areal thermal resistance of the i-envelope of the interior building shell.

The difference between design and experimental values of k_t^r shows the amount of difference between the as-constructed building compared to the design one.

Using experimental data, it is determined that the normalized annual building space-heating consumption per unit of floor area is:

$$q = \frac{(Q_2 - Q_1)\Delta q}{(t_2 - t_1) \times \Delta t/24} \times (t_{int} - t_{ht}) \times Z_{ht}/A_f \tag{3}$$

where t_{int} = the design indoor air temperature (20 °C), t_{ht}, Z_{ht} = the average temperature (°C) and duration of the heating period (d/year) respectively, A_f = the total floor area (m^2) of the house, and t_{ht} = the meteorological average outdoor temperature.

Energy consumption monitoring of single-family houses

This joint project with NRDC is intended to determine the energy-relevant properties of single-family homes. Once these characteristics are determined, it is possible to evaluate the most cost-effective energy conservation measures for typical single-family homes in Russia. A standard two-story, unoccupied single-family wooden panelized house, with three rooms on the first floor and two rooms on the second floor, was chosen (Fig. 1). This fabricated test house was assembled on-site in Kirov where the average winter temperature is $t = -5.8$ °C, duration of the heating season is $z = 231$ days, average wind velocity is $v = 5.2$ m/s, and the design temperature is $t = -34.5$ °C.

The floor area of the house is 112.8 m^2, the volume is 313 m^3, inside air temperature is 20 °C. The wall structure is 160 mm thick, and consists of three-tier panels and wooden framework. The panel consists of softwood chipboard both inside and out and an insulating core of mineral wool. The joints between the panels are sealed with frost-resistance sealants and covered with strips of wood. Windows are double-glazed with a coupled-type double sash. The floor structure consists of decking on joists. Gaps between joists are filled with mineral

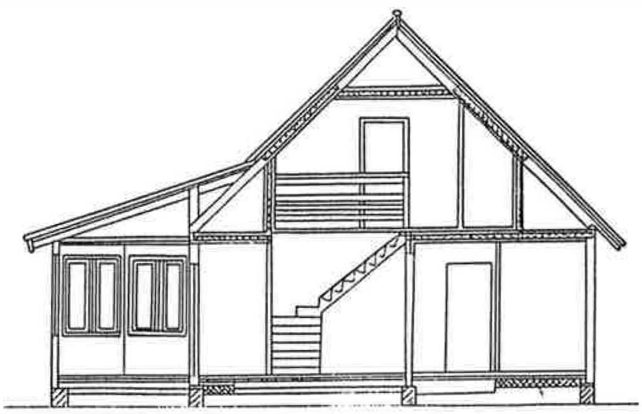

Fig. 1. Section of the house examined.

wool, 120 mm thick. The roof uses the same insulating materials as the floor.

Total surface area of the building is $A = 306$ m^2 consisting of a 79.3 m^2 footprint, 130.4 m^2 wall area, 14.8 m^2 window area, and a roof area of 81.4 m^2. The areal thermal resistances of the floor, walls, windows and roof are 1.2, 2.04, 0.39 and 2.04 (m^2 °C)/W, respectively.

Building infiltration tests were performed on this house and five analogous houses using similar methodologies [5, 6]. The first method tests the building as a whole. The second test was used in order to determine airtightness of the windows by isolating one or two windows using plastic sheeting. The results of the metered data analysis are given in Fig. 2 compared with data from other countries [7]. It should be noted that results are presented in a form relative to infiltration areas. The plot of Russian data in Fig. 2 shows the distribution of the areas received from data measured in many single-family houses from 1988–92.

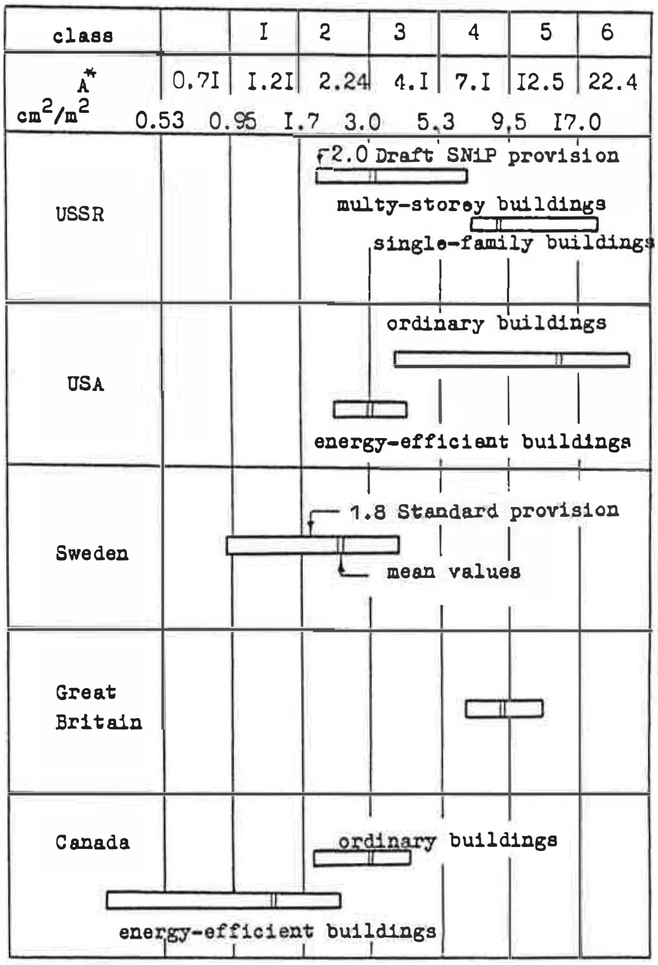

Fig. 2. Comparison of air permeability in buildings of different countries.

Measured results from these experiments show that overall airtightness of the test house ranged from 8.1 to 9.6 kg/(m^2 h). The mean airtightness of the opaque envelope was 3.4 kg/(m^2 h). The mean airtightness of the windows was 100 kg/(m^2 h), ten times less than the rated value of 10 kg/(m^2 h). After calculations [8] and using mean values of outdoor air $t = -3.36$ °C and air velocity $v = 1.75$ m/s during the experiment, a mean air change rate of 1.06 h^{-1} was calculated for the house.

To measure energy consumption, the house was equipped with nine electric radiators of 1 kW capacity each. Radiators were connected to a single thermostat set at 20 °C $\pm$ 1 °C. Total energy consumption was measured by an electric meter. Measurements of outside and inside air temperatures and heat flows through the envelope were taken every three hours.

Figure 3 presents the curves of outdoor air temperature and heating energy consumption of the house. The outdoor air temperature changed from -7 °C to $+0.2$ °C. It can be seen how the heating system responded to changes in temperature.

Figure 4 presents data of energy consumption (Q) at 3-h intervals as a function of the difference of mean 3-h outdoor and indoor air temperature Dt. A direct regression of these values was computed by:

$$Q = 1.04 \times t - 13.92 \tag{4}$$

The value of the correlation coefficient in eqn. (4) was found to be $R^2 = 0.48$. Using this relationship and eqns. (1) and (3), one can estimate the main energy and thermal parameters of the test building. The normalized annual heating energy consumption q is calculated by eqn. (3) and the experimental data to be $q = 443$ kWh/(m^2 yr). It should be noted

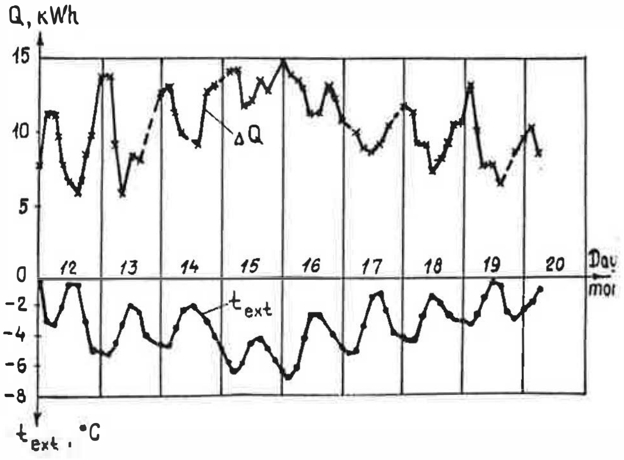

Fig. 3. Plots of variation of outdoor temperatures and energy consumption for a nine-day period (March 12–20, 1992).

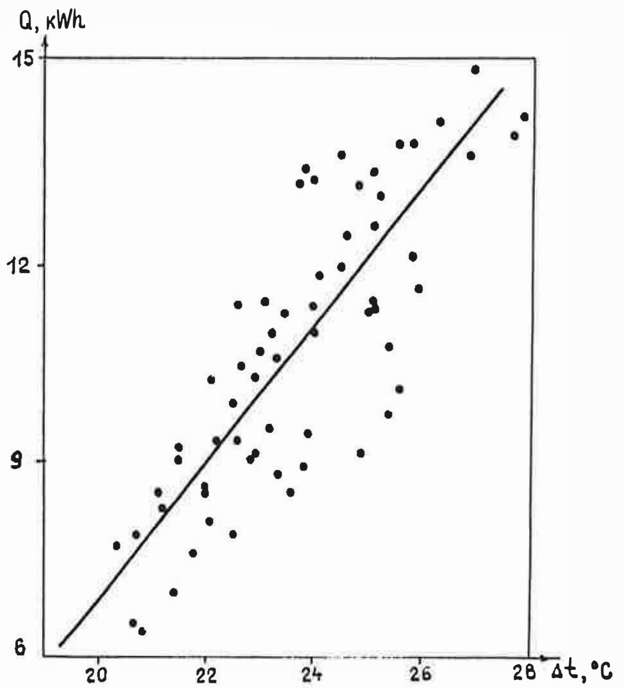

Fig. 4. Three-hour energy consumption versus the difference of mean three-hour temperatures of outdoor and indoor air and their linear correlation.

that the specific energy consumption is calculated for an electric space-heating system. For a fuel-fired space-heating system, this value could be estimated by using the system coefficient of performance, COP. For example, heating season energy consumption of a boiler using natural gas (at a representative COP ≈ 0.6) is approximately 748 kWh/(m^2 yr); using an oil or coal boiler (COP ≈ 0.55) it is 806 kWh/(m^2 yr); finally, a coal stove (COP = 0.45) gives a value of 996 kWh/(m^2 yr).

Using the experimental data and eqn. (5), peak power use of a heating system under design outdoor temperature $t_{ext} = -34.5$ °C, and temperature difference, $\Delta t = t_{int} - t_{ext} = 20 - (-34.5)$ °C, is:

$$P = \frac{\Delta Q}{3} = \frac{1.04 \times 54.5 - 13.92}{3} = 14.3 \text{ kW} \quad (5)$$

This power is calculated for an electric heating system. For a gas boiler the power is $P \approx 24$ kW, for the oil and coal boiler the power is $P \approx 26$ kW, for the stove the power is $P \approx 32$ kW.

The overall heat transfer coefficient k_t^r of the entire building is calculated as, $k_t^r = 0.68$ W/(m^2 °C) using eqn. (2). Using the regression line represented by eqn. (4), the effective overall heat transfer coefficient from the experiment, $k_m^{ef} = 1.133$ W/(m^2 °C). As this coefficient encompasses both the transmission and the infiltration losses, the overall (transmission) heat transfer coefficient k_t^r is calculated as $k_t^r = 0.736$ W/(m^2 °C) from eqn. (6).

$$k_t^r = k_m^{et} - (c\gamma IV)/(3600 A_{ext}) \quad (6)$$

where $c\gamma$ = specific heat capacity and the average density of outdoor air during the experiment (kg/m^3), I = the average air exchange rate ($\hat{h}^{-1}$), and V = the volume of the house (m^3).

This measured value of overall heat transfer coefficient characterized well the real thermal insulation of the test house. It should be noted that the Kirov region has a somewhat higher average wind velocity ($v_{nt} = 5.2$ m/s) during the heating season. Thus, the average air change rate greatly affects the normalized effective heat transfer coefficient k_m^{et} in comparison with the expected value. The normalized air change rate and k_m^n were calculated as 1.63 $\hat{h}^{-1}$ and 1.635 W/(m^2 °C). They should be compared with the test values of 1.06 $\hat{h}^{-1}$ and 1.133 W/(m^2 °C). As regards the maximum value of k_m, this value is estimated under design temperature $t = -36$ °C and by 1.2 times more than the average value of the heating period.

Figure 5 shows results of parametric studies [9] on energy consumption for variants of the house with different levels of insulation and airtightness. Parametric evaluation allows easy comparison of separate heat losses through the walls, windows, ceiling, ground floor and by air infiltration. The influence of separate parts of the shell on energy consumption can also be evaluated this way. Comparing the results of these solutions with the results obtained by the PEAR program, which predicts energy consumption modeled by Lawrence Berkeley Laboratory runs of the DOE2 program, for towns in the states of Minnesota and Alaska, which have similar climatic conditions as the region used in Russia, one can see good agreement. The parametric runs show that the largest effect on the energy performance of the building can be achieved by reducing air infiltration of the windows to the rated value (10 kg/m^2 h), and by increasing the thermal insulation levels of the wall and ceiling. Reducing air permeability to the rated value reduced energy use by 30% (see Variant I). Doubling the thermal resistance of the floor reduced heating consumption about 25% (see Variant III). Variant IV, which is the most realistic option in practical terms, reduces infiltration and increases shell insulation, and provides rather low energy consumption results for this configuration. Variant VI is more expensive but produces optimum results.

Implementation of the following actions (from Variant IV) provides a good level of airtightness: using frost-resistant weather stripping between the sash and frame of the window, and sealant between

case No.	overall heat transfer coef., W/(m².°C)	air change of the house, 1/h	Specific annual space heating consumption, KWh/(m². year)			Distribution of heat losses for the separate envelops MJ/year				
			electricity	gas	coal or oil	ext. walls	windows	ceiling	floor	infiltration
0	0.736	1.63	448	748	806	35202	20907	22036	46000	96905
I	0.736	0.85	334	585	630	35202	20907	22036	46000	50533
II	0.736	0.69	310	552	594	35202	20907	22036	46000	41021
III	0.7	0.69	295	530	571	35029	14746	21927	45774	41021
IV	0.6	0.69	253	470	506	35546	21111	22251	13197	41021
V	0.564	0.69	238	449	483	34946	14711	21875	22805	41021
VI	0.52	0.65	220	422	455	34882	14685	14521	22764	41021

Fig. 5. Parameter study on energy consumption of single-family houses.

sash and glass. Airtightness can also be improved by caulking around the windows, between the frame and panel siding, caulking the joints between wall panels, between the panels and ceiling, between the panels and first floor and also by providing 15-cm-thick batt insulation on the first floor. Now Variant IV is used in the manufacturing processes in factories producing new single-family building components.

This combination of insulation and infiltration measures should reduce specific heating energy consumption by 37% from 448 to 253 kWh/(m^2 yr) using electric heating. Comparable figures calculated for other fuels are reductions from 748 to 470 kWh/(m^2 yr) using gas heating, from 806 to 506 kWh/(m^2 yr) using coal or residual oil. Insulating the floor area also has important infiltration considerations, because the various foundation designs under construction in different climate zones do not always provide good infiltration protection of the crawl space. This study, along with the implementation of Variant IV, shows that there exist ways with relatively low capital investments which may result in large energy-saving effects on single-family buildings in Russia.

Energy consumption for high-rise apartment buildings

These joint projects with NRDC consist of experiments to evaluate energy consumption in high rise apartment houses placed in real maintenance and climate conditions in Russia*. For this purpose, two field monitoring projects of building energy performance were developed.

Field test of "superwindow" performance

The first monitoring project analyzed the effectiveness of US superwindows** installed in a single flat in a six-story Moscow apartment building under rehabilitation. The walls of this buildings are 70 cm thick and consist of masonry bricks with plaster facing. Double-glazed windows are made of separate wooden casements joined by nails and/or glue. Two identical flats situated one under another on the 3rd and 4th floors (Fig. 6) were chosen in one section of the building. The flat on the third floor equipped with ordinary double-paned windows was used as a reference flat. The test flat on the fourth floor used superwindows with a low-conductance wooden frame manufactured by Southwall Technologies Inc. These superwindows have net energy

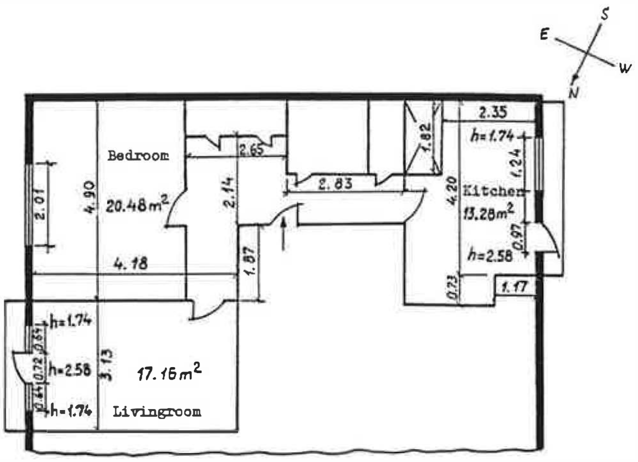

Fig. 6. Floor plan of the flat.

*Average winter temperature in Moscow is $t = -3.6$ °C; duration of heating season is $z = 213$ days and average wind velocity is $v = 3.8$ m/s; the design temperature is $t = -26$ °C; heating degree-days (reference temperature: 18 °C) = 4731 dd.

**The superwindow consists of two sheets of polyester film with low-ϵ coating suspended between the inner and outer panes, effectively creating three air gaps in the window.

impacts when solar gain is factored in comparable to conventional wall sections [10].

Laboratory tests of one of the window units in the NIISF climatic chamber confirmed its high thermal properties. In the center of the window unit, the thermal resistance was 1.27 (m^2 °C)/W, and the resistance of the wooden frame was 0.77 (m^2 °C)/W. Total thermal resistance of the window unit (including the frame) was 1.17 (m^2 °C)/W. Average heat flows and calculated thermal resistances at different points of the window unit are given in Fig. 7. In comparison with an ordinary Russian double-paned window, the superwindow has an R-value 2.2 times as large.

Temperature and heat flow sensors were placed at different locations on the envelopes of both flats. Because the hydronic heating system in this section of the house was cut off during the experiment, the two flats were heated by electric oil-filled radiators. Heating energy consumption was measured by electric meter.

To prevent vertical heat flows into identical flats of second and fifth floors the indoor air temperature of these flats was controlled at the same level as in the experimental flats, also using electric radiators. The hydronic heating system in the adjacent flats was operating, but without thermostatic control, so

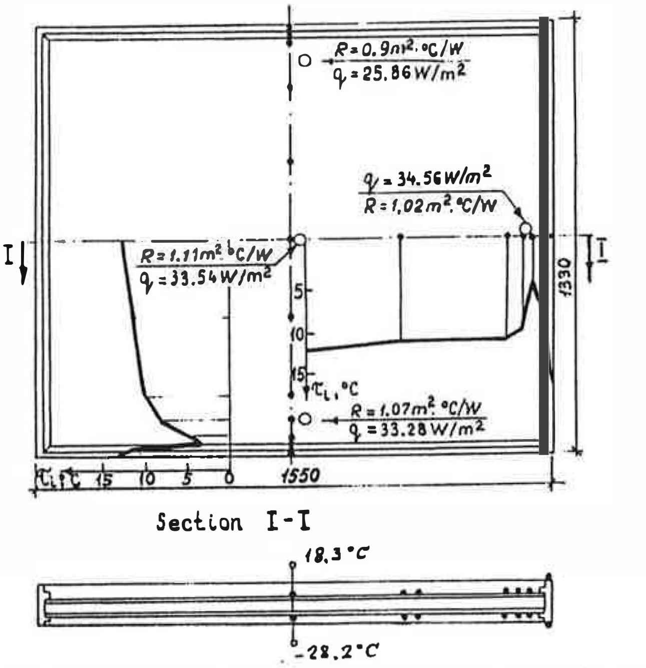

Fig. 7. Temperatures (curves) (°C), heat flows q (W/m^2) and calculated thermal resistances R (m^2 °C/W) at different points of the window unit. ● = a thermocouple located on the surface of the casement and panes; ○ is a thermocouple located at a 100 mm distance from the surface one; ◯ is a heat flow meter.

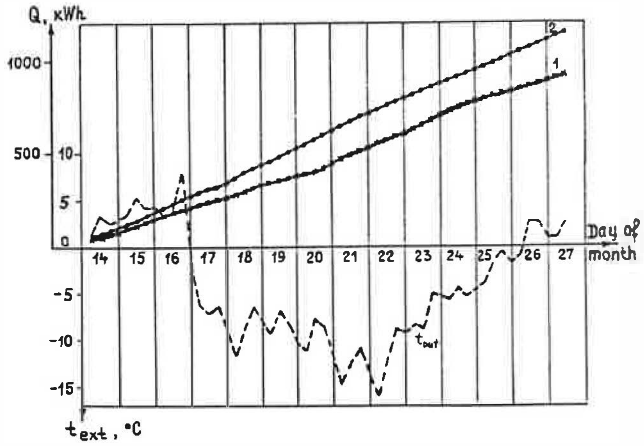

Fig. 8. Variation of outdoor air temperatures and energy consumptions for the flat with superwindows (curve 1) in comparison for the flat with conventional windows (curve 2) for a 14-day period (Feb. 14–27, 1992).

some uncontrolled heat flux occurred between these apartments and the experimental flats.

During tests conducted between February 14 and 27, 1992, the temperatures, heat flows and energy consumption were measured every six hours. Figure 8 presents plots of cumulative energy consumption and outdoor temperature. It can be seen by the diverging lines of energy consumption for each flat that the superwindows achieved more than 200 kWh of savings at the end of the experiment.

The overall heat transfer coefficients of the external walls and windows for both flats were determined from the results of these measurements in accordance with the standard [4]. The following values were obtained:

$k_t^r = 0.94$ W/(m^2 °C) for the superwindow flat

$k_t^r = 1.4$ W/(m^2 °C) for the reference flat.

Linear regression relating energy consumption of the two flats to temperature differences, [$Q = f(\Delta t)$ (Fig. 9)] produces the following equations:

for the reference flat and $R^2 = 0.90$

$$Q = 0.4\ \Delta t + 11.9$$

for the flat with superwindow and $R^2 = 0.90$

$$Q = 0.35\ \Delta t + 8.33$$

However, it was not possible to use these equations for an assessment of the resistance of the external envelope, as the heat flows of the experimental flats resulted from both the external and internal envelopes.

As shown in Fig. 8, cumulative heating energy consumption registered by the electric meter during

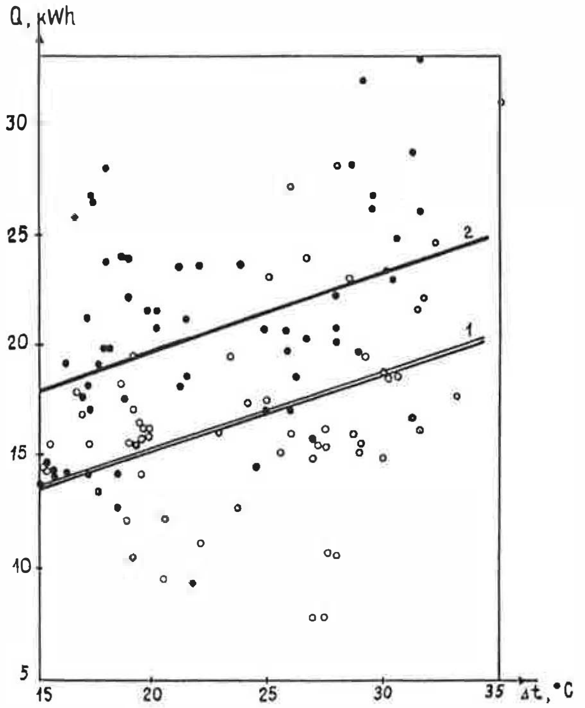

Fig. 9. Results of energy consumption versus the difference of outdoor and indoor air temperatures and their linear correlation for the flat with superwindows (O and curve 1, $Q=0.35\times\Delta t+8.33$) in comparison with the flat with ordinary windows (● and curve 2, $Q=0.4\times\Delta t+11.9$).

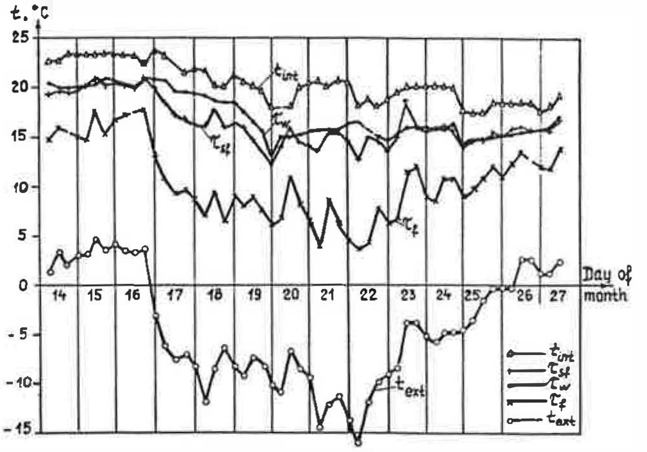

Fig. 10. Plots variation of indoor air temperatures t_{int}, of inner surface temperatures (τ_w) for the walls and the windows (τ_{sf}, τ_f) versus the outdoor air temperatures (t_{ext}) for a 14-day period, Feb. 14–27, 1992.

the test period for the reference flat was 1095 kWh. The superwindow flat consumed 880 kWh over the same period. Transmission heat losses are calculated at 371 and 249 kW, respectively.

Air leakage of the superwindow met the required air permeability of 10 kg/(m^2 h), so the infiltration heat losses through superwindows were determined to be 220 kW. Assuming that heat losses through the internal envelope for both flats were equal, then the infiltration heat losses through conventional windows in the reference flat on the third floor were 313 kW. In this way, the total energy conservation during the test period using superwindows was 215 kWh, broken down into the following components: reduced transmission heat losses −122 kWh; and lower infiltration heat losses −93 kWh. Extrapolating these results to the entire heating season, the annual heating energy saving is estimated at 3246 kWh or 50 kWh per square meter per year.

A comparison of the inner surface temperature for the windows and walls of the test and reference flats is shown in Fig. 10. It can be seen that the superwindow has nearly the same surface temperature as the wall, while the ordinary window always has a surface temperature 4–5 °C lower than that of the wall. Since the radiant temperature of inner surfaces closely affects thermal comfort, the apartment using superwindows will provide superior comfort in comparison to one using ordinary windows.

This study shows that the implementation of highly insulating windows into buildings in Russia may result in a large energy-saving effect in the near future.

Simplified whole-building energy measurement methodology

The second monitoring project studied the energy consumption of a high-rise building as a whole. Measurements were conducted during the heating season from October 1992 to May 1993 on an occupied 17-story apartment building in Moscow. The building has four sections, 15 005 m^2 of floor area and 256 flats. Last year, about 35% of all newly constructed buildings in Moscow were of this type. In 1993, 2.7 million m^2 of new housing were erected in Moscow.

The building was constructed of three-layer prefabricated panels comprised of exterior layers of concrete and a 10-mm-thick foam plastic layer inside. The concrete layers are tied across the plastic foam with metal rods, which results in a reduced thermal resistance of the panel of 1.35 (m^2 °C)/W. This is the design value for the panel; it has been verified experimentally. Double-glazed windows are made of mechanically joined wooden casements. The basement location of supply mains for space heating and domestic hot water increased the air temperature in the cellar so that flows through the floor are reduced. Air outlets for natural ventilation empty into the attic so the air temperature is higher than usual, which also reduces the heat flow through the ceiling.

A single-pipe heating system with upper water distribution is used in this building, and no valves or by-pass are available at the convection-type radiators. The heating system in each section is connected directly to the distribution system through an elevator (a jet pump). All heat supply loops of the buildings have an independent connection through a four-pipe system (separately for the heating systems and the hot water supply) with the central heat distribution substation. Automatic weather compensation controls that vary the temperature of heating supply water are calibrated according to an established heating curve. Hot water is pumped at constant flow from the substation.

As field energy monitoring is a difficult and costly affair, only time-dependent and climatic parameters were collected for the experiment. Temperatures were measured, recorded, and processed using a Solartron Data Logging System. The data logger scans the sensors every 15 minutes and stores the values on magnetic tape. The recorded 15-min data are then averaged over 3-h increments.

The data set includes the outside air temperature measured on the second and ninth floors, the average inside air temperature measured at the outlet ducts of the natural ventilation system, the air temperatures in the cellar and attic, and the water temperature at the supply and return pipes of the heating system. Additionally, the surface temperatures of the envelope and heat flows were measured to determine the areal thermal resistance of the envelope. The overall airtightness of individual flats was measured using the blower door technique. Electricity consumption of the building was collected manually from the electric meters.

The measurement period from October through March was characterized by relatively stable outdoor air temperatures ranging from zero to −10 °C. There were four significant cold periods, when the temperature dropped to −18 °C for 3–4 days. Average indoor air temperature of the premises fluctuated between 20 and 23 °C. The diurnal flow rate in the return main was about 620 m^3 and was independent of the outdoor air temperature.

Figure 11 presents measured data on diurnal supply and return water temperatures as a function of the diurnal outdoor air temperature. As can be seen in Fig. 11, the diurnal water temperatures were unstable in comparison to the direct regressive lines. However, the temperature *differences* of the supply and return water were relatively stable at 15–18 °C, in spite of fluctuations in the supply water temperature ranging from 58 to 77 °C and the return water ranging from 45 to 57 °C. The direct regression lines based on the water temperatures as varying

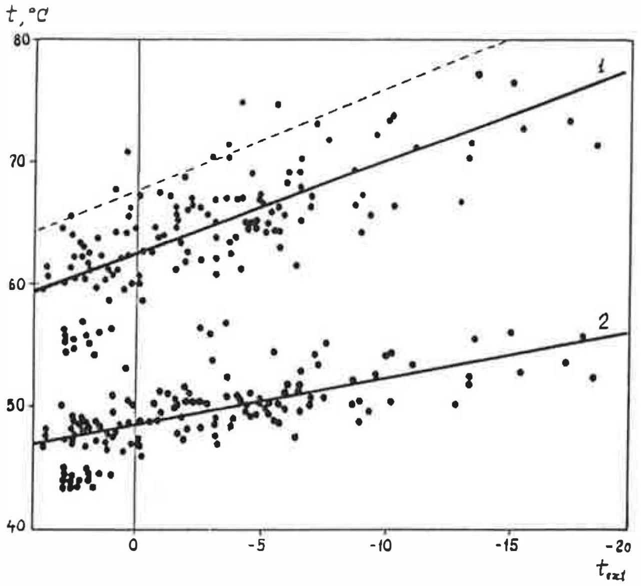

Fig. 11. Variation of supply and return water temperatures (t) as a function of the average diurnal temperatures of outdoor air (t_{ext}) and their linear correlation. The temperatures of the supply water are indicated by the set of points around curve 1 ($t = 62.4 - 0.74 \times t_{ext}$) with $R^2 = 0.80$. The temperatures of the return water are indicated by the set of points around curve 2 ($t = 48.4 - 0.37 \times t_{ext}$) with $R^2 = 0.80$.

with the outdoor temperature are also given in the same Figure. The dashed line shown on Fig. 11 illustrates how the temperature of the supply water exiting the substation varies with outdoor air temperature. Because the test building is the second structure connected in series downstream from the district heating substation, the supply water temperature of the test building is nearly identical to the return water temperature of the first building. Similarly, the test building's return water temperature is nearly identical to the return water temperature at the substation, the discrepancy being losses from the system piping. Given the temperature difference in the supply and return water and the flow rate through the water mains, it is possible to collect total energy use for the two buildings on the loop.

If we compare the measured data of the supply water temperature with the theoretical temperature graph, it can be seen that the deviations are more pronounced: +12 °C at an outdoor air temperature of 4 °C and −9 °C at an air temperature of −15 °C. Figure 12 presents experimental data on energy consumption as a function of the difference of mean diurnal outdoor and indoor air temperatures during the heating season. Using these experimental data, a direct regression of type $Q = 2981 + 307\ \Delta t$ can be plotted, with correlation coefficient $R^2 = 0.65$. Since the design outdoor air temperature in Moscow

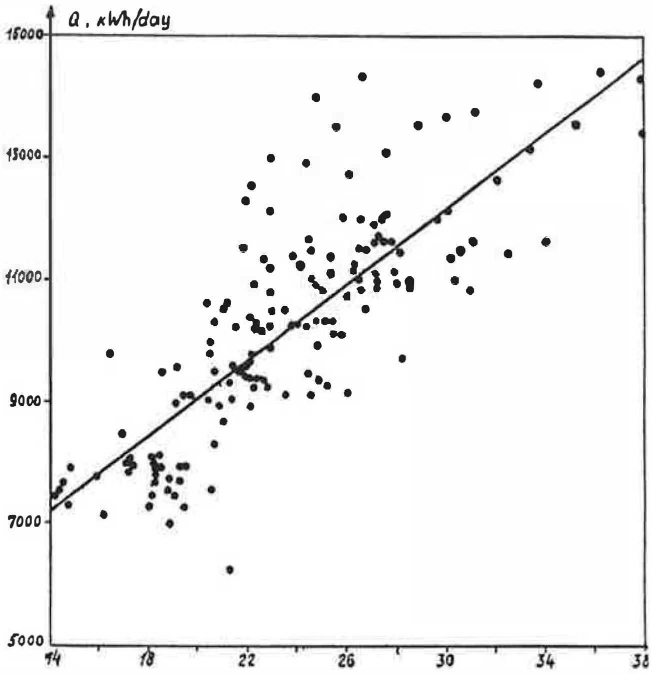

Fig. 12. Diurnal energy consumption ΔQ (kWh) as a function of the difference of average diurnal temperatures Δt (°C) of the indoor and outdoor air and their linear correlation ($Q=2981+307\ \Delta t$).

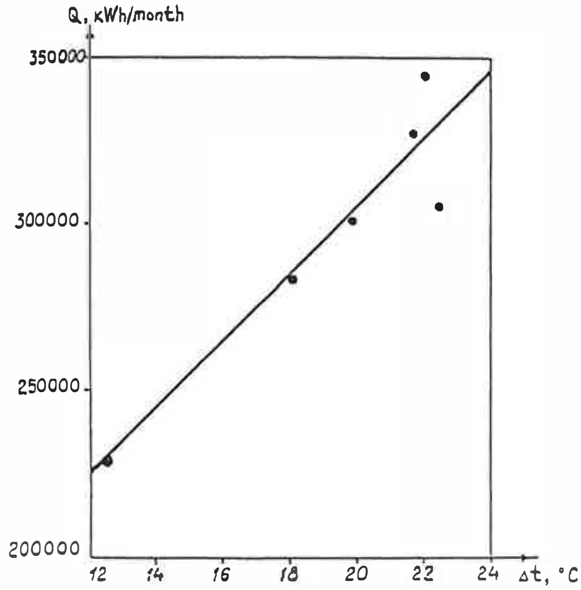

Fig. 13. Monthly energy consumption Q (kWh) as a function of the difference of average monthly temperatures Δt (°C) of the indoor and outdoor air and their linear correlation ($Q=101649+9963\ \Delta t$).

is -29 °C, the maximum theoretical energy consumption at the indoor air temperature of 18 °C is equal to $Q=17\ 410$ kWh/day or the respective power of 725 kW, which is at least 1.6 times less than the design level.

Figure 13 plots the average monthly energy consumption for heating purposes as a function of average monthly outdoor air temperatures and their regression line is

$$Q=101\ 649+9963\times\Delta t \tag{6}$$

with $R^2=0.87$.

Using Moscow design conditions, one calculates a figure of 18 997 kWh/day or 792 kW, 9% higher than the value imputed from Fig. 12. The comparison of the regression lines in Figs. 12 and 13 shows some discrepancy but fairly similar results.

Using the results of blower door testing on individual flats and using average parameters for Moscow heating season*, an air exchange rate of 0.41 h^{-1} can be calculated.

With eqn. (1) and the regression relationship eqn. (6), the measured regression effective overall heat transfer coefficient for the building envelope can be calculated as $k_m{}^{ef}=1.5$ W/(m^2 °C). With calculated transmission losses and the experimental result of measured airtightness, the overall transmission heat transfer coefficient can be calculated as: $k_t{}^r=0.99$ W/(m^2 °C).

As a result of *in situ* testing, the following values for areal thermal resistance of the external envelopes were determined: for the facade walls $R=1.25$ (m^2 °C)/W; for the gable end walls $R=1.65$; for the windows $R=0.39$; for the ceiling under the roof, equivalent** $R=5$; for the floor above the cellar, equivalent $R=3$ (m^2 °C)/W.

We find good agreement between the overall heat transfer coefficient calculated above the value derived from eqn. (2), $k_{lr}=0.98$ W/(m^2 °C).

In conclusion, the proposed methodology is less costly and labor-intensive which allows the collection of energy information from many buildings during one heating season and the easy derivation of all essential energy parameters for the building. This methodology will be especially useful for the city of Moscow as it undertakes data collection efforts for its new "Energy Passport" system.

The Energy Passport, sometimes called an Energy Rating System, will be introduced in the 1994 draft of the Moscow Building Standard for thermal protection and energy and water supply of buildings. The main objectives of the Energy Passport are to show compliance of the building design with the energy code by inspection after the building has

*Where the outdoor air temperature is -3.6 °C, wind speed is 3.8 m/s and heating season duration is 213 d/year.

**Where "equivalent" R-values account for the warm air present under the roof and below the floor.

been erected. The following parameters will be required to show compliance with the Energy Passport:

- The year of construction, the configuration and orientation of the building, the building plan, the floor area, the floor-to-floor height, the volume, the area of the exterior envelope, including all walls, the roof, and all windows and doors exposed to outside air.
- Data for thermal protection of the building, including the thermal resistance and air-permeability resistance of the separate components of the envelope; the overall heat-transfer coefficient and the air-permeability coefficient for the entire building; the specific normalized annual space-heating consumption; and the so-called specific thermal characteristic of the building, which is the heating power at the design temperature difference, normalized by the building volume. These data should be included in the Energy Passport at the time of design and also after the building has stabilized after a year or more of operation, using the proposed *in situ* measurement methodology.

Using the data of the Energy Passport, it will be possible to classify buildings by the level of thermal protection. These classifications will serve as incentives for municipal and federal governments to erect energy-efficient buildings and support energy conservation. Buildings will be categorized by the decrease of the specific normalized annual space-heating consumption in comparison with a standard level, as noted in Table 1.

TABLE 1. Categories of normalized annual space-heating consumption

Categories of thermal protection	Decrease in specific heating consumption (%)
Standard	0
Higher	20
Highest	35

A building's energy rating could be used to set electricity or heat supply rates. For example, the Moscow Department for Energy and Energy Conservation (MDEEC) has developed rules to penalize energy waste. These rules specify a higher energy tariff if a building uses more energy compared with the standard level. Similarly, tariff reductions might be offered in the case of reduced energy consumption. The MDEEC is responsible for performing the energy audits for the Energy Passport, while the Regional Energy Commission will make decisions about building tariffs based on the data in the Energy Passport.

The following qualimetric* methodology is suggested as a means of deriving the data necessary for completing Moscow's Energy Passport form for each building:

- collect data of monthly heating energy consumption during the heating season;
- take from the meteorological station or collect *in situ* data of average monthly outdoor air temperature;
- make measurements of air permeability for some parts of external envelope of some individual premises or building as a whole.

These data would then be used to derive a linear equation for energy consumption as a function of temperature differential outdoor and indoor air. Then, using the additional data of:

- the monthly electric consumption for lighting and other living purposes;
- the number of people who live in the building;
- the intensity of direct and diffuse sun radiation;
- all energy parameters can be calculated.

Conclusion

To summarize, in the light of Russia's transition to a market economy with its attendant rise in electricity and heating costs, it is becoming more important than ever to know the quantity of heating energy consumed to maintain winter comfort. On-site testing methodologies can be used to determine the extent to which existing residential buildings use energy and to allow calculation of how heating consumption can be affected by different conservation measures.

Given the huge savings potential of Russia's existing housing stock, capturing these energy savings should be a top priority of Russian energy policy in the upcoming years. Policies to reduce heating energy use are also likely to result in improving the indoor comfort of these buildings.

Qualimetric evaluation methods are an important tool in evaluating the simultaneous improvement of comfort and reduction of energy consumption in Russian buildings.

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*Qualimetry is defined as a science studying quantitative methods for estimating the quality of a product.

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