# Increasing Thermal Performance and Energy Efficiency of Buildings in Russia: Problems and Solutions

**Yurij A. Matrosov, PhD** **Mark Chao** **Cliff Majersik**

## ABSTRACT

*Over the past decade, a new generation of building energy codes has taken effect in Russia. These codes, which mandate a reduction of at least 40 percent in energy consumption for heating, have led to the need for an increase of 2.5 to 3 times in envelope thermal performance. Consequently, a fundamental transformation has taken place, toward the production, sale, and use of energy-efficient construction materials and products, and changes in building design methods*

*New technologies and design approaches for building envelopes include design of widened buildings with a lower surface-area-to-volume ratio; energy-efficient windows with sealed glass units; use of efficient thermal-insulation materials in exterior-wall systems; and others. Implementation of these new systems and technologies has run into some problems both in design and in operation. This paper discusses these problems and the solutions that have emerged.*

## INTRODUCTION

Increasing the energy efficiency of the buildings sector of Russia is a complex problem. Its successful resolution can be viewed in terms of national energy security and environmental protection, rational use of non-renewable natural resources, as well as mitigating the "greenhouse effect" by curtailing emissions of carbon dioxide and other substances into the atmosphere. The resolution of this problem is possible by combining work on energy efficiency in buildings (Matrosov 2004), and work on energy efficiency in ventilation, heat delivery, and heat supply of buildings (Dmitriev 2005). Such an approach corresponds with Russian policy, as the state has an interest, ultimately, in reducing consumption of primary fuel and energy resources – the strategic bases of its long-term existence.

At the G-8 summit in St. Petersburg in July 2006, the problem of energy security was a leading priority. At this meeting it was resolved that "energy saved is energy produced…Efforts to improve energy efficiency and energy saving contribute greatly to lowering the energy intensity of economic development thus strengthening global energy security. Increased energy efficiency and conservation reduce stress on infrastructure and contribute to a healthier environment through decreased emission of greenhouse gases and pollutants." The states must "increase efforts to adopt the most stringent energy efficiency standards that are technically feasible and economically justified."

## A SHORT HISTORY OF THE CREATION OF BUILDING ENERGY CODES IN RUSSIA

The Research Institute for Building Physics of the Russian Academy of Architectural and Construction Sciences (known by its Russian initials as NIISF), together with an array of Russian organizations, the Russian State Construction Committee (Gosstroi) and regional executive agencies, has developed, approved, and implemented new approaches to building energy codes. First, in 1992-93, with the participation of specialists from the United States, a new ideology of building codes was developed from the point of view of energy (Matrosov and Goldstein 1996), then in 1994 Russia's first regional code was developed and approved, for the city of Moscow. In 1995, fundamental amendments were introduced

***Yurij A. Matrosov*** *is Head of the Energy Conservation and Microclimate Laboratory at the Research Institute for Building Physics of the Russian Academy of Architectural and Construction Sciences (NISF), Moscow, Russia.* ***Mark Chao*** *is Senior Program Director at the Institute for Market Transformation, Ithaca, NY.* ***Cliff Majersik****, LEED AP, is Program Director at the Institute for Market Transformation, Washington DC.*

into the federal code on building thermal engineering, providing for a 20 percent reduction in energy consumption for heating, and 40 percent starting in 2000. In 1996 NIISF, in conjunction with a group of organizations, first developed and then Gosstroi confirmed a standard, GOST 30494-96 (1996) on parameters for the indoor microclimate of residential and public buildings, to provide for comfortable conditions for occupants. From 1998 to 2003, NIISF and the Institute for Market Transformation (Matrosov et al 1998) and regional specialists around Russia developed and implemented regional building energy codes in more than 50 regions of Russia. Among these, a new edition of the energy code was developed and confirmed for the city of Moscow (MGSN 2.01-99). The new federal code SNiP 31-02-01, entitled “Single-Family Residential Buildings”, developed in 2001, contained a code requirement for specific energy consumption as an alternative for low-rise buildings. In this very period, a set of three standards was developed and then approved by Gosstroi on energy auditing of existing buildings (GOST 31166-03, GOST 31167-03 and GOST 31168-03). On the basis of the experience gained in the regions of Russia, a new national building code, SNiP 23-02-2003, “Thermal Performance of Buildings” (Gosstroi 2003) was developed and adopted in 2003, as well as the accompanying design manual Code of Practice SP 23-101-2004 “Design of Thermal Performance of Buildings” (Gosstroi 2004), and the new code SNiP 31-01-2003 “Multifamily Residential Buildings” with a section entitled “Energy Efficiency”. And, finally, in 2004, chapters on energy conservation and thermal performance were developed for the new regional code of the city of Moscow, on high-rise buildings -- MGSN 4.19-2005 (City of Moscow 2005).

As a result, a new generation of the system of codes and regulations was created on the design and operation of buildings with efficient use of energy, providing for a reduction of 40 percent in energy consumption for heating, starting in 2000. This has led to the need for an increase of 2.5 to 3 times in thermal performance in new and renovated buildings in Russia. An array of standards and energy documentation requirements (“Energy Passports”) have provided for energy audits and verification of code compliance. The new codes are harmonized with international levels and, in particular, their parameters for energy efficiency have been made consistent with the requirements of the laws (directives) of the European Union -- directives 2002/91/EC (2003) and 93/76 SAVE.

As a result of the implementation of the new codes and standards, a fundamental transformation has taken place in the Russian building sector, toward the production, sale, and use of energy-efficient construction materials and products, and changes in building design methods. A new architectural form of widened buildings with a lower surface-area-to-volume ratio; buildings with monolithic-frame construction using lightweight aggregate concrete; energy-efficient windows with energy-efficient glass; external insulation systems with use of efficient thermal insulation; double-wall systems; the use of regulated air intake systems; energy-efficient heating and ventilation equipment; heat delivery systems for individual apartments – this is far from a complete list of design solutions under the influence of the new set of codes.

## FUNDAMENTALS OF RUSSIAN BUILDING ENERGY CODES

In selecting the level of thermal performance for a building, one must observe code requirements for whole-building specific energy consumption over the heating season. In design of thermal performance, the following calculation tasks are carried out in sequence in each individual case:

1. For a given category of energy efficiency of the building, A, B or C (Matrosov et al 2004), the code-stipulated value for specific energy consumption is determined for the type of building being designed, and degree-days are calculated for the relevant region.
2. Through a variety of options, the code-stipulated level of thermal performance is calculated for separate elements of the building envelope, either on the basis of a whole-building energy consumption requirement, or on the basis of a prescriptive table of thermal-resistance values or formulae for individual elements. In either case, the design value of specific energy consumption for the heating season is defined, and an Energy Passport is completed for the building for verification of compliance of design values with code-stipulated values.
3. The overall thermal resistance of the designed building envelope is calculated, the result is compared with the level defined in task 2 (see preceding paragraph), and changes to the design are carried out as necessary. In addition, moisture protection and air permeability are determined and compared with code-stipulated values.

Four principles are key for creation of energy-efficient buildings:

- first, selection of a geometric form for the building that reduces heat losses;
- then reduction of demand for energy by increasing thermal-performance level, including reduction of air permeability;
- provision of required air exchange with the help of organized air intake;
- and, finally, meeting remaining needs for energy in the most effective manner.

Energy consumption for heating buildings can be reduced by means of a combination of the following measures:

- Increasing the level of insulation of the building envelope, including roofs, attic floors, walls, and floors on the first story;
- Use of energy-efficient windows and balcony doors, including sealed glass units filled with gases with low

**Table 1. Overall Annual Heat Consumption for Heating Residential Buildings of Typical Series in the City of Moscow per 1 m$^2$ of Floor Area**

| Design Series | Number of Stories | Maximum Permitted Heat Consumption | | Design Heat Consumption | |
|---|---|---|---|---|---|
| | | kWh/(m$^2$·yr) | kBtu/(Ft$^2$·yr) | kWh/(m$^2$·yr) | kBtu/(Ft$^2$·yr) |
| P44T | 14-17 | 95 | 30 | 95-105 | 30-34 |
| KOPE | 22 | 95 | 30 | 80-85 | 26-27 |
| P3M | 16-17 | 95 | 30 | 86-90 | 28-29 |
| Pd4 | 12-16 | 95 | 30 | 92-98 | 29-31 |
| P-46M | 14 | 95 | 30 | 93-98 | 30-31 |
| P-55M | 14 | 95 | 30 | 88-92 | 28-29 |
| 111/17 | 17 | 95 | 30 | 75-85 | 24-27 |
| PZM | 9 | 95 | 30 | 98-103 | 31-33 |
| P46M | 9 | 105 | 34 | 104-109 | 33-35 |
| P46M | 5 | 120 | 38 | 117-122 | 38-39 |

heat conductivity, heat-reflective films on the glass, and insulated frames;

- Reduction of air permeability of the building envelope including windows and balcony doors;
- Organization of controlled air exchange, taking account the partial role of air permeability of the building envelope;
- Optimal orientation of buildings with the goal of passive use of solar energy;
- Use of energy-efficient heating systems;
- Use of sources of renewable energy and heat pumps for partial reduction of energy consumption.

According to the data of V. I. Livchak (2006), the head of the department of energy efficiency in buildings for the Moscow State Inspection Agency, “all designs of newly constructed, renovated, or capitally-repaired residential and public buildings in the city of Moscow -- more than 1000 designs per year -- comply with the requirements of MGSN 2.01-99 and SNiP 23-02-2003”. In Table 1, the design indices of specific consumption of heat energy for residential buildings in Moscow are shown.

It must be noted under previous, less stringent levels of thermal performance, the conductive heat losses made up a significant portion of overall heat losses to the point that other heat losses could practically be disregarded. Figure 1 presents a diagram of a heat balance of a three-section 9-story building of in the city of Orenburg, calculated according to SNiP 23-02 (left bars, with solid outlines). (The building is built to standard design “series 131,” which is one of many standard design series created by Russia’s Central Research and Design Institute of Dwellings. In this figure, $Q_h{}^y$ is the overall consumption of energy, $Q_t$ is conductive heat losses, $Q_{inf}$ is heat losses via air exchange, and $Q_i$ and $Q_s$ are internal and solar heat gains. The vertical axis is heat consumption in megajoules (one megajoule, or MJ equals a million joules). It

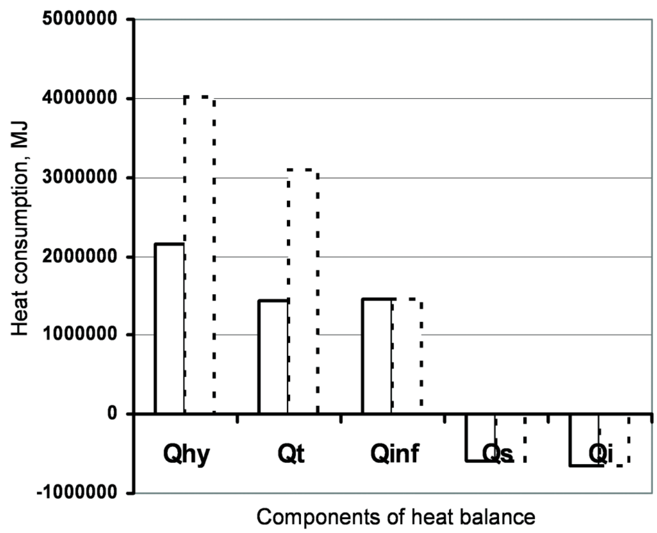


***Figure 1*** *Heat balance of a three-section nine-story building of a series 131, Orenburg.*

is evident that heat losses from air exchange are comparable with conductive heat losses and overall heat gains in the building. For comparison, in the same figure, the heat balance for the same building is presented, but based on the old code requirements from before 1995 (right bars, dotted outlines). The overall consumption of energy and conductive heat losses in this case exceed by almost two times the values calculated according to new code requirements, even as heat losses of air exchange and internal and solar gains have remained at practically the same levels as previously. From this diagram one can also see that the overall reduction of energy consumption under new codes in relation to 1995 has been achieved by means of reduction of conductive heat losses from buildings.

The same result has emerged in Germany (Gertis 1995) and in other developed countries, significantly increasing the level of thermal performance of buildings over the last decade (see Tables 2a and 2b).

## ASSESSING THE EFFECTS OF ENERGY CODES

In the period from 2002 to 2005 the calculated energy-saving effect in terms of primary fuel stood at nearly 240 PJ (one petajoule, or PJ equals 1 x $10^{15}$ joules), or 8.6 million tons of coal equivalent, and has also led to an overall reduction in emissions of greenhouse gases of 16.4 million tons. With the growth in building stock has come steep growth in energy consumption for heating these buildings. The timely development of a new generation of system energy-saving codes and standards and their introduction into force has put the brakes on this growth -- the annual expenditures for fuel, spent on generation of heat energy for the heat supply system up to the end of 2005, has grown only by 151 PJ, in comparison with 252 PJ, if these codes had not been introduced (see Figure 2).

The forecast for expected energy savings in terms of primary fuel and reduction of $CO_2$ emissions is shown in Table 3. It is based on Russian government projections, which assume annual growth of about 12-percent in residential construction volumes in Russia (Yakovlev 2005). We project that a decade (2000-2010) of the new generation of codes will result in fuel savings of more than 1.1 EJ (one exajoule, or EJ, equals 1 x $10^{18}$ joules) or 47.8 million tons of coal equivalent, which translates to a reduction of $CO_2$ emissions of 80 million tons.

**Table 2a. Code-Stipulated Thermal Resistance of Building Envelope Elements in European Countries**

| Country | Code-Stipulated Thermal Resistance, $m^2 \cdot °C/W$ | | | |
|---|---|---|---|---|
| | Roofs | Walls | Floors on the Ground | Windows |
| Sweden | 5.0–10.0 | 5.0–10.0 | 5.0–10.0 | 0.67–1.0 |
| Finland | 5.0–10.0 | 3.3–5.0 | 3.3–5.0 | 0.5–0.67 |
| Denmark | 5.0–10.0 | 3.3–5.0 | 5.0–10.0 | 0.4–0.67 |
| United Kingdom | 5.0–10.0 | 2.5–3.3 | 3.3–5.0 | 0.4–0.67 |
| Netherlands | 3.3–5.0 | 2.5–5.0 | 3.3–5.0 | 0.4–0.67 |
| Germany | 3.3–5.0 | 1.67–2.0 | 2.0–2.5 | 0.67–1.0 |
| France | 3.3–5.0 | 2.0–2.5 | 2.5–3.3 | 0.4–0.67 |
| Italy | 2.5–3.3 | 2.0–2.5 | 2.0–2.5 | 0.29–0.4 |
| Russia | 2.9–8.2 | 1.9–5.6 | 2.57–7.3 | 0.26–0.8 |

**Table 2b. Code-Stipulated Thermal Resistance of Building Envelope Elements in European Countries**

| Country | Code-Stipulated Thermal Resistance, R-Value (Windows are in U-factors) | | | |
|---|---|---|---|---|
| | Roofs | Walls | Floors on the ground | Windows |
| Sweden | 28.4–56.8 | 28.4–56.8 | 28.4–56.8 | 0.26–0.18 |
| Finland | 28.4–56.8 | 18.8–28.4 | 18.8–28.4 | 0.35–0.26 |
| Denmark | 28.4–56.8 | 18.8–28.4 | 28.4–56.8 | 0.44–0.26 |
| United Kingdom | 28.4–56.8 | 14.2–18.8 | 18.8–28.4 | 0.44–0.26 |
| Netherlands | 18.8–28.4 | 14.2–28.4 | 18.8–28.4 | 0.44–0.26 |
| Germany | 18.8–28.4 | 1.67–2.0 | 11.4–14.2 | 0.26–0.18 |
| France | 18.8–28.4 | 11.4–14.2 | 14.2–18.8 | 0.44–0.26 |
| Italy | 14.2–18.8 | 11.4–14.2 | 11.4–14.2 | 0.61–0.44 |
| Russia | 16.5–46.6 | 10.8–31.8 | 14.6–41.5 | 0.68–0.22 |

## GENERAL REQUIREMENTS FOR THERMAL PERFORMANCE OF BUILDINGS

The influence of new codes on the building sector of Russia has been in the stimulation of the market for new energy-saving technologies. The transition to increased thermal performance of buildings can be realized either by means of use of efficient thermal insulation materials, or by use of new technologies for building envelopes, or both. However, a long time frame is often required for new technologies to achieve market success. Reasons for the prolongation of the process include lack of reliable information, inertia of manufacturers, and mismatch of interests of various groups of market entities.

The general requirements for thermal performance of buildings consist of the following. Building envelopes must provide for a code-stipulated level of thermal resistance with hermetically-sealed joints and a minimum of thermal bridges,

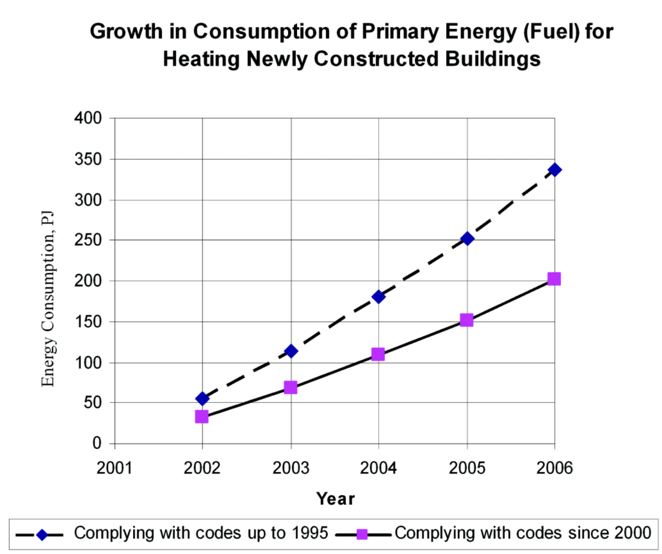


*Figure 2 Growth in consumption of primary energy (fuel) for heating newly constructed buildings.*

**Table 3. Projected Energy Savings and Reduction of $CO_2$ Emissions through 2010, under Expected Annual Growth Rate of 12% for Residential Construction Volumes in Russia**

| | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| Planned volume of residential construction, million sq. meters | 43.6 | 50.8 | 56.3 | 63.1 | 70.6 | 80 |
| Yearly energy savings from newly built or renovated buildings, PJ | 25.8 | 30.1 | 32.8 | 36.8 | 41.1 | 46.6 |
| Cumulative effect in terms of primary fuel saved, relative to the beginning of 2002, PJ | 217.5 | 338.7 | 492.6 | 683.3 | 915.2 | 1193.6 |
| Overall reduction in $CO_2$ emissions, relative to the beginning of 2002, (thousand tons) | 14796 | 23033 | 33503 | 46472 | 62239 | 81177 |

with a reliable vapor barrier, which maximally protects against the penetration of water vapor into the envelope. Building envelopes must have the required durability, hardness, stability, and expected lifetime. From both the interior and the exterior sides, they must have protection from outside influences. Moreover, they must satisfy general architectural, operational, and sanitary-hygienic requirements.

The necessary flow of air into occupied areas must be provided for via special regulated vents in walls, placed either in the frames of fenestration or in the walls themselves, or especially via the air permeability of windows or walls themselves. Exhaust of air is provided for by means of a ventilation system.

## Thermal Insulation

Thermal insulation, in combination with energy-efficient windows, occupies the key position in increasing energy efficiency of buildings and ultimately in reducing CO2 emissions, and light thermal insulation materials may completely provide for fulfillment of stringent code requirements.

The structure of the use and basic thermal-engineering characteristics of the main types of light thermal-insulation materials in 2005 is presented in the Table 4. Fibrous materials have achieved the widest proliferation -- mineral wool and fiberglass. Overall demand for these products as of 2006 is estimated at 18 million m3 per year. The volume of private-sector production in Russia in 2005 of these products was about 8 million m3 of mineral wool and about 3 million m3 of fiberglass (preliminary calculation). Much of Russia's growing insulation production capacity is provided by factories recently built by joint ventures between Russian and Western firms; joint ventures are currently constructing additional insulation factories. Imported insulation satisfies demand in excess of what Russian factories can meet. The last ten years of experience have shown that with the use of these materials and others not shown in the table, it is possible to develop building envelopes that completely satisfy the requirements of the aforementioned code documents.

Recommendations on the choice of building envelope materials and elements are shown in the code document SP 23-101 (Gosstroi 2004). This document also contains requirements for building envelopes that must:

**Table 4. Light Thermal Insulation Materials**

| Materials | Market Share, % | Density, kg/m$^3$ | Design Coefficient of Thermal Conductivity, W/(m·°C) |
|---|---|---|---|
| Mineral wool | 45 | 25–250 | 0.045–0.084 |
| Glass fiber | 25 | 11–150 | 0.045 - 0.07 |
| Plastic foam | 20 | 15–150 | 0.031–0.064 |
| Lightweight aggregate polystyrene-concrete | 3 | 150–600 | 0.06–0.2 |

- Provide for a code-stipulated level of thermal resistance with a minimum of thermal-engineering heterogeneity in combination with reliable vapor barriers, to reduce as much as possible the penetration of water vapor into the envelope
- Have a required strength, rigidity, stability, frost-resistance, expected service life, and fire resistance
- Satisfy general architectural, operational, and sanitary-hygienic requirements
- Have an expected service life of over 100 years
- Be subject to routine maintenance, with the possibility of the use of materials with a lesser expected lifetime, but not less than 30 years, if such materials can be replaced easily
- Have stable thermophysical properties of thermal-insulation materials at the time

If there emerge no problems in meeting new code requirements in the design of roofs and attic floors, then new requirements can be met in the design and choice of materials for external walls.

## Degree-Day Calculations

The thermal-performance properties of walls are linked with the climatic characteristics of the locality, reflected in the number of degree-days of the heating season. Thus the possibility for using any given building elements is limited by the highest number of degree-days under which a building element provides for the necessary level of thermal performance and has an acceptable thickness. Degree-days vary from 1500 in the south up to 12,000 at the extreme north, and are determined by a Russian method, which differs from the one used in the USA.

Figures 3 and 4 show graphically the difference in methods for calculating degree-days in the United States and in Russia, respectively. In Figure 3, degree-days from the Russian method are shown as the sum of the areas of the shaded bars showing temperature differences between the outdoor air temperature at the beginning and the end of the heating season and average monthly outdoor air temperatures, across each month of the heating season. In Figure 4, degree-days according to the American method are presented as shaded areas, with boundaries between the base temperature of 18.3°C and the average monthly outdoor air temperature. The difference in the areas of these figures reflect the difference in results of degree-day calculations by these methods. Thus, for example, New York City has 2745 degree-days according to the American method, but 2339 by the Russian method. Examples from a few other American cities include Boston (Logan International Airport) 3128 and 2640; Washington (Reagan International Airport) 2353 and 1811; Minneapolis (Intl. ap) 4376 and 4092.

In a comparative analysis of thermal-performance codes of America with those of Russia, it is necessary to make a correction in the transition from one degree-day method to another. Such a correction is carried out in this way: the code-stipulated value established for the given climatic region of the USA, divide it by the number of degree-days derived from the US method (in SI units), and then multiply by the number of degree-days for this climatic point, derived by the method used in Russia.

For example, let us carry out a comparison of codes for walls for the American city of Boston and the Russian city of Moscow. According to American codes (ASHRAE 2004), the thermal resistance of walls in the city of Boston must be no less than 1.95 m2·oC/W. First we carry out a correction of this value by revising the calculation of degree-days from the American method to the Russian method. The corrected code requirement for thermal resistance of walls will be equal to 1.95·2640 / 3128 = 1.65 m2·oC/W. Now let us determine the equivalent of this Boston code requirement, but for the conditions of the city of Moscow. For this goal, we must correct the thermal-resistance requirement by dividing by the number of Boston degree-days (calculated by the Russian method) and multiply by the number of Moscow degree days (also by the Russian method) -- (1.65 / 2640)·4943 = 3.09 m2·oC/W. The code-stipulated value for Moscow from SNiP 23-02 (Gosstroi 2003) equals 3.13 m2·oC/W. It is evident that the code-stipulated values for the two cities are closely comparable to each other.

## BUILDING ENVELOPE MATERIALS AND DESIGN APPROACHES

### Wall Systems

From a thermal-engineering point of view, people conventionally make a distinction between two general types of walls: single-layer and multi-layer.

In single-layer walls, appropriately lightweight aggregate concretes are used both for monolithic and for piece-by-piece applications with protective layers inside and out. As seen in work (Matrosov and Yarmakovsky 2006), such walls, with modified polystyrene- aggregate concretes applied to low thermal conductivity and low-sorption active composite binders (MPSB), are used for buildings in regions that have up to 6000-7000 degree-days in the heating season with wall thicknesses not more than 350-400 mm. The basic advantage of single-layer walls made of lightweight aggregate concrete is its high thermal homogeneity, as well as an expected service life of not less than 100 years. Its deficiency is limitation of applicability to regions with relatively few degree-days in the heating season.

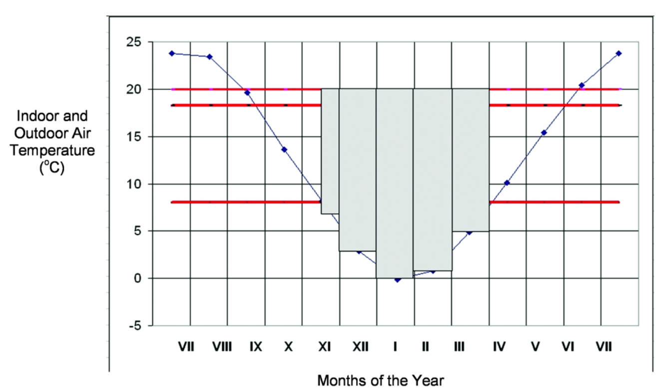


***Figure 3*** *Calculation of Heating Degree-Days (HDD) for New York City by the Russian Method (2339 HDD).*

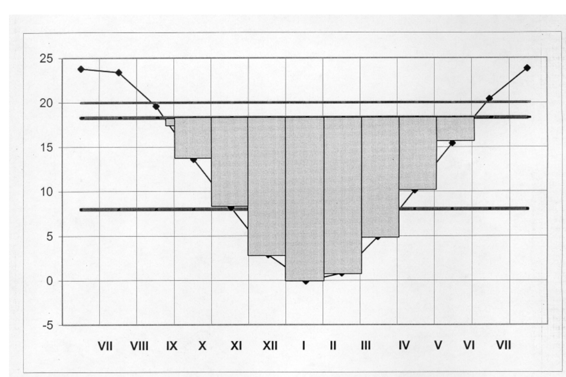


***Figure 4*** *Calculation of Heating Degree-Days (HDD) for New York City by the American Method (2745 HDD).*

Multilayer walls have achieved widespread market proliferation. These walls differ in the positioning of thermal insulation material -- internally (three-layer) and externally (two-layer). The thermal-performance properties of multilayer wall elements depend to a large degree on the equilibrium moisture content of the thermal insulation; therefore it is necessary to proceed with great caution in determining the arrangement of insulation and vapor-retarder layers. As a consequence of the difference in water vapor pressure across the wall unit, water vapor diffuses to the outside. Therefore the task in design of multilayer building envelopes is to weaken the diffusion of water vapor into the interior layer of the wall and to avoid the formation of moisture emerging inside the envelope. With this goal, designers design vapor retarders such that they must be positioned as close as possible to the interior surface of the wall. Use of thermal insulation starting from the interior wall is allowed only where there is a reliable vapor retarder on the side facing the occupied area, which in practice is difficult to implement.

Three-layer walls with a thickness of 350-450 mm with polystyrene or mineral wool insulation 200-300 mm thick in the middle, with flexible ties, may be used in regions where the heating season has 6000-7000 degree-days. Multiple calculations to define the overall thermal resistance, taking account of three-dimensional temperature fields, have shown that the coefficient of thermal homogeneity of such envelope elements is 0.67-0.8. The disadvantage of three-layer walls is that simple routine maintenance is not possible.

Another type of three-layer walls is monolithic lightweight aggregate concrete with inside and outside lagging. This type is according to the Swiss technology by the "Plastbau" system. This construction system employs an encasement made of cellular polystyrene, which is not removed after construction; hence the construction of the wall is three-layered, with the middle layer made of the lightweight aggregate concrete. The width of the external primary lagging from cellular polystyrene is 150 mm; the internal layer (additional lagging) is 50 mm. From the inside the cellular polystyrene is protected by two layers of gypsum board with width of 25 mm, and from the outside, by a plaster with a width of 35 mm over reinforcing fabric. The external and internal layers of the lagging are connected by stationary rods with a diameter of 2-6 mm at a distance of 200 mm from each other.

The basic advantage of two-layer walls is their usefulness for buildings built in regions without degree-day limits. Two-layer walls are amenable to routine maintenance, which is another advantage. A deficiency of two-layer walls, as with three-layer walls, is their low thermal homogeneity, because of the presence of thermal bridges. Another deficiency is that the expected useful service life of thermal insulation is not more than 30 years. But international experience shows that this service life may be doubled.

Two-layer walls have been developed in façade systems. Two variants of façade systems are generally used: 1) systems with external plaster layer or a protective outer layer of brick without an air space; and 2) systems with a ventilated air space, so call double wall.

Variant 1 is based on the use of thermal-insulation materials of a thickness up to 150 mm (mineral-wool or fiberglass slabs) and up to 250 mm (polystyrene slabs), affixed to the wall by rivets with steel tie elements and polyamide cartridges. Thermal insulation is protected from weather by a vapor-permeable fixative layer, equipped with a fiberglass net, and a decorative vapor-permeable layer (plaster or paint), or brick too. One peculiarity of this variant is the necessity of the use of safe, durable, compatible components, partially or completely eliminating cracking or breaking of insulation layers of the building façade. Stringent requirements also apply to corrosion protection of the rivets. A disadvantage of these systems is that they can be installed only in positive Celsius outdoor air temperatures, which limits their use across Russia, where the warm season in many areas is short.

Problems of systems of variant 1:

- A substantial influence of metallic affixation elements on thermal homogeneity (thermal bridges);
- Insufficient vapor permeability of the external plaster layer, and the possible accumulation of moisture in insulation;
- Formation of cracks in plaster if a netting of glass fabric is absent;
- Discontinuity of insulation after incorrect installation.

Variant 2 differs from variant 1 because of the absence of any limitation on the thickness of the insulation layer -- mineral wool or fiberglass slabs, which are also affixed to the wall with rivets. The insulation layer is protected by façade panels made of any of various materials, installed on metal elements affixed to the wall (steel, aluminum alloy, or a combination of the two). These metal elements substantially affect thermal homogeneity (thermal bridges). In addition, insulation is protected by a vapor-permeable sheet such as Tyvek, installed on site. For organization of air movement throughout the space, intake and exit openings are included. Moreover, between the façade panels and the insulation there is an air space with a thickness of between 60 and 150 mm. To prevent the spreading of fire, every three stories the air space is enclosed with a non-flammable material. Another trait that makes such systems worthwhile is that they can be assembled year-round, which is very important for many regions of Russia, even though these systems are 20-25 percent more expensive than systems of variant 1.

Problems of systems of variant 2:

- Even greater influence than with variant 1 of affixation elements on thermal homogeneity;
- Corrosion of the affixation elements of the ventilated façade if there is insufficient anticorrosion coating;
- Discontinuity of insulation after incorrect installation;
- Disregard of recommendations on density of insulation material (70-80 kg/m3); vertical filtration of air where

lighter insulation materials are used (30-35 kg/m3) in the absence of a vapor-permeable sheet;

- Increased speed of air movement in the air layer (more than one m/s) if recommendations on areas of openings are not observed, and gradual breakage of insulation from the side of the surface that faces the air space;
- Trapping of insulation in places with surfacing where there is a minimal thickness of the air layer because of uneven wall layers;
- Absence of fireproof barriers over the entire height of the air layer;
- Problems with the outer surface layer -- insufficient thickness of seams, excessive caulking of seams;
- With a thickness of the air layer greater than 150 mm, emergence of wind noise.

### Fenestration

The new generation of windows is based on the use of one- and two-chamber sealed glass units, which make it possible to increase the level of thermal performance relative to previously-produced fenestration. The use of windows with separated frames with a single pane and single-chamber sealed glass with selective coatings and argon fill increases the reduced thermal resistance of window units to as much as 0.65-0.72 $m^2 \cdot °C/W$, and the very same window block with a two-chamber sealed glass unit, up to 0.81–0.82 $m^2 \cdot °C/W$. The code requirement in regions with 12,000 degree-days in the heating season is 0.8 $m^2 \cdot °C/W$, and thus these windows satisfy the requirements of SNiP 23-02. On a qualitatively different level, the problem of sealing off drafts is solved, as a rule, by three bands of weatherstripping.

The brightest example is new technology for the production of windows with vinyl frames and sealed glass units made of K-glass (glass with a selective coating). Thus, for example, in the city of Moscow over one million square meters of mass residential construction is being introduced each year with windows with vinyl frames and sealed glass units. In comparison with wood-framed windows, windows with vinyl frames can provide for increased thermal performance properties as well as required levels of air permeability, and therefore are promising for construction of energy-efficient buildings.

Implementation in Russian construction practice of vinyl-framed windows with increased thermal performance has carried in its wake an array of errors in thermal-engineering design of facades of buildings and installation of window openings. One mistake of initial implementation of these windows was linked to the small (50-55 mm) thickness of window frame. In connection with this, on the internal surfaces of window slopes there emerge zones with lowered temperatures, which leads to the formation of condensate or even freezing. To eliminate this problem, it is necessary to choose a window with greater thickness of the frame (not less than 100 mm) and to place it in the window opening at one-quarter depth in from the façade of the wall (125 mm), filling the space between the window block and the internal surface of the opening with foam insulation material.

Other mistakes are linked with insufficient consideration of the air permeability of windows. The code-stipulated air permeability of openings filled with wood-framed windows equals 6 kg/(m2·h), and for vinyl-framed windows 5 kg/(m2·hr) under a pressure difference of 10 Pa. Certification testing of vinyl-framed windows shows that air permeability strictly of the spaces in opened elements of windows was in the range of 0.5 up to 2 kg/(m2·hr). Because of the reduced air permeability of the spaces of vinyl-framed windows (and of the newest types of wood-framed windows) and the high airtightness of the borders of windows and walls, there is deficient air exchange in occupied areas and, as a consequence, increased humidity within. To avoid this occurrence, it is necessary to carry out periodic airing of the living space; opening windows, "framugi," or "fortochki" (the latter two are types of small windows). For example, opening framugi for 10-15 minutes provides for the required air exchange and does not lead to notable heat losses. Together with this, contemporary windows have already begun to be equipped with controllable devices for ventilation (acoustic-insulation valves, specially-organized openings in the window cross-section, rotating-folding mechanisms, window stops), which may provide for any variant of airing of the occupied area as desired by the user.

## MONITORING, OVERSIGHT, AND ENERGY AUDITS

As the building enters into operation and first becomes occupied, the new codes require that thermal-imaging quality control of thermal performance be carried out for each building, to reveal construction defects. Regulations for monitoring and oversight make it possible at a distance, by the intensity of thermal radiation from the surface of the envelope to reveal thermal irregularities -- in particular, ones not foreseen by the building design -- with the goal of removing any hidden defects in construction. The method is based on measurement of the intensity of thermal radiation as a function of temperature of the building envelope surface and representing it in graphic form. External and internal surfaces of the building envelope are subjected to thermographic monitoring. Overall thermal-imaging monitoring of the building envelope is first carried out with the goal of revealing anomalous zones with irregular thermal-performance properties, and then a more detailed thermogram of the indicated zones is obtained by means of taking images of thermal radiation from external and internal surfaces of the envelope.

Upon entry of the building into operation, the new codes also require selective monitoring of air-permeability in 3-4 units or enclosed living spaces located on the first, middle, and top stories including one corner apartment or enclosed space, in accordance with GOST 31167 (Gosstroi 2003). The method for measurement makes it possible to define the air exchange rate of apartments, or residential or public spaces of buildings, from infiltration under a pressure difference between indoors and outdoors of 50 Pa, as well as air permeability of elements of the building envelope, and to verify compliance with code-stipulated values. The average air permeability, in accordance with SNiP 23-02, must provide for an air exchange rate under an indoor-outdoor air pressure difference of 50 P with natural ventilation of n50 ≤ 4 hours-1, but not less than the values established in Table 5 for the "normal" category, and with mechanical ventilation, n50 ≤ 2 hours-1. Where categories of "moderate", "high", "very high" air permeability are applicable, measures are taken to reduce the air permeability of the premises. Where "low" and "very low" categories are applicable in premises having natural ventilation, it is necessary to take measures to provide for an additional flow of air.

Selective energy auditing of buildings is carried out by means of field testing (monitoring) for determination of actual thermal-engineering and energy parameters of the building. A building energy audit consists of a sequence of activities, directed at collecting field data, processing them, and defining indices normalized design conditions for energy efficiency and thermal performance properties of the building. A building energy audit is carried out not earlier than the second heating season, and only when the percent of occupied units of the building is not less than 70. In accordance with SNiP 23-02, the parameter for energy efficiency of a building is the specific energy consumption of the building over the heating period $\mathbf{q_h^{des}}$. The $\mathbf{q_h^{des}}$ parameter is established from the results of testing (monitoring) via an "express-method" in accordance with GOST 31168 (Gosstroi 2003). As a result of the processing of data in an energy audit, an actual overall coefficient of heat transfer $\mathbf{K_m}$, /($^{2}$·) for the building envelope is also calculated, in addition to the specific energy consumption figure. The result of the energy audit is the establishment of a category rating for the energy efficiency of the building. A brief summary of an energy audit and an example is shown in source (Matrosov et al 2004).

## CONCLUSION

In conclusion, it should be noted that:

- development and introduction into force of the new generation system of codes and regulations on design and operation of buildings with a 40-percent reduction in energy consumption has contributed to national energy security and is consistent with state policy in this area;
- the new codes have provided for design of energy-efficient buildings, and the system of standards have provided for monitoring and oversight over code-stipulated parameters for thermal performance and energy during building operation;
- the new codes have created the possibility of achieving required parameters by means of improved design quality and wide possibility in the selection of architectural forms and technical solutions;
- the experience of large-scale construction in Moscow and other Russian regions has shown that contemporary construction materials and products can allow for the creation of buildings with normal and elevated energy efficiency;
- the new generation of codes and standards has stimulated domestic Russian industry to produce new progressive construction materials and products at the level of world standards and, in particular, to improve production of high-quality efficient insulation materials, energy-saving building envelopes, and new types of energy-efficient windows. It has also made possible a construction boom, increased employment rates, has reduced susceptibility of the indoor environment of buildings to emergency situations (such as the temporary unavailability of heat supply), increased thermal comfort in buildings, and led to real energy savings.

**Table 5. Categories of Air Permeability of Building Envelopes**

| Air Exchange Rate $n_{50}$, hours$^{-1}$, under $\Delta p$ = 50 Pa | Name of Category |
|---|---|
| $n_{50} < 1$ | very low |
| $1 \le n_{50} < 2$ | low |
| $2 \le n_{50} < 4$ | normal |
| $4 \le n_{50} < 6$ | moderate |
| $6 \le n_{50} < 10$ | high |
| $10 \le n_{50}$ | very high |

## ACKNOWLEDGMENT

The authors gratefully acknowledge financial support for this project and for this paper by the US Environmental Protection Agency and the Renewable Energy & Energy Efficiency Partnership (REEEP).

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