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# ENERGY EFFICIENCY OF THE BUILDING

Bachelor's thesis
Building Services Engineering

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**Name of the bachelor's thesis**
Energy efficiency of the building

**Abstract**

The subject of bachelor's thesis is about energy efficiency of the building. Much attention is being paid to energy saving problems all over the world. In the first part it theoretic base for thermal performance requirements of buildings. It includes main positions of Russian requirements for thermal performance. Also it is about general types of building envelope. The second part is about energy audit of buildings. In this part there is an energy efficiency assessment methodology. Energy efficiency of the building in Saint-Petersburg was provided. There are three parts of them. In the first estimation of the energy efficiency was based on project data. In the second part assessments was on real values, and in the third part there are results of the thermal vision survey. Very important to take into account factors which influence heating regime of buildings. This part describes general factors such as relative air humidity inside the building, moisture content in the building envelope and air infiltration. In Finland, as in most developed nations much attention to energy efficiency of the building is paid. In this country method of building energy efficiency evaluation was created. In this case Finish norm (national building code D5) is used. The estimation of building energy efficiency was made. For correct comparison of two methods consumption of hot water and electric energy were not taken into account. Difference of methods was defined. Energy passport of that building was created. It is based on real values. Class of the building energy efficiency remained "Normal" by Russian method, but consumption of the heat energy rose. It is determined by reducing of the building heat protection characteristics, because there was another heat-moisture regime, quality of montage, latent defects during construction production on plant. Thereby, necessity of providing a building energy audit is confirmed.

**Subject headings, (keywords)**
Energy efficiency of the building, energy audit, energy passport of the building, comparisons of Russian and Finish methods

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**CONTENTS**

**1 INTRODUCTION**

Much attention is being paid to energy saving problems all over the world as well as in Russia these days. Law №261 /11/ of the Russian Federation concerning energy saving and improving of energy efficiency was passed on 26 November 2009. This law states that energy audits must be provided until the end of 2012. According to the results of energy audit building energy passport is created. Energy efficiency of the building is estimated, improving of building energy efficiency arrangements are worked out in case of necessity.

Requirements for the energy passport are determined federally, for industrial establishment in GOST P 51379 99 "Energy conservation. Power engineering certificate of fuel-energy resources for the industrial consumer" and for residential and public buildings in SNiP 23-02-2003 "Thermal performance of the buildings"/1/. The energy passport of a building is created at the stage of projects in the section which is called "energy efficiency". It is corrected in compliance with the real measured value of the envelope thermal resistance. The category of the energy efficiency rating is determined by the value of the specific energy demand during a building's heating season. If a building's energy efficiency rating category does not correspond to the standard requirements, the building is not accepted for utilization by technical inspectors in Russia.

Currently, methodical recommendations for arranging energy audits in accordance with Law №261 of the Russian Federation are not created. The energy passport form of residential buildings which was represented in /1/ must be added by section "control and regulation of energy consumption". Consumption of hot domestic water should be also taken into account.

The objectivities of bachelor's thesis were to provide an energy audit of a building in Saint-Petersburg, determination of a building's energy efficiency according to Russian and Finnish standards and to compare Russian energy efficiency estimation method to Finish D5 calculation method.

## 2 THERMAL PERFORMANCE REQUIREMENTS OF BUILDINGS IN RUSSIA

Requirements for improving building thermal performance are an important part of state regulations in most countries of the world. These requirements are envisaged as environmental protection, resource management, reduction of the "greenhouse" effect, reduction of carbon dioxide and other harmful substance emissions into the atmosphere.

Normative documents require creating effective thermal performance of buildings, improving engineering equipment efficiency and reduction of energy losses for production and delivering.

Factor of building energy efficiency is specific energy demand for heating of a building of a heating season. Class of the building energy efficiency is determined project stage of building and exploitation period. There are three classes of energy efficiency for new and reconstructed buildings (A, B, C). Criterion for estimation is determined by the following ratio/1/.

$$\frac{q_h^{des} - q_h^{req}}{q_h^{req}} \tag{1a}$$

or

$$\frac{q_h^{fac} - q_h^{req}}{q_h^{req}} \tag{1b}$$

$q_h^{des}$   is designed specific energy consumption of the building

$q_h^{req}$   is required specific energy consumption of the building

$q_h^{desfac}$ is factual specific energy consumption of the building.

The building has a "normal" class of energy efficiency, if its actual specific energy demands for heating are less than 10% of that which is required. Categories of the energy efficiency rating are represented in Table 1.

**Table1. Category of the energy efficiency rating /1/.**

| Designation of category | Name of the energy efficiency rating category | Value of deviation at specific energy demand for heating of a building of a heating season $q_h^{des}$ from normative | Actions which are recommended by government |
|---|---|---|---|
| For new and reconstructed buildings | | | |
| A | Very high | Less than minus 51 | Economical stimulation |
| B | High | From minus 10 till minus 50 | Same |
| C | Normal | From plus 5 till minus 9 | - |
| For existence buildings | | | |
| D | Low | From plus 6 till plus 75 | Advisable reconstruction |
| E | Very low | More than 76 | Needful a reconstruction |

Calculated specific need for useful heat energy on heating the building for heating period $q_h^{des}$ (kJ/m$^3$°C×day) is calculated by formula /1/.

$$q_h^{des} = \frac{10^3 Q_h^y}{A_h D_d} \quad \text{or} \quad q_h^{des} = \frac{10^3 Q_h^y}{V_h D_d} \tag{2}$$

$Q_h^y$    is consumption of heat energy for heating the building for heating period, MJ

$A_h$    is area of the heated premises, m$^2$

$D_d$    is degree days of the heating period, °Cd

$V_h$    is heated volume, m$^3$.

General heat losses through envelope of the building for heating period $Q_h$ (MJ) is calculated by formula /1/

$$Q_h = 0864 K_m D_d A_e^{sum} \tag{3}$$

$D_d$      is degree-days of the heating period

$A_e^{sum}$    is general area of the buildings envelope, $m^2$

$K_m$      is general coefficient of heat transfer , $W/m^{2o}C$.

General coefficient of heat transfer of the buildings is /1/.

$$K_m = K_m^{tr} + K_m^{inf} \tag{4}$$

$K_m^{tr}$    is general coefficient of heat transfer of the buildings, $W/(m^2 \cdot {}^oC)$

$K_m^{inf}$ is reduced infiltrations coefficient of the buildings heat transmission, $W/(m^2 \cdot {}^oC)$.

General coefficient of heat transfer $K_m^{tr}$ is calculated by formula /1/.

$$K_m^{tr} = \frac{\beta\left(\dfrac{A_w}{R_w} + \dfrac{A_F}{R_F} + \dfrac{A_{ed}}{R_{ed}} + \dfrac{A_c}{R_c} + n\dfrac{A_c}{R_c} + n\dfrac{A_f}{R_f}\right)}{A_e^{sum}} \tag{5}$$

$\beta$      is additional heat losses, for residential buildings $\beta$= 1,13 and for other buildings 1,1 ($\beta$ depends on the sides of horizon orientation, with designs of the angular premises. It also depends on the supply of cool air through entrance of residential buildings)

$A_w$      is area of windows, $m^2$

$A_F$      is area of floors, $m^2$

$A_{ed}$     is area of external doors and gates, $m^2$

$A_c$,      is area of overlapping over warm lofts, $m^2$

$A_f$       is area of overlapping over warm cellar, $m^2$

$R_w$      is coefficient of thermal resistance of walls, $m^2$ (°C/W)

$R_F$,     is coefficient of thermal resistance windows and balcony doors, m$^2$ (°C/W)

$R_{ed}$     is coefficient of thermal resistance of external doors and gates, m$^2$ (°C/W)

$R_c$     is coefficient of thermal resistance of overlapping over warm lofts, (°C/W)

$R_f$     is coefficient of thermal resistance of overlapping over warm cellar, m$^2$ (°C/W)

n     is coefficient which depends on positioning of surface building envelope for external air (table 6 in reference /1/).

Parameter $K_m^{inf}$ (W/m$^2$/K) is calculated by formula /1/.

$$K_m^{inf} = \frac{0,28 \cdot c \cdot n_a \cdot \beta_v \cdot V_h \cdot \rho_a^{ht} \cdot k}{A_e^{sum}}$$
(6)

c     is heat capacity of air,  1 kJ/kg°C

$n_a$     is  average air changes for heating period of the, 1/h

$\beta_v$     is coefficient of reducing volume of air in the building

$\rho_a^{ht}$     is average density of supply air for heating period, kg/m$^3$

k     is coefficient of the heat flows account  into the windows.

Average density of supply air for heating period is /1/

$$\rho_a^{ht} = \frac{353}{[273 + 0,5(t_{int} + t_{ext})]}$$
(7)

$t_{int}$     is internal temperature, °C

$t_{ext}$     is external temperature, °C.

However, empirical coefficients are not concerned with real conditions of the buildings exploitation's in this methodology. Accordingly, experimental methods of real thermal resistance determination are more preferable. Thermal protection requirements of buildings must be provided by using ecological materials, which guarantee durability. Durability of envelope is provided by using materials, which must have suitable, withstanding ability: cold endurance, humidity resistance, bio withstand ability, corrosion resistance, high temperatures, thermal oscillation.

Existing norms define three factors of thermal protection in buildings /1/:

1. reduction of thermal resistance of different elements of the building envelope,

2. sanitary-hygienic,

3. Specific energy demand for heating of a building during a heating season.

It is allowed to be varied by envelope heat protection values. In order to archive normative specific energy demand we can vary volume area decisions and the choosing of air conditioning systems. Requirements of building heat protection will be satisfied if requirements "1" and "2" or "2" and "3" are completed.

## 3   TYPES OF ENVELOPE, WHICH PROVIDE REQUIRED HEAT PROTECTION

High requirements for thermal performance of buildings result ~~to~~ in the necessity for the designing and implementation of a building's envelope energy efficiency. For instance, in Saint-Petersburg the necessity insulation for a residential sector is estimated at 25-30 millions $m^3$ in 2010. The main types of heat insulation use are mineral wool, at more than 65% of usage, glass wool at about 8%, cellular polystyrene is 20%, and heat insolated concrete is 3%. /1/

In accordance with energy saving requirements, reduction of thermal resistance is determined by mean temperature and length of the heating season. For Saint-Petersburg the value of the reduction of thermal resistance of external walls is determined by $R_w^{req} = 3,08$ $m^2K/W$ (4796 degree days of heat season. /3/

There are three main types of external walls:

- single-layer construction of walls
- double-layer construction of walls
- and triple-layer construction of walls.

**3.1 Single-layer construction walls.**

Single - layer construction walls are the simplest type to install and exploit. They are produced of constructional thermal insulation material, which combines carrying capacity and thermal protection functions. Taking into consideration requirements for heating protection, walls made of gas concrete are the most acceptable ones. It is possible to use these materials in regions where:

- degree days of heating season are 6000-6500 /3/
- density of gas concrete is less than 500 kg/m$^3$
- wall thickness ≤ 500mm
- coefficient of thermal conductivity λ is less than 0.15 W/ (mK).

Expansion of application domain gas concrete for regions where the degree days of heating season are more than 6500 is possible due to increasing of wall thickness up to 700-750mm, by my own calculations. Generally walls of gas concrete are designed to be self-supporting and obligatorily protected from external atmospheric forcing face work, plasterwork and etc. Walls of effective brick designed to withstand harsh climatic conditions are the most optimal for St. Petersburg.

**3.2 Double - layer construction walls**

Two layer construction of walls contain thermal protective layers. The thermal performance layer can be located inside and outside of the building. Internal insulation must provide protection from moisture and the accumulation of humidity inside of the insulation. It requires special thermo-technical calculations and careful fabrication. Systems with external insulation have many benefits: high thermo technical homogeneity, maintainability and a variety of architectural facade designs.
These types of construction are more popular currently. There are two types of these methods: with external plasterwork on a thermally insulated "wet facade" and with ventilated a facade. The special requirements for a system's "wet facade": thickness of mineral wool not exceeding 150 mm, thickness of cellular polystyrene plates not exceeding 250 mm. They are fixed on the wall by dowels. Thermal insulation is protected from atmospheric forcing by a base-bonding agent, reinforced by a glassy

bond and plasterwork. It is necessary to use safe, durable and compatible components, which partially or completely exclude cracking or crushing of the facades of thermal insulation layers. In accordance with that fact, the components, the materials and the products which are going to be used must be checked against technical validity. Ventilated facade systems differ from "wet facade "systems by the absence of any restrictions towards the thickness of thermo-insulation used. It is protected by facade plates made of various materials, which are attached to a wall with the help of light constrictions, usually produced of a metal profile. Thermo insulation is additionally protected by a vapor barrier. Air-gap clearance is foreseen to have its thickness at about 60mm between facade plates and thermal insulation. Safety and durability of this type depends on many factors including the providing of anticorrosion protection requirements of attaching elements and their connections. Currently external thermal insulation systems are used on most building construction projects with monolith reinforced concrete framing and also when panel and brick buildings are being reconstructed. In such walls thermal insulation should be located outside. If it is located inside the building, humidity accumulation might happen in the thermal insulation layer. In this case the thermal conductivity of this layer will increase, and as a result general thermal resistance of the wall will be reduced.

## 3.3 Triple - layer construction walls

Triple - layer constructions walls include carrying, thermal protection and face-work layers. Brickwork which uses small-pieces products must provide high thermo technical homogeneity of the wall till 0.64-0.74. Using these constructions restricts wall thickness in 500-750 mm. Triple - layer walls from concrete are used in the building of industrial buildings. They have a lower value of thermal resistance than is required. For improving thermo technical homogeneity, hard connections between external and internal layers are replaced by flexible metal connections like separate dowels or combinations of them. In this case plate-overflowing or overflowing thermal insulation are used. Currently there are many examples of three layer constructions, which fit actual norms. Walls from triple layer of light "sandwich panels" triple layers of light "sandwich panels" continue to be widely used mainly in industrial engineering.

### 3.4 Windows

Windows highly influence the heat protection of buildings. Practically, windows' area comprises 17% of a building envelope's total area. For residential buildings, reduction thermal resistance is 0.51 $m^2$K/W /1/. The main types of windows are represented in Table 2.

**Table 2. Reduction thermal resistance $R^Y_f$ of windows.**

| Type of window | $R^Y_F$, ($m^2$K/W) |
|---|---|
| Double glass in separate window sash with solid selective cover of internal glass | 0,48 |
| Triple glazing in separately-ganged cover | 0,55 |
| Single-chamber double-glazed window 4M-16-4M: | |
| - with solid selective cover | 0,51 |
| - with soft selective cover | 0,56 |
| 4M-16Ar-4M | 0.65 |
| Two-chamber double-glazed window 4M-10-4M-10-4M | |
| - usual glass | 0,51 |
| - usual glass (with interglass distance 12 mm) | 0,54 |
| - with solid selective cover | 0,58 |

Accordingly, if reduction thermal resistance is increased from 0,51 $m^2$K/W to 0,65 $m^2$K/W, then specific energy demand for building heating of a heating season is reduced by 15%, it took by my own calculation. In the construction industry, it is necessary to account for the quality of materials used and the quality of work performed. Thermo technical parameters of an envelope influence the heat energy consumption of buildings. Therefore the improving of building thermal performance is one of the most effective ways to conserve heat energy consumption. After analysis, it is estimated that for the residential buildings, reduction of heat energy consumption in buildings with improved thermal protection is about 40% it based on my own calculation.

## 4   ENERGY AUDIT IN RUSSIA

### 4.1 Basic position of energy audit in Russia.

Energy certification of energy resources for consumers is an important instrument for improving energy efficiency. Energy passports confirm the correspondence between real values of energy efficiency and normative values. An energy audit project must include the following main stages:

1.   Analysis of project documentation
     ( chapter "Energy efficiency" in energy passport)
2.   Determination of the thermal technical values of building materials
3.   Survey of building service engineering
4.   Analysis of buildings' heat consumption
5.   Creating or correction of an energy passport
6.   Determination and qualification of operating personnel
7.   Developing of energy conservation actions
8.   Estimation of these actions and their payback time
9.   Implementing of energy saving projects and the monitoring of energy consumption.

Economy of energy in a year ($kW/m^2$year) must be calculated by the results of an energy audit. Economy is estimated in rubles or euro in a given year. Also, total cost of energy saving activities must be estimated. If the realization of all actions related to energy efficiency is too expensive, then it is necessary to realize more profitable projects. /11/

### 4.2 Demands to energy passport of a building.

Energy passport of a building contains features of energy resources consumption of this building. It characterizes thermo technical and energy factors. Energy passport is the most important document in the following situations: During the evaluation of a project by the State Energy Supervision, during a building's application process for exploitation by state architectural building supervision and during inspection of factual values when a building is exploited. Energy passport is filled at the stage of

project creation, at the stage of building inspection for exploitation, taking into consideration all the changes that were implemented during building construction and at the stage of exploitation and after the annual period of a building exploitation. For buildings which already exist, energy passport is developed on the basis of the results of a building's energy audit. Energy passport is created as a separate or complete document for housing and offices. Quality control of a building's heating protection is executed by providing the measurement of a thermo technical building envelope in natural conditions. Energy passports are created in four copies. One of the copies is kept by the project organizers, the second one is kept by the State Architectural Building Supervision inspector, the third passport is sent to the customer, and the fourth is sent to the organization in charge of the building exploitation.

## 4.3 Main terms and determinations

Terms and determinations are used during the creation of energy passport. They are represented in table 3.

**Table 3. Terms and determinations.** /10/

| 1 Thermal performance of a building | Thermal protection characteristics of building envelope, which provides target level of heat energy consumption. |
|---|---|
| 2 Specific energy demand for heating of a building of a heating season | Quantity of heat energy for heating season. It is necessary for compensation of building heat losses. It also takes into account air change rate and additional heat gains. |
| 3 Category of the energy efficiency rating | Designation of building energy efficiency level. It is characterized by interval of specific energy demand for building heating of a heating season. |
| 4 Indoor climate of a premise | Condition of premises internal ambient, which influences human. It is characterized by air temperature, air humidity and air velocity. |
| 5 Optimum parameters of indoor climate of the premises | Combination of indoor climate parameters. During long occupation time 80% of humans feel good in these conditions. |
| 6 Internal heat gain to a building | It is heat, which is supplied into building premises from humans, electricity equipment, electricity motor and others, also from solar radiation. |
| 7 Index of the shape of a building | It is ratio between total area of a building envelope and heated volume. |
| 8 Glazing-to-wall ratio | It is ratio between windows and total area |
| 9 Heating volume of a building | Volume, which is restricted by internal surfaces of a building external envelope – walls, floor, roof. |
| 10 Cold (heating) season of a year | Period of the year, which is characterized by mean daily temperature of air less than 10 or 8°C. |
| 11 Warm season of a year | Period of the year. It is characterized by mean daily temperature of air more than 10 or 8°C. |
| 12 Length of the heating season | Predicted period when heating system works. |
| 13 Mean temperature of outdoor air of the heating season | Calculated temperature of external air, which is averaged per heating season by mean daily temperature of external air. |

**4.4 Application to energy passport**

Example of energy passport is in appendix 1. General information of project includes address of the building, designer of the project, number of the project, type of the building and type of the walls, the roofing, the windows and heating system.

Accounting conditions (climatic conditions) are given and taken for Saint Petersburg temperature of the premises. Temperature of the internal air $t_{int}$ for residential building is 20 $^o$C and temperature of the outdoor air $t_{ext}$ is –26 $^o$C/3/. The duration of the heating period $z_{ht}$ is 220 days for Saint-Petersburg and average temperature of outdoor air for heating period $t^{av}_{ext}$ is –1,8 $^o$C /3/. Degree-days of the heating period Dd is 4796 $^o$Cd /3/.

The functionality, type and design of the building (all characteristics) are taken from project of the building. Area and volume are calculated in accordance to requirements of standards. General area of the building envelope $A_e^{sum}$ is area of the walls, including windows and balcony doors, and external doors and gates.

Area $A_{w+F+ed}$ is calculated by formula /1/

$$A_{w+F+ed} = \Sigma p_{sti} \cdot H_{hi}$$
(8)

$\Sigma P_{sti}$ is internal perimeter to surfaces of external walls I floor, m

$H_{hi}$ is height of the floors.

Area of the external walls $A_w$ is calculated by formula /1/.

$$A_w = A_{w+F+ed} - A_F - A_{sky}$$
(9)

$A_F$ is area of the windows, m$^2$

$A_{ed}$ is area of the external doors and gates, m$^2$

$A_{sky}$ is area of windows which are installed in horizontal direction.

General area of the building envelope $A_e^{sum}$ is calculated by formula /1/

$$A_e^{sum} = A_{w+F+ed} + A_f + A_{\tilde{n}} + A_{scy}$$

$$(10)$$

$A_f$      is area of windows

$A_n$      is area of doors

$A_{scy}$      is area of skylight.

Area of the heated premises $A_h$ is calculated in the project. Heating volume of the building $V_h$ ( $m^3$ ) is calculated by formula /1/

$$V_h = \sum A_{sti} \times H_{hi}$$

$$(11)$$

$A_{sti}$      is building area

$H_{hi}$      is building height

Factors of volume's designs are calculated by formula glazing-to-wall ratio /1/

$$p = A_F / A_{w+F+ed}$$

$$(12)$$

$A_F$      is area of the windows.

Index of the shape of a building is calculated by formula/1/

$$k_e^{des} = A_e^{sum} / V_h$$

$$(13)$$

Section «Energy's factors » includes thermal-technical and thermal-energy's factors. According to the building standards and rules /1/ reduction thermal resistance of different external envelope determines. Value $R_o^r$ ($m^2$K/W) must be taken not below required value $R_o^{req}$.

General coefficient of heat transfer is calculated by formula /1/

$$K_m^{tr} = \beta \left( \frac{A_w}{R_w} + \frac{A_F}{R_F} + \frac{A_{ed}}{R_{ed}} + n \times \frac{A_c}{R_c} + n \times \frac{A_f}{R_f} \right) / A_{sum}$$

(14)

$\beta$      is additional heat losses (depends on the sides of horizon orientation, with designs of the angular premises. It also depends on the supply of cool air through entrance of residential buildings), $\beta$ is 1,13 for residential buildings and for other buildings 1,1

$A_w$      is area of wall, m$^2$

$A_F$,      is area of windows and balcony doors, m$^2$

$A_{ed}$,      is area of external doors and gates, m$^2$

$A_c$,      is overlapping over warm lofts, m$^2$

$A_f$      is area of overlapping over warm cellar, m$^2$

R      is coefficient of thermal resistance of walls, windows and balcony doors, external doors and gates, overlapping over warm lofts and overlapping over warm cellar, m$^2$ °C/W

n      is coefficient depends on positioning of surface building envelope for external air according to table 6 in /1/.

Required air change rate of residential building $n_a$ (h$^{-1}$) according to SNiP 2.08.01 for dwelling premises is 3 m$^3$/h removing air forms 1 m$^2$ of dwelling's premises and kitchen. Air change rate of buildings $n_a$ is calculated by formula /10/

$$n_a = 3*A_l/V_h$$

(15)

Reduced infiltrations coefficient of the buildings heat transmission is calculated by formula /1/

$$K_m^{inf} = 0,28 c n_a \beta_v V_h \rho_a^{ht} k / A_e^{sum}$$

(16)

$c$      is heat capacity of the air, 1 kJ/(kg·°C)

$\beta_v$      is coefficient of reducing volume of air in the building

$\rho_a^{ht}$      is average density of air supply for heating period, kg/m$^3$.

Average density of air supply for heating period, kg/m$^3$ is calculated by formula /1/

$$\rho_a^{ht} = 353/[273 + 0.5(t_{int} + t_{ext})]$$

(17)

$n_a$     is average air changes for heating period

$t_{int}$     is internal temperature, °C

$t_{ext}$     is external temperature, °C.

General coefficient of heat transfer of the buildings $K_m$ (W/ (m$^2$·°C)) is calculated by formula /1/

$$K_m = K_m^{tr} + K_m^{inf}$$

(18)

General heat losses through envelope of the building for heating period $Q_h$ (MJ) are calculated by formula /1/.

$$Q_h = 0.0864 K_m D_d A_e^{sum}$$

(19)

Internal heat gains to a building for heating period $Q_{int}$, (MJ) are calculated by formula /1/

$$Q_{int} = 0.0864 \times q_{int} \times Z_{ht} \times A_{sum}$$

(20)

$q_{int}$     is specific heat gains from installed equipments and from humans, W/m$^2$

$Z_{ht}$     is length of the heating season

$A_{sum}$     is general area of the building envelope.

Heat gains from solar energy for heating period $Q_s$ (MJ) is calculated by formula /1/

$$Q_s = \tau_F \times k_F \left( \sum_{i=1}^{n} A_{Fi} \times I_i \right) + \tau_{scy} k_{scy} A_{scy} I_{hor}$$

(21)

$\tau_F$ , $\tau_{scy}$     is coefficients dependent on shading of the window

$k_F$, $k_{sky}$        is coefficients relative of penetration solar radiation according to the

   amount of the windows.

$A_{Fi}$        is area of the windows oriented on four directions, $m^2$

$I_1$, $I_2$, $I_3$, $I_4$    is average for heating period value to solar radiation on vertical

   surfaces. According to the orientation of the building on four parts of

   the world, $MJ/m^2$ (coefficients are taken from table 4.4 /1/).

Energy demand for heating of a building of a heating season $Q_h^v$, (MJ) is calculated by formula /1/

$$Q_h^y = [Q_h - (Q_{int} + Q_s)v\zeta]\beta_h \tag{22}$$

$Q_h$    is general heat losses through envelope of the building for heating period, MJ

$Q_{int}$    is heat gains in to the building from heating period, MJ

$Q_s$    is heat gains throw the windows from solar energy for heating period, MJ

$v$    is coefficient of reduction heat using heat inertness of envelope, recommended

   value is $v$=0,8

$\zeta$    is the coefficient to efficiency of auto regulation heating supply in the heating

   systems, which is chosen in appendix «Г»/1/.

 Calculated specific need for useful heat energy on heating the building for heating

period $q_h^{des}$, (kJ/$m^3$°C×day) is calculated by formula /1/

$$q_h^{des} = 10^3 Q_h^y / (A_h D_d) \tag{23} \text{ or } q_h^{des} = 10^3 Q_h^y / (V_h D_d), \tag{24}$$

$Q_h^y$    is consumption of heat energy for heating the building for heating period, MJ

$A_h$    is area of the heated premises, $m^2$

$V_h$    is heated volume, $m^3$

$D_d$    is degree-days of the heating period.

Calculated coefficient of the energy efficiency for a building heating system from district heating $\eta_o^{des}$ is calculated accordingly to section 5 of /10/. In this case the building is connected to the central heating supplying system. In the studied case the building is connected to the central heating system, so $\eta_o^{des} = 0.5$ /1/.


## 5  ENERGY SURVEY IN RUSSIA

### 5.1 Energy survey of buildings

Energy survey of a building includes two things: providing a thermal vision survey and determination of the real values of building's envelope thermal resistance. Thermal resistance of the envelope can be experimentally determined by two examinations. Those are thermal vision examination and contact method of the measurements, which are provided in accordance with the following standards GOST 26629-85 «Buildings and structures. Methods of thermal vision inspection of enclosing structures thermal insulation quality» and SNiP 23-02-2003 «thermal performance of buildings», GOST 26254-84. Buildings and structures. Methods for determination of thermal resistance of enclosing structures and ISO 6781 «Thermal insulation, qualitative detection of thermal irregularities in building envelopes, Infrared Method».

Complex methods of the quality thermo insulation inspection of building envelopes are approved and recommended by Gosstroy Russia supervision quality of heat insulation envelope of the buildings by method of thermo vision control in natural conditions (letter of the Gosstroy Russia№ 9-14/93 at 23.01.02).

### 5.2 Thermal and vision surveys of building envelopes

Objectivities of thermal and vision surveys are determination of latent defects and cracks in a building envelope, poor providing of wall panels connections, absence or shrinkage loss of the thermal insulation and incorrect installation of windows and balcony doors. Internal and external surfaces of the building's envelope are subjected to thermal and vision survey.

Results of thermal and vision survey are a determination of places and section values, which must be improved and renovated. It will get heat losses reduction and economy of energy resources.

Thermal and vision methods are based on distance measurements and the registration of temperature field on surface of the building's envelope by a thermo - vision camera .The Analysis of temperature field allows defining defects of thermal insulation. Temperature differences between internal and external surfaces of the building's envelope must be sufficient during the thermo vision survey.

**Table 4. Equipments.**

| Thermal and vision camera   TermoCAM$^{TM}$E45 : |
| --- |
| - Thermal range       $0.1^{o}$C on $30\ ^{o}$C. <br> - Spectral range       7-13 mkm. <br> - Temperature range     - $20\ ^{o}$C … +$250\ ^{o}$C. <br> - range of moisture       20 –80%. |
| Digital camera- DIGITAL CAMERA Power Shot G2 <br>    - Size of picture 1400*8000 pixel. <br>    - Lens  16 X. |
| Thermometer contact digital TK- 5.05: <br> - Range of temperature – 199 oC …+1300 oC. <br> - Definition 0.1 oC. <br> - Inaccuracy of measuring the temperature ±0.5 oC. |

It is recommended to make thermal and vision estimations in the heated buildings. Temperature differences of internal and external air must be more than 20°C.

Atmospheric precipitations, mist, smoke content and etc. are inadmissible during thermal and vision survey. Surfaces must be outside of areas, which are influenced by direct solar irradiation.

Minimum temperature difference $\Delta t_{min}$ is calculated by formula /6/

$$\Delta t_{min} = \Theta R_o^n \frac{\alpha r}{1 - r}$$

(23)

$\theta$      is limit of temperatures sensitive of the thermo

$R_o^n$      is design's value of thermal resistance

$\alpha$      is coefficient of heat transfer

r      is relative resistance of heat transfer on defects part.

## 5.3. The analysis of inspection results

Analysis of inspections results is provided by computer, with using special soft programs. Defect areas are determined by results of thermal pictures analysis. In figure 1 and 2 there are some examples of thermo vision's examinations.

Local temperature of upper corner is 4.4 °C, it means that insulation of corner is poor.

Local temperature of upper part of the wall is 5.5 °C. It is lower of dew point. Defect of the construction.

There is the defect of windows montage.
Temperature in lower part of the windows is minus.
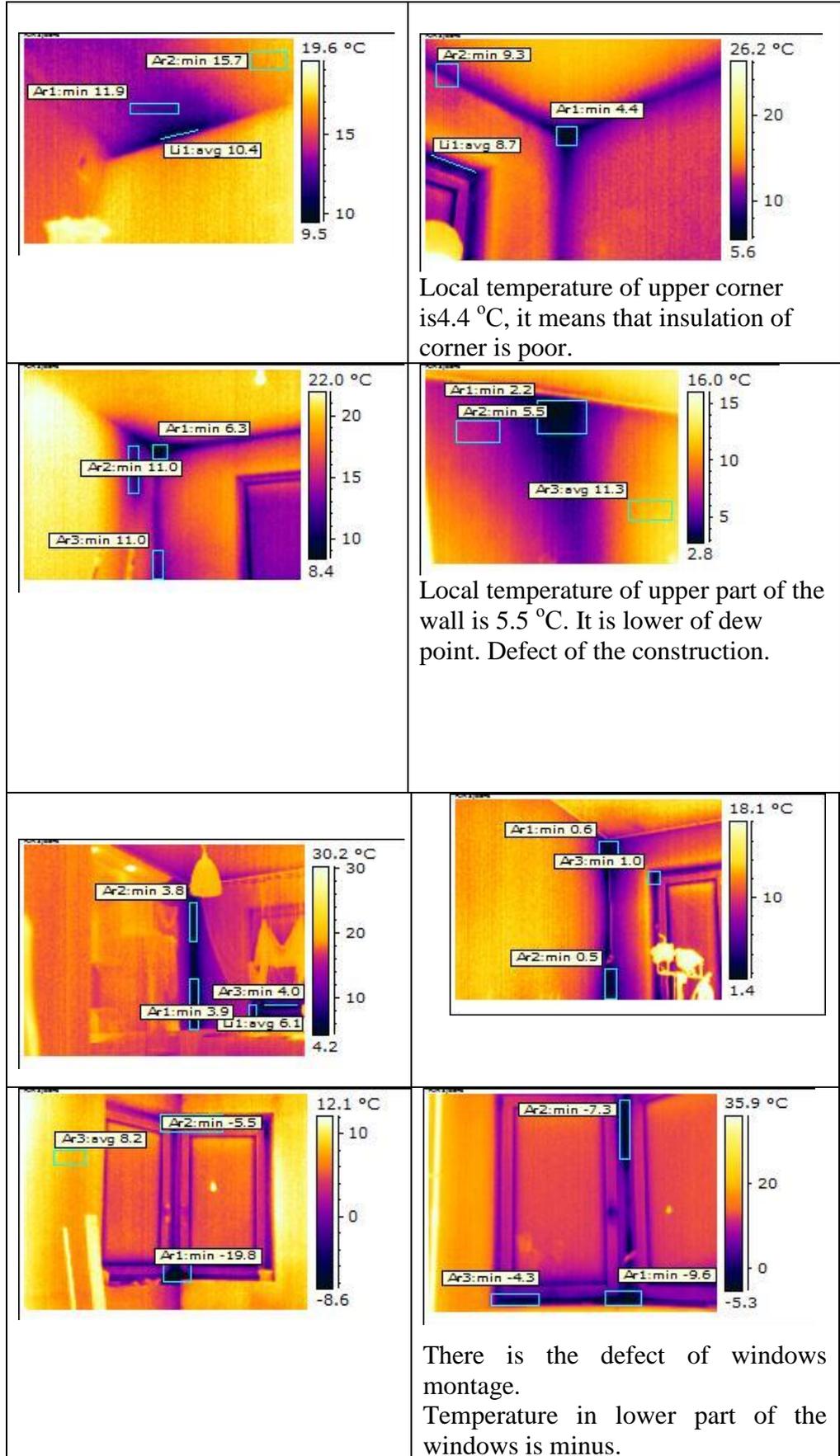
**Figure 1. Thermograph of internal surfaces of premises.**
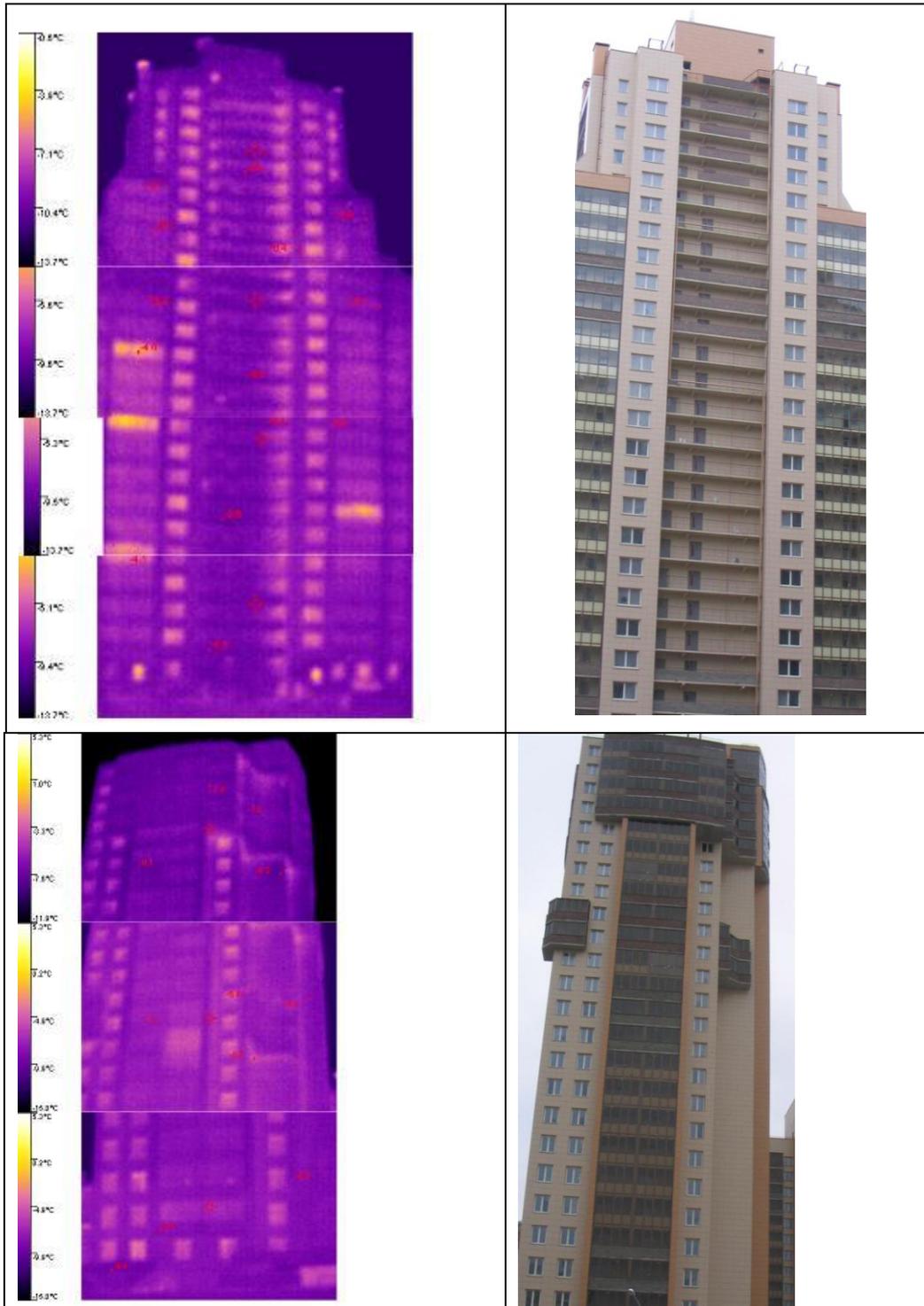
**Figure 2. Thermograph of external surfaces of premises.**

Temperature $\tau_B{}^{calc}$ is defined by Thermo-Vision shoot results on surfaces of the base area (Fig.1) by formula /8/

$$\tau_B^{calc} = t_\text{в} - (t_\text{в} - \tau_\text{в}') \cdot \alpha_\text{в} / \alpha_\text{в}' \qquad (24)$$

$\tau_B{}^{calc}$ is temperature on surface of basic area

$\tau_\text{в}'$ is temperature on internal surface of envelop

$\alpha$ is heat-transfer coefficient of internal surface in experiment

$\alpha'$ is value of heat-transfer coefficient of internal.

Temperature of internal surface for enclosing structures is

$$\tau_\text{â}' = t_\text{â} - (t_\text{â}^{\acute{y}} - \tau_\text{â}^{\acute{y}}) \cdot (t_\text{â} - t_\text{í}) / (t_\text{â}^{\acute{y}}, t_\text{í}^{\acute{y}}) \qquad (25)$$

$\tau_\text{â}'$ is temperature of internal surface for enclosing structures /9/

$t_\text{â}$ is calculation's temperature of internal air (GOST 12.1.005)

$t_\text{â}^{\acute{y}}, t_\text{í}^{\acute{y}}$ is average internal and external temperatures of air on measurements period

$\tau_\text{â}^{\acute{y}}$ is average temperature of internal surface of the building's envelope on measurements period

$t_\text{í}$ is calculation temperature of external air.

Resistance of heat transfer is calculated by formula /9/

$$r(x,y) = \frac{(t_\text{â} - t_\text{í}) \cdot (t_\text{â}^\text{á} - \tau_\text{â}^\text{á})}{(t_\text{â}^\text{á} - t_\text{í}^\text{á}) \cdot (t_\text{â} - \tau_\text{â}(x,y))} \qquad (26)$$

$\tau_\text{â}(x,y)$ is temperature of the isotope, going through the point with coordinates x, y.

Critical value of the relative resistance is determined by formula /9/

$$r_{\hat{e}\eth} = \frac{R_0^{\grave{o}\,\eth}}{R_0^{\acute{a}}}$$

(27)

where

$$R_0^{\acute{a}} = \frac{(t_{\hat{a}i} - t_{\i i}) \cdot R_{\hat{a}i}}{(t_{\hat{a}i} - \tau_{\hat{a}i})}$$

(28)

or

$$R_0^{\acute{a}} = \frac{(t_{\hat{a}i} - \tau_{\hat{a}i})}{q_{\hat{o}\,i}} + \frac{(\tau_{\hat{a}i} - \tau_{\i i})}{q_{\hat{o}\,i}} + \frac{(\tau_{\i i} - t_{\i i})}{q_{\hat{o}\,i}}$$

(29)

$$R_{\hat{a}i} = \frac{1}{(\alpha_{\hat{e}i} - \alpha_{\ddot{e}i})}$$

(30)

## 5.4. Determination of real thermal resistance

Determination of real thermal resistance is provided in climatic camera by test centre «BLOK» with using qualified equipment «SISTOK» in accordance to GOST 530-95, GOST 26254-84 and GOST 30256-94.Complectation of « SISTOK » is represented in table 5.

Basic sections for survey are determined by thermal and vision examinations Thermal couple and heat meter are installed on internal and external building surfaces. Measurements of thermal resistance are provided after stabilization of regimes. The registration of heat flow and temperature changes through building's envelopes during two weeks is represented in figures 3 and 4.

**Table 5. COMPLETING «SISTOCK».**

| Name | Quantity | Note |
|---|---|---|
| Meter to density of the heat flow (heat-measures) GOST 25380-82. | 15 | The Meter to density of the heat flow has a certification as working facility of the measurement within the range from 10 till 250 W/m$^2$ with inaccuracy ±4. |
| Thermo-electrical transformer (thermocouple) of the type copper-constant GOST 1790-77. | 32 | Thermo-electrical transformer has an individual dialing with inaccuracy not more than ±0.1 $^0$C. |
| Meter of the temperature many-server IT-2, connected to personal computer and printer through port RS 232. (Windows 98, MS Office 2000). | 1 | The Meter of the temperature many-server IT-2, which has acting certificate about check in set with personal computer. |
| Aspirated psychrometer, MB-4M (GOST6353-52). | 2 | |
| Package of the applied programs in composition: installation IT-2-96. | 1 | Must be installed on a personal computer. |
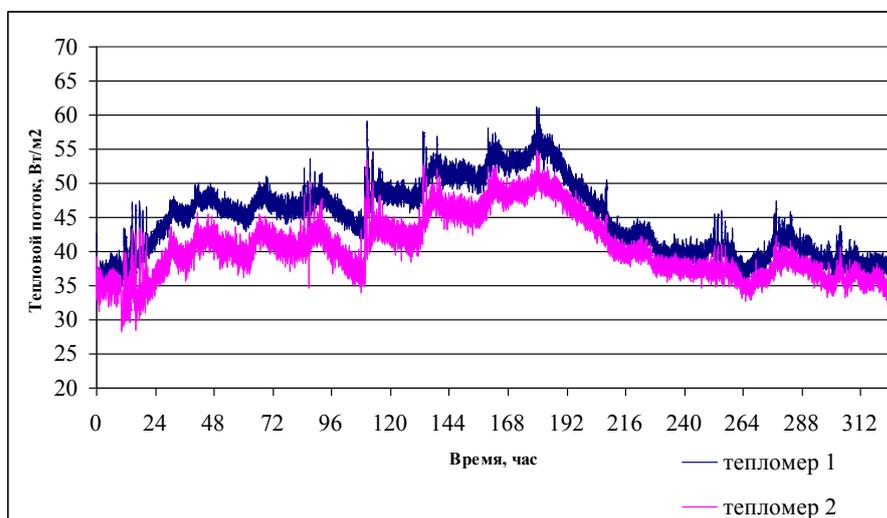


Тепловой поток, Вт/м$^2$- Heat flow W/m$^2$. Время, час- time, hour. Тепломер- heat meter.

**Figure 3. Heat flow.**
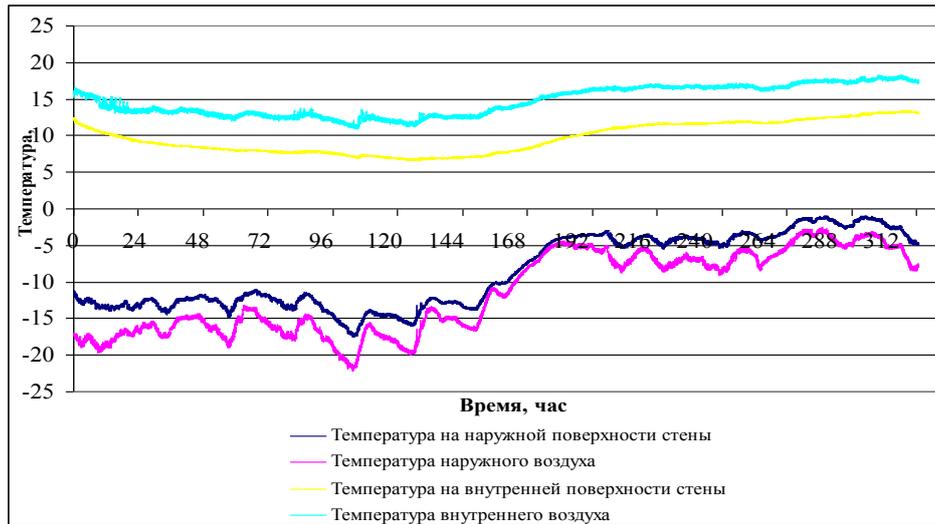
Температура- temperature.

Температура на наружной поверхности стены- temperature of walls external surface.

Температура наружного воздуха- temperature of external air.

Температура на внутренней поверхности стены- temperature of walls internal surface.

Температура внутреннего воздуха- temperature of internal air.

**Figure 4. Temperature.**

The analysis of curves can show that choice of stable zones is very difficult. Inaccuracy depends on this factor. A stabilizer of temperature regimes is used for improving of measurement accuracy. It consists of two flat square heaters which have 800 mm in height and 1200 mm in width. They are connected to the regulators of temperature, which provide a stable thermal regime. It is represented in the figure 5
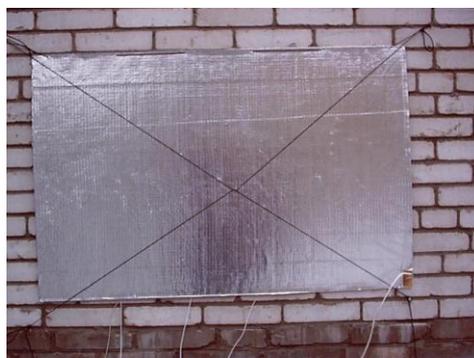


**Figure 5. Flat heater, which provides stable thermal regimes.**

Usage of this heater provides a possibility to take measurements in various weather conditions with accuracy requirement. It allows reduce the measurement time down to 2-7 days.

There is high inaccuracy of determination windows thermal resistance during measurement in real conditions. Thermal resistance of windows is determined in climatic camera for reduction of measurement inaccuracy.

Fragment of the building's envelope (external wall, windows and overlap) is installed in embrasure of climatic camera. It is represented in figure 6. Thermal couple and heat meter are installed on internal and external surfaces. Location of thermo couple is determined by the results of thermo vision survey.



**Figure 6. Location construction in climatic camera.**

During the process of examination in cold chamber temperature is supported at the level of -26 $^{o}$C -30 $^{o}$C with air humidity 70%. In warm chamber temperature is provided at the level of18–20 $^{o}$C. Gradient of temperature in climatic camera should not exceed 1.5 $^{o}$C.

For determination of the temperature and heat flow measurement system "SISTOK» is used. It also has an output of information on a computer. 15 calorimeters are located

on the warm sides of the panels. Every calorimeter has two thermocouples. One of them is located on the warm part and the second on the cool side of the panel. There are 30 thermocouples in total. Two thermocouples are used for determination of the temperature in both parts of the climatic camera. Determination of the reduction of thermal resistance is provided during the stationary regime of heat transfer. The output on stationary condition is defined according to the heat flow record on a computer. The reduction of thermal resistance is defined as an average result of 10 measurement series. The resistance to heat transfer is determined by formula /8/.

$$R_O = \frac{A}{\sum_{i=1}^{n} \frac{A_i \times R_{oi}}{R_{oi}}}$$

(31)

$A_i, R_{oi}$ are part of constructer and resistance to heat transfer

A is area of «base area».

Values $R_i$ is calculated by formula /12/

$$R_i = \frac{\Delta T_i}{q_i}$$

(32)

$\Delta T_i$ is temperature difference between internal and external surfaces (it is fixed by thermocouples, q- heat flow, i- number of calorimeter)

Reduction thermal resistance of the constructions is determined by formula /8/

$$R_{i\delta} = \frac{1}{\alpha_{\hat{a}}} + R_o + \frac{1}{\alpha_i}$$

(33)

## 6 ENERGY PASSPORT BASED ON REAL VALUES

### 6.1 Result of measurements

Result of measurements in accordance to methodology which is represented in table 6.

**Table 6. Result of thermal resistance measurements.**

| | Thermo technical factors | | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| | Reduction thermal resistance of envelope | $R_o{}^r, м^2 x°C/Bm$ | |
| | - walls | $R_w$ | 2,85 |
| | - windows | $R_F$ | 0,53 |

These results were used for correction of the energy passport of the building, which was based on these project dates.

**Table 7. Thermal-technical factors.**

| № | Factor | Symbols designation and units | Normative value of the factor | Calculated (design) value factor | Real value |
|---|---|---|---|---|---|
| | | Thermal-technical factors | | | |
| | | Thermal factors | | | |
| 1 | 2 | | 4 | 5 | 6 |
| 19 | Reduction thermal resistance of: | $R_o{}^r, m^2 x°C/W$ | | | |
| | - walls | $R_w$ | 3,08 | 3,50 | 2.85 |
| | - windows and balcony doors | $R_F$ | 0,44 | 0,48 | 0.53 |
| | - doors | $R_{ed}$ | 1,2 | 1,2 | 1.2 |
| | - overlapping warm lofts | $R_c$ | 4,6 | 4,4 | 4.4 |
| | - overlapping on warm cellar | $R_f$ | 4,06 | 4,1 | 4.1 |
| 20 | Heat transfer coefficient | $U_m{}^{tr}, W/(m^2 \times °C)$ | -- | 0,63 | 0.64 |
| 21 | Air changes per hour | $n_a, h^{-1}$ | | 0,49 | 0.49 |
| | Air changes per hour with 50Pa | $n_{50}, h^{-1}$ | | -- | -- |
| 22 | Ifiltrtation coefficient of heat transmission of the building | $U_m{}^{inf}, W/(m^2 \times °C)$ | -- | 0,54 | 0.54 |
| 23 | General coefficient of heat transmition of the building | $U_m, W/(m^2 \times °C)$ | -- | 1,17 | 1.19 |

**Table 8. Thermal energy factors.**

| № | Factor | Symbols designation and units | Normative value of the factor | Calculated (design) value factor | Real value |
|---|--------|-------------------------------|-------------------------------|----------------------------------|------------|
| | | | **Thermal energy factors** | | |
| | | | **Energy factors** | | |
| 24 | General heat losses through the building envelope for heating period | $Q_h$, MJ | -- | 4724298 | 4780228 |
| 25 | Specific internal heat gains to a building | $q_{int}$, $W/m^2$ | min 10 | 13 | 13 |
| 26 | Internal heat gains to a building | $Q_{int}$, MJ | -- | 1649444 | 1649419 |
| 27 | Heat gains from solar radiation | $Q_s$, MJ | -- | 418711 | 418711 |
| 28 | Energy demand for heating of a building of a heating season | $Q_h^y$, MJ | -- | 3591101 | 3653203 |
| 29 | Specific energy demand for heating of a building of a heating season | $q_h^{des}$, $kJ/m^2$ $*°C×day$ | 70 | 68 | 74 |
| | | | **Comparison with normative requirements** | | |
| 30 | Calculated coefficient of the energy efficiency for building heating system from district heating | $h_o^{des}$ | | 0,5 | 0,5 |
| 31 | Normative Specific energy demand for heating of a building of a heating season | $q_h^{req}$, $kJ/(m^2×°C×day)$ | | 70 | 70 |
| 32 | Meets the requirements of the design of the building | | | Yes | Yes |
| 33 | Category of the energy efficiency rating | | | *C* | *C* |
| 34 | Should the design be improved? | | | No | No |

**6.2 The analysis of the building energy passports**

Usually, factual thermal resistance is lower than theoretical. It is explained, that, moisture of a building construction is higher than in theoretical calculations. Consequently, energy consumption is higher than calculated values in the first three years.

The defects of constructions give additional heat losses. Validity of predicted heat consumption for maintenance of microclimatic parameter requirements depend on accuracy determination of envelope thermal resistance.

**7 FACTORS WHICH INFLUENCE HEATING REGIME OF BUILDINGS**

**7.1 Moisture content of building materials**

Practically, panel constructions have primary moisture content. It depends on the mode of production and drying process. In the first years of exploitation panel moisture is twice as large as normative values and influences microclimatic premises.

At external side of building envelope during prime period of exploitation conditioning ice "membrane" is generated in winter. It reduces conditioning of construction drying. Average thickness moisture on walls of envelope is practically equal to primary value. Moisture of material is established after 3-5 years.

Texture layer makes a resistance to moisture evaporation. Consequently, moisture of single - layer constructions is less 1.5-2 times, than in single - layer with texture coat and double - layer panels.

There is high moisture, which is content in building materials with capillary leak-in. Value of moisture depends on materials properties and density. For instance, value of moisture content of gas-concrete: with $\rho=400kg/m^3$- 60%, with $\rho=700kg/m^3$- 40%. Existence of the protection cover reduces water absorption of gas-concrete to18-20%.

Moisture regimes of constructions also depend on internal air humidity, which is determined by processes in premises, quality of heating and ventilation systems.

Internal air humidity is standardized for residential and public buildings in interval 50-70%.

Water vapor, which can exist in premises air, can be condensed on internal surface of the envelope, if temperature is less than dew point of the air. It is the most probable situation when there is fast reduction of air temperature. In process of diffusion through construction vapor it is condensed inside the wall during its contact with cold layers. During this process liquid phase is also formed. Liquid phase is transformed into ice when the temperature is cold. Periodical and frequent recurrent events of capillary condensation result in stage-by-stage destruction of small pores and capillary surfaces.

We need to take into account humidification of construction by atmospheric moisture in consequence of sorption, because air humidity is about 80-90% in Saint – Petersburg(during transition periods of the year). For example, during sorption humidification with φ=100% moisture of expanded-clay concrete is 6%, gas concrete-13%.

In normal conditions of exploitation moisture, which is accumulated in construction during cold period of the year, must be deleted in warm period. Otherwise heightening content of moisture may bring to following negative consequences: corrosion of metal items, lime carbonate extraction from concrete, reducing thermo technical properties of construction, formatting of mould on walls, reducing life span of an envelope. During dysfunction of heating regime moisture of constructions is increased as a result of sorption and condensate humidification.

Thermo protection properties of buildings depend on material moisture. Most of building materials─ porous, they content many pores, which are filled by air in dry condition. During increasing moisture pores are filled by humidity. Coefficient of thermal conductivity of water is in twenty times more than of the air. It reduces thermal protection characteristics of building materials. For this reason during designing and building process of houses it is necessary to make barrier to humidification by atmospheric condensation, ground water and moisture.

**7.2 The influence of air infiltration**

The main cause of air infiltration is the stack effect and wind pressure, pressure differences between internal and external sides of envelopes. Wind pressure depends on the aerodynamic coefficient (which depends on the building mode and direction of wind), the area of the envelope (which is exposed to action of wind and air permeability) the internal planning of a building, the air tightness of windows and doors and the building height. Additional air changes in residential buildings are raised by leakage through the envelope, practically in windows and balcony doors. The stack effect depends on the temperature difference and the location of air leakage rates. The infiltration of air is reduced by increasing of number of storeys. On first floor of a high building air infiltration is higher than on the upper floor. It is very important to take into account that the air infiltration in buildings influences the air penetration through cracks and chinks in walls, roofs and window frames. Heat losses of buildings by air infiltration through jointing, windows and balcony doors can achieve 50%, it based on my own calculation.

In accordance with building roles № 23-101-2004 air change is $3m^3/m^2$ of dwelling area is recommended. In our building air changes the rate is 0.49. Dependence on total heat losses through building envelope for heating period and specific energy demand for buildings' heating during the heating period from air changes rate is represented in table 9.

**Table 9. Dependence on total heat losses through building envelope.**

| air changes rate | 0,4 | 0,49 | 0,6 | 0,7 | 0,8 | 0,9 | 1 |
|---|---|---|---|---|---|---|---|
| Total heat losses $Q_h$ , MJ | 4338724 | 4724265 | 5243296 | 5695582 | 6147868 | 6600154 | 7052440 |
| Energy demand for heating of a building of a heating season $Q_h^y$, MJ | 2159059 | 2661096 | 3163134 | 3591084 | 4167209 | 4669246 | 5171284 |
| Specific energy demand for heating of a building of a heating season $q_h^{des}$, *kJ/m²* *°C×day* | 41 | 51 | 60 | 68 | 79 | 89 | 99 |
| % from norm | -14 | -2 | 14 | 27 | 41 | 55 | 68 |
| Class of energy efficiency | High | Normal | Low | | | | |

In the table 9 we can see, that air change rate influences the class of the building energy efficiency. According to class norms of energy efficiency "normal" corresponds to air change rate 0.49. If air change rate rises from 0.5 till 1, then energy demand for the building heating will rise in two times. Class of the building energy efficiency will be "low". So, building can change class "normal" into "low", but it has the thermal protection which is required to the norms of thermal performance of

buildings. We also need to take into account that it is  true, if automation system is installed and parameters of heat flow depend on the temperature of internal and external air. It is necessary to install supply and exhaust mechanical ventilation with heat recovery for achievement comfortable parameters of microclimate. Actions for reducing heat losses by air infiltration: improving of entrance doors hermiticity, rise air tightness of the windows, lower mortise ought to be installed in internal doors between dwelling premises. Air velocity indoor's mortises must be less than 0.3m/s. Installation of exhaust air ducts individual exhaust axial ventilator with electrical motor and inverted valve and designing apartments without through ventilation.

## 8 EVALUATION OF THE BUILDINGS ENERGY EFFICIENCY BY FINISH METHODS D5

### 8.1 Introduction

In Finland, as in most developed nations much attention to energy efficiency of the building is paid. In this country method of building energy efficiency evaluation was created. In this case Finish norm (national building code D5) "D5 Rakennuksen energiankulutuksen ja lämmitystehontarpeen laskenta, Suomen rakentamismääräyskokoelma ympäristöministeriö, Asunto ja rakennusosasto, 2007" is used. For correct comparison of two methods consumption of hot water and electric energy are not taken into account.

### 8.2 General methods of D5

Heat losses through building envelope is calculated by formula.

$$Q_{joht} = \sum H_{joht} \left( T_s - T_u \right) \Delta t / 1000$$

(34)

$O_{joht}$     is heat losses through building envelope, kWh

$H_{joht}$     is nominal conductivity of the envelope, W/K

$\Delta t$     is time hours of specific month, h

$T_s$     is indoor temperature of air, °C

$T_u$     is average outdoor temperature of air of the month, °C.

Nominal conductivity of the envelope is calculated by formula

$$\sum H_{joht} = \sum(U_{ulkoseinä}\, A_{ulkoseinä}) + \sum(U_{yläpohja}\, A_{yläpohja}) + \sum(U_{alapohja}\, A_{alapohja}) +$$
$$\sum(U_{ikkuna}\, A_{ikkuna}) + \sum(U_{ovi}\, A_{ovi}) \tag{35}$$

$\sum H_{joht}$        is nominal conductivity of the envelope, W/K

$U_{ulkoseinä}$       is coefficient of thermal transmittance of the wall W/(m²K)

$A_{ulkoseina}$       is area of the wall, m²

$U_{yläpohja}$       is coefficient of thermal transmittance of the roof, W/(m²K)

$A_{ylapohja}$       is area of the roof, m²

$U_{alapohja}$       is coefficient of thermal transmittance of the floor, W/(m²K)

$A_{alapohja}$       is area of the floor, m²

$U_{ikkuna}$       is coefficient of thermal transmittance of the window, W/(m²K)

$A_{ikkuna}$       is area of the windows, m²

$U_{ovi}$       is coefficient of thermal transmittance of the door, W/(m²K)

$A_{ovi}$       is area of the doors, m².

Average annual temperature of the ground $T_{maa,vuosi}$ (°C) is calculated by formula.

$$T_{maa,\ vuosi} = T_{u,\ vuosi} + \Delta T_{maa,\ vuosi} \tag{36}$$

$T_{u,\ vuosi}$       is average annual temperature of the external air, °C

$\Delta T_{maa,\ vuosi}$      is difference of the temperature between average annual temperature and the ground below floor (D5, table 4.1), ° C.

Average monthly temperature of the ground $T_{maa,kuukausi}$ (°C) is calculated by formula.

$$T_{maa,kuukausi} = T_{maa,\ vuosi} + \Delta T_{maa,kuukausi} \tag{37}$$

$T_{maa,\ vuosi}$       is average annual temperature of the ground, °C

$\Delta T_{maa,\ kuukausi}$     is difference of the temperature between average monthly temperature and the ground below the floor (D5, table 4.2), °C.

## 8.3 Energy demand of heating of leakage air

Heat losses by leakage of air are calculated by formula

$$Q_{vuotoilma} = H_{vuotoilma}(T_s - T_u)\,\Delta t/1000$$

<div align="right">(38)</div>

$Q_{vuotoilma}$      is heat losses by leakage of air, kWh

$H_{vuotoilma}$      is specific heat load of leakage air, W/K

$T_s$      is indoor temperature of air, °C

$T_u$      is outdoor temperature of air, °C

$\Delta t$      is amount of hours in the month, h.

Specific heat loss of leakage air is calculated by formula

$$H_{vuotoilma} = \rho_i c_{pi} q_{v,\,vuotoilma}$$

<div align="right">(39)</div>

$\rho_i$      is density of the air, 1,2 kg/m³

$c_{pi}$      is specific heat capacity of the air, 1000 Ws/kg°C

$q_{v,\,vuotoilma}$      is leakage air flow rate, m³/s.

Leakage air flow rate is calculated by formula.

$$q_{v,\,vuotoilma} = n_{vuotoilma}\,V/3600$$

<div align="right">(40)</div>

$q_{v,\,vuotoilma}$      is leakage air, m³/s

$n_{vuotoilma}$      is air change rate , normal value is 0.16 h$^{-1}$

V      is air volume of the building, m³

3600      is factor of transformation to m³/h >m³/s.

## 8.4 Losses of heating systems

Heat losses of the heating system are calculated by formula.

$$Q_{\text{lämmitys, tilat, häviöt}} = Q_{\text{lämmitys, tilat, kehityshäviöt}} + Q_{\text{lämmitys, tilat, jakeluhäviöt}} + Q_{\text{lämmitys, tilat, luovutushäviöt}}$$
$$+ Q_{\text{lämmitys, tilat, säätöhäviöt}} + Q_{\text{lämmitys, tilat, varaajahäviöt}}$$

(41)

| | |
|---|---|
| $Q_{\text{lämmitys, tilat, häviöt}}$ | is heat losses of heating system, kWh |
| $Q_{\text{lämmitys, tilat, kehityshäviöt}}$ | is heat losses of production, kWh |
| $Q_{\text{lämmitys, tilat, jakeluhäviöt}}$ | is heat losses of distribution, kWh |
| $Q_{\text{lämmitys, tilat, luovutushäviöt}}$ | is heat losses of heat emitters, kWh |
| $Q_{\text{lämmitys, tilat, säätöhäviöt}}$ | is heat losses of control system, kWh |
| $Q_{\text{lämmitys, tilat, varaajahäviöt}}$ | is heat losses of heat storage, kWh. |

All values take from D5 (table 6.1).

## 8.5 Heat gains

Heat gains from people are calculated by formula

$$Q_{\text{henk}} = \phi_{\text{henk}} \, n \, \Delta t_{\text{oleskelu}} / 1000 \tag{42}$$

| | |
|---|---|
| $Q_{\text{henk}}$ | is heat gain from persons, kWh |
| $\phi_{\text{henk}}$ | is quantity of heat produce by people, W/person |
| N | is amount of persons, |
| $\Delta t_{\text{oleskelu}}$ | is time of living, h. |
| 1000 | is factor of transformation to kWh. |

Heat gains from heating system are calculated by formula.

$$Q_{\text{lämmitys,kuorma}} = 0{,}7 \, Q_{\text{lämmitys,tilat,häviöt}} \tag{43}$$

| | |
|---|---|
| $Q_{\text{lämmitys, kuorma}}$ | is heat gains from space heating system, kWh |
| $Q_{\text{lämmitys, tilat, häviöt}}$ | is heat losses of the space heating system, kWh. |

Heat gains from lighting and electrical equipment is calculated by formula

$$Q_{säh} = Q_{sah,omin} \cdot A_{br} \tag{44}$$

$Q_{säh}$         is heat gains from lighting and electrical equipment, kWh

$Q_{sah,omin}$     is specific heat gain (D5, table 8.3), kWh/brm$^2$

$A_{br}$          is brutto area, brm$^2$.

Heat gains from solar radiation is calculated by formula.

$$Q_{aur} = \sum G_{säteily,\,vaakapinta} F_{suunta} F_{läpäisy} A_{ikk}\, g = \sum G_{säteily,\,pystypinta} F_{läpäisy} A_{ikk}\, g \tag{45}$$

$Q_{aur}$           is heat gains from solar radiation, kWh/month

$G_{säteily,\,vaakapinta}$   is total solar radiation on horizontal surface per of area, kWh/ m$^2$ month

$G_{säteily,\,pystypinta}$   is total solar radiation on vertical surface per of area, kWh/ m$^2$ month

$F_{suunta}$         is coefficient of transformation penetration solar radiation to the building from horizontal surface

$F_{läpäisy}$        is correction factor for total penetration of radiation

$g$              is coefficient of solar radiation penetration through the glass

$A_{ikk}$          is area of the window, m$^2$.

Correction factor for total penetration of radiation is calculated by formula.

$$F_{läpäisy} = F_{kehä}\, F_{verho}\, F_{varjostus} \tag{46}$$

$F_{läpäisy}$        is correction factor for total penetration of radiation, m$^2$

$F_{kehä}$          is coefficient of frame

$F_{verho}$         is coefficient of curtain

$F_{varjostus}$       is coefficient of shading.

Coefficient of shading is calculated by formula.

$$F_{varjostus} = F_{ympäristö} \; F_{ylävarjostus} \; F_{sivuvarjostus} \tag{47}$$

$F_{varjostus}$     is coefficient of shading

$F_{ympäristö}$     is horizontal shading of hills, buildings and trees (table 8.6 D5)

$F_{ylävarjostus}$     is shading above the window (table 8.7 D5)

$F_{sivuvarjostus}$     is site shading wall, (table 8.8D5).

## 8.6 Utilized energy from heat gains

The share of heat gains (surplus of heat) which is utilized for heating $Q_{sis,lämpö}$ is calculated by formula.

$$Q_{sis.lämpö} = \eta_{lämpö} \; Q_{lämpökuorma} \tag{48}$$

$\eta_{lämpö}$     is the utilization factor of the heat gains

$Q_{lämpökuorma}$     is the heat gain, kWh.

The utilization factor $\eta_{lämpö}$ is defined by formula

$$\eta_{lämpö} = \frac{1 - \gamma^{a}}{1 - \gamma^{a+1}}$$

where the numerical parameter a is calculated by formula

$$a = 1 + \frac{\tau}{15} \tag{49}$$

and the parameter $\gamma$ by formula

$$\gamma = \frac{Q_{lampokuorma}}{Q_{lampohavio}} \tag{50}$$

$Q_{lämpöhäviö}$     is heat loss energy of the building, kWh.

Time constant τ is defined by the formula

$$\tau = \frac{C_{rak}}{H}$$
(51)

$C_{rak}$     is the building's interior effective heat capacity, Wh/K

$H$     is the specific heat loss of the building, W/K

The specific heat loss of the building H (W/K) is

$$H = \frac{Q_{lampohavio}}{(T_s - T_u) \cdot \Delta t} \cdot 1000$$
(52)

$\Delta t$     is time, h.

## 8.7 Class of energy efficiency

Class of energy efficiency (kWh / brm$^2$/year) is calculated by formula

$ET = \Sigma \ [Q_{lammitys} + W_{laitesahko} + Q_{jaahdytys,\ tilat}] \ / \ \Sigma \ A$ (kWh/brm$^2$/year)
(53)

ET     is class of energy efficiency (rounded to the next greater whole),
kWh / brm$^2$/year

$Q_{lammitys}$     is the building's heating energy consumption, kWh/year

$W_{laitesahko}$     is equipment electrical energy consumption of building's, kWh/year

$Q_{jaahdytys,\ tilat}$    is energy consumption for cooling space of the building, kWh/year

$\Sigma A$     is area of the heated premises, brm$^2$.

The class of energy efficiency is chosen from tables (asetus 765/2007, liite 1).

## 8.8. Results of estimation

Results of the building energy efficiency class are represented in appendix 2.

## 9 COMPARISONS OF RUSSIAN AND FINISH METHODS

Estimation of the building energy efficiency category was provided by Russian and Finish methods. Difference of methods was defined. In Finish method calculation is provided by average monthly temperature, but in Russian by average temperature of heating period. In method D5 water and electricity consumption is used separately, also energy for building ventilation is taken into account. In Russian method consumption of hot domestic water is not used, and electricity consumption is used in internal heat gains to the building for the heating season. There is difference between calculations of heat gains to the building by solar radiation. It is explained by different level and empirically determined coefficient. In Finish method temperature of the ground is taken into account. The main results of the building energy efficiency calculation, which is based on design dates, are represented in table 10.

**Table 10. Results of calculations which are based on projects dates.**

| | Heat losses by heat transmition | Heat losses by infiltration | Total heat losses | Class of energy efficiency |
|---|---|---|---|---|
| Finnish method | 613442 kWh | 741581 kWh | 1355023 kWh | B "Normal" |
| percent of heat losses , % | 45% | 55% | 100% | |
| Russian method | 702661 kWh | 609634 kWh | 1312295 kWh | C "Normal" |
| percent of heat losses , % | 54% | 46% | 100% | |
| | Heat gains from solar radiation | | | |
| Finnish method | 233859 kWh | | | |
| Russian method | 116308 kWh | | | |
| | Difference between two methods is 50% | | | |
| | Specific need for useful heat energy on heating the building | | | |
| Finnish method | 116 kWh/brm$^2$ | | | |
| Russian method | 90 kWh/brm$^2$ | | | |
| | Difference between method is 22% | | | |

The results of the building energy efficiency calculation, which is based on real values, are represented in table 11.

**Table 11. Results of calculations which are based on real dates.**

| | Heat losses by heat transmition | Heat losses by infiltration | Total heat losses | Class of energy efficiency |
|---|---|---|---|---|
| Finnish method | 623930 kWh | 741581 kWh | 1365511 kWh | Class C "Lower" |
| percent of heat losses , % | 46% | 54% | 100% | |
| Russian method | 718188 kWh | 610038 kWh | 1328226 kWh | Class C "Normal" |
| percent of heat losses , % | 54% | 46% | 100% | |
| | Calculated specific need for useful heat energy on heating the building | | | |
| Finnish method | 125 kWh/brm2 | | | |
| Russian method | 93 kWh/brm2 | | | |

## 10 RECCOMENDATIONS

Possible ways of improving building energy efficiency were found and they are (inexpensive actions)

- Installation of communal equipments of water, heat, gas consideration.

- Installation of water meter in point with most consumption.

- Installation heat-reflective panel over heat emitters.

- Heat insulation of heating system and domestic hot water tubes.

- Flushing of heating system.

- Installation of thermostatic valves on heat emitters.

- Drying of roof space insulation.

- Replacement tungsten filament lamp by energy efficiency luminescent light source or light-emitting diode lamp.

- Replacement Hg-lamp of street lighting on light-emitting diode lamp or sodium-vapor lamp.

- Heat insulation of basement at internal side.

Payback time of these actions is about 1-2 year. Possibility of energy efficiency improving is 30-50% it took from my own calculation. Actions with mean level of expense are

- Using offices and household appliances with class of energy efficiency A+ or A++.

- Replacement of windows on plastic or wood with double glass pane.

- Installation of automatic ventilation valves on windows and walls.

- Replacement and airtight packing of entrance door.

- Construction of additional of portal.

- Installation of modern automatic district heating substation.

- Installation of mechanical ventilation with heat recovery.

- Improving of building envelope heat insulation.

- Implementation of heat pump.

- Additional heating with using heat utilization from sewerage and return water by heat pump.

- Additional heating and domestic hot water supply by using a solar collector.

- Exclusion of draft and air douche in elevator shaft.

- Implementation of programmable heating system.

- Adjusting and balancing of heating system.

Payback time of these actions is less than 5 year. Possibility of energy efficiency improving is 20-60% it based on my own calculation.

## 11 CONCLUSION

In this work estimation of the building energy efficiency was provided in accordance to Russian and Finish standards. Comparison of these dates was completed.
Heat losses by transmition can be comparable with heat losses by infiltration in both cases.

Heat losses by transmition give less value for average monthly temperature than for average temperature of heating period. In this case D5 method is more correct. In Russian method during total heat losses calculation we use one value- average temperature of heating period. If we calculate energy demand for the building heating of heating season for average monthly temperature, this value will reduce on 6.5%.

Heat gains into the building by solar radiation are bigger than two times by Finish method. It is explained by different level and empirically determined coefficient. Accounting of heat flow per month can give correct estimation of the building heat balance. However, heat gains by solar radiation for the heating season are 9% of total heat losses. It is very important to consider surrounding countryside around the building.

In both cases class of the building energy efficiency is "Normal". But specific energy demand for the building heating of heating season differs on 22%.
It is explained by some differences of two methods and empirically determined coefficients.

Methodology of the building energy audit was created. Energy audit of the building in Saint-Petersburg was provided on the basis of this methodology. Energy passport of that building was created. It is based on real values. Class of the building energy efficiency remained "Normal" by Russian method, but consumption of the heat energy rose. It is determined by reducing of the building heat protection characteristics, because there was another heat-moisture regime, quality of montage, latent defects

during construction production on plant. Thereby, necessity of providing a building energy audit is confirmed.

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**APPENDICES**

ENERGY PASSPORT

Residentional building with built-in premises, address:
Russia, Saint-Petersburg, quarter 9 of district Shuvalovo-Ozerki, (lot 2, 3, 4, 9, 10),
building.6.

Student: Dmitry Bocharnikov

Mikkeli 2009

**Table 12. Energy passport which is based on Finish method.**

| № | | | | |
|---|---|---|---|---|
| **General information** | | | | |
| | Date of the filling | 13.11.2008 | | |
| | Address of building | Russia, Saint-Petersburg, quarter 9 of district  Shuvalovo-Ozerki, (lot 2, 3,4,9,10), building.6. | | |
| | Designer of the project | OOO "Yakko Peuru Group" | | |
| | Adress and tel.number of a customer | 191119, Quay Obvodnogo channel,building.93A, tel. 3205748 | | |
| | Number of a project | 0409.2-04 | | |
| **Accounting conditions** | | | | |
| № | Name accounting parameter | Indication of the symbol | Units | Design value |
| 1 | Calculated temperature of the internal air | $t_{int}$ | °C | 20 |
| 2 | Calculated temperature of the outdoor air | $t_{ext}$ | °C | -26 |
| 3 | Calculated temperature of the warm lofts | $t_c$ | °C | 14 |
| 4 | Calculated temperature  warm  cellar | $t_c$ | °C | 7 |
| 5 | Lenght of the heating season | $z_{ht}$ | days | 220 |
| 6 | Average temperature outdoor air of heating period | $t_{ht}$ | °C | -1,8 |
| 7 | Degree-days of the heating period | $D_d$ | °C×days | 4796 |
| **Functionality, type and overall design decision of the building** | | | | |
| 8 | Assignment | Residentional building with built-in premises | | |
| 9 | Location | detached building | | |
| 10 | Type | 23 floors | | |
| 11 | Constructive decision | The Wall: brick, insulation, gas-concrete blocks, decorative plaster, the roofing: flat from 2 layer rubber with insulation "Ruf Batts", the window: metal-plastic profile with two cameras by glass-block. The System of the heating-one pipe. | | |

| № | Factor | Symbols designation and units | Normative value of the factor | Calculated (design) value factor |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| **Geometric factors** | | | | |
| 12 | - general area of the building envelope | $A_e^{sum}$, $m^2$ | -- | 9727 |
| | including: | | | |
| | - walls | $A_w$, $m^2$ | -- | 6741 |
| | - windows and balcony doors | $A_F$, $m^2$ | -- | 1627 |
| | - external doors and gates | $A_{ed}$, $m^2$ | -- | 25 |
| | - covering (combined) | $A_c$, $m^2$ | -- | -- |
| | - adjoining walls | $A_w$, $m^2$ | -- | -- |
| | - overlapping warm lofts | $A_c$, $m^2$ | -- | 667 |
| | - overlapping on warm cellar | $A_f$, $m^2$ | -- | 667 |
| | - overlapping on not heating cellar or subfield | $A_f$, $m^2$ | -- | -- |
| | - skylight | $A_f$, $m^2$ | -- | -- |
| | - floor on ground | $A_f$, $m^2$ | -- | -- |
| 13 | Area of the heated premises | $A_h$, $m^2$ | -- | 10933 |
| 14 | living area (public buildings) | $A_l$, $m^2$ | -- | 615 |
| 15 | Area of dwelling premises and kitchen | $A_l$, $m^2$ | -- | 6675 |
| 16 | Heating volume of a building | $V_h$, $m^3$ | -- | 41268 |
| 17 | Glazing-to-wall ratio | $p$ | 0,18 | 0,19 |
| 18 | Index of the shape of a building | $k_e^{des}$ | 0,25 | 0,24 |

| № | Factor | Symbols designation and units | Normative value of the factor | Calculated (design) value factor |
|---|--------|------------------------------|------------------------------|----------------------------------|
| **Thermal-technical factors** | | | | |
| **Thermal factors** | | | | |
| 1 | 2 | | 4 | 5 |
| 19 | Reduction thermal resistance of: | $R_o^r$, $m^2 x°C/W$ | | |
| | - walls | $R_w$ | 3,08 | 3,50 |
| | - windows and balcony doors | $R_F$ | 0,44 | 0,48 |
| | - doors | $R_{ed}$ | 1,2 | 1,2 |
| | - covering (combined) | $R_c$ | -- | -- |
| | - adjoining walls | $R_w$ | -- | -- |
| | - overlapping warm lofts | $R_c$ | 4,6 | 4,4 |
| | - overlapping on warm cellar | $R_f$ | 4,06 | 4,1 |
| | - overlapping on not heating cellar or subfield | $R_f$ | -- | -- |
| | - skylight | $R_f$ | -- | -- |
| | - floor on ground | $R_f$ | -- | -- |
| 20 | Heat transfer coefficient | $U_m^{tr}$, $W/(m^2×°C)$ | -- | 0,63 |
| 21 | Air changes per hour | $n_a, h^{-1}$ | | 0,49 |
| | Air changes per hour with 50Pa | $n_{50}, h^{-1}$ | | -- |
| 22 | Ifiltrtation coefficient of heat transmission of the building | $U_m^{inf}$, $W/(m^2×°C)$ | -- | 0,54 |
| 23 | General coefficient of heat transmition of the building | $U_m$, $W/(m^2×°C)$ | -- | 1,17 |

| № | Factor | Symbols designation and units | Normative value of the factor | Calculated (design) value factor |
|---|--------|-------------------------------|-------------------------------|----------------------------------|
| **Thermal-energy's factors** | | | | |
| **Energy's factors** | | | | |
| 24 | General heat losses through the building envelope for heating period | $Q_h,$ $MJ$ | -- | 4724298 |
| 25 | Specific internal heat gains to a building | $q_{int}$ , $W/m^2$ | min 10 | 13 |
| 26 | Internal heat gains to a building | $Q_{int}$, $MJ$ | -- | 1649444 |
| 27 | Heat gains from solar radiation | $Q_s,$ $MJ$ | -- | 418711 |
| 28 | Energy demand for heating of a building of a heating season | $Q_h^y,$ $MJ$ | -- | 3591101 |
| 29 | Specific energy demand for heating of a building of a heating season | $q_h^{des}$, $kJ/m^{2\ *°C\times day}$ | 70 | 68 |
| **Comparison with normative requirements** | | | | |
| 30 | Calculated coefficient of the energy efficiency for building heating system from district heating | $h_o^{des}$ | | 0,5 |
| 31 | Normative Specific energy demand for heating of a building of a heating season | $q_h^{req},$ $kJ/(m2\times°C\times day)$ | | 70 |
| 32 | Meets the requirements of the design of the building | | | Yes |
| 33 | Category of the energy efficiency rating | | | **C** |
| 34 | Should the design be improved? | | | No |

| Class of energy efficiency: | | |
|---|---|---|
| | | |
| Normal | C | 68 kJ/(m$^2$×°C×day) |

| Recommendations on increasing energy efficiency | | |
|---|---|---|
| 36 | Recommendations: <br><br> - | |
| | | |
| 37 | Passport is filled | - |
| | Organization | Mikkeli University of Applied Sciences |
| | Address and telephone | Finland, Tarkk'ampujankuja 1, MIKKELI, 50101 Tel. +358 15 355 61 |
| | Account contact man | Dmitry Bocharnikov |

Application to energy passport

General information of project

Address of the building– Russia, Saint-Petersburg, section 9 of Shuvalovo-Ozerki district, (lot 2, 3, 4, 9, 10), building 6.

Type of the building: residential 23- floor building with built-in premises.

The Wall: brick, insulations, gas-concrete blocks, decorative plaster, the roofing: flat from 2 of layer rubber with insulation "Ruf Batts", the window: metal-plastic profile with two cameras by glass-block. The heating system of building is heating-one pipe.

Designer of the project – OOO "Yakko Peuru Group"

Number of project – 0409.2-04

Accounting conditions: climatic conditions are given and taken for Saint Petersburg temperature of the premises:

Calculated temperature of the internal air $t_{int}$ :

For residential building $t_{int}$ = 20 ºC.

Calculated temperature of the outdoor air $t_{ext}$:

$t_{ext}$ = −26 ºC.

Duration of the heating period $z_{ht}$:

$z_{ht}$ = 220 days.

Average temperature of outdoor air for heating period $t_{ext}^{av}$:

$t_{ext}^{av}$ = −1,8 ºC.

Degree-days of the heating period $D_d$:

$D_d$ = 4796 ºC·days.

The functionality, type and design of the building:

All characteristics are taken from project of the building.

Area and volume of the building.

Area and volume are calculated in accordance to requirements of standards.

General area of the building envelope: $A_e^{sum}$

Area of the walls, including windows and balcony doors, and external doors and gates, $A_{w+F+ed}$, м² is calculated by formula:

$$A_{w+F+ed} = \sum p_{sti} \times H_{hi}, \tag{52}$$

$p_{sti}$ – Is internal perimeter to surfaces of external walls I floor, m,

$H_{hi}$ – Is height of the floors.

$A_{w+F+ed}$ = 8393 m²

Area of the external walls $A_w$, м² is calculated by formula:

$$A_w = A_{w+F+ed} - A_F - A_{ed} \tag{53}$$

$A_F$ – Is area of the windows is calculated as a sum of all windows, $A_{ed}$ – is area of the external doors and gates.

For this building:

$$A_F = 1627 \text{ m}^2.$$

$$A_{ed} = 25 \text{ m}^2.$$

Then $A_w$ = 8393-1627-25 = 6741 m².

- overlapping warm lofts $A_{ñ}$, m²

$$A_{ñ} = 667 \text{ m}^2$$

- overlapping on warm cellar $A_f$, m²

$$A_f = 667 \text{ m}^2$$

General area of the building envelope $A_e^{sum}$ is calculated by formula:

$$A_e^{sum} = A_{w+F+ed} + A_f + A_{ñ} + A_{scy} = 8393+667+667 = 9727 \text{ m}^2 \qquad (54)$$

Area of the heated premises $A_h$ is calculated in the project:

$$A_h = 10933 \text{ m}^2$$

Heating volume of the building $V_h$, m³ is calculated by formula:

$$V_h = \sum A_{sti} \times H_{hi} = 41268 \text{ m}^3, \qquad (55)$$

Factors of volume's designs are calculated by formula:

Glazing-to-wall ratio $p$ :

$$p = A_F / A_{w+F+ed} = 1627/8393 = 0.19 \qquad (56)$$

$A_F$ – Is area of the windows.

– Index of the shape of a building $k_e^{des}$

$$k_e^{des} = A_e^{sum}/V_h = 9727/41268 = 0.24 \qquad (57)$$

Section «Energy's factors » include thermal-technical and thermal-energy's factors. According to the building standards and rules ("SNiP") 23-02-2003 reduction thermal resistance of different external envelope determines:

$R_o^r, m^2$ ·°C/W, must be taken not below required value $R_o^{req}$ ,

– Walls $R_W^{req} = 3{,}08$ m² °C/W

– Windows and balcony doors $R_F^{req} = 0.44$ m² °C/W

– External doors and gates $R_F^{req} = 1.2$ m² °C/W

– Overlapping warm lofts $R_{\tilde{N}}^{req} = 4.6$ m² °C/W

– Overlapping on warm cellar $R_f^{req} = 4.06$ m² °C/W

Project's thermal resistance value of different external envelope determines:

– Walls $R_W = 3.50$ m² °C/Вт

– Windows and balcony doors $R_F = 0.48$ m² °C/W

– External doors and gates $R_F^{req} = 1.2$ m² °C/W

– Overlapping warm lofts $R_{\tilde{N}} = 4.4$ m² °C/W

– Overlapping on warm cellar $R_f = 4.1$ m² °C/W

Reductions transmition coefficient of heat transfer of the building

$K_m^{tr}$, W/ (m²·°C), calculated by formula (Г5):

$$K_m^{tr} = \beta\left(\frac{A_w}{R_w} + \frac{A_F}{R_F} + \frac{A_{ed}}{R_{ed}} + n \times \frac{A_c}{R_c} + n \times \frac{A_f}{R_f}\right)/A_{sum} , \qquad (58)$$

$\beta$ - Is factor, taking into account additional heat losses. It depends on the orientation the sides of horizon, with barrier of the angular premises. It also depends on supply of cool air through entrance of the buildings: for residential buildings $\beta$ =

1,13, for other types of buildings $\beta$ = 1,1, $A_w$, $A_F$, $A_{ed}$, $A_c$, $A_f$ - area correspondingly of walls , windows and balcony doors, external doors and gates, overlapping warm lofts, overlapping on warm cellar, m$^2$,

$R_w$, $R_F$, $R_{ed}$, $R_c$, $R_f$ - of walls , windows and balcony doors, external doors and gates, overlapping warm lofts, overlapping on warm cellar, m2 °C/W,

n − Coefficient dependent on positioning of surface building envelope for external air according to the table 6, (SNiP) construction norms and regulations 23-02-2003.

$$K_m^{tr} = 0.63 \text{ Вт/(м}^2 \cdot {}^\circ\text{C)}$$

Required air change rate of residential building $n_a$, h$^{-1}$, according to SNiP 2.08.01 for dwelling premises is 3 m$^3$/h removing air forms 1 m$^2$ of dwelling's premises and kitchen.

$$n_a = 3*A_l/V_h \tag{59}$$

$$n_a = 0.49 \text{ h}^{-1}$$

Reduced infiltrations coefficient of the buildings heat transmission

$K_m^{inf}$ W/ (m$^2 \cdot {}^\circ$C) is calculated by formula (Г6):

$$K_m^{inf} = 0,28 c n_a \beta_v V_h \rho_a^{ht} k / A_в^{sum}, \tag{60}$$

$c$ - Is heat capacity of the air equals 1 KJ/(kg·°C),

$\beta_v$ - Is coefficient of reducing volume of air in the building.

$V_h$ and $A_в^{sum}$ - ditto in formula (4) and (3) , m$^3$ and m$^2$ accordingly.

$\rho_a^{ht}$ - Is average density of air supply for heating period, kg/m$^3$

$$\rho_a^{ht} = 353/[273 + 0,5(t_{int} + t_{ext})], \tag{61}$$

$n_a$ - Is average air changes for heating period of the, h$^{-1}$ are calculated by formula (4).

$t_{int}$ - Is internal temperature (2), °C.

$t_{ext}$ - Is external temperature (3), °C.

$$K_m^{inf} = 0.28 \cdot 1 \cdot 0.49 \cdot 0.85 \cdot 41268 \cdot 1.19 \cdot 0.85 / 9727 = 0.54 \text{ W/ (m}^2 \cdot {}^\circ\text{C)}$$

General coefficient of heat transmission of the buildings $K_m$, W/ (m$^2 \cdot {}^\circ$C) is calculated by formula (Г.4):

$$K_m = K_m^{tr} + K_m^{inf}, \tag{62}$$

$K_m = 0.63 + 0.54 = 1.17$ W/ (m$^2 \cdot {}^\circ$C)

Thermal-energy factors

General heat losses through envelope of the building for heating period

$Q_h$ MJ, calculated by formula (Г3):

$$Q_h = 0,0864 K_m D_d A_e^{sum} \tag{63}$$

$Q_h = 0.08641 \cdot 1.17 \cdot 4796 \cdot 9727 = 4724298$ MJ

Specific heat gains from installed equipments and from humans $q_{int}$ W/m$^2$. in this particular case we take 13 W/m$^2$.

Internal heat gains to a building for heating period $Q_{int}$, MJ are calculated by formula (Г.10):

$$Q_{int} = 0.0864 \times q_{int} \times Z_{ht} \times A_{sum} = 1649444 \text{ MJ.} \tag{64}$$

Heat gains from solar energy for heating period $Q_s$ MJ is calculated by formula (Г11):

$$Q_s = \tau_F \times k_F \left( \sum_{i=1}^{n} A_{Fi} \times I_i \right) + \tau_{scy} k_{scy} A_{scy} I_{hor} \tag{65}$$

$\tau_F$, $\tau_{scy}$ - Represent coefficients dependent on shading of the window.

$k_F$, $k_{scy}$ - Represent coefficients relative of penetration solar radiation according to the amount of the windows.

$A_{Fi}$ -Is' area of the windows oriented on four directions. $I_1$, $I_2$, $I_3$, $I_4$ – average for heating period value to solar radiation on vertical surfaces,

According to the orientation of the building on four parts of the world, MJ/m$^2$ coefficients are taken from table 4.4.

$\tau_F$ =0.50 , $k_F$ =0.76

$$Q_s = 0{,}5*0{,}76*(394*385+650*425+650*419+1009*398)=418711 \text{ MJ}$$

Energy demand for heating of a building of a heating season $Q_h^v$, MJ is calculated by formula (Γ.2):

$$Q_h^y = [Q_h - (Q_{int} + Q_s)v\varsigma]\beta_h \tag{66}$$

$Q_h$ - Is general heat losses through envelope of the building for heating period, MJ are calculated by formula 10(Γ.3).

$Q_{int}$ - Is heat gains in to the building from heating period $Q_{int}$, MJ are calculated by formula Γ.6.

$Q_s$ - Is heat gains throw the windows from solar energy for heating period, MJ are calculated by formula (Γ.11).

$v$ - Is coefficient of reduction heat using heat inertness of envelope, recommended value is $v = 0{,}8$.

$\varsigma$ - Is the coefficient to efficiency of auto regulation heating supply in the heating systems, recommended values.

$\varsigma$ =0.9 for this kind of heating system

$$Q_h^y = [4724298 - (1649444 + 418711)\cdot0{,}8\cdot0{,}9]\cdot1{,}11 = 3591101 \text{ MJ}.$$

Calculated specific need for useful heat energy on heating the building for heating period $q_h^{des}$ , kJ/m$^3$°C×day is calculated by formula (Г.1):

$$q_h^{des} = 10^3 Q_h^y / (A_h D_d) \text{ or } q_h^{des} = 10^3 Q_h^y / (V_h D_d),$$ (67)

$Q_h^y$ - Is consumption of heat energy for heating the building for heating period, MJ.

$A_h$ - Is area of the heated premises, м$^2$.

$V_h$ - Is heated volume, м$^3$.

$D_d$ - Is degree-days of the heating period.

$$q_h^{des} = 3591101 *1000 /10933*4796= 68 \text{ kJ/m}^2°C×day$$

Calculated coefficient of the energy efficiency for a building heating system from district heating $\eta_o^{des}$ is calculated accordingly to section 5 of SP 23-101-2004. In this case the building is connected to the central heating supplying system. In the studied case the building is connected to the central heating system, so $\eta_o^{des}$ = 0.5.

Normal specific energy demand for heating of a building during the heating season $q_h^{req}$ is taken from the table 9, equal 70 kJ/m$^2$ ° C × days.

The deviation between calculated specific need for heating energy of the building heating and norm is absent. Consequently, project of the building corresponds to the requirements. /1/

**Table 13. Energy passport which is based on Finish method.**

| Initial data | | | | | | |
|---|---|---|---|---|---|---|
| | **Designer values** | | | **Constants** | | |
| **Geometric factors** | **U-arvo** | **A** | | $T_s$ | 20 | °C |
| | **W/m²K** | **m²** | | $n_{vuotoilma}$ | 0,49 | 1/h |
| **Walls** | **0,35** | **6741** | | $q_{v,vuotoilma}$ | 5,617 | m³/s |
| **Overlapping warm lofts** | **0,23** | **667** | | $r_i$ | 1,2 | kg/m³ |
| **Overlapping on warm cellar** | **0,24** | **667** | | $c_{pi}$ | 1000 | Ws/kgK |
| **Windows and balcony doors** | **1,89** | **1627** | | n | 0,5 | 1/h |
| **External doors and gates** | **0,83** | **25** | | $q_{v,poisto}$ | 0,000 | m³/s |
| | | | | $t_d$ | 1 | h/24h |
| **Amount of bydrooms** | $n_{MH}$ | **299** | kpl | r | 1 | |
| **Area of the heated premises** | $A_{br}$ | **10933** | m² | $t_v$ | 1 | vrk/7vrk |
| **Heated volume** | **V** | **41268** | m³ | $T_{s,lask,keski\ m.}$ | 23 | °C |

| **Orientation of the windows** | **North** | **West** | **South** | **East** | |
|---|---|---|---|---|---|
| | $A_{ikk}$ | $A_{ikk}$ | $A_{ikk}$ | $A_{ikk}$ | |
| | 385 | 419 | 398 | 425 | |
| | $g_{kohtisuora}$ | $g_{kohtisuora}$ | $g_{kohtisuora}$ | $g_{kohtisuora}$ | |
| | 0,5 | 0,5 | 0,5 | 0,5 | |

| | |
|---|---|
| Total heat losses of the building, kWh | 1355023 |
| Heat losses by heat transmition, kWh | 613442 |
| Heat losses by infiltration, kWh | 741581 |
| Heat gains from solar radiation, kWh | 233859 |
| Heat losses of the heating systems | 271251 |
| Specific need for useful heat energy on heating the building, kWh/brm2 | 116 |