Visegrad Fund

Integrated Systems in Buildings - HVAC in an office building

Lic. Vitalii Soloviov

Master thesis
2015

Tomas Bata University in Zlín
Faculty of Applied Informatics

Tomas Bata University in Zlín
Faculty of Applied Informatics
Academic Year: 2014/2015

MASTER'S THESIS ASSIGNMENT

(PROJECT, ARTWORK, ARTISTIC PERFORMANCE)

Degree, First Name and Surname:	**Lic. Vitalii Soloviov**
Personal Code:	**A13861**
Degree Programme:	**N3902 Engineering Informatics**
Degree Course:	**Integrated Systems in Buildings**
Thesis Topic:	**Integrated Systems in Buildings – HVAC in an Office Building**
Thesis Topic in Czech:	**Integrované systémy v budovách – Systémy techniky prostředí v administrativní budově**

Thesis Guidelines:

1. **Study of energy efficient office buildings from the view of building physics, energy consumption, inner environment, lighting and accoustics, with the consideration of renewables usage.**
2. **Description of the requirements on building structures, building architecture, HVAC systems, lighting systems, including monitoring and control.**
3. **Design of suitable HVAC systems for a specific building.**
4. **Implementation of renewable technologies.**
5. **Design of an acceptable communication, control and monitoring system with SCADA visualization.**

Thesis Extent:

Appendices:

Form of Thesis Elaboration: **tištěná/elektronická**

Bibliography:

1. **AMERICAN SOCIETY OF HEATING, Refrigerating and Air-Conditioning Engineers. 2005 ASHRAE handbook fundamentals. I-P and SI eds. Atlanta, Ga: ASHRAE, 2005. ISBN 19-318-6273-7.**

2. **Taschenbuch für Heizung und Klimatechnik [13/14]: einschließlich Warmwasser- und Kältetechnik. München: Oldenbourg Industrieverlag, c2013, 1852 s. , 40 s. příl. ISBN 978-3-8356-3301-8.**

3. **MCDOWALL, Robert a Ross MONTGOMERY. Fundamentals of HVAC control systems. I-P ed. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, c2011, viii, 348 p. ISBN 978-193-3742-922.**

4. **KAVANAUGH, Stephen P a Ross MONTGOMERY. HVAC simplified. I-P ed. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, c2006, xi, 236 p. ISBN 978-193-1862-974.**

5. **SPITLER, Jeffrey D a Ross MONTGOMERY. Load calculation applications manual. Second edition. I-P edition. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, c2006, pages cm. ISBN 978-193-6504-756.**

6. **HAINES, Roger W a Michael E MYERS. HVAC systems design handbook. 5th ed. New York: McGraw-Hill, c2010, xvi, 560 p. ISBN 00-716-2297-7.**

Thesis Supervisor: **Ing. Martin Zálešák, CSc.**
Department of Automation and Control Engineering

Date Assigned: **24 July 2015**

Thesis Due: **26 August 2015**

Zlín, 24 July 2015

L.S.

doc. Mgr. Milan Adámek, Ph.D.
Dean

prof. Ing. Vladimír Vašek, CSc.
Head of Department

PROCLAMATION

I hereby declare that:

- I understand and acknowledge that, by submitting my Bachelor´s / Master´s thesis, I agree to the publication of my thesis in accordance with Act No. 111/1998 Coll., On Universities, and according to changes or amendments by other Acts (The Higher Education Act), as amended by subsequent legislation, and regardless of the outcome of the Thesis Defense. [1)]
- I understand and acknowledge that my Bachelor´s / Master´s thesis will be stored electronically in the Tomas Bata University in Zlín´s information system and available for inspection; further, that a copy of the thesis will be stored in the reference library of the Faculty of Applied Informatics, Tomas Bata University in Zlín, and that one copy shall be deposited with the Tutor supervising the thesis.
- I have been made aware of the fact that my Bachelor´s / Master´s thesis is fully covered by the Act No. 121/2000, Coll., On Copyright and Rights Related to Copyright, as amended by certain Acts (The Copyright Act), as further amended by subsequent legislation, and in particular, § 35, Paragraph 3 [2)]
- I understand and acknowledge that, pursuant to: § 60 [3)], Paragraph 1 of the Copyright Act, that Tomas Bata University in Zlín has the right to a license agreement on the use of school work, in accordance with § 12, Paragraph 4 of the Copyright Act.
- I understand and acknowledge that, pursuant to: § 60 [3)], 2 and 3, I may enjoy the rights to my Bachelor´s / Master´s thesis, or to license its use only with the prior written consent of Tomas Bata University in Zlín, which in such a case is entitled to eventually require from me a reasonable contribution to the costs that were incurred by Tomas Bata University in Zlín on the creation of the work, (up to, and including their actual full cost).
- I understand and acknowledge that if, in the elaboration of the Bachelor´s/ Master´s thesis, the use of software provided by Tomas Bata University in Zlín, or other legal subjects only for study and research purposes, (i.e. only for non-commercial use), the results of the Bachelor´s / Master´s thesis cannot be exploited for commercial use purposes.
- I understand and acknowledge that if the output of my Bachelor´s / Master´s thesis is any kind of software product, it is considered that a component of the thesis equally is any source code or – as the case may be, files which the project consists of. Not surrendering this component may be reason for the non-defense of the Bachelor´s / Master´s thesis.

I hereby declare,

- That I worked independently on my Bachelor´s/Master´s thesis and have cited all the literature I used.
- That the submitted version of my Bachelor´s/Master´s thesis and the electronic version uploaded into the university´s IS/STAG system are identical.

In case of the publication of the results, I shall be mentioned as co-author.

In Zlín: 25.08.2015 ....

ABSTRAKT

Cílem této práce je návrh integrovaného technického systému v kancelářské budově, se zaměřením na úspory energie a zajištění komfortu pro obyvatele. Práce prezentuje studii o perspektivách rekonstrukci starých budov v Moldavsku, v souladu s moderními přístupy v oblasti energetické účinnosti a systémů řízení budov. Požadavky stavebních konstrukcí, spotřeby energie, tepelné pohody, osvětlení a akustiky jsou analyzovány z národní a evropské perspektivy. Cíl je realizován pomocí návrhu systému HVAC, přípravy teplé vody a osvětlení pro konkrétní stavbu a zlepšení izolace obálky budovy. Možnost využití obnovitelných zdrojů energie je analyzována při použití solárního kolektoru pro přípravu teplé vody a fotovoltaického systému. Principy činnosti Inteligentní budovy jsou realizovány prostřednictvím řídicího systému KNX a monitorovacího systému SCADA. Dopad navrhovaných opatření je ekonomicky hodnocený z hlediska existujících okolností.

Klíčová slova: integrovaný systémy v budovách, energetická účinnost, inteligentní budovy, Moldavsko, stavební fyzika, systém HVAC, osvětlení, obnovitelné zdroje energie, KNX, SCADA.

ABSTRACT

Scope of this Thesis is designing an integrated technical system for an office building, with the focus on energy savings and provision of comfort for inhabitants. Thesis presents a study on the perspectives of old buildings renovation in Moldova, according to modern approaches on energy efficiency and building management systems. Requirements towards building structures, energy consumption, thermal comfort, lighting and acoustics are analyzed from national and EU perspective. Aim is realized by designing HVAC, hot water preparation and lighting systems for a specific building and improvement of its building envelope insulation. Possibility of using renewable sources of energy is analyzed by design of solar collector for hot water preparation and photovoltaic system. Intelligent building operation principles are implemented through KNX control and SCADA monitoring systems. Finally, impact of proposed measures is economically evaluated in terms of existing circumstances.

Keywords: integrated building system, energy efficiency, intelligent building, Moldova, building physics, HVAC system, lighting, renewable energy, KNX, SCADA.

ACKNOWLEDGEMENTS

I would like to kindly thank Ing. Martin Zálešák for his efforts in leading me through the study process, his advices, willingness to share his experience and directing my activity during Master Thesis preparation.

Special gratitude shall be expressed to the Visegrad Fund team, for giving me the possibility of pursuing Master degree at Tomas Bata University in Zlin and supporting my studies during last two years.

Besides, I greatly appreciate the help and collaboration of my colleagues from ISB 2015 promotion and the support of my family and friends during my studies.

CONTENTS

INTRODUCTION

Issues related to provision of population with housing, improvement of housing quality conditions and formation of urban environment which best suits the needs of modern society have played a significant role in the economy of Republic of Moldova in the last 70 years. Drastic economical fluctuations of this period brought housing sector to a powerful upturn, followed by a deep crisis in ‘90s.

Fast development and large-scale urbanization in 20-th century required fast, reliable and cheap building solutions, which had to keep the fast pace of economical and demographical boom. Together with low price, large availability of resources and lack of environmental awareness it resulted in high energy consumption building practices. Crisis, erupted in ’90s, and transition to market economy resulted in stoppage of governmental investments in supporting state of housing fund. In the same time individuals did not have financial possibilities for capital building renovation expenses and the business sector was not interested in long-term and low-payback investments. This resulted in a large fund of abandoned or semi-abandoned buildings.

Current Thesis analyzes the possibilities of revival and usage of old structures in the conditions of current energy efficiency requirements and modern approach to operation of buildings. This is realized through an example of a real project in the center of Chisinau.

Through studying the concept of low-energy consumption buildings and intelligent system in buildings, and applying it to the existing project, it is possible to assess perspectives and benefits of revitalization.

First, theoretical, part of the Thesis provides insight in regulations and practices, accepted in design and construction of energy efficient buildings and intelligent systems. Considering current transition of Moldova’s legislative base to European standards, a parallel is driven between currently valid design regulations, based on SNIP and GOST standards, and European regulations on the example of Czech National Standards.

Practical part contains actual system design. In order to assure a low-energy consumption rating and maximal comfort, next measures and systems were proposed: improvement of thermal parameters by effective building envelope insulation, optimal heating system design, power feeding and lighting system design and KNX-based intelligent system implementation with SCADA visualization.

I. THEORY

1 CHARACTERISTIC OF EXISTING BUILDINGS SECTOR IN MOLDOVA

1.1 General description

Housing stock in the Republic of Moldova is relatively new from a historical perspective. Around 84% of it dates back to 1960 and 65% to 1970. Housing stock in cities is distributed in next proportions: 63% - apartment blocks, 25% - family houses and 12% - hostels.

Soviet-time apartment blocks are mostly large prefabricated slab buildings (panel houses). Around 50% of urban apartments are in nine storey buildings or more [1].

Housing segment is the most energy consuming in Moldova. Besides other factors, it is conditioned by the structure of Moldovan economy. Since '90s, biggest national industrial producers ceased their activity or significantly reduced it, increasing the rate of housing energy consumption. Due to continuing urbanization and increase in life quality over the years, it has a growing trend. In 2002, fuel consumption for housing segment accounted for 43.8% of total consumption in the country, increasing to 48.7% in 2009 [2]. In the same time, thermal energy consumption for residential sector increased from 43.7% in 2002 to 58.1% in 2009. Together with commercial sector, it sums up to 79.3% of overall thermal energy consumption.

Energy use is greater in urban areas where people rely on district heating systems and gas and oil.

Energy prices for residential customers are no longer subsidized by State and there have been significant price rises in recent years. The most recent price rises occurred in July 2015, causing a sharp discussion in society.

Improving energy efficiency in residential properties in Moldova presents significant opportunities to reduce energy and reduce the energy costs to homeowners. Moldova has no coal and gas reserves and only small reserves of crude oil, which is less than 0.1% of the total energy supply. Hydroelectric potential is present, but is very low. Moldova is therefore highly dependent on energy imports from the Russia and Ukraine. These imports cover 96% of energy consumption. Therefore, competent energy efficiency projects, besides their obvious environmental effect, would reduce dependence on energy imports, which currently influences political and social processes in the country.

Characteristic to Moldova's energy sector are significant historical debts, technically outdated power generation systems and inefficient energy and heating distribution systems. Improving energy efficiency would reduce the load on these systems.

Facing substantial poverty issue, fuel poverty is a special part of this problem in the country. Moldova has the lowest GDP in Europe, being 132nd in the IMF world list at 2233 USD per capita in 2014 [3]. Most vulnerable to poor housing conditions are people with low-income, being unable to heat their homes properly. For example, average monthly central heating bill for a 2-room apartment in Chisinau equals to 36% of average monthly income.

Refurbishment of existing housing would improve these conditions and lower energy expenses in future.

The "whole building" approach when implementing energy efficiency is much more efficient than performing improvements apartment by apartment. But in practice this approach is barely possible to realize in the case of residential apartment blocks. This requires development of a range of measures, especially financial ones, and defining a step-by-step methodology in energy efficient improvements [4].

Better situation is with the buildings owned by companies. Their owners are mostly dynamic in terms of seeking profitable investment possibilities and have full control over the building, being freer in decision-making process. One of these cases is analyzed in current work.

Low investment possibilities in available housing stock resulted in a big number of broken windows and leaking roofs. Many properties are in poor condition due to a symbiosis of factors like: fuel poverty, damaged or outdated infrastructure and insufficient heat supply to apartments, especially on the periphery of the central heating system. These conditions are common for all urban agglomerations in Moldova.

1.2 Energy tariffs in Moldova

Assessing energy policies in Moldova, it is relevant to compare them to other non-EU countries in the region, which participate in similar development programs. Comparing to other participants of the former Eastern Partnership (EaP), Moldova has highest gas and electricity prices [5] (Fig. 1 and Fig. 2).

Energy tariffs in Moldova are not subsidized. It is one of the few countries, where residential consumers pay higher rates than industrial ones, due to implementation of voltage differentiated tariffs. From another side, efforts to stimulate the energy sector have an encouraging trend. As one of the measures, Government announced plans to separate power distribution and supply in 2016.

Energy sector of Moldova is regulated by:

- The Law on Energy (2008);
- The Law on Electricity (2010; includes elements of EU Directive 2003/54/EC);
- The Law on Natural Gas (includes elements of EU Directive 2003/55/EC);
- The “Energy Act" (2010), which includes the law on National Agency for Energy Regulation and Budget.

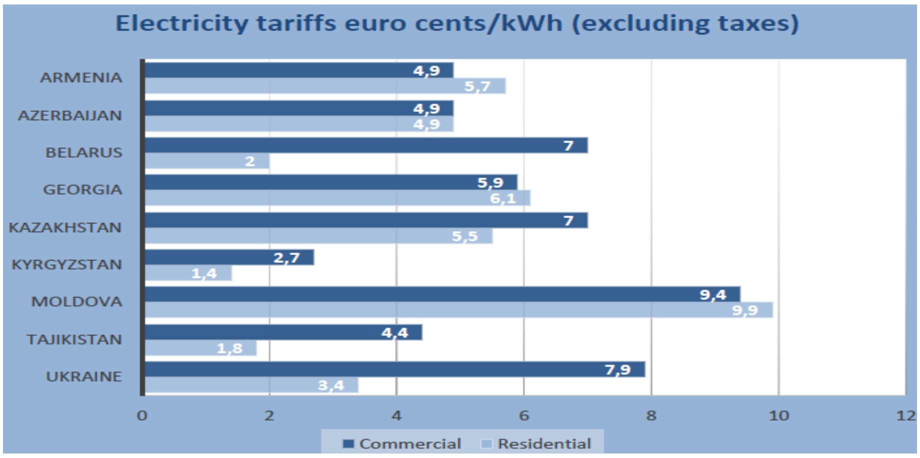


Fig. 1. Comparison of electricity prices between EaP countries

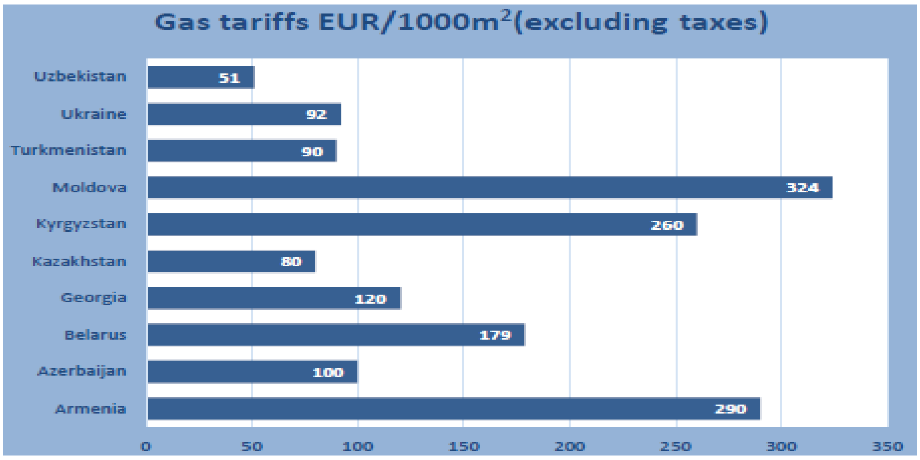


Fig. 2. Comparison of gas prices between EaP countries

In compliance with Moldova’s official vector of integration with EU, efforts are given to harmonize energetic legislation to EU energy norms. Moldova became a member of the

Energy Community in May 2010, and is pathing its way to membership in ENTSO-E (the European Network of Transmission System Operators for Electricity).

An important performance indicator, which allows to evaluate industrialization degree of a country is energy intensity. Energy balance and intensity of Republic of Moldova can be assessed basing on data from table (Tab. 1).

Tab. 1. Evolution of energy balance and intensity in Moldova [6]

Characteristic	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Energy consumption in housing sector, [ktoe]	429	477	575	656	704	691	598	632	660	689	708	639
Total energy consumption, [ktoe]	1735	1892	1978	2144	2278	2271	2160	2191	2044	2189	2237	2145
GDP, [mln MDL]	19.05	22.56	27.62	32.03	37.65	44.75	53.43	62.92	60.43	71.85	82.35	88.23
Energy intensity, [toe/(1000·GDP)]	0.091	0.084	0.072	0.067	0.067	0.051	0.040	0.035	0.034	0.030	0.027	0.024

Energy balance evolution from year 2001 to 2012 is presented in the figure (Fig. 3).

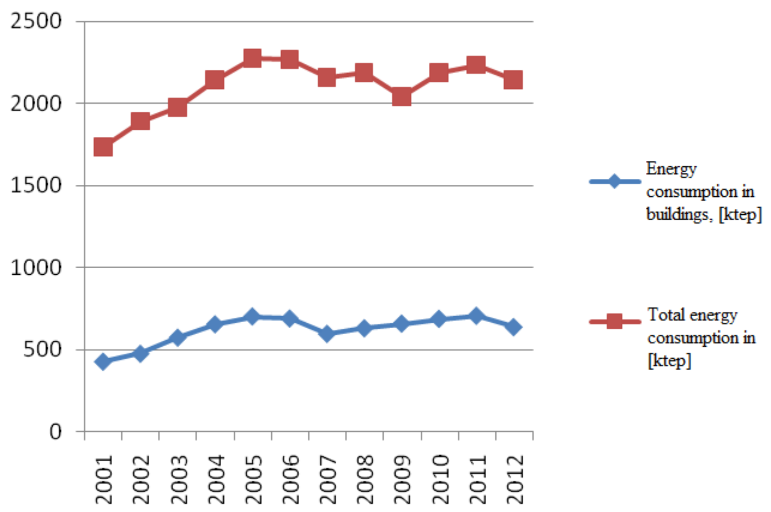


Fig. 3. Energy balance evolution in Moldova

1.2.1 Electricity tariffs

Electricity sector is currently in the process of unbundling into generation, transmission and distribution entities. Distribution was functionally separated into distribution and supply and is expected to legally separate in 2016.

Electricity needs in the amount of 80% are covered by imports, all of it being from Ukraine. Electricity is imported through a single buyer, EnergoCom, which is reseller of the power to supply companies and eligible customers. Currently, ANRE develops tariff methodologies for local electricity generation, transmission and distribution.

There are three distribution companies, two of them being state owned and one privatized. Energy is distributed on three levels:

- high voltage - distribution networks with a voltage of 35-110 kV;
- medium voltage - distribution networks with a voltage of 6-10 kV;
- low voltage - distribution networks with a voltage of 0.4 kV and lower.

Internal generation covers 20% of internal consumption. It is mainly produced at CHP plants that provide district heating together with electricity. Generation tariffs are individual for each station and are calculated on a cost-based methodology, which includes operational expenditure and return on assets

Renewable generation benefits from regulatory stimulating conditions: guarantee on renewable energy sales; mandatory purchase of a fixed share of electricity generated from renewable sources, return on assets at favorable rates.

ANRE approved inflating Weighted Average Cost of Capital for electricity distribution companies with a coefficient: for the first five years - 1.5, for the next five years - 1.3, and for the last five-year period – 1.1.

End-user tariffs are set separately for three voltage groups. Tariff approach is combined: cost-based for uncontrollable operating cost recovery and incentive for operating controllable costs depending on national consumer price index and an efficiency factor of 20%.

Tariffs, classified by distribution companies and voltage groups are given in table (Tab. 2).

Tab. 2. Electrical energy tariffs in Moldova [5]

Distribution company	**Voltage [kV]**	**Price [MDL/kWh]**	**Price [EUR/kWh]**
"RED Union Fenosa" JSC	35,11	1,17	0,06
	6,1	1,4	0,07
	0,4	1,58	0,08
JSC "RED Nord"	6,1	1,57	0,07
	0,4	1,71	0,08
JSC "RED Nord-Vest"	35,11	1,2	0,06
	6,1	1,57	0,07
	0,4	1,73	0,08

Time-of-day tariffs are available when consumers have the conforming metering systems and the distributor has an equivalent power purchase agreement with suppliers. Non-residential consumers with an installed capacity of 50 kVA or more and monthly active energy consumption of 10,000 kWh may be charged by a tariff with penalization of low power factor.

1.2.2 Gas tariffs

Distribution of natural gas consumption in Moldova (201) is shown in figure 3. Biggest primary consumer field is electricity generation. Residential and commercial usage account for 17% altogether (Fig. 4). Total annual consumption of natural gas accounts to 3-3.5 bln m^3 [7].

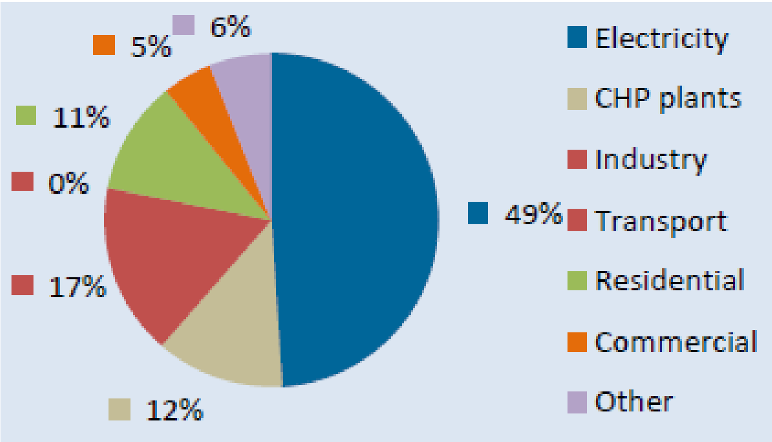


Fig. 4. Natural gas consumption in Moldova

Currently 100% of natural gas is imported from Russia through Ukraine. All gas transmission assets are owned by MoldovaGaz company and its subsidiaries, which is owned 50%

by Gazprom, 36.6% by Moldovan State and 13.4% by Transnistria administration.

In 2015, Iasi-Ungheni gas pipeline construction was finished, financed by EU (7 mln EUR) and Romania (21 mln EUR). Its main goal was energy security through diversification of energy supply and elimination of external political pressure instruments. At maximal transfer capacity of 1.5 bcm, it could cover 50% of gas consumption. But operation at maximal power would be possible only after overcoming internal Romanian export legislative barriers, constructing a set of distribution facilities and extending the line to Chisinau, which is not planned in predictable future.

Distribution tariffs are cost-based, in order to cover operational expenditure, depreciation and return on assets. Import cost is included in tariffs based on predictable demand and import price level.

Gas tariff rates, depending on the consumer category, are presented in the table (Tab. 3).

Tab. 3. End-user gas tariffs in Moldova

Tariff	Price [MDL/m^3]
1. Natural gas supplied by distribution companies whose networks are connected to the output pipeline distribution station (GDS)	5.044
2. Natural gas supplied by JSC «Moldovagaz» distribution networks of businesses that are not included in JSC «Moldovagaz» for further distribution to final consumers:	
- gas distribution companies that are connected to high pressure networks	5.154
- gas distribution companies that are connected to the networks of medium pressure	5.367
3. Natural gas supplied to thermal electric Centralia (CHP), the thermal power plants to generate and provide thermal energy to consumers through a centralized urban heating system	5.237
4. Natural gas supplied to residential customers in the amount of up to 30 m^3 (inclusive) per month per apartment (house)	5.961
5. Natural gas supplied to residential customers in excess of 30 m^3 per month per apartment (house)	6,221
6. Natural gas supplied to other consumers, including thermal power plants to generate and provide thermal energy to consumers through a local heating system, NGV filling stations connected to the distribution network:	
- high pressure	5.537

Tariff	Price [MDL/m^3]
- medium pressure	5.835
- low pressure	6.221
7. Transportation of natural gas transport networks served by LLC «Moldovatransgaz»	20.9
8. Distribution and supply of natural gas distribution networks served by enterprises of JSC «Moldovagaz»	559.92

1.3 Energy efficiency policy

In 2007, Moldova accepted Energy Strategy 2020, which has three main goals [8]:

a) Providing energy supply security by increasing the energy transfer capacities with Romania and Ukraine. Specific performed measures are:
   - Joint Operational Programme Romania – Ukraine – Moldova, finished in 2013. As a result, Iasi – Ungheni gas pipeline was built with funding from European Union.
   - Implementation of synchronization of the energy systems of Moldova with the ENTSO-E (on-going).

b) promotion of energy efficieny thorugh:
   - gradual approximation of national legislation with EU „*acquis communautaire*“.
   - achieving energy production of energy from renewable sources: 20% until 2020.

c) liberalization of energy market and restructurization of energy industries. Law on Electricity and Law on natural gas were adopted in 2009 under this vector of development.

Main regulatory institutions in energy efficiency domain in Moldova are:

a) National Agency for Energy Regulation (ANRE) – established in 2007, regulates and supervises electricity, oil, natural gas and district heating sectors.

b) Agency for Energy Efficiency (EEA) – established in 2010 and activating asa a department of Ministry of Economy. Its main areas of responsibility are:
   - implementing state policies in the field of energy efficiency and renewable energy;

- participation in drafting nromative acts, technical standards and regulations in the field of energy efficiency and renewable energy;
- defining energy efficiency requirements for devices and equipment produced or imported to Moldova and guide the process of their approval by the central authority of corresponding branch of the energy sector;
- participation in drafting national action plans and programmes in energy efficiency;
- provide assistance to national and local public authorities in outlining innovative programmes and their implementation.

Until recent time, there was a lack of energy efficiency oriented specific legislation. Measures and requirements are still defined in separate building codes and norms (based on SNIP and GOST), designed in '80es with different approaches to energy consumption and in the circumstances of very low energy prices, with some improvements over next decades. Current legislative framework in energy efficiency is defined by next acts:

a) Law on Electricity (2009) – is the key normative act of electricity sector, transposing Directive 2003/54/EC regarding common rules for the internal market in electricity. Article 52 of this act stipulated that electricity market should be fully liberalized by 1 January 2015. Objective wan not fullfiled.
b) Law on Natural Gas (2009) – transposes Directive 2003/55/EC regarding common rules for internal market in natural gas into national legal field.
c) Law on Energy Efficiency (2010) – partially transposes Directive 2006/32/CE on energy end-use efficiency and energy services. Art. 27 sets the development and adoption of next legislative acts:
    - National Programme on Energy Efficiency for 2011-2020;
    - Natinal Action Plan on Energy Efficiency for 2011-2014;
    - Law on Energy Performance of Buildins;
    - Regulation on Mnimum Energy Efficiency Requirements for Buildings;
    - requirements for ecological design.
d) Law on Renewable Energy Resources (2007) – stipulated goals for development of renewable energy sources:
    - Art. 6 of law ensures that by 2020 20% of total energy production will be from renewable energy sources;

- Introducton of feed-in tarrifs for a 15 years period, including: guaranteed acccess to the grid; prices based on cost of renewable energy generation; long-term contracts for acquiring produced energy. Is still in development;
- Creation of Energy Efficiency Fund (EEF).

An important step in regulation of heating tariffs was done by transferring responsibility for heat tariff setting from local public authorities to ANRE in 2009. Same amendments transferred responsibility for ANRE's budget approval and administration assignment from Government to the Parliament. It allowed setting heat tariffs at cost-recovery level.

In July 2014, Moldova became one of the first non-EU member states to transpose the EU Directive on Energy Performance of Buildings into local law, adopting the Energy Performance in Buildings Law. It includes:

- Obligations of building owners on energy efficiency;
- Obligations of state institutions on energy efficiency in buildings;
- Introduction of instruments for energy efficiency in buildings (e-certification, regular inspection, methodology for assessment, minimum requirements);
- Monitoring system on energy efficiency in the building sector.

Although adopted, it is not in force yet.

2 ENERGY EFFICIENT OFFICE BUILDINGS

2.1 Perspectives of development

Private businesses, as well as governmental companies own and operate commercial buildings, which include both residential and non-residential types of buildings, mostly being not lower than three stories. They are massive consumers of energy in the developed areas. For example, commercial buildings account for 36% of U.S. electricity consumption, being responsible for 18% of CO2 emissions. On average, potential of savings accounts to 30% of lost energy. Office buildings account for about 20% of all energy consumed by commercial buildings, and are therefore an important focus for energy efficiency improvements. According to data supplied by Building Research Establishment (BRE) in UK [4], commercial offices are responsible for 28% of CO2 emissions from commercial buildings (Fig. 5).

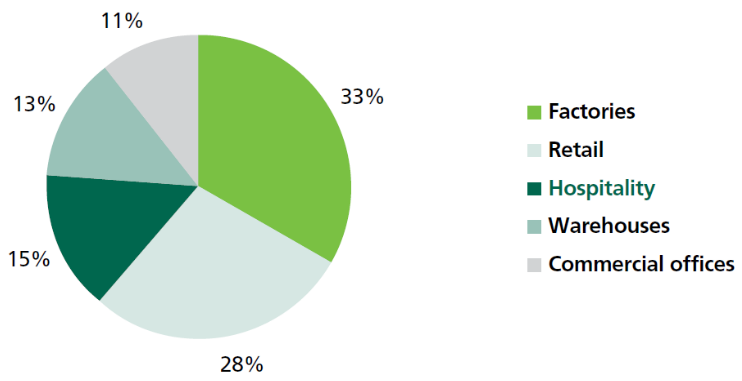


Fig. 5. CO2 generation repartition between commercial buildings

Energy efficient buildings conception appeared as a result of global energy crisis of 1974, starting with the report of International Energy Conference at UNO. Since then, development of low-energy buildings escalated quickly.

There is a number of obvious financial reasons for investment in energy saving measures:

- Easily achieved savings of 5 to 20% from the energy bill, depending on type of building and investments;
- Higher degree of energy efficiency increases attractivity of owned property. This is especially important in the case of low occupancy and good leasing rates (case, analyzed in practical part);
- In case when a „flat fee“ is charged by landlord, including utilities, rate of direct profit from leasing payment will be proportional to energy savings;

- Increased market value on resale;
- Investing in energy efficiency together with thermal comfort results in loyalty of occupants and higher productivity.

2.2 Office buildings energy efficiency concept

Main principles of energy efficient office buildings are [10]:

a) Energy efficiency:
   - Minimization of heat loss through external building envelope structures, for example by creating a compact building (reducing the rate of external surface to the total building area);
   - Recuperation of heat, escaping together with outgoing air through exhaust ventilation;
   - Using solar energy;
   - Using waste excessive heat of specific technological processes;
   - Economical usage of existing thermal and electrical resources;
   - Installing energy efficient windows;
   - Increasing thermal resistance of the building envelope;

b) Resource Efficiency – minimizing costs of the basic building systems; compactness; thickness and simplicity of the walls; Thickness and simplicity of the slabs.

c) Intelligent building design:
   - Adjustability and controllability;
   - Automatic reduction of air temperature after working hours;
   - Automatic reduction of air temperature at heat gain surplus, for example, from the office equipment (personal computers, servers);
   - Controlled ventilation;
   - Control of natural light;
   - Control of artificial lighting by zones, in accordance with decrease in natural light (with increasing distance from the windows);
   - Separation of the room into different microclimatic systems and their different degrees of regulation. Possible decentralization of heating and ventilation or a combination of a centralized system with a decentralized one.

d) Industrially produced building - production of the building or its parts, such as facade constructions through industrial methods. This leads to better quality of the structures, accelerated speed of production, accelerated installation time.

A more energy-saving approach – passive house, considers creation of passive microclimatic environment through:

a) Structural solutions:
   - Minimal number of windows on northern side, to reduce heat loss;
   - More intensive wglazing on southern and south-eastern sides to make use of solar radiation for heating;
   - Using „Trombe wall“ for heating purpose;
b) Active usage of renewables – solar collectors, ground heat pumps, etc.
c) Using specifics of orientation towards the sun:
   - South – heat inflow prevails over the outflow of heat;
   - East or West – inflow and outflow of heat through the windows might be balanced;
   - North – always an outflow of heat from the building;
d) Using day – night modes:
   - Significant heat outflow during the night from the windows;
   - Heat inflow during the day through windows;
e) Taking into account orientation towards wind direction. Measures in order to minimize wind pressure on the facade.

2.3 Classification of buildings by energy consumption

In conformity with Energy Performance principles, according to their level of energy consumption buildings are classified in next categories [11]:

a) Old buildings – require for their operation (heating and cooling) over 200 kWh/m^2 per year. In European practice, it is mostly represented by houses built before 1970s. Many houses built in Moldova now, under the absence of mandatory energy efficiency compliance, belong to this type as well. Typical features: outdated heating system, high-emission heat source, natural ventilation (windows), non-insulated building.

b) New buildings – between 80 and 140 kWh/m^2 per year. Typical features: heating using high-power boilers, natural ventilation (windows), structures according to norms.
c) Low-energy buildings – between 15 and 50 kWh/m^2 per year. Typical features: low-power heating system, usage of renewable sources, controlled ventilation, good structure insulation.
d) Passive house - between 5 and 15 kWh/m^2 per year. Total primary energy consumption (including source energy for power generation, heating and cooling) must not be over 120 kWh/m^2 per year. Good airtightness - Air circulation between building and exterior environment should not exceed 0.6 times the house volume per hour. Typical features: low-volume hot air heating with heat recuperation, excelent thermal insulation, advanced windows (U value between 0.85 and 0.7 W/(m^{2}K), emphasis on natural lighting.
e) Zero-energy building – lower than 5 kWh/m^2 per year. Is defined as a building which does not use more energy than it generates. Energy efficient design is performed from initial steps of building design. Building is designed in a way to make use of all available environmental passive and active resources not only by implemented technology but including structural design and positioning. Dual usage of energy, like using refrigeration heat output to heat the domestic water, air and shower drain heat exchangers, etc. Has more advanced energy efficiency features than passive house, active usage of renewable sources.
f) Plus-energy building – produces more energy than harvests, making maximal usage of available renewables. Combines microgeneration with low-energy building technologies.

3 INNER ENVIRONMENT PARAMETERS

Inner environment parameters in buildings are described in the CEN Standard EN 15251 "*Indoor environmental input parameters for design and assessment of energy performance of buildings - addressing indoor air quality, thermal environment, lighting and acoustics*". Every EU country has it integrated in its national standards system.

Buildings energy consumption highly depends on criteria of indoor environment (temperature, ventilation, lighting) and building design.

Energy consumption of buildings depends significantly on the criteria used for the indoor environment (temperature, ventilation and lighting) and building (including systems) design and operation. Indoor environment also affects health, productivity and comfort of the occupants. In practice, cost of unsatisfactory indoor environment may be higher for the building owner, than the cost of consumed energy in the same building. It is especially relevant to office buildings, where good indoor environment results in higher productivity and job satisfaction.

In the same time, same indoor environment criteria can differ for various circumstances. For example, criteria for cooling season (summer) are different from heating season (winter). It is an integral part of building energy calculations. Poorly evaluated indoor parameters may result in direct loss as well, for example by actions, taken individually by inhabitants to provide comfort.

3.1 Environmental parameters

Main environmental parameters are measurable and provide an objective representation of inner environment. Main of them are [12]:

- Mean radiant temperature t_r [°C] – is uniform temperature of all surfaces of enclosed space, in which radiant heat transfer from the human body equals with radiant transfer in non-uniform enclosure. It is a main parameter of assessing thermal comfort indexes. Experimentally is measured by a black-globe thermometer.
- Air temperature t_a [°C] – reflects temperature of air in the room without considering the influence of thermal radiation of surrounding surfaces.
- Speed of airflow w [m/s] – significantly affects the subjective perception of the air temperature. Is determined by the intensity and direction.

- Air humidity $\boldsymbol{\varphi}$ [%] – is represented though relative air humidity, which is the ratio of partial pressure of vapor to the saturated pressure of water at specific temperature, being a function of both water and temperature. It is an important factor for inner thermal comfort, especially in winter. The heat that is added to the space to cover the heat loss, will cause a drying effect and lower the indoor air humidity, if an indoor moisture source is not present. Exposure to dry air for longer periods of time has sensitive effects on human body and causes discomfort. When increasing air humidity to above 50%, more than 80% of inhabitants will feel comfortable. Generally, relative humidity between 40% and 70% does not have a major impact on thermal comfort.

3.2 Personal factors

Personal factors are individual for every human. Providing an inner environment parameters, that will satisfy a large group of people completely is a hardly realizable task, therefore, compromises should be found, assuring maximal level of thermal comfort satisfaction. Main personal thermal parameters are:

- Metabolic rate (human body heat) of a person $\boldsymbol{M}$ [W/m] – is a measure of human body heat production. Often measured in own unit of measure [Met], where 1 Met = 58 W/m^2, what corresponds to an average person at rest. The mean surface area of a person is 1.8 m^2. Metabolic rate depends on the type of performed activity, increasing at resource-demanding activities. Total heat from a person is obtained by multiplying metabolic heat value with area.
- Heat resistance of clothing $\boldsymbol{R}$ [m^2·K/W] – one of the main parameters, influencing heat transfer between a person and environment. In evaluation of thermal comfort, a special unit of measurement was defined – [clo], one clo corresponds to $\boldsymbol{R}$ = 0.155 m^2·K/W. This value corresponds to thermal insulation properties of a regular men's clothing, together with cotton underwear. $\boldsymbol{R}$ = 0 clo corresponds to a naked person, while $\boldsymbol{R}$ = 1 clo corresponds to the clothing level needed to maintain a person in comfort sitting at rest in a room at 21 °C with air movement of 0.1 m/s and humidity less than 50%.

3.3 Thermal comfort

Thermal comfort of a person is evaluated through several criteria, like: operative temperature t_0, mean radiant temperature t_r, clothing insulation, metabolic rate M, predicted mean vote index ***PMV***, predicted percentage dissatisfied index ***PPD***, draft ***DR***, relative humidity φ, air speed w.

3.3.1 Operative temperature

Operative temperature t_o [°C], also called *resultant temperature,* represents a uniform temperature of a radiantly black enclosure, where an occupant would exchange the same amount of heat by radiation and convection as in the actual nonuniform environment [5].

In practice, it represents an average value between air temperature and mean radiant temperature, weighted by their heat transfer coefficients [6]. It can be measured by an eupatheoscope. Its calculation formula is:

$$t_0 = \frac{(h_r t_{mr} + h_c t_a)}{h_r + h_c} \tag{1}$$

where: - h_c is convective heat transfer coefficient [W/(m^2·K)];

- h_r is linear radiative heat transfer coefficient [W/(m^2·K)];

- t_a is temperature of air [°C];

- t_{mr} is mean radiant temperature [°C].

Operative temperature is used in the basics of HVAC design. It is specified on the x-axis of the psychrometric chart.

3.3.2 Predicted Mean Vote index

Predicted Mean Vote (***PMV***) approach is based on heat balance equations together with empirical studies on skin temperature providing comfort. It allows prediction of mean response of a large group of people regarding their thermal sensation, on a scale from (-3) to (+3), for a specific combination of air temperature, mean radiant temperature, relative humidity, air speed and clothing [14]. Ideal value corresponds to zero, which is a thermally neutral state. Comfort zone corresponds to the interval between (-0.5) and (+0.5).

Calculation of ***PMV*** is based on Fanger’s equation [15]:

$$PMV = (0.303\ e^{-0.036\,M} + 0.028) \cdot L \tag{2}$$

where: **M** – metabolic rate [W];

L – thermal load, defined as the difference between the internal heat production and the heat loss to the actual environment [W];

Representation of comfortable humidity-temperature combinations [7], is shown in figure (Fig.6) [16].

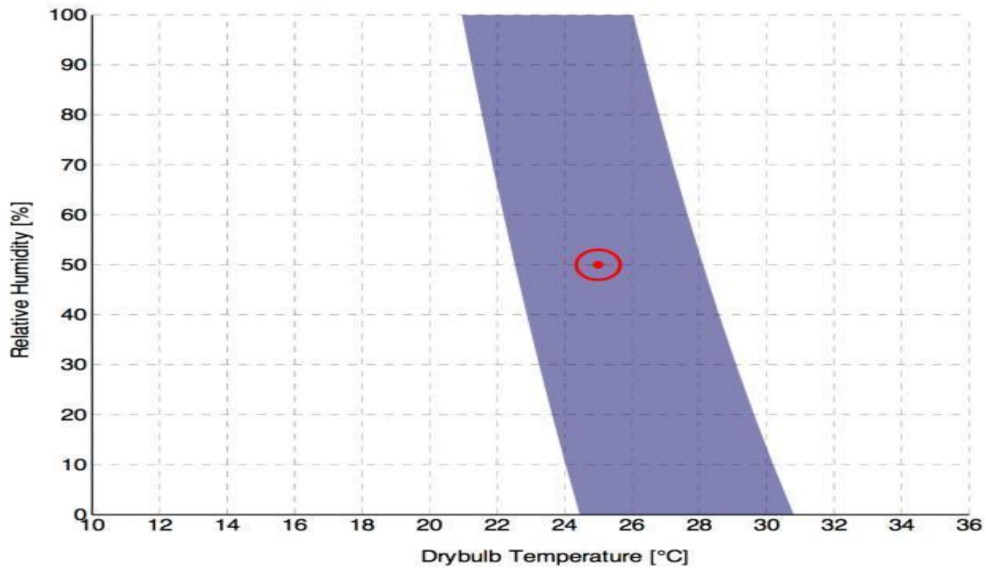


Fig. 6. Thermal comfort combination of humidity and temperature

3.3.3 Predicted Percentage of Dissatisfied index

While ***PMV*** is a qualitative measure of thermal comfort appreciation, in order to evaluate quantitative values of thermal comfort in groups of people, ***PPD*** index was introduced. Studies which allowed determination of ***PPD*** values were performed in a fully controlled environment. ASHRAE standard of thermal comfort requires that 80% of people should be satisfied.

PPD being a function of ***PMV***, it can be defined by relation [8]:

$$PPD = 100 - 95e^{-(0.3353 PMV^4 + 0.2179 PMV^2)} \tag{3}$$

As it can be seen on PMV – PPD diagram (Fig. 7), 100% of people can never be satisfied completely. At the best conditions, 5% of people are still insatisfied.

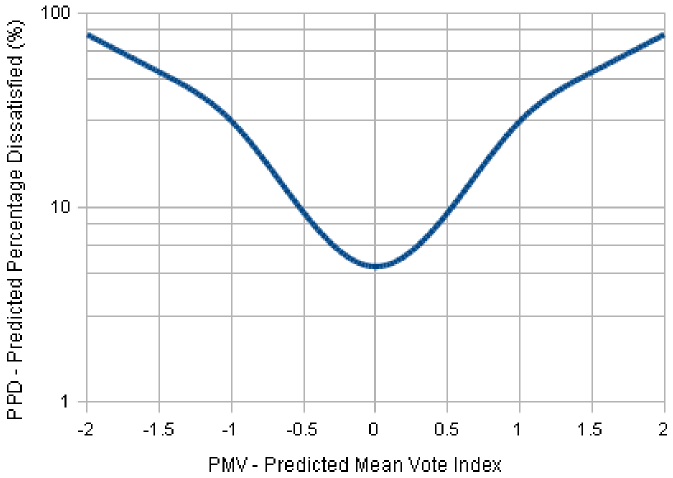


Fig. 7. PMV – PPD diagram

3.3.4 Predicted percent dissatisfied due to draft

Another statistical thermal comfort parameter is predicted percent dissatisfied due to draft (Draft Rate - ***DR***), reflecting number of persons expressing thermal discomfort due to drafts. Draft is defined as "*unwanted local cooling of the body caused by air movement*" [5].

Draft sensation depends on the air velocity, fluctuation of the air velocity (turbulence), air temperature and clothing insulation. Sensitivity to draft is higher where body is not covered by clothing, especially the neck and head region and the ankle and leg region [9].

The ***DR*** equation is:

$$DR = [(34 - t_a) \cdot (w - 0.05)^{0.62}] \cdot (0.37 \cdot w \cdot T_u + 3.14) \quad (4)$$

where: t_a – local air temperature [°C];

w – local average air velocity [m/s];

T_u – local intensity of turbulence [%].

3.4 Acoustical comfort

Acoustical requirements towards a building are a sanitary norm and are given by national regulations. Acoustics are an important feature of office building design, as it directly influences on productivity and health condition. Conducted studies [15] show that even in offices, noise is one of the main annoyance sources, and it leads to increased stress for occupants. In the case of energy-efficient buildings, where thermal comfort and energy saving technologies are implemented, noise is often the most bothering factor. Speech privacy can be a more important issue than noise itself. This happens because that acoustical insulation is often considered of low importance relatively to other parameters and contractors try to achieve maximal savings in the fields that do not directly affect energy expenses. Therefore, acoustics often do not receive the level of attention as HVAC and other engineering considerations. Excessive noise sources in the workspace include extensive use of speakerphones, phone ringing, office equipment and chatter.

Sensible for human ear sound diapason is between 16 Hz and 16 kHz. \Main acoustical evaluation parameter is acoustic pressure level ***L*** [dB]. It represents the difference between barometric air pressure and its immediate value at acoustical action, and can be defined through relation:

$$L = 20 \cdot \log(\frac{p}{p_0}) \text{ [dB]} \quad (5)$$

where: $\boldsymbol{p}$ – root mean acoustic pressure [dB];

$\boldsymbol{p_0}$ – reference value of acoustic pressure [dB].

Acoustical requirements towards the buildings in Moldova, based on *NCM E.04.02-2006 "Sound protection"*, are presented in the table (Tab. 4) [17].

Tab. 4. Sound level requirements of national standards

Purpose of the space	**Admissible sound level A [dB]**
Medical institutions	25
Residential rooms, living rooms, hotel rooms, sleeping rooms in kindregartens, schools, etc.	30
Study rooms, conference rooms	40
Office spaces	50
Cafes, restaurants, bars, dining room	55
Commercial spaces, stations, consumer services	60

3.5 Lighting

Correct design of lighting system is important from both power consumption and sanitary conditions. Lighting level affects not just human vision health and performance of a person, it also alters his physical and psychoemotional state.

It is especially valid for office spaces, because of high load on human vision, imposed by intellectual work. Required level of lighting is strictly reglemented by sanitary and technical norms. Valid for Moldova is national standard *NCM C.04.02–2005 „Functional requirements. Electrical installations. Natural and artirificial lighting“.* It is based on *SNIP 23-05-95 „Natural and artirificial lighting“*. Besides, it is regulated by series of sanitary norms, specific for various fields of applications.

Evaluation of lighting norms is done according to the level of illuminance, measured in lux (lx). One lux being equal to 1 lumen per m^2. Defined values of illuminance are valid for flat surface of the tables, in the case of office, classroom, etc., or floor surface in the case of open ground, staircase, hallway, etc.

Required illuminance level is defined for groupes of spaces, according to their functional usage. Common types of office building spaces and lighting level requirements are given in table (Tab. 5).

Tab. 5. Required illuminance according to standard [18]

Type of room	**Illuminance level according to SNIP [lx]**
General purpose office with PC usage	200-300
Large office space with open layout	400
Office, where design work is performed	500
Conference hall	200
Staircases	20-50
Hall, corridor	50-75
Archive	75
Storage	50

4 BUILDING PHYSICS REQUIREMENTS

Under building physics, we understand the variety of hygrothermal properties of the building structures. Building physics have to deal with different criteria, which require finding a compromise. On the one hand, requirements relate to assuring human comfort and health, on the other hand, economical, environmental and architectural restrictions should be respected [19].

When analyzing and designing thermal protection of the building in current study, a series of estimation indicators are used:

- Estimated coefficient of thermal conductivity $\boldsymbol{\lambda}$, [W/(m·K)];
- Coefficient of heat absorption (during 24 h) ***s***, [W/(m^2 · K)];
- Specific heat $\boldsymbol{c_0}$, [kJ/(kg·K)];
- Overall heat transfer coefficient ***U***, [W/(m^2 · K)];
    - Calculated heat transfer coefficient $\boldsymbol{U_c}$;
    - Required heat transfer coefficient (*ČSN 730540-2*) $\boldsymbol{U_{req1}}$;
    - Required heat transfer coefficient (*SNIP 23-02-2003*) $\boldsymbol{U_{req2}}$;
- Condensation of water vapor inside the wall ***M***, [kg/(m^3·year)];
    - Condensed mass of water vapor inside the wall $\boldsymbol{M_c}$;
    - Evaporated mass of water vapor inside the wall $\boldsymbol{M_{ev}}$;
- Internal surface temperature factor ***f***;
    - Desired lowest temperature factor of the inner surface $\boldsymbol{f_{Rsi,N}}$,
    - Calculated temperature factor of inner surface $\boldsymbol{f_{Rsi}}$.

Specific requirements for minimal heat transfer coefficient, sensible temperature decrease, thermal resistance, temperature of the inner surface and requirement for moisture spread in the structure for Czech Republic are given by *ČSN 73 0540, ČSN EN ISO 13788* and *ČSN EN ISO 6946*. In Moldova, they are regulated by *NCM E.04.01-2006* and *SNIP 23-02-2003*.

4.1 Heat transmission in structures

Every structure allows a certain level of heat transmission, which is proportional with heat loss through the structure. It is very important to limit heat transfer through structures, especially external ones, as much as possible. Heat transmission is evaluated using two main factors: heat transfer coefficient ***U*** and lowest interior surface temperature f_{Rsi}.

4.1.1 Heat transfer coefficient

Heat transfer coefficient ***U***, in general terms represents a coefficient between the heat flux and heat flow thermodynamic driving force, like temperature difference. It is the main parameter to consider when analyzing thermal properties of structures. Its value, according to *ČSN 73 0540* is given in table (Tab. 6) [20].

Tab. 6. Heat transfer coefficient of structures - ČSN 73 0540, Ureq1 [W/(m2K)]

Exterior wall	Ceiling under unheated attic	Floor and walls adjacent to the soil	Opening in the exterior wall (window)	Opening in the exterior wall (door)
0.3	0.3	0.85	1.5	1.7

Currently Moldova does not have legislative norms, which define mandatory requirements regarding U-value. Situation will start changing with the implementation of Energy Performance Law in 2015. On the other hand, valid building regulations - *SNIP 23-02-2003* operate with recommended heat resistance, R_0^{req}, [(m^{2}K)/W] (6).

$$R_0^{req} = a \cdot D_d + b \tag{6}$$

where: D_d – degree-days, (For Moldova D_d = 3142.8 days);

a, ***b*** – coefficients, depending on the type of building and structure.

Heat transfer coefficient, determined from heat resistance, is given in the table (Tab. 7) [21].

Tab. 7. Heat transfer coefficient of structures - SNIP 23-02-2003, U_{req2}, *[W/(m2K)]*

Parameter	Exterior wall	Floor	Ceiling under unheated attic	Doors and windows
a	0.0003	0.00007	0.00035	0.00005
b	1.2	1	1.3	0.2
R_0^{req}, [(m^{2}K)/W]	2.14	1.22	2.4	0.36
U_{req2}, [W/(m^{2}K)]	0.47	0.82	0.416	2.8

Required normative value of ***U*** is given for an average design temperature between 18 and 20 ^{0}C. In case if designed temperature is out of that range, it has to be corrected:

$$U_N = U_{N,20} \cdot \frac{16}{t_{im} - 4} \quad [\mathrm{W/(m^2}\,K)] \tag{7}$$

where: $\boldsymbol{U_N}$ – required heat transfer coefficient value [W/(m^{2}K)];

$\boldsymbol{U_{N,20}}$ – heat transfer coefficient, imposed by standard [W/(m^{2}K)];

$\boldsymbol{t_{im}}$ – interior design temperature [^{0}C].

In the further analysis, the requirements of *ČSN 73 0540* will be considered, considering their higher level of competence regarding current energy efficiency principles and current transition of Moldovan standards to EU regulation.

When calculating heat transfer coefficient for a building, first step is determining individual ***U*** coefficient of every structure and checking it for compliance with standards. In case it does not correspond to the requirements, it can be improved by proper insulation.

Overall heat transfer coefficient ***U*** of the structure is determined by relation:

$$U = \frac{1}{\frac{1}{h_i} + \sum \frac{d_n}{\lambda_n} + \frac{1}{h_e}} \quad [\mathrm{W/(m^2}\,K)] \tag{8}$$

where: $\boldsymbol{h_i}$ – heat transfer coefficient of the internal surface ($\boldsymbol{h_i} \approx 6$ [W/(m^2·K)]);

$\boldsymbol{h_e}$ – heat transfer coefficient of the external surface ($\boldsymbol{h_i} \approx 12$ [W/(m^2·K)]);

$\boldsymbol{d_n}$ – thickness of layer n, [m];

$\boldsymbol{\lambda_n}$ – heat conductivity of layer n, [W/(m·K)].

When calculating heat transfer coefficient, it is necessary to take into account correction coefficient for thermal bridges $\Delta \boldsymbol{U_{tb}}$ [W/(m^2·K] by relation (9). According to *ČSN 730540-4*, thermal bridges coefficient for regular buildings without thermal bridges optimization, $\Delta \boldsymbol{U_{tb}} = 0.1$ W/(m^2·K).

$$U_t = U + \Delta U_{tb} \tag{9}$$

Mean heat transfer coefficient of the building is determined individually by the method of reference building. By reference building is understood an object of similar size and layout as evaluated object. It represents an average of all required values of structures (10):

$$U_{em,N,20} = \frac{\Sigma U_{Nj} \cdot A_j \cdot b_j}{\Sigma A_j} + 0.02,\ [\mathrm{W/(m^2}\ K)] \quad (10)$$

where: $\boldsymbol{U_{N,j}}$ – required by standard heat transfer coefficient of structure *j* [W/(m^{2}K)];

$\boldsymbol{A_j}$ – area of considered structure *j* [m^2];

$\boldsymbol{b_j}$ – thermal reduction coefficient of structure *j*.

4.1.2 Lowest interior surface temperature of structure

Interior surface temperature t_{si} is evaluated in the form of ratio, as a thermal factor of inner surface f_{Rsi}, which is a specific characteristic of construction and does not depend on surrounding temperature [19]. It is calculated with relation (11):

$$f_{Rsi} = \frac{t_{si} - t_e}{t_{ai} - t_e} \quad (11)$$

where: $\boldsymbol{f_{Rsi}}$ – interior surface temperature factor;

$\boldsymbol{t_{si}}$ – interior surface temperature [^{0}C];

$\boldsymbol{t_e}$ – temperature of outside air [^{0}C];

$\boldsymbol{t_{ai}}$ – design temperature of inside air [^{0}C].

It is essential to meet the condition during winter $\boldsymbol{f_{Rsi}} > \boldsymbol{f_{Rsi,N}}$, in every part of the building which falls under regulations with standardized interior surface thermal factor $\boldsymbol{f_{Rsi,N}}$.

To prevent condensation and mould formation, temperature factor $\boldsymbol{f_{Rsi}}$ is higher than 0.7 everywhere. In contrast with the average operative indoor temperature, the minimum surface temperature may deviate by a maximum of 4.2 K. A bigger difference may lead to unpleasant cold air descent and perceptible radiant heat deprivation.

4.2 Moisture transfer through the structure

Moisture is transferred through the structure by diffusion. Important requirement is to avoid the condensation of water vapor inside the structure. This may lead to reducing mechanical properties of the material or mould formation. Therefore, one of the main tasks of moisture analysis is to determine in which point of the structure condensation occurs. Balance of water vapor in the structure is evaluated by condensed and evaporated amount.

Structure should not allow formation of condensed water vapor inside it. Condensate may lead to growth and spread of mould and lowers thermal technic characteristics of the structure, as well as its mechanical properties and stability. Condensation can occur when outside temperature falls under 0.

Structures may be divided depending on influence of potential condensate on the state of the structure in two groups. First group can be damaged by condensate and it should be absolutely avoided. Second group will not suffer critical damage because of condensate.

In structures, where condensate may occur, amount of condensed water vapor should be limited by criteria (12):

$$M_c < M_{C,N} \ [\mathrm{kg/(m^2 \cdot year)}] \qquad (12)$$

where: $\boldsymbol{M_c}$ – amount of condensed water over an year [kg/(m^2·year)];

$\boldsymbol{M_{C,N}}$ - maximal amount of condensed water over an year [kg/(m^2·year)].

Structures with densities greater than 100 kg/m^3 allow maximal weight of condensed water vapor during the year not more than 3% of its total weight. For structures with density lower than 100 kg/m^3, an amount of 6% of its weight is considered. For structures with incorporated wood elements and the external thermal insulation system, $\boldsymbol{M_{C,N}} = 0.1$ kg/(m^2·year). For other structures, $\boldsymbol{M_{C,N}} = 0.5$ kg/(m^2·year).

Amount of the condensate, formed inside the wall during the year ($\boldsymbol{M_C}$) should be lower than the annual capacity of its evaporation ($\boldsymbol{M_{ev}}$). It is represented by annual balance of condensed and evaporated water vapor. These conditions help minimizing the effects of condensation.

4.3 Heat loss

Crucial point of thermal analysis is determination of heat loss in the building. Complex image can be obtained only by computing heat losses of each room individually.

Simplified methodology of heat loss calculation in Moldova was elaborated by Energy Efficiency Fund basing on *ISO EN 13790* standard. Generally, *SNIP II-3-79 “Buildings Thermal Engineering”* is currently valid in terms of heat loss calculation recommendations.

Due to on-going transition to EU standards, in current work heat loss is calculated according to the norm *ČSN EN 12831*, according to the required inside air temperature in each room.

4.3.1 Total heat loss

Total heat loss of the heated space, $\boldsymbol{\Phi_i}$ is determined by sum of heat loss by transmission and ventilation [22]:

$$\Phi_i = \Phi_{T,} + \Phi_{V,i} \ [W] \tag{13}$$

where: $\boldsymbol{\Phi_{T,i}}$ – design heat loss by transmission of the heated space, [W];

$\boldsymbol{\Phi_V}$ – design heat loss by ventilation of the heated space, [W].

4.3.1.1 Heat loss by transmission

Designed heat loss by transmission of the heated space $\boldsymbol{\Phi_{T,}}$ is described by relation:

$$\Phi_{T,} = (H_{T,ie} + H_{T,iue} + H_{T,ig} + H_{T,ij}) \cdot (\theta_{int,i} - \theta_e) \ [W] \tag{14}$$

where: $\boldsymbol{H_{T,ie}}$ – heat loss coefficient from the heated space (i) to exterior environment (e) of the building envelope, [W/K];

$\boldsymbol{H_{T,ue}}$ – heat loss coefficient from the heated space (i) to the ground in a steady state, [W/K];

$\boldsymbol{H_{T,g}}$ – heat loss coefficient from the heated space (i) to the ground (g) in a steady state, [W/K];

$\boldsymbol{H_{T,j}}$ – heat loss coefficient from the heated space (i) to another space, heated to a considerably different temperature (j), [W/K];

$\boldsymbol{\theta_{int,i}}$ – design interior temperature of the considered space, [^{0}C];

$\boldsymbol{\theta_e}$ – calculation temperature of the exterior environment, [^{0}C].

4.3.1.2 Heat loss by ventilation

Designed heat loss by ventilation $\boldsymbol{\Phi_{V,}}$ is determined next way:

$$\Phi_V = H_{V,i} \cdot (\theta_{int,i} - \theta_e) \ [W] \tag{15}$$

where: $\boldsymbol{H_{V,i}}$ – coefficient of design heat loss by ventilation, calculated using formula (16) [W/K];

$\theta_{int,i}$ – design indoor temperature of the considered space, [^{0}C];

θ_e – calculation temperature of the outdoor environment, [^{o}C].

Assuming that circulating air has constant density and specific heat capacity, coefficient of design heat loss by ventilation is given by expression:

$$H_{V,} = V_i \cdot 0.34 \ \ [W/K] \tag{16}$$

where: V_i – air circulation in the considered space, [m^3/h].

Calculation methodology makes a distinction between objects with natural ventilation and forced ventilation systems. In case if it is assumed that there is no forced ventilation system, the incoming air has thermal properties of the outside air. On these basis, the value of the air exchange in the heated space is determined according to the relationship for the natural ventilation:

$$V_i = max(V_{inf,i} + V_{min,i}) \ \ [m^3/h] \tag{17}$$

where: $V_{inf,i}$ – air circulation through gaps and joints of the building envelope (19), [m^3/h];

$V_{min,i}$ – minimal air circulation required from point of view of hygiene (18), [m^3/h].

$$V_{min,i} = n_{min,i} \cdot V \ \ [m^3/h] \tag{18}$$

where: $n_{min,i}$ – minimal required air circulation intensity, [1/h];

V – air volume of the space, [m^3].

$$V_{inf,i} = 2 \cdot V \cdot n_{50} \cdot e_i \cdot \varepsilon_i \ \ \ [m^3/h] \tag{19}$$

where: n_{50} – intensity of air exchange at pressure difference between interior and exterior environment equal to 50 Pa, [1/h];

e_i – shading factor;

ε_i – altitude correction factor.

4.3.2 Designed heating power

In order to perform accurate and corresponding design of the heating system, selection and sizing of heaters, it is not enough to consider the calculated heating losses. Designed heating power should be considered. Besides the heating loss itself, it includes the heating losses in case of interrupted heating [23] (20):

$$\Phi_{HL} = \sum\Phi_T + \sum\Phi_V + \sum\Phi_{RH} \ \ \ [W] \tag{20}$$

where: $\sum \boldsymbol{\Phi}_T$ – sum of heat loss by transmission of all heated spaces, [W];

$\sum \boldsymbol{\Phi}_V$ – sum of heat loss by ventilation of all heated spaces, [W];

$\sum \boldsymbol{\Phi}_{RH}$ – sum of required heating power for reheating of all heated spaces (for the case of interrupted heating), [W].

Reheating load of a room $\boldsymbol{\Phi}_{RH}$ depends on its floor area and reheating coefficient (15):

$$\Phi_{RH,i} = A_i + f_{RH,i} \; [W] \tag{15}$$

where: $\boldsymbol{A}_i$ – floor area of the room, [m^2];

$\boldsymbol{f}_{RH,i}$ - reheating coefficient, depending on the reheating time and temperature drop during the downturn, values are given in the standard according to mass of the building and reheating time (Tab. 8) [W/m^2].

Heating cannot be downturned for a long period. Downturn mode is set together with the building owner. According to regulations accepted in EU, in our case represented by *ČSN EN ISO 12831*, downturn has to be chosen so that the reheating time should not be more than 4 hours and the temperature drop not more than 4 °C.

Current simplified calculation method is given by the standard, and can be applied to next applications:

- Residential buildings with heating pause up to 8 hours and structures that are not light (wooden beam structures, etc.);
- Nonresidential buildings with a break up to 48 hours during weekend, 8 hours on weekdays and design temperature of 20-22 °C.

Tab. 8. Reheating coefficient, fRH [21]

Reheating time, [h]	$\boldsymbol{f_{RH}}$, **[W/m^2]**								
	Expected fall in internal temperature during thermal decay								
	2 K			3 K			4 K		
	Mass of the building			Mass of the building			Mass of the building		
	low	med.	high	low	med.	high	low	med.	high
1	18	23	25	27	30	27	36	27	31
2	9	16	22	18	20	23	22	24	25
3	6	13	18	11	16	18	18	18	18
4	4	11	16	6	13	16	11	16	16

5 EQUIPMENT FOR INNER CLIMATE CREATION

In order to provide required parameters of inner environment, corresponding equipment should be selected with considering its effectiveness, accessibility of fuel and spare parts, structural parameters of the building (size, position, etc.) and economic effects.

In Moldova, the most popular heating fuel is natural gas, for the case of individually installed heating systems. Most of the older structures are connected to the central heating system, which distribute heat generated at two thermoelectrical stations. These stations' primary role is generating electricity from fuel oil or coal, heat being a secondary product. It is collected from water vapor which comes out of the electric turbine after electricity generation. Popularity of gas as a heating fuel relies on: accessible gas prices, relatively low initial cost of installation, proved reliability of gas boiler systems and their ease of usage, wide availability and choice of equipment, good automation solutions. The prevailing role of natural gas in Moldova's energy supply can be seen in figure below (Fig. 8).

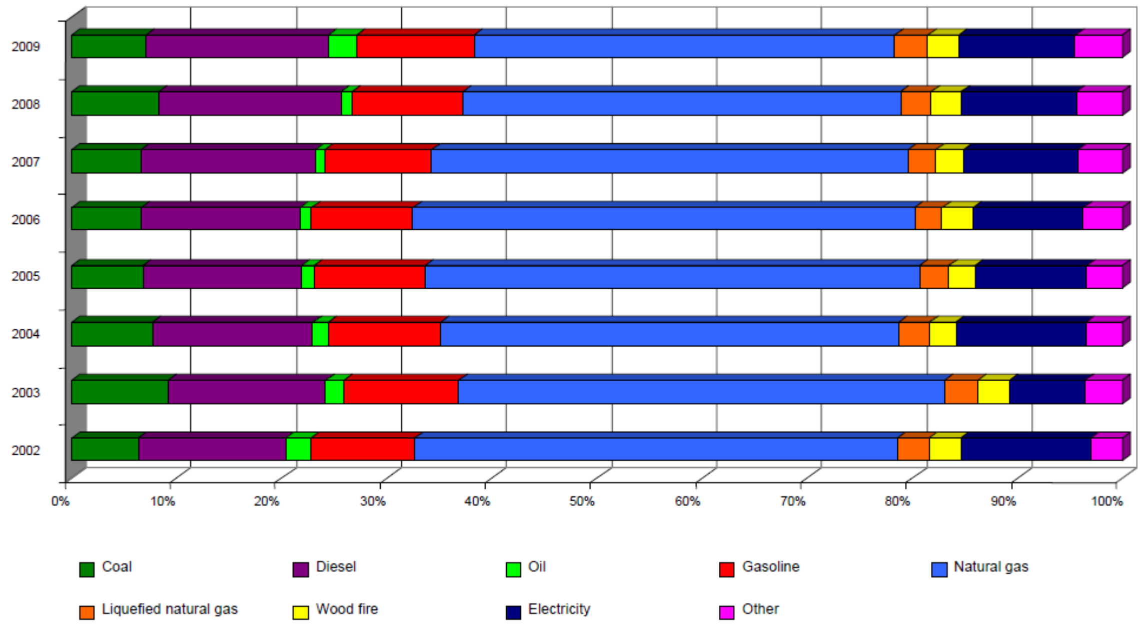


Fig. 8. Total primary energy supply by fuel [7]

Most important technical system of inner environment formation is the heating system. Properly designed heating system is vital not only for health and comfort of inhabitants, but for the condition of the building structures. Lower temperatures and condensation inside the structures can reduce mechanical and thermal properties of structures and lead to mould formation.

5.1 Gas boilers

5.1.1 Operating principles

Gas boiler is a device for generating heat energy by combustion of the gaseous fuel, primarily for purposes of heating closed spaces of various functions, water heating for domestic and other purposes. Used gaseous fuels for gas boilers is mostly natural gas – methane (when central gas distribution is available) or propane-butane (in case of remote locations) [24].

The principle of boilers operation is that when gas is supplied to the boiler, piezoelectric or electronic ignition is activated. From spark, the pilot light is ignited, which is always on. Gas supply to the burning chamber when burner is inactive is unacceptable because of the potential gas explosion. From the pilot light, the main burner is lighted up. It warms the cooling agent in the boiler until desired temperature, set in the thermostat, is reached and then automated system turns off the burner. When the temperature drops in the boiler, the temperature sensor (thermocouple) commands the valve to open the gas supply and the burner is ignited again. Water is heated through the heat exchanger. All gas boilers have pre-installed automated control system with the required safety equipment (valves, drain, exhaust, etc.), which executes control through heat and pressure sensors. Components of a gas boiler and their position are shown in figure (Fig. 9).

Conventional standing pilot, which is always on, can be substituted by electronic or mechanic ignition system. These systems save up to 5% of heating energy by igniting the pilot just in the moment of the heating signal from the thermostat. Some new systems use a ceramic “hot surface igniter" which eliminates completely the pilot. The igniter is energized electrically and quickly reaches a very high temperature. When the gas valve opens, the gas is ignited by coming into contact with the hot surface igniter.

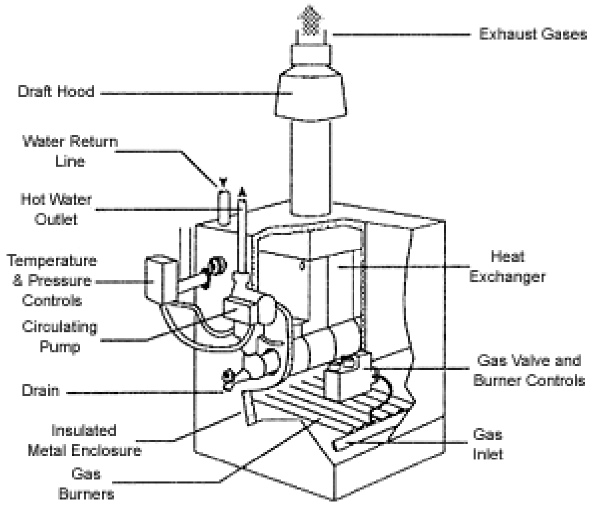


Fig. 9. Gas boiler components

When selecting boilers, it is preferable to split the heat load between multiple boilers, instead of choosing a large one, for the next reasons [25]:

- Compensation of over-sizing effects. Boilers are designed for the peak heat power. They do not usually operate at the maximum load more than 5% of operation time. Oversized boilers do not operate very efficiently because there will be frequent on/off cycling since the load is less than what the boiler is capable to produce. Boiler will never operate in a steady-state mode, for which it is designed. As a result it will not be able to output declared efficiency and increased equipment usage will occur. With multiple smaller boilers, when the load on the building is light, only one of the boilers may be required to heat the space. This smaller boiler will operate for a long run cycle, increasing its operating efficiency and saving the equipment resource of the others;
- Largely available residential boilers can be used to achieve a total high power output, making the maintenance cheaper and having accessible replacement parts;
- High reliability. If a boiler runs out of service, another one can compensate for it, until it is replaced. It results in ease of maintenance works as well.

5.1.2 Classification

There are several generally accepted classifications of gas boilers [26].

By placement:

a) Floor mounted. Are placed on the floor or a special platform:

- Steel fire-tube boilers. Are characterized by high power (up to several MW), sufficient efficiency value. Cylindrical shaped heat exchangers are used is these boilers, welded and consisting of steel pipes for heating agent circulation. Inner part of the cylinder is the combustion gas chamber. Gas-air mixture is prepared and suuplied to the combustion chamber from a special blow burner.
- Cast-iron gas boilers. Boilers with cast iron heat exchanger, often of section type. Are equipped with tubular or blow burners. Have average usable power value (up to several hundred kW), which is limited by heat exchanger significant weight. Thanks to the material of the heat exchanger, they have the greatest lifetime in comparison with other types of boilers. However, due to physical properties of cast iron (fragility), they have specific requirements towards operating temperature modes. Are often supplied in sections because of enormous weght and therefore imply higher installation and transportation costs.

b) Wall mounted. Are placed on the wall or a special frame. They are compact, low-power (up to 100 kW), with a tubular burner and steel or copper heat exchanger. Advantages of wall mounted boilers include: space savings, pre-assembled key-turn state (usually includes all necessary elements for boiler operation, including safety and control equipment).

Functional possibilities:

a) Single-circuit. These are boilers, capable in standard mode just for serving heating purposes. If hot water preparation is also required, an external indirect water heating system should be designed and connected.
b) Double-circuit (combined). Boilers, capable of providing both heating and hot water preparation for domestic hot water supply. Heating of hot water preparation circuit is carried out in a flow-through heat exchanger (can be separate plate or coaxial bithermal) or in a built-in cylindrical indirect heater.

By type of draft:

a) With natural draft (with atmospheric burner and open combustion chamber) - boilers, in which the air intake for combustion is carried out from the room where the boiler is situated. Products of combustion are evacuated due to natural draft.

These boilers must be placed in special rooms, corresponding to relevant regulations (*MDS 41-2.2000* for Moldova).

b) Forced draft (turbo burners with closed combustion chamber) - boilers, in which the air intake and exhaust of combustion gases is done directly to outdoor environment or, more rarely, to other premises, with the help of built-in fans through special ducts of small diameter. Advantages of this type of boiler are: high flexibility in placement position, including apartment heating applications; it does not require a pre-equipped standard vertical chimney of a large cross-section; possibility of horizontal exhaust duct through the wall.

By type of ignition

a) Piezo igniton - requires manually pressing a button. They are non-volatile, being irreplaceable where there are power supply interruptions.
b) Electronic ignition - starts itself automatically. Has an advantage of energy savings, as a pilot light does not operate constantly.

By rate of fuel energy usage:

a) Conventional - uses only the net calorific value. The main principle in the design of the heating system with a conventional boiler is preventing condensation of water vapor with the acid dissolved in them on the walls of the heat exchanger, furnace and the chimney. To achieve this, the temperature of the output and return lines has to differ slightly. Best solution is to use radiator heating with temperature parameters of at least 80 °C (supply circuit) / 60 °C (return circuit). This guarantees prevention of condensation, which begins at the temperature of 55-57 °C for water. Besides, it is possible to use a four-way mixer for mixing of heating agent between supply and return line of the boiler circuit.
b) Condensing – achieves the efficiency of over 90% of higher heating value (gross calorific value) by using waste heat in flue gases to pre-heat cold water entering the boiler through economizer. For optimal realization of the condensation effect it is necessary to achieve the reduction of the outflow and especially return flow temperature to dew point temperature. Best solution is using a low-temperature underfloor heating. Besides, a device for lowering the temperature of the return line can be used, for example, using return heating agent of the radiator circuit in the supply line for the underfloor heating circuit.

5.2 Solar water heating equipment

Solar collectors are devices, used for harvesting thermal energy of the Sun, transferred by visible light and infrared radiation. Collected energy is used to heat the heat carrier material. They are used for hot water preparation and heating of enclosed spaces.

Main principles of solar collector operation are [27]:

- Equilibrium effect. Due to heat loss of the hot object, it tends to return to thermal equilibrium with surrounding temperature. It is realized through conduction, convection and radiation, latter two being most important. Heat loss from the surface of collector directly determines its efficiency. In that case, efficiency is the rate of thermal energy which can be contained for a certain time interval). In order to minimize the heat loss to the environment, collector is thermally insulated.
- Temperature gradient effect. Heat loss increases together with difference in temperature between heated object and the environment. In the case of solar collector, this difference is represented by thermal gradient between environment temperature and collector surface temperature.

Main component of solar collector is the absorber plate. It represents a coated metal plate, which absorbs sun radiation, raising its temperature higher than the temperature of environment. Then absorber tends to release energy to its surroundings through radiation and convection. In that way, heating agent is heated by flowing through pipes which are in contact with absorber, transferring heat to the hot water later.

5.2.1 Types of solar collectors

Two main types of solar collector are flat plate and evacuated tube collectors [28]:

a) Flat-plate collector (Fig. 10) is composed of absorber, transparent cover, frame, and insulation.
   Cover is made of iron-poor safety glass usually, because of its ability to transmit high amount of short-wave light spectrum. Besides, it minimizes loss of heat from the absorber to surroundings. It prevents convection loss of heat by carrying it away with wind. Another function of cover (together with frame) is protection of the absorber from dangerous weather conditions and mechanical damage.
   Frame is produced mostly from aluminium and galvanized steel.

Heat loss to the surroundings by conduction is prevented by insulation on the sides and back of collector, usually made of polyurethane or mineral wool.

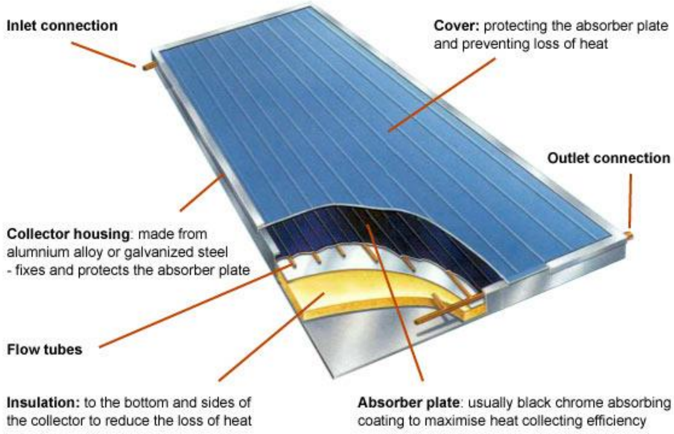


Fig. 10. Flat plate solar collector

b) In evacuated tube collectors, absorber is placed in an evacuated and pressure resistant glass tube. Heat agent flows directly through the absorber in a U-tube or tube-in-tube system. Solar collector is thus composed of a network of inter-connected tubes. Connection can be done serially or through a manifold.
   Heat collector pipes are filled with special heating agent with a very low evaporation temperature. Its steam rises inside the individual pipes and heats up through a heat exchanger the main pipe with heat-transfer fluid inside it. After that, fluid condenses and flows back to the base of individual pipe.
   Pipes shall be oriented at a specific angle to provide optimal evaporation and condensation process. Collector can be connected to circulation system by extending heat exchanger into the manifold (wet connection), or connecting manifold by a heat-conducting material (dry connection).

Usage of evacuated tube collectors is recommended in regions with wide range of temperature and climatic variations, while flat plate collectors are more efficient at constant sunny conditions.

5.2.2 Types of solar heating systems

There are two basic conceptions of solar heating system design:

- Passive systems rely on heat-driven convection or heat pipes to circulate water or heating fluid in the system. They cost less and have extremely low or no maintenance, but the efficiency of a passive system is significantly lower than that of an active system. Overheating and freezing are major concerns.

- Active systems use one or more pumps to circulate water and/or heating fluid in the system. Though slightly more expensive, active systems offer several advantages:
    - The storage tank can be situated lower than the collectors, allowing increased freedom in system design and allowing pre-existing storage tanks to be used;
    - The storage tank can be hidden from view;
    - The storage tank can be placed in conditioned or semi-conditioned space, reducing heat loss.
    - Drainback tanks can be used.
    - Superior efficiency.
    - Increased control over the system.

There are two types of active solar heating systems: closed-loop (indirect) and open-loop (direct):

- Open-loop system is the one, where you have a “feed and expansion tank” in the loft which fills the boiler system initially and keeps it topped up with water on a long-term basis to replace losses form evaporation and/or minor leaks. A float valve in the tank, connected to water feeding system keeps the water level in the tank and the heating system correct. The primary advantages of an open-vented system are: simple in operation - no user intervention is required to keep the system topped up with water; simplier and cheaper to install; higher efficiency of heat transfer due to the absence of heat exchanger and direct heat transfer; is easily expanded in the case if adding capacity is required.
- Close-loop systems use a heat exchanger to transfer heat to the water heating circuit. They use equipment, such as valves pumps and controllers to circulate the heat agent, which is usually a polypropylene glycol-water antifreeze mixture. This mixture make closed-loop systems effective when operation at low-temperatures is required. Advantags are that: multiple heat exchangers can be used for various applications, with switching between them; freeze protection; lower power of the pump is required. However, they are more expensive in installation and operation, collectore loop needs to be pressurized (8-12 psi), usage of heat exchanger lowers

the efficiency. Besides the heat exchanger, pump and valves, a heat dump has to be design for overhating control.

There is no common and universal solution for designing solar panels. Each application has specific conditions depending on such factors as: location of installation (radiation values differ depending on geographical position, respectively varies angle of installation and operation conditions), required power, shape and available space of the roof, etc.

6 PHOTOVOLTAIC EQUIPMENT

6.1 General description

Photovoltaic system (PV) is a system, designed to supply electric power by converting solar energy into direct current electricity through semiconductor materials that possess the photovoltaic effect.

A PV is based on solar panels, which are composed of a multiplicity of solar cells that convert solar power in DC electricity. First step of the converting process is the photoelectric effect, after which an electrochemical process occurs, ionizing crystallized atoms in series, generating electrical current. Composition of a typical solar module is shown in figure (Fig. 11).

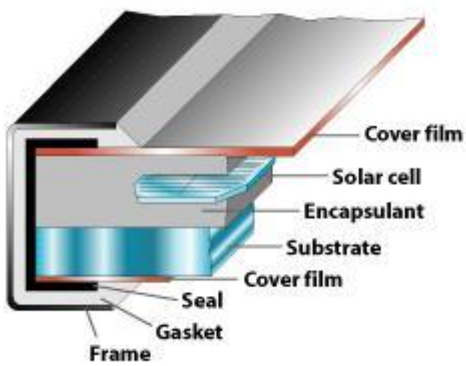


Fig. 11. PV module composition

PV systems quietly generate electricity from light without producing noise, waste heat, air pollution or hazardous waste. There are different types of solar PV systems, but the principle on which they operate and the components they consist of are similar. Key components of any rooftop solar photovoltaic systems are the array of solar cells (modules) and the inverter. Other important components of a rooftop solar PV system include a PV generation meter, mains fuse box, electricity export meter, and connecting cables and sockets.

All PV cells operate at a low voltage, therefore they are often connected together in series to form PV modules that may be up to several meters long and a few meters wide with different sizes and power output for household needs. The PV modules convert sunlight into electricity. The amount of electricity produced depends on the amount of light that falls on the PV modules. PV does not require direct sun rays, but only diffused light to generate electricity, however, the output from a PV module depends on the intensity of the light.

The PV modules are connected to the inverter that converts the direct current (DC) electricity generated by the panels into alternating current (AC) electricity that matches the building's mains electrical grid supply. If the building is not grid connected the inverter is usually replaced with a battery bank to store the electricity generated.

The PV technology is proven and established. Unlike wind turbines, a solar PV system is silent and can be integrated into or mounted on an existing roof, however, roofs that have any shaded areas for any part of the day would not be suitable for Solar PV systems. The panels have no moving parts, which means that maintenance costs are kept to a minimum.

Solar PV modules are rated at peak output power. Watts peak (Wp) is the peak power in Watts (W) produced in standard test conditions. These conditions are rarely achieved consistently in practice as the output fluctuates with solar radiation levels, which vary considerably during the day and also during the year. According to the Joint Research Centre of the European Commission, the yearly sum of global irradiance incident on optimally-inclined south-oriented photovoltaic modules for Moldova ranges between 1300-1700 kWh/m2. It is estimated that for a Moldovan home the yearly sum of solar electricity generated by 1 kWp PV system will be around 1100 kWh/kWp.

Favorable feed-in-tariffs which should be soon introduced in Moldova for the grid connected solar PV systems will make them a viable investment opportunity for the Moldovan households interested in generating electricity at their homes and selling it to the grid.

Moldova is situated in the moderate zone of solar energy flux, with 2200 annual sunny hours. This means that there are favorable conditions for solar energy harvesting.

6.2 Characteristics of PV panels

Essential for estimating operational efficiency of PV module are electrical current and power characteristics, depending on the voltage – I(U) and P(U). Both radiation value and ambient temperature influence the output of a module.

Characteristics of the module for specific conditions are obtained using a sequence of relations [30].

Short-circuit current $\mathbf{I_{sc}}$ [A]:

$$I_{sc} = \frac{G}{G_{st}} \cdot I_{sc\_st} \text{ [A]} \tag{16}$$

where: ***G*** – global radiation in the given conditions [W/m^2];

G$_{st}$ – global radiation in standard conditions [W/m^2];

I$_{sc_st}$ – short-circuit current in standard conditions [A].

Cell temperature ***t$_c$*** [˚C]:

$$t_c = t_a + \frac{NOCT - 20}{0.8} \cdot G \text{ [°C]} \tag{17}$$

where: ***t$_a$*** – ambient average temperature [˚C];

NOCT – Nominal operating cell temperature [˚C].

Open circuit voltage ***U$_0$*** [V]:

$$U_0 = U_{0\_st} - 0.0034 \cdot n_c \cdot (t_c - 25) \text{ [V]} \tag{18}$$

where: ***U$_{0_st}$*** – Open circuit voltage at standard conditions [V];

n$_c$ – number of cells.

The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero.

Current in operating point ***I$_m$*** [A]:

$$I_M = I_{M\_st} \cdot \frac{G}{G_{st}} \text{ [A]} \tag{19}$$

where: ***I$_{M_st}$*** – nominal current at standard conditions [A];

Voltage in operating point ***U$_m$*** [V]:

$$U_M = U_{M\_st} - 0.0034 \cdot n_c \cdot (t_c\text{-}25) \text{ [V]} \tag{20}$$

where: ***U$_{M_st}$*** – nominal voltage at standard conditions [A];

The "fill factor" ***FF***, is a parameter which, in conjunction with ***U$_0$*** and ***I$_{sc}$***, determines the maximum power from a solar cell [31]. The ***FF*** is defined as the ratio of the maximum power from the solar cell to the product of ***U$_0$*** and ***I$_{sc}$***. Graphically, the ***FF*** is a measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the IU curve:

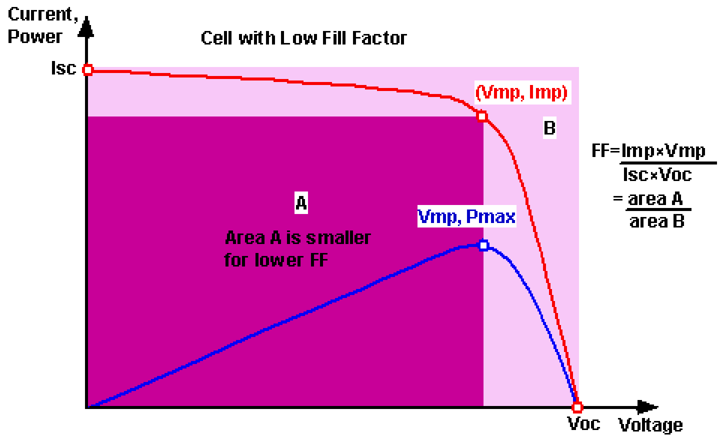


Fig. 12. Graph of cell output current and power as a function of voltage

$$FF = P_{M\_st} \cdot \frac{U_{0\_st}}{I_{sc\_st}} \tag{21}$$

where: $\boldsymbol{P_{M\_st}}$ – power of the module at standard conditions [W].

Maximal power $\boldsymbol{P_c}$ [W]:

$$P_c = FF \cdot U_0 \cdot I_{sc}\ [W] \tag{22}$$

6.3 Types of PV modules

Almost 90% of PV modules today are manufactured using silicon technologies [27]. Depending on the technology of manufacturing silicon solar cells can be monocrystalline, polycrystalline or hybrid.

Monocrystalline cells are produced by cutting slices from pure crystalline silicon bars. Cell are completely oriented in one direction, what makes them most efficient when they are exposed to direct sun radiation at optimal angle. To absorb maximal amount of radiation, their color is black. Because used pure cells are octagonal, when combining a number of cells into a module, space in the corners of cells remains unused.

Polycrystalline modules are produced from silicon offcuts. Cells are made of several slices of pure crystal by moulding offcuts in blocks. It is not possible to ideally align crystals together, and therefore losses occur at joints. From another perspective, it makes them more efficient at various angles of sunlight. Since their form is rectangular, space is not wasted on the corners of cells.

Hybrid panels present a very concentrated type of modules, having higher efficiency and prices disproportionately higher than the relative efficiency rise per unit.

Although production of polycrystalline modules is slightly more waste-efficient, monocrystalline modules offer a range of relative advantages:

- Lifetime – most performance warranties go for 25 years, but as long as surface is kept clean, practice demonstrates their successful usage for 50 years;
- Efficiency – panels made from monocrystalline solar cells are able to convert the highest amount of solar energy into electricity of any type of flat solar panel;
- Lower installation costs – structure for mounting the models is easy to install;
- Higher heat resistance – monocrystalline panels have lower loss of efficiency at extremely high temperatures (over 50 °C) comparing to polycrystalline ones;
- Lower environmental impact – higher electricity generation rate results in lower usage of fossil fuels, besides heavy metals are not used in production.

7 KNX CONTROL SYSTEM

Broad variety of suppliers and functionality of devices and systems used in buildings raised the main problem on the way of implementation of efficient control systems – compatibility and common integration of the entire range of used equipment. Effective transfer of control data between various devices and systems became possible after creation of a common communication protocol – KNX. These systems are decentralized control networks with distributed intelligence [32].

KNX is a universal OSI-based communication protocol for design and implementation of control systems in intelligent buildings. It is standardized by *EN 50090* and *ISO/IEC 14543* standards.

Interaction of the system devices is realized by connecting them to KNX medium by: twisted pair wiring (based on BatiBUS and Instabus standards), radio frequency (KNX-RF), power line (based on EIB and EHS systems) or IP/Ethernet (KNXnet/IP). Bus devices are sensors or actuators required for the building management equipment control like: lighting fixtures, blinds, HVAC systems, security and monitoring systems, interfaces to service and building control metering, etc.

KNX equipment can be divided into three major groups:

- Sensors (input devices – temperature, movement, daylight, wind sensors). Are initial step of every action, acquiring information and sending it as data telegrams through the bus. Acquired information can be both sensor information and manual input through push buttons.
- Actuators (controlled devices – electrical heating valves, pumps, dimmers, motors). They receive data telegrams, transposing them to action. It can be: blinds control, lights dimming or HVAC tuning. They are composed of a bus coupler and an application module with relevant application program.
- System components (line-couplers, binary inputs, etc.).

Designed program is uploaded to the destination devices through USB or serial interface from a PC, connected to the bus.

The application program is loaded into the devices together with the project design and commissioning software via a system component called interface (either serial or USB interface) connected to the PC and the bus.

Standard ISO-16484-2 defines a three-level hierarchy of building automation systems:

- Lower level (fieldbus) – comprises end equipment – sensors, actuators, valves.
- Middle level – contains controllers, receiving infromation from lower level equipment and transmitting it to upper level, as well as network equipment.
- Upper level (control) – includes operator stations.

KNX systems belong to the first two levels.

KNX systems are designed to be compatible with any hardware platform. KNX network can be controlled by any control device, depending on application specifics. Software used for KNX system design is ETS (EIB Tools Software), distributed exclusively by Konnex association.

KNX systems offer next advantages:

- Lowering operation costs by increasing energy savings. Energy consumption is reduced by switching on or off various building management systems (heating, lighting, etc.). Control can be performed basing on pre-set time programs or presence detection. Lighting can be automatically controlled depending on current natural lighting level by using daylight sensors. Lights are dimmed and blinds are controlled depending on required illumination level.
- High flexibility and expansion possibilities. KNX control system can be easily extended or changed according to new requirements. There is no need to make changes in the entire system when adding or modifying a component. Architecture and logic of the system can be changed with minimal physical changes, by just reprogramming.
- Time saving. Installation and design efforts and time are greatly reduced by integration of all devices in a single bus network. A common software, which is independent from hardware manufacturer is used for system design and configuration.

7.1 Logical topology

Being completely distributed, KNX network can include up to 65536 devices in a 16-bit Individual Address space [33]. Sub-network organization structure allows 256 devices on one line. As it can be seen on figure 13, lines may be grouped together with a main line into an area. A domain is formed from 15 areas and a backbone line.

Speed of data transmission through a twisted couple of open topology is 9.6 Kbit/s. KNX/EIB technology uses the method of bus multiple access with the CSMA/CA control. Maximal distance between nodes of one line cannot exceed 700 m, between network node and power supply – 350 m and common length of the cable of one line – 1000 m.

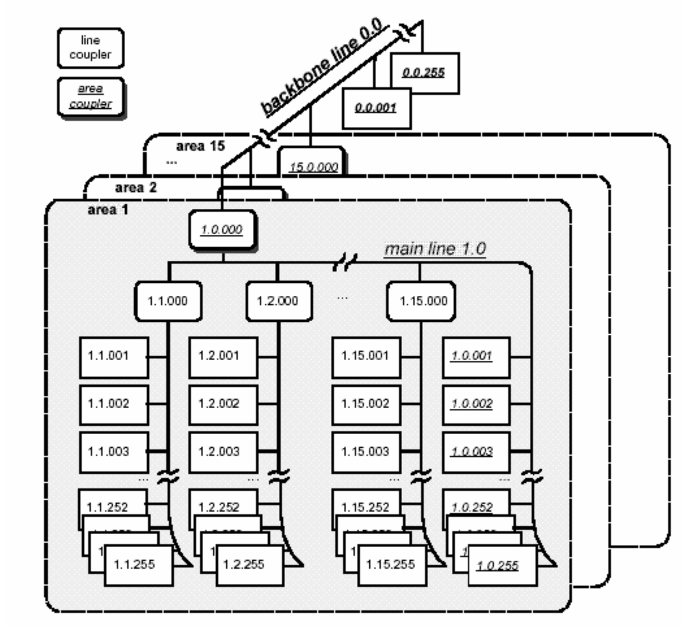


Figure 13. KNX logical topology

KNX topology is realized in the numerical structure of the addresses, which are unique identifiers of nodes on the network.

When powerline medium is used, domains are logically separated with a 16-bit Domain Address. Respectively, (255 x 16) x 15 + 255 = 61455 devices may be included in a KNX network. In practice, this number is restricted by physical factors, such as application limits (power supply, transmission medium, etc.), environmental or financial concerns. Two-byte individual address consists of three fields: area (4 bits), line (4 bits) and device (8 bits).

In case of radio frequency medium, interference between two adjacent devices is evaded thanks to extended address scheme, which links the addresses with unique device identifier. This allows considering unidirectional devices, which can be used at lower expenses for sensor functions.

Lines and segments are connected by couplers. They can function as a repeater, bridge, router, package filter etc. There is a variety of couplers available.

II. ANALYSIS

8 OBJECT DESCRIPTION

The object, chosen for the HVAC system design, is an office building situated in Chisinau, Republic of Mold ova.

The four storey building (Fig. 13) was constructed in the year 1965 as a part of Chisinau Tractor Plant, and accommodated design departments of the factory, as well as production spaces. During the crisis in 90's, building was abandoned. In 2011, Industrial Park "*TRACOM*" was opened on the territory of the former tractor plant and an engineering company – *"SALONIX-TEH" SRL*, acquired the building.

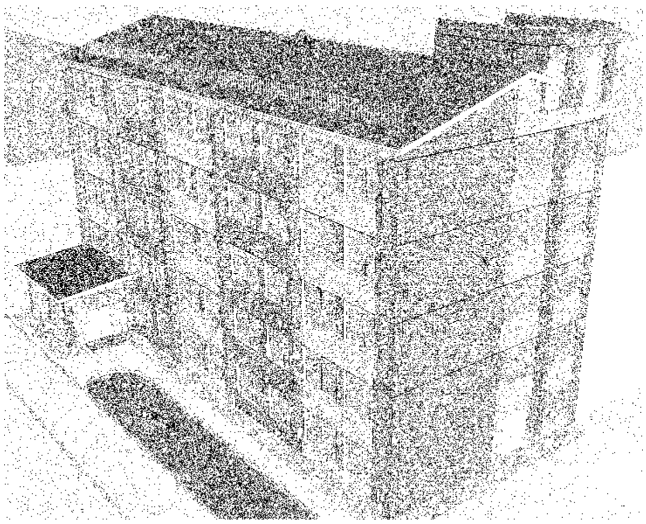


Fig. 13. General view of the building

Taking into consideration the disastrous state of the building, it was decided to perform essential building renovation, which included:

1) Construction of the 5th floor and the boiler room;
2) Modification of interior space, according to company's needs;
3) Cosmetic renovation;
4) Increasing the level of energy-efficiency of the building (replacement of windows and doors with more energy-efficient ones, thermal insulation of the construction);
5) Design of HVAC systems (implementing an independent heating system instead of the old central heating, ventilation, etc.).

Current Thesis deals with the last two points of the renovation plan.

8.1 General characteristics of the building

Designed building (Fig. 14) has five floors (four floors of the old building and a newly constructed one).

Fig. 14. South-West facade

The constructional layout of all floors, except of the fourth floor, is generally similar. With large working space, around 70% of total floor area, rest of the space being occupied by smaller offices, halls and stairs.

First floor (Fig. 15) is reserved for production space, storage and a shop. The production process at „*SALONIX-TEH*“ consists mainly of manual assembly of power and control cabinets. Therefore, no heavy machinery or industrial equipment is expected to be present.

Floors nr. 2, 3 and 5, with a similar layout with the first floor, have a large common office space and are reserved for design departments and renting the space to third parties.

Floor nr. 4 (Fig. 16) is planned to fit the needs of administration, marketing, sales and financial departments, and is separated into smaller offices.

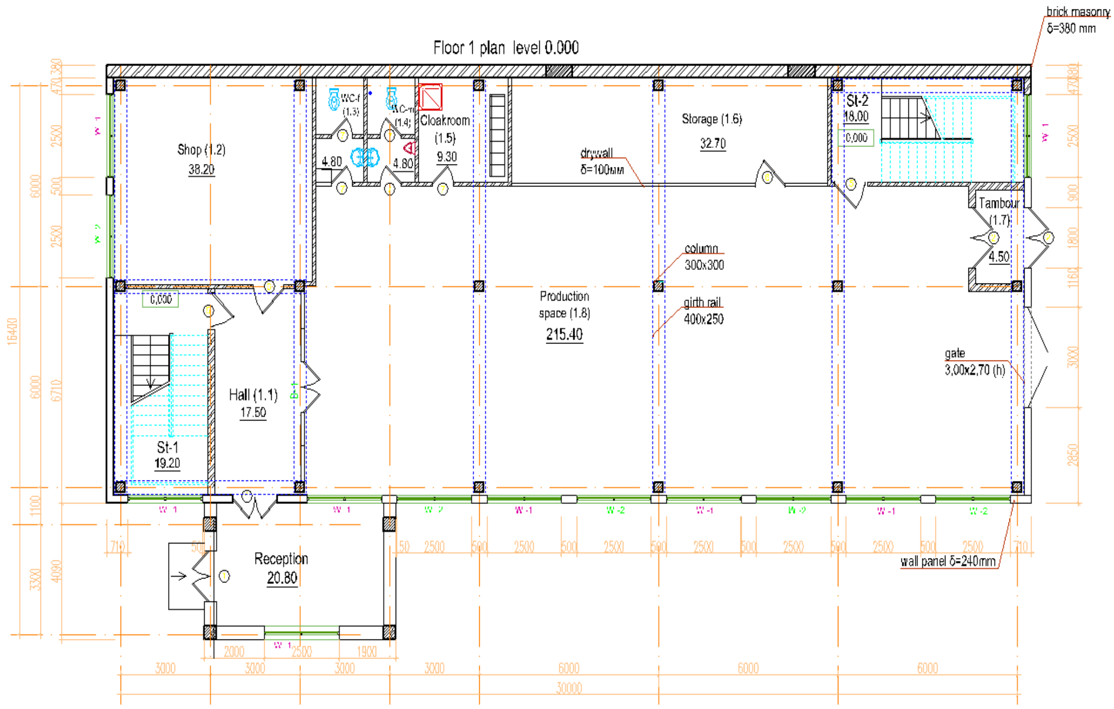


Fig. 15. First floor plan

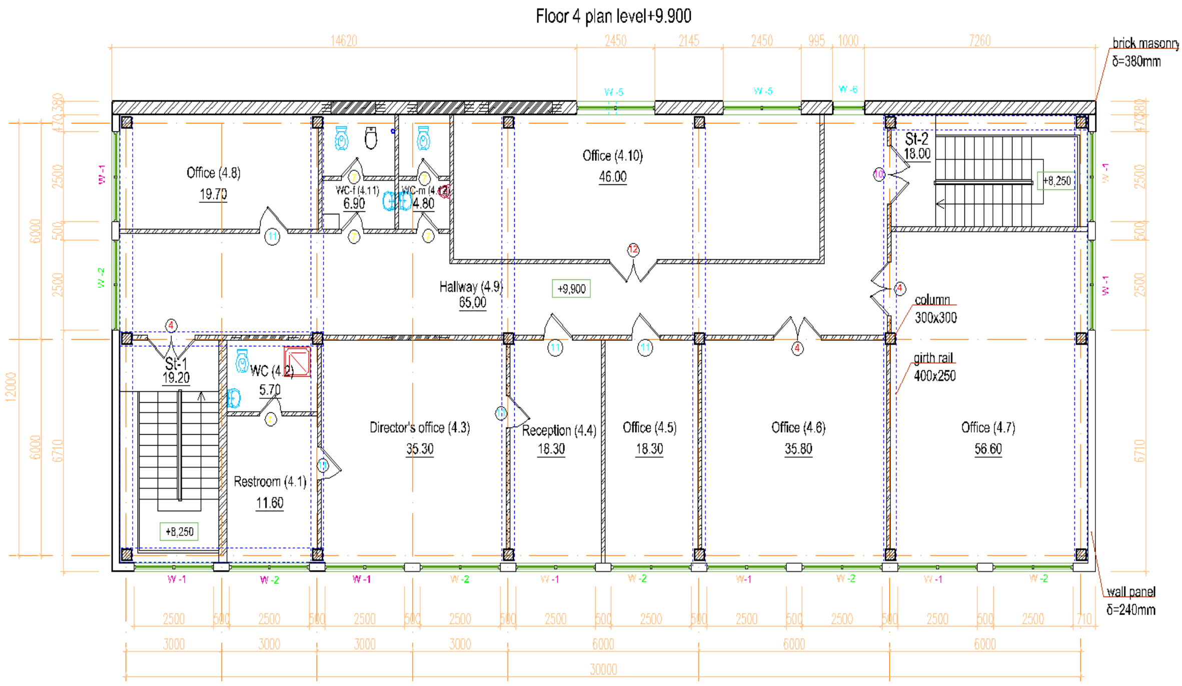


Fig. 16. Fourth floor plan.

Building has two entrances. The main one is on the north side of the building, through a reception hall (Fig. 15, room 1.1). Another entrance is on the south side and is reserved for production needs. There are two staircases in the building (Fig. 15, Fig. 16 - St-1 and St-2). Staircase St-1 is in the southern corner of the building, connecting all 5 floors. Staircase St-

2 is placed in the northern corner and connects the 5 floors with an exit to the roof and the boiler room. An intermediate tambour precedes every entrance.

Ground floor is in direct contact with soil.

Detailed properties of rooms are listed in table (Tab. 9). General features:

- Floor area = 360 m^2;
- Exposed perimeter of the building = 87.8 m;
- Total air volume = 5506 m^3.

Tab. 9. List of rooms in the building.

Floor	Room nr.	Description	Area, [m^2]	Perimeter, [m]	Volume, [m^3]
I	1.1	Hall	17.5	18	52.5
	1.2	Shop	38.2	24	114.6
	1.3	WC-f	4.8	9	14.4
	1.4	WC-m	4.8	9	14.4
	1.5	Cloakroom	9.3	12.68	27.9
	1.6	Storage	32.7	28.08	98.1
	1.7	Tambour	4.5	9.2	13.5
	1.8	Production space	215.4	74	646.2
	St-1	Stairs	19.2	19.3	57.6
	St-2	Stairs	18	19.58	54
II	2.1	Tambour	5.7	10.34	17.1
	2.2	Conference hall	38	25.62	114
	2.3	Office	262.7	76.985	788.1
	2.4	Hall	5.7	11.32	17.1
	2.5	WC-f	6.9	11.48	20.7
	2.6	WC-m	4.8	9	14.4
	2.7	Archive	7.6	11.92	22.8
	St-1	Stairs	19.2	19.3	57.6
	St-2	Stairs	18	19.58	54
III	3.1	Office	38	25.4	114
	3.2	Hall	5.7	11.32	17.1
	3.3	WC-f	6.9	11.48	20.7
	3.4	WC-m	4.8	9	14.4
	3.5	Office	277.6	72.845	832.8
	St-1	Stairs	19.2	19.3	57.6
	St-2	Stairs	18	19.58	54

Floor	Room nr.	Description	Area, [m^2]	Perimeter, [m]	Volume, [m^3]
IV	4.1	Restroom	11.6	14.6	34.8
	4.2	WC	5.7	10.32	17.1
	4.3	Director's office	35.3	24.76	105.9
	4.4	Reception	18.3	18.76	54.9
	4.5	Office	18.3	18.76	54.9
	4.6	Office	35.8	24.76	107.4
	4.7	Office	56.6	30.8	169.8
	4.8	Office	19.7	19.66	59.1
	4.9	Hallway	65	63.04	195
	4.10	Office	46	31.76	138
	4.11	WC-f	6.9	11.48	20.7
	4.12	WC-m	4.8	9	14.4
IV	St-1	Stairs	19.2	19.3	57.6
	St-2	Stairs	18	19.58	54
V	5.1	Office	264	79.81	792
	5.2	Hall	4.8	9.78	14.4
	5.3	Hallway	20.3	26.85	60.9
	5.4	Office	20.1	19.44	60.3
	5.5	WC-f	7.6	11.66	22.8
	5.6	WC-m	5.2	8.38	15.6
	St-1	Stairs	19.2	19.3	57.6
	St-2	Stairs	18	19.58	54
	St-3	Stairs	11.8	19.16	35.4
VI	6.1	Boiler room	15.2	20.04	45.6

9 BUILDING PHYSICS AND THERMAL PARAMETERS

Initial step in the process of energy assessment of the building and HVAC design is determining the existing state of the building structures, exposed to the external environment. In current chapter, the thermal parameters of current structures are assessed. Further, the building is improved by applying various thermal insulation methods.

In order to determine the thermal and moisture characteristics of the structures, the "Svoboda Software" application was used, module "Teplo 2014". Resulted characteristics were compared with the requirements of the standard *ČSN 730540-2*. It was chosen over the Moldovan standard *CP E.04.05 – 2006*, due to higher requirements and more advanced energy considerations.

9.1 External conditions and design requirements

External parameters of the environment and method of their determination is given by Moldovan standard *NCM A.07.05-06* "Building Climatology", which is based on Russian *SNIP 23-01-99 "Building Climatology*". External conditions for Chisinau, according to it, are given in table (Tab. 10)

Tab.10. External conditions for Chisinau, Moldova [34]

Air temperature of coldest 5 days, t_{ext}, [°C]	Air temperature of coldest day, [°C]	Absolute minimal air temperature, [°C]	Duration and average air temperature of period with average daily temperature ≤ 8 , [°C]		Average relative humidity of coldest month, [%]	Dew point, t_{dew}, [°C]
			Duration, days, z_{ht}	Average temperature, t_{ht} [°C]		
-17	-20	-32	162	0.6	81	10,7

According to *CP E.04.05 – 2006*, calculated average temperature of inside air, t_{int}=20 °C. Relative humidity of inside air, φ_{int} = 55% [35].

Heating season starts when during three days, the average outside air temperature is equal or lower than 8 °C, and end when the temperature is higher than 8 °C for 3 days in a row.

For the assessment of environmental parameters, value of degree-days is determined, D_d:

$$D_d = (t_{int} - t_{ht}) \cdot z_{ht} \ [°C \cdot days] \tag{23}$$

$$D_d = (20\text{-}0.6) \cdot 162 = 3142.8\ °C\cdot days$$

Average specific weight of outside air during the heating season, $\boldsymbol{\gamma_a^{ht}}$:

$$\gamma_a^{ht} = 3463/(273+ t_{ht})[N/m^3] \quad (24)$$

$$\gamma_a^{ht} = 3463/(273+0.6) = 12.65\ N/m^3$$

Average density of supply air during the heating season, $\boldsymbol{\rho_a^{ht}}$:

$$\rho_a^{ht} = 353/[273+0.5\cdot(t_{int}+t_{ext})]\ \ [kg/\ m^3] \quad (25)$$

$$\rho_a^{ht} = 353/[273+0.5\cdot(20+(-17)] = 1.28\ kg/\ m^3$$

9.2 Existing building structures

Built in 1965, analyzed building is a typical example of panel block construction of that period, which was the mass method of building construction at that time, offering low-cost and fast building possibilities. Construction was carried out according to respective building norms and regulations of 60's (*SNIP II-L.2-62, SNIP II-A.1-62*, etc.), which ignored the issues of energy efficiency. Luxury of the low-cost energy resources, led to poor thermal insulation practices in construction. Another factor was low attention to the issues of thermal comfort of inhabitants at the time. Buildings of that period were designed with a central, one-pipe heating system.

Main component of thermal assessment of the building is the evaluation of its primary thermal control layer. It is composed of the structures, presenting immediate physical thermal barrier between the inner and outer environment, like: exterior walls, ceiling under the attic and the floor adjacent to the ground.

9.2.1 Exterior walls

Due to the specifics of placement of the building and construction of the fifth floor, there are 4 types of exterior walls present in the building.

9.2.1.1 Paneled wall ("Outer wall 1")

Constitutes the South-East, South-West and North-West exterior wall of the old floors. Detailed specifications of this type of walls can be found in *GOST 11024-84 "Concrete and reinforced concrete panels for external walls of residential and civil buildings. General specifications"*.

This wall is made of single-walled lightweight concrete panels (Fig.17, b), of single-story height.

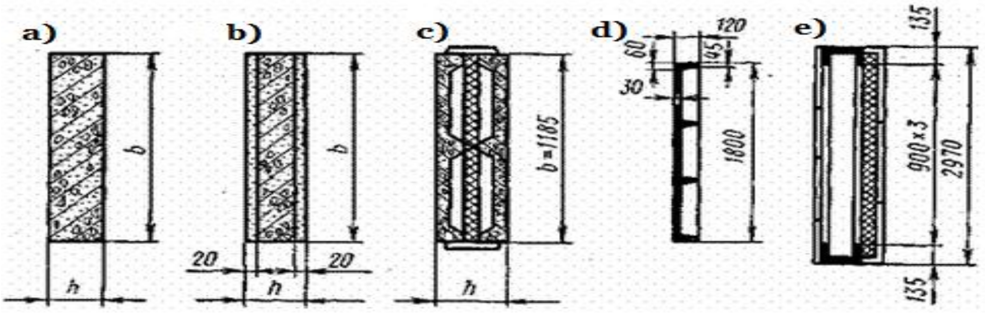


Fig. 17. Wall panels: a - from cellular concrete; b - from lightweight concrete; c - from heavy concrete (three-layer); g - reinforced ribbed concrete for unheated buildings; d - metal with insulation [36].

Lightweight concrete panels are can be made of: expanded clay, perlite concrete, agglo-porite concrete of grade 50, density of 700-1000 kg/m^3. The panels are reinforced with welded frame and a steel grid of class AI, A-III and reinforcing wire of VR-1 class. To attach the panels to the building frame columns, they are provided with steel inserts. When installing the panels joints between them are filled with sealants: gernitom, poroizol, thiokol and polyisobutylene mastics.

Panels of expanded clay and aggloporit concrete can be used in buildings with humidity no higher than 75%, and the ones of perlite concrete with humidity up to 60%.

Composition of the wall, as well as the properties of each layer and thermal technical assessment are given in tables (Tab. 11 and Tab. 12).

Tab. 11. Composition of Outer Wall 1

Nr.	Layer material	Depth	Heat transfer coefficient, λ	Specific heat capacity, c	Density, ρ	Diffusion resistance factor, Mi
		[m]	[W/(m*K)]	[J/(kg*K)]	[kg/m3]	
1	Lime-cement plaster	0.02	0.99	790	2000	19
2	Expanded clay concrete	0.2	0.28	880	700	8
3	Lime-cement plaster	0.02	0.99	790	2000	19

Heat transfer coefficient is calculated according to equation (6) from p.4.1.1.

$$U = \frac{1}{\frac{1}{6} + \sum(\frac{0.02}{0.99} + \frac{0.2}{0.28} + \frac{0.02}{0.99}) + \frac{1}{12}} = 0.995 \text{ W/(m}^2 K)$$

Thermal bridges are considered, according to relation (7) from p.4.1.1:

$$U_t = 0.995 + 0.1 = 1.095 \ \ W/(m^2 \cdot K)$$

The manually computed value ($\boldsymbol{U_{calc}}$ =1.095 W/(m^2·K)) slightly differs from the result of Teplo 2014 ($\boldsymbol{U_{comp}}$ =1.081 W/(m^2·K)) because of the considered approximation in the manual calculation.

For Outer Wall 1, heat transfer coefficient is calculated basing on data from table (Tab. 10). Resulted thermal properties are given in table (Tab. 12)

Tab. 12. Thermal assessment of Outer Wall 1

Structure name	**Heat transfer coefficient, U, [W/(m*K)]**			**Year-round moisture balance, [kg/(m2*year)]**		**Thermal factor**	
	U_{calc}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Outer Wall 1	1.081	0.3	0.44	0.199	4.713	0.816	0.761

As we can see, minimal requirement of heat transfer coefficient is not met for both standards ($\boldsymbol{U_{cal}} > \boldsymbol{U_{req1}}$; $\boldsymbol{U_{cal}} > \boldsymbol{U_{req2}}$).

According to the results from „Teplo 2014“ (Fig.18), amount of condensate is 0.199 kg/(m2·year) and capacity of evaporation is 4,173 kg/(m2·year), which is much higher and meets the requirement. Besides, applications algorithm of calculation ignores influence of sun radiation, which rises the evaporation capacity in practice. Condensation will occur inside the layer of plaster, on the depth of 7 mm from the surface, and will be evaporated easily (Fig.19).

Internal surface thermal factor is 0.761, which is unsatisfactory value, being lower than the value of 0.816 imposed by *ČSN 73 0540-2*.

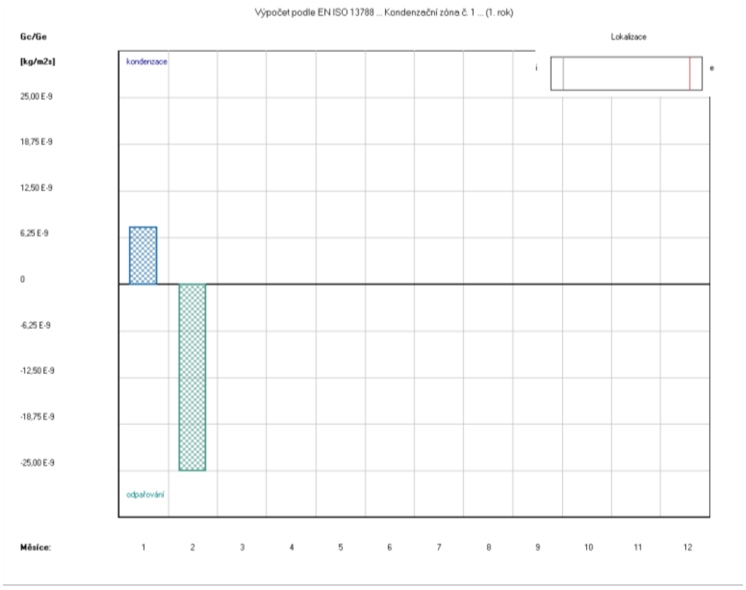


Fig. 18. Amount of condensed and evaporated water vapor in Outer Wall 1.

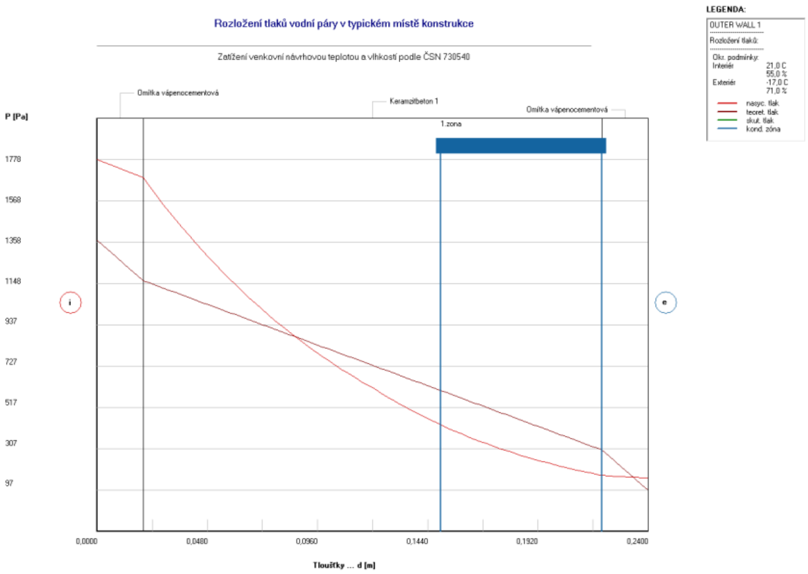


Fig. 19. Vapor pressure distribution in Outer Wall 1.

9.2.1.2 Brick wall („Outer wall 2")

Northeastern side of the building was adjacent to an immense production space. Because it was abandoned 23 years ago, its exterior structures are in bad condition, it lacks heating, it was considered having the same properties as exterior environment. The Northeastern wall was made of brick masonry with a total depth of 380 mm and covers the old 4 floors.

Tab. 13. Composition of Outer Wall 2

Nr.	Layer material	Depth	Heat transfer coefficient, λ	Specific heat capacity, c	Density, ρ	Diffusion resistance factor, Mi
		[m]	[W/(m*K)]	[J/(kg*K)]	[kg/m3]	
1	Lime-cement plaster	0.02	0.99	790	2000	19
2	Brick masonry	0.35	0.86	960	1800	15
3	Lime-cement plaster	0.02	0.99	790	2000	19

Tab. 14. Thermal assessment of Outer Wall 2

Structure name	Heat transfer coefficient, U, [W/(m*K)]			Year-round moisture balance, [kg/(m2*year)]		Thermal factor	
	U_{calc}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Outer Wall 1	1.647	0.3	0.44	0.017	1.699	0.816	0.656

Heat transfer coefficient is 1.647 W/(m*K), which is far below any admissible value. Internal surface thermal factor is under the required level as well.

9.2.1.3 Sandwich panel wall („Outer wall 3“)

The newly built wall of the 5th floor above the concrete panel wall „Outer wall 1“, was constructed of a sandwich panel.

Used sandwich wall panel represent a layered structure with polyurethane core (Fig. 20), pressed between metal sheets. Having a low thermal conductivity ratio and airtight concealed fixing joint design, this energy efficient panel offers excellent thermal properties.

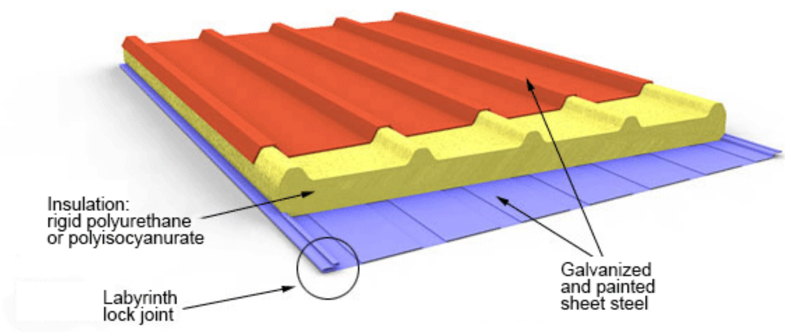


Fig. 20. Polyurethane sandwich wall-panel.

Tab. 15. Composition of Outer Wall 3

Nr.	**Layer material**	**Depth**	**Heat transfer coefficient, λ**	**Specific heat capacity, c**	**Density, ρ**	**Diffusion resistance factor, Mi**
		[m]	[W/(m*K)]	[J/(kg*K)]	[kg/m^3]	
1	Baumit stucco plaster	0.02	0.47	790	1800	25
2	Sandwich panel	0.12	0.029	1510	35	220

Tab. 16. Thermal assessment of Outer Wall 3

Structure name	**Heat transfer coefficient, U, [W/(m^2*K)]**			**Year-round moisture balance, [kg/(m2*year)]**		**Thermal factor**	
	U_{calc}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Outer Wall 3	0.23	0.3	0.44	0.0017	0.4369	0.816	0.944

Being newly built from materials with high heat insulation properties, that structure meets all the necessary requirements and does not need any insulation. Heat transfer coefficient is 0.23 W/(m*K), which is a very good value. Quantity of evaporated moisture is 257 times over the deposited condensate quantity.

9.2.1.4 Brick wall of the 5th floor ("Outer Wall 4")

The Northwestern wall of the fifth floor, built over the old brick wall, was constructed of brick masonry, using modern bricks with high thermal insulation properties, good heat accumulation capability and water vapor permeability. Masonry was faced with stucco plaster on the inside and special plastering for facing brickwork.

Tab. 17. Composition of Outer Wall 4

Nr.	**Layer material**	**Depth**	**Heat transfer coefficient, λ**	**Specific heat capacity, c**	**Density, ρ**	**Diffusion resistance factor, Mi**
		[m]	[W/(m*K)]	[J/(kg*K)]	[kg/m3]	
1	Baumit stucco plaster	0.05	0.47	790	1800	25
2	Brick masonry	0.24	0.28	960	1000	7
2	Plastering	0.02	0.97	840	1850	25

Tab. 18. Thermal assessment of Outer Wall 4

Structure name	**Heat transfer coefficient, U, [W/(m^2*K)]**			**Year-round moisture balance, [kg/(m2*year)]**		**Thermal factor**	
	U_{calc}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Outer Wall 4	0.854	0.3	0.44	0.2098	3.5568	0.816	0.806

Heat transfer coefficient and internal surface factor is unsatisfactory and thermal insulation is reasonable.

9.2.2 Floor in contact with soil

First floor is situated directly on the ground, with no technical space under it. Therefore, it should represent a highly reliable structure to provide protection from moisture accumulation and high degree of thermal insulation. Design of the floor was done in *SNIP 2.03.13-88*, valid for Moldova. According to it, construction site should meet a number of requirements in order to allow construction of floor on the ground. For example, level of ground waters should be not higher than 5 m below the ground, soil should not be loose, such as sand, etc [37].

Floor presents a layered structure (Fig. 21). First layer is a bulk compacted layer of sand, followed by a thick layer of compacted gravel (Fig. 21, 6). This layer can prevent ground waters from rising, and offers an additional surface smoothing. Compacting is done with mechanical vibratory plates. Next is underlayment concrete screed of M200 concrete, reinforced with metal mesh (Fig. 21, 5).

Polystyrene concrete M300 is used as the main thermal insulation barrier, being one of the most popular floor insulation materials (Fig. 21, 4). It is made by using small lightweight Styrofoam or EPS balls as an aggregate instead of the crushed stone that is used in regular concrete. It is not as strong as stone-based concrete mixes, but has other advantages such as increased thermal and sound insulation properties. Above it, a hydroisolation polyethylene film is placed (Fig. 21, 3). The main objective of the waterproofing layer is to prevent the absorption of moisture by concrete. Therefore, the film is placed overlapping. In order to avoid cracks joints are secured with tape.

Next is cement-sand mortar screed (Fig. 21, 2), which will be the base for finished surface. Reinforcement is mandatory for this layer. Finally, floor is covered with ceramic tile (Fig. 21, 1).

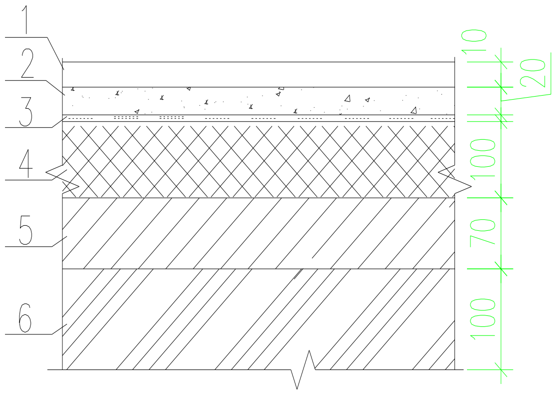


Fig. 21. Floor layering

a)

b)

Fig. 22. Floor construction: a) hydroisolation and reinforcement; b) polystyrene concrete

Tab. 19. Thermal assessment of floor in contact with soil

Structure name	**Heat transfer coefficient, U, [W/(m*K)]**			**Year-round moisture balance, [kg/(m^2*year)]**		**Thermal factor**	
	U_{calc}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Floor	0.617	0.82	0.85	-	-	0.816	0.853

Tab. 20. Composition of floor in contact with soil

Nr.	Layer material	Depth	Heat transfer coefficient, λ	Specific heat capacity, c	Density, ρ	Diffusion resistance factor, Mi
		[m]	[W/(m*K)]	[J/(kg*K)]	[kg/m³]	
1	Ceramic tile	0.01	1.01	840	2000	200
2	Screed, cement-sand mortar M200	0.02	1.16	840	2000	19
3	Hydroisolation, polyethylene film	0.0005	0.16	960	1400	16700
4	Insulation, polystyrene concrete M300	0.1	0.086	900	350	20
5	Underlayment, concrete B15 M200	0.07	1.36	1020	2300	23
6	Foundation with compacted gravel	0.1	0.65	800	1650	15
7	Sand	0.05	0.95	960	1750	4

Calculation results show that heat transfer coefficient and internal surface thermal factor meets the requirements. It can be seen on the pressure distribution diagram (Fig. 23) that moisture is not deposited in the floor.

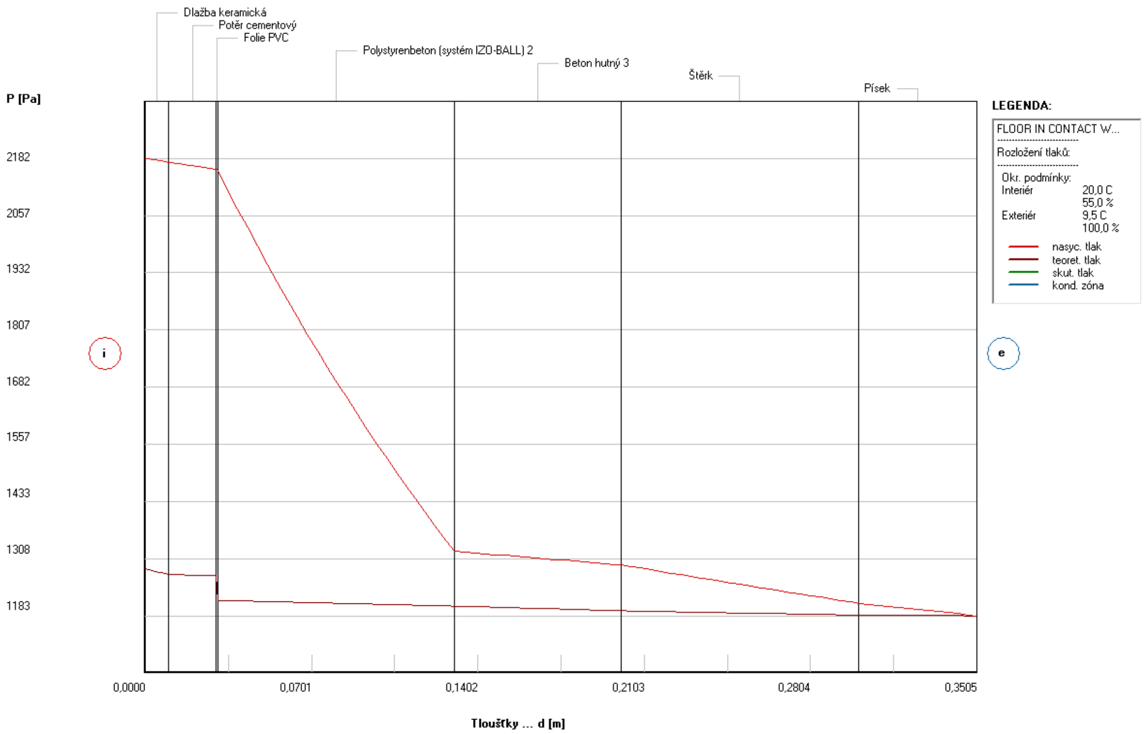


Fig. 23. Pressure distribution in the floor

9.2.3 Ceiling under the attic

Roof, as well as the 5th floor, was constructed by the „steel frame“ technology (Fig. 24). Above the upper ceiling of the 5th floor there is an unheated attic. Main component of ceiling insulation is a thick layer of mineral wool from the external side. It is preceded with vapor insulation film (Jutafol N220). From the internal side, ceiling is planked with gypsum plasterboards.

Roof supporting structure consists of trusses or beams, made from a thin-walled galvanized steel. The supporting structure of the ceiling is located in the "cold zone" above the insulated attic floors. Realization of connection nodes of supporting structures and attic floor eliminates "thermal bridges". Application of formed sections of thin sheet metal in the roof system reduces the load on the supporting structures.

Fig. 24. Roof structure

Tab. 21. Composition of ceiling

Nr.	Layer material	Depth	Heat transfer coefficient, λ	Specific heat capacity, c	Density, ρ	Diffusion resistance factor, Mi
		[m]	[W/(m*K)]	[J/(kg*K)]	[kg/m3]	
1	Gypsum boards	0.02	0.22	1060	750	9
2	Jutafol N 220 vapor barrier film	0.0003	0.39	1700	880	312000
3	Mineral wool	0.100	0.064	880	200	2

Roof structure and insulation were designed during the reconstruction project and fifth floor erection.

Tab. 22. Thermal assessment of ceiling

Structure name	**Heat transfer coefficient, U, [W/(m*K)]**			**Year-round moisture balance, [kg/(m2*year)]**		**Thermal factor**	
	U_{calc}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Ceiling	0.539	0.3	0.42	-	-	0.816	0.853

9.2.4 Window and door structures

Designed building has a multifunctional variety of spaces, what determining a multitude of door types and dimensions. Detailed sizing of used doors and windows is given in Fig. 25.

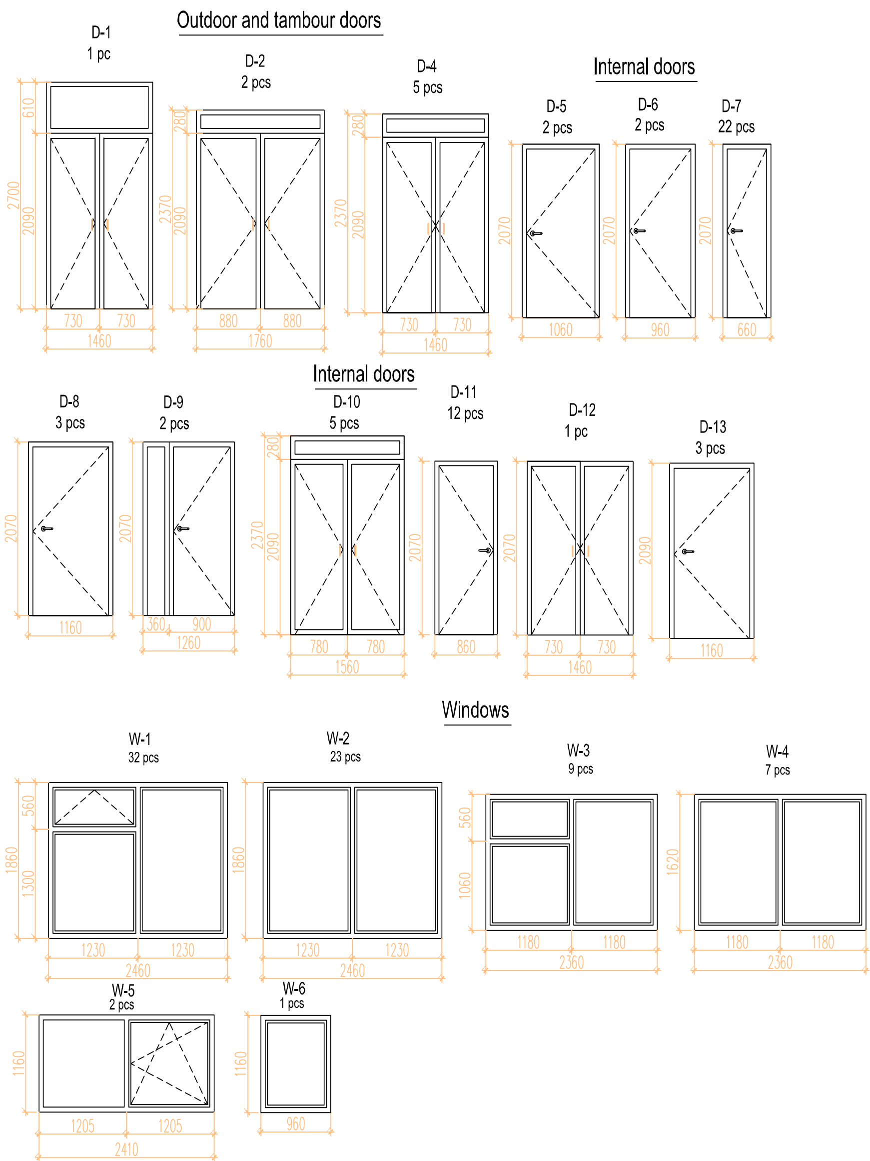


Fig. 25. Windows and doors types

Their placement in the building, under the same notations, is represented in the drawings given in chapter 8.1. Existing windows in the building are typical for 80'es double-glassed windows with wooden frame.

These windows contain a big amount of cracks and after all possible measures are still allowing infiltration of fresh air. Best achieved heat transfer coefficient of windows is U = 2.6 W/(m^{2}K).

9.3 Improved building structures

Thermal analysis of the existing building proved that a number of structures does not correspond, from the point of view of heat transfer coefficient, with either of the standards considered: *ČSN 73 0540* and *SNIP 23-02-2003*.

Tab. 23. Structures with unsatisfactory parameters

Structure name	**U_{calc}**	**U_{req1}**	**U_{req2}**	**$f_{Rsi,n}$**	**f_{Rsi}**
	[W/(m*K)]			[-]	
Outer wall 1	1.081	0.3	0.44	0.816	0.761
Outer wall 2	1.647	0.3	0.44	0.816	0.656
Outer wall 4	0.854	0.3	0.44	0.816	0.806
Ceiling (5th floor)	0.539	0.3	0.42	0.816	0.853
Windows	2.6	1.5	2.8	-	-

In order to achieve required level of thermal comfort with the possible economy of energy expenses, heat losses through these structures should be reduced by bringing heat transfer coefficient to the required level. This shall be done by proper thermal insulation of walls, ceiling and installation of modern windows with high thermal resistance.

9.3.1 Insulation of exterior walls

An exterior wall insulation is a thermally insulated, protective and decorative exterior cladding procedure. Exterior wall insulation systems contain 2 main functional layers:

- Insulation layer, which helps to achieve the required thermal performance. Today, the main materials used are: expanded polystyrene, mineral wool, polyurethane foam or phenolic foam;

- Protected weatherproof finish, which usually a render, usually comprised of reinforced cement based, mineral or synthetic finish and plaster. Brick slips, decorative boards and tiles and can also be used.

In the analyzed case, mineral wool "Isover Fassil" was chosen as the insulation material, due to next advantages:

- High insulation efficiency, λ=0.035 W/(m·K);
- Non-combustibility, A1 fire classification according to European standards (maximal operation temperature – 200 ºC, melting temperature ≥ 1000 ºC);
- Low vapor resistance - good water vapor penetrability (moisture resistance factor, μ=1);
- Excellent acoustic properties in terms of noise absorption (acoustic absorption coefficient α=0.62);
- Dimensional stability during temperature change, which is especially important in the case of multi-storey building (dimensional stability at temperature of 70 ºC ≤ 1%);
- Long life span, being resistant to wood-destroying pests, rodents, and insects.

Mineral wool is supplied in the form of slabs, for the simplicity of installation works. Installation process is described below [38]:

a. Substrate preparation – boards can be glued only on flat, coherent and sufficiently firm surface, free of dust and other contaminants. It is recommended to wash the facade with water under pressure, or cover it with new plaster.

b. Gluing the insulation boards – boards are covered with adhesive (Baumit adhesive mortar) so that the contact glued area shouldn't be less than 40%.

c. Anchoring – after fixing the boards and hardening of the adhesive (min. 24 h), their surface is polished with abrasive plates, in order to remove any irregularities. After that, anchoring is performed with insulation anchors. Size, location and amount of anchors can be determined according to manufacturer's specifications and ČSN 73 2902.

d. Edge protection and insulation during installation – corners and edges should be reinforced by special profiles or double reinforced mesh. Areas near windows and doors need additional diagonal reinforcement with fabric stripes, in order to compensate the increase stress in these locations.

e. Priming of the base – is performed to reduce and uniform the absorption of reinforcing layer, in order to subsequently apply the upper thin plaster. Weber.dur 130 light base coat was chosen.

f. Basic reinforcement layer – is performed usually 1-3 days after installing the insulation boards and anchoring. Reinforcement is usually done by pressing the fiber glass mesh to pre-applied leveling material on the insulation layer. Leveling substance that pervaded mesh is then smoothed. Mesh is laid usually downwards with an overlap of at least 100 mm. The points of contact of different kinds of thermal insulators or in areas with high requirements for resistance to puncture, it is recommended to apply a double layer.

g. Surface finishing – for surface finishing of contact thermal insulation systems are most commonly used noble thin plasters of different composition, color and structures. Most common are acrylic, silicone, silicate and silicone-silicate plasters. In our case silicate Baumit plaster and Baumit silicate paint was used.

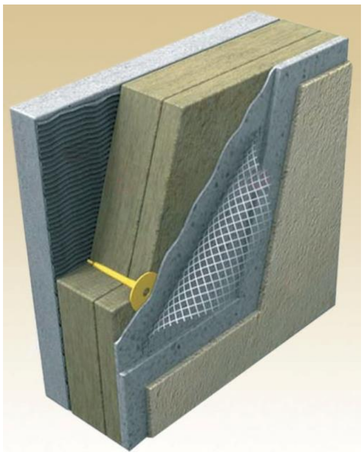


Fig. 25. Wall insulation with mineral wool

Detailed composition of the insulated walls is given in table (Tab. 24).

From overall thermal characteristics, given in table (Tab. 25), it can be seen that the values of heat transfer coefficient and thermal factor correspond with the requirements of both considered standards.

Tab. 24. Composition and thermal properties of insulated external walls

Structure	**Nr**	**Layer material**	**Depth**	**Heat transfer coefficient, λ**	**Specific heat capacity, c**	**Density, ρ**	**Diffusion resistance factor, M_i**
			[m]	[W/(m·K)]	[J/(kg·K)]	[kg/m3]	
Outer wall 1	1	Lime-cement plaster	0.02	0.99	790	2000	19
	2	Expanded clay concrete	0.2	0.28	880	700	8
	3	Lime-cement plaster	0.02	0.99	790	2000	19
	4	Baumit adhesive mortar	0.003	0.8	920	1400	18
	5	Isover Fassil mineral wool boards	0.1	0.037	800	50	1
	6	Webe.dur 130 light base coat	0.003	0.39	850	1300	20
	7	Baumit silicate plaster	0.003	0.7	920	1800	40
	8	Baumit silicate paint	0.0002	0.7	900	1600	50
Outer wall 2	1	Lime-cement plaster	0.02	0.99	790	2000	19
	2	Brick masonry	0.35	0.86	960	1800	15
	3	Lime-cement plaster	0.02	0.99	790	2000	19
	4	Baumit adhesive mortar	0.003	0.8	920	1400	18
	5	Isover Fassil mineral wool boards	0.1	0.037	800	50	1
	6	Webe.dur 130 light base coat	0.003	0.39	850	1300	20
	7	Baumit silicate plaster	0.003	0.7	920	1800	40
	8	Baumit silicate paint	0.0002	0.7	900	1600	50
Outer wall 4	1	Baumit stucco plaster	0.05	0.47	790	1800	25
	2	Brick masonry	0.24	0.28	960	1000	7
	3	Plastering	0.02	0.97	840	1850	25
	4	Baumit adhesive mortar	0.003	0.8	920	1400	18
	5	Isover Fassil mineral wool boards	0.08	0.037	800	50	1
	6	Webe.dur 130 light base coat	0.003	0.39	850	1300	20
	7	Baumit silicate plaster	0.003	0.7	920	1800	40
	8	Baumit silicate paint	0.0002	0.7	900	1600	50

Tab. 25. Thermal assessment of insulated exterior walls

Structure name	Heat transfer coefficient, U, [W/(m*K)]				Year-round moisture balance, [kg/(m²*year)]		Thermal factor	
	U_{old}	U_{new}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Outer Wall 1	1.081	0.274	0.3	0.42	0.0732	8.5334	0.816	0.934
Outer Wall 2	1.064	0.3	0.3	0.42	-	-	0.816	0.927
Outer Wall 3	0.854	0.299	0.3	0.42	0.0385	8.7422	0.816	0.928

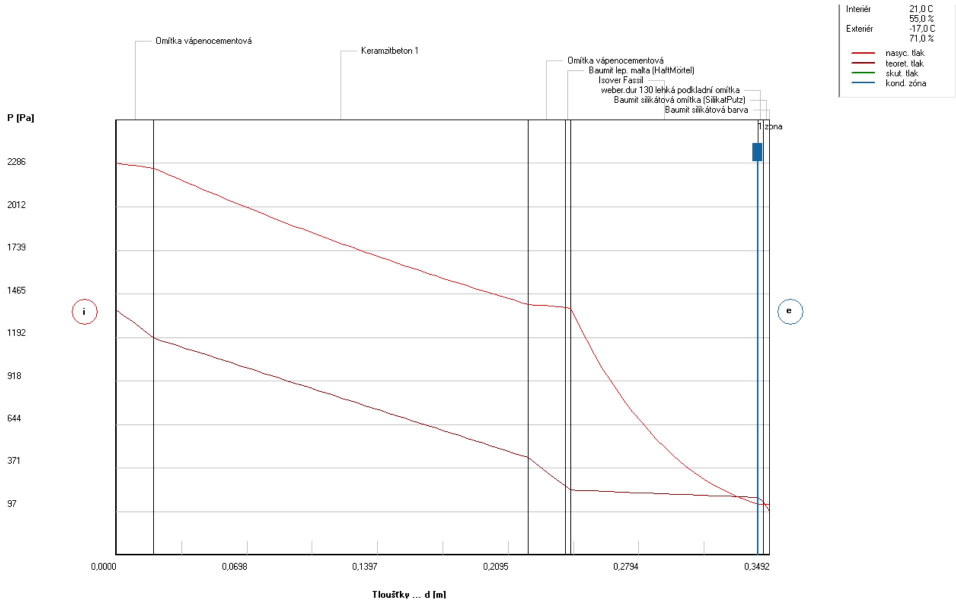


Fig. 26. Water vapor pressure distribution in Outer Wall 1

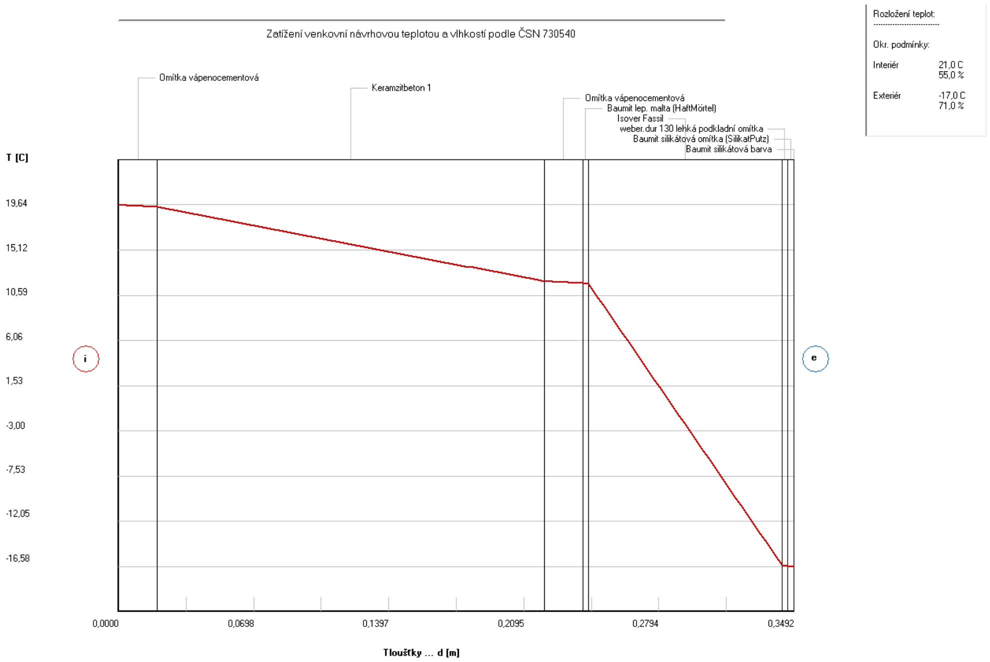


Fig. 27. Temperature distribution inside Outer Wall 1

Small amount of condensation occurs in Outer Wall 1 and Outer Wall 2 near the surface, and is easily evaporated. In case of Outer Wall 2, no condensation is expected to occur inside the structure.

9.3.2 Ceiling insulation

In order to correct the U-value of the ceiling, it was decided to add a layer of mineral wool boards, designed for ceiling insulation – Isover NF 333, with thickness of 80 mm. Thermal properties of ceiling after insulation are given in table (Tab. 26).

Tab. 26. Thermal assessment of ceiling

Structure name	**Heat transfer coefficient, U, [W/(m*K)]**			**Year-round moisture balance, [kg/(m²*year)]**		**Thermal factor**	
	U_{calc}	U_{req1}	U_{req2}	M_c	M_{ev}	$f_{Rsi,n}$	f_{Rsi}
Ceiling	0.3	0.3	0.42	-	-	0.816	0.928

On pressure distribution graph (Fig. 28) it can be seen that condensation does not occur in the ceiling.

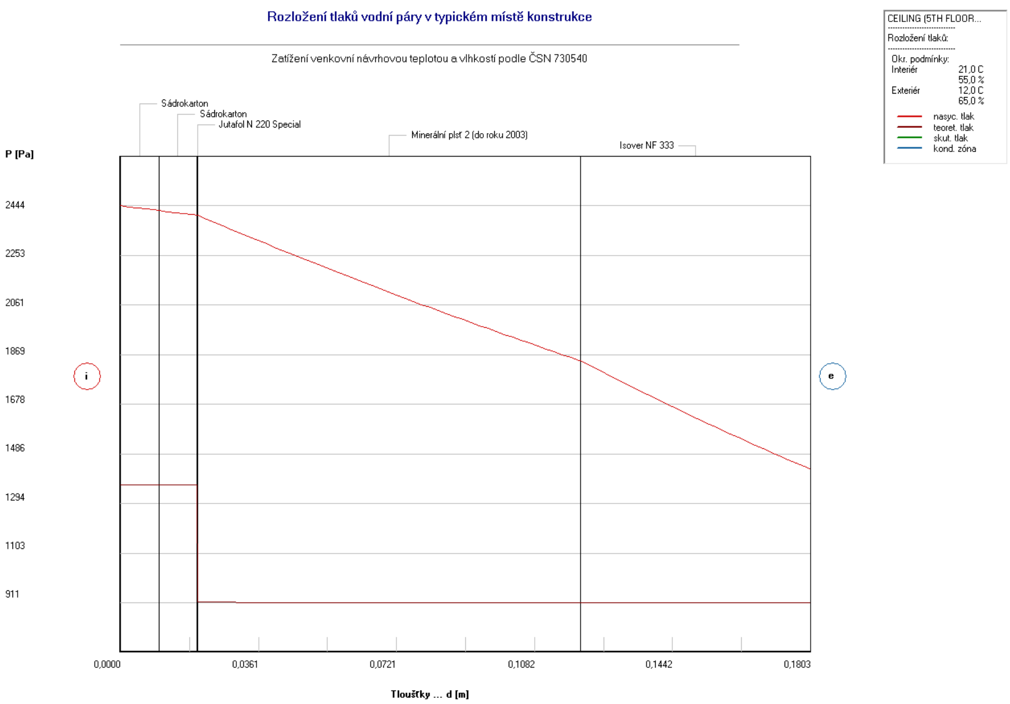


Fig. 28. Water vapor pressure distribution in ceiling

9.3.3 Replacement of windows

With a total area of 314.8 m^2, and poor thermal insulation properties, windows are the main source of heat losses. Therefore, their replacement with modern, energy efficient multi-glazed windows is crucial for improving general thermal resistance of building envelope.

A glazing unit is made by sandwiching two or more sheets of glass with a spacer bar in between, sealing it up and filling it with gas. Because there is dehumidifier in the spacer - molecular sieve, the air between the panes does not contain moisture, and therefore temperature drop on the glass does not cause any condensation.

Characteristics of the glass are influenced by such factors as the number and type of glass sheets in the pane, the distance between the panes.

After comparison of the options on the local market, triple-glazed windows were chosen, of the type 4M1-10Ar-4M1-10Ar-4M1(i) [39] (Fig. 29). Notations in the formula are as follows: 4M1 – polished glass of 4 mm thickness; (i) – energy efficient “low-E glass”; 10Ar – 10 mm layer in between the glass, filled with argon gas. Windows have Heat transfer coefficient is 1 W/(m^2·K) and thickness of 32 mm.

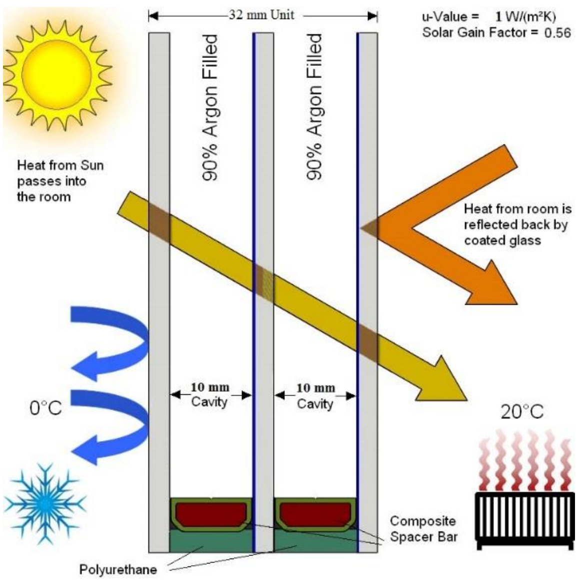


Fig. 29. Triple-glazed window

9.4 Energy certificate of the improved buiding

Thermal assessment of the object was performed basing on the determination of average heat transfer coefficient. After evaluating individually all the structures of the building envelope, it is necessary to perform a complex evaluation of the building energy characteristics. As a representation instrument of thermal technical properties of the building and its correspondence with the standards, Energy Performance Certificate (EPC) is used.

Primary data for preparing EPC is the calculated heat transfer coefficient value of the structures, values imposed by the considered standards (*ČSN 730540-2*) and basic building characteristics:

- Volume of the building, ***V*** (external volume of the heated area, doesn't contain attics, foundations, etc.) – 5506 m^3;
- Total area, ***A*** (external surface of the structures in contact with external environment or unheated spaces) – 2029.9 m^2;
- Volume factor of the building shape (***A / V***) – 0.37 m^2 / m^3.

Characteristics of the building envelope structures are given in tables (Tab. 27, Tab. 28). EPC was formed using Ztraty 2014 module of the Svoboda Software application (Fig. 30).

Tab. 27. Energy characteristics of structures – existing building

Structure name	**Area, [m^2]**	**R, [m^2K/W]**	**U, [W/m^2K]**	**$M_{a,max}$, [kg/m^2]**	**Thermal reduction coefficient, b_i**	**Specific heat loss, H_T, [W/K]**
Outer wall 1	420.8	0.755	1.081	0.199	0.98	445.6
Outer wall 2	385.1	0.437	1.647	0.017	0.99	629.1
Outer wall 3	96.4	4.180	0.23	0.0017	0.94	20.8
Outer wall 4	74.9	1.001	0.854	0.2098	0.93	59.2
Floor	359.9	1.451	0.617	-	0.57	127.2
Ceiling	356.4	1.654	0.539	-	0.69	132.8
Doors	234.1	0.67	1.52	-	0.05	17.8
Windows	314.1	0.385	2.6	-	0.99	808.8
Thermal bridges						149.3
Total specific loss through heat transfer, **H_T**						2406.3
Average heat transfer coefficient, **U_{em}= H_T/A**						**1.19**

Tab. 28. Energy characteristics of structures – insulated building

Structure name	**Area, [m²]**	**R, [m²K/W]**	**U, [W/m²K]**	**$M_{a,max}$, [kg/m²]**	**Thermal reduction coeffi-cient, b_i**	**Specific heat loss, H_T, [W/K]**
Outer wall 1	420.8	0.755	0.27	0.199	1	113.6
Outer wall 2	385.1	0.437	0.3	0.017	0.99	114.4
Outer wall 3	96.4	4.180	0.23	0.0017	0.94	20.8
Outer wall 4	74.9	1.001	0.3	0.2098	0.93	20.9
Floor	359.9	1.451	0.617	-	0.57	127.2
Ceiling	356.4	1.654	0.3	-	0.7	74.8
Doors	234.1	0.67	1.52	-	0.05	17.8
Windows	314.1	0.385	1	-	0.99	311.1
Thermal bridges						149.3
Total specific loss through heat transfer, $\mathbf{H_T}$						965.8
Average heat transfer coefficient, $\mathbf{U_{em}= H_T/A}$						**0.48**

Initial requirement for average heat transfer coefficient, $U_{em,N}$, according to ČSN 730540-2, for internal temperature from 18 to 22 °C, is equal to 0.48 W(m²·K).

Class of the building envelope is determined by ratio of U_{em} to $U_{em,N}$. Respectively:

$$Cl_{existing\ building} = U_{em} / U_{em,N} = 1.19/0.48 = 2.48; \qquad (26)$$

$$Cl_{insulated\ building} = U_{em} / U_{em,N} = 0.48/0.48 = 1;$$

Classification limits are given in table (Tab. 29). According to them, we can see that existing building corresponds to the class F, which represents an extremely inefficient building.

Tab. 29. Classes of thermal transmittance of building envelope

Classification limits	**Relation to $U_{em,N}$**	**Unit**	**Value**
A-B	$0.5 \cdot U_{em,N}$	W/(m²·K)	0.24
B-C	$0.75 \cdot U_{em,N}$		0.36
C-D	$U_{em,N}$		0.48
D-E	$1.5 \cdot U_{em,N}$		0.72
E-F	$2 \cdot U_{em,N}$		0.96
F-G	$2.5 \cdot U_{em,N}$		1.2

After the implemented insulation measures, the class of the building rises to C, which corresponds to the regulations requirements. Considering that the building is of administrative application, class C is sufficient in our case.

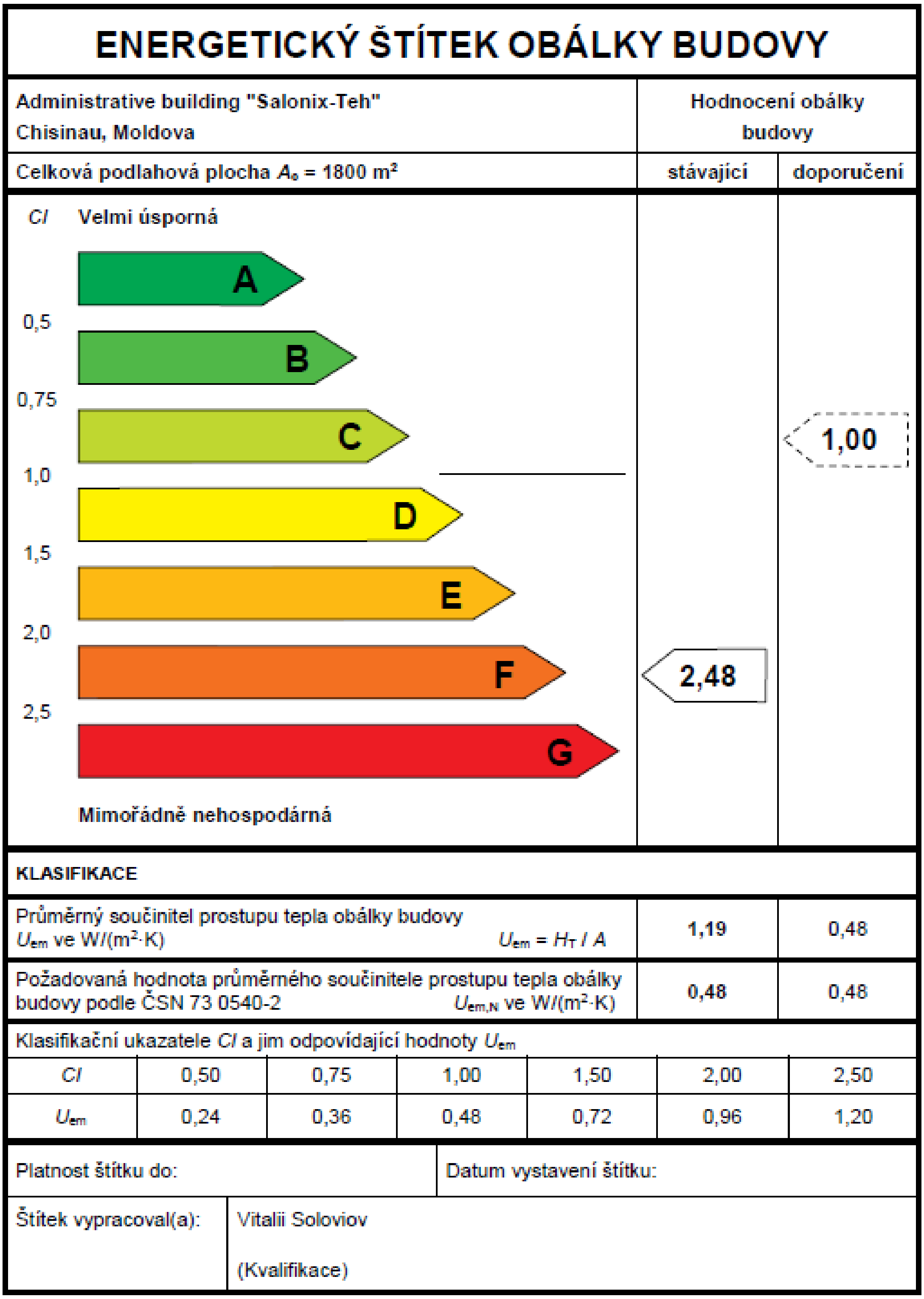


Fig. 30. Energy label of the designed building

9.5 Calculation of heat loss

Calculations were done according to standard thermal conditions for Chisinau area.

Primary data for calculation of thermal losses is:

- External climatic conditions for Chisinau (Tab. 10);
- Internal environmental requirements (temperature and humidity);
- Thermal characteristics of the building structures (Tab. 28);
- Detailed drawing of the building with layout of all the rooms.

Heat loss of the building is calculated by methodology described in p. 4.3, according to recommendations of *CSN EN 12831* standard.

Considering high amount of data, which needs to be processed in order to obtain a complex image of heat losses for the entire building, module "Ztraty 2014" of Svoboda Software was used. Results of the calculations are presented in table (Tab. 30).

Tab. 30. Heat losses of the building

Nr.	**Description**	**Area, [m²]**	**Volume, [m³]**	**$\Phi_{T,i} + \Phi_{V,i}$, [W]**	**$\Phi_{RH,i}$, [W]**	**Total heat load, Φ_{HL}, [W]**
Floor 1						
1.1	Hall	17,5	52,5	150	227,5	377,5
1.2	Shop	38,2	114,6	1705	496,6	2201,6
1.3	WC-f	4,8	14,4	183	62,4	245,4
1.4	WC-m	4,8	14,4	183	62,4	245,4
1.5	Cloakroom	9,3	27,9	216	120,9	336,9
1.6	Storage	32,7	98,1	638	425,1	1063,1
1.8	Production space	215,4	646,2	7649	2800,2	10449,2
St-1	Stairs	19,2	57,6	3523	249,6	3772,6
St-2	Stairs	18	54	2529	234	2763
	Total floor 1			**16776**		**21454,7**
Floor 2						
2.1	Tambour	5,7	17,1	-77		
2.2	Conference hall	38	114	1458	494	1952
2.3	Office	262,7	788,1	7926	3415,1	11341,1
2.4	Hall	5,7	17,1	-129		
2.5	WC-f	6,9	20,7	213	89,7	302,7
2.6	WC-m	4,8	14,4	149	62,4	211,4
2.7	Archive	7,6	22,8	9	98,8	107,8
	Total floor 2			9549		**13915**

Nr.	Description	Area, [m²]	Volume, [m³]	$\Phi_{T,i} + \Phi_{V,i}$, [W]	$\Phi_{RH,i}$, [W]	Total heat load, Φ_{HL}, [W]
Floor 3						
3.1	Office	38	114	1439	494	1933
3.2	Hall	5,7	17,1	-109		
3.3	WC-f	6,9	20,7	213	89,7	302,7
3.4	WC-m	4,8	14,4	177	62,4	239,4
3.5	Office	277,6	832,8	8166	3608,8	11774,8
	Total floor 3			**9886**		**14249,9**
Floor 4						
4.1	Restroom	11,6	34,8	469	150,8	619,8
4.2	WC	5,7	17,1	153	74,1	227,1
4.3	Director's office	35,3	105,9	1145	458,9	1603,9
4.4	Reception	18,3	54,9	582	237,9	819,9
4.5	Office	18,3	54,9	582	237,9	819,9
4.6	Office	35,8	107,4	1148	465,4	1613,4
4.7	Office	56,6	169,8	2032	735,8	2767,8
4.8	Office	19,7	59,1	914	256,1	1170,1
4.9	Hallway	65	195	-199	845	646
4.10	Office	46	138	1723	598	2321
4.11	WC-f	6,9	20,7	245	89,7	334,7
4.12	WC-m	4,8	14,4	170	62,4	232,4
	Total floor 4			**8964**		**13176**
Floor 5						
5.1	Office	264	792	10246	3432	13678
5.2	Hall	4,8	14,4	119	62,4	181,4
5.3	Hallway	20,3	60,9	169	263,9	432,9
5.4	Office	20,1	60,3	1089	261,3	1350,3
5.5	WC-f	7,6	22,8	331	98,8	429,8
5.6	WC-m	5,2	15,6	226	67,6	293,6
6.1	Boiler room	15,2	45,6	110	197,6	307,6
	Total floor 5			**12290**		**16673,6**
	Total			**57465**		**79469,2**

Designed building belongs to the category of nonresidential buildings with a break up to 48 hours during weekends, 12 hours on weekdays and design temperature of 20-22 °C.

It is a building of a medium mass and the reheating period is set to be 4 hours. Temperature drop is assumed to be of 3 K. According to the standard, reheating coefficient is 13 W/m² (Tab. 8).

Total heat loss represent 57465 W, of which heat losses by convection represent 29861 W and heat loss by ventilation are 27.604 W. Graphical repartition of heat loss between structures (Fig. 31) shows that ventilation heat loss represent almost 50% of the total loss. Besides, they are considerably higher than the loss through any particular structure. That is a direct indicator of a well-insulated building.

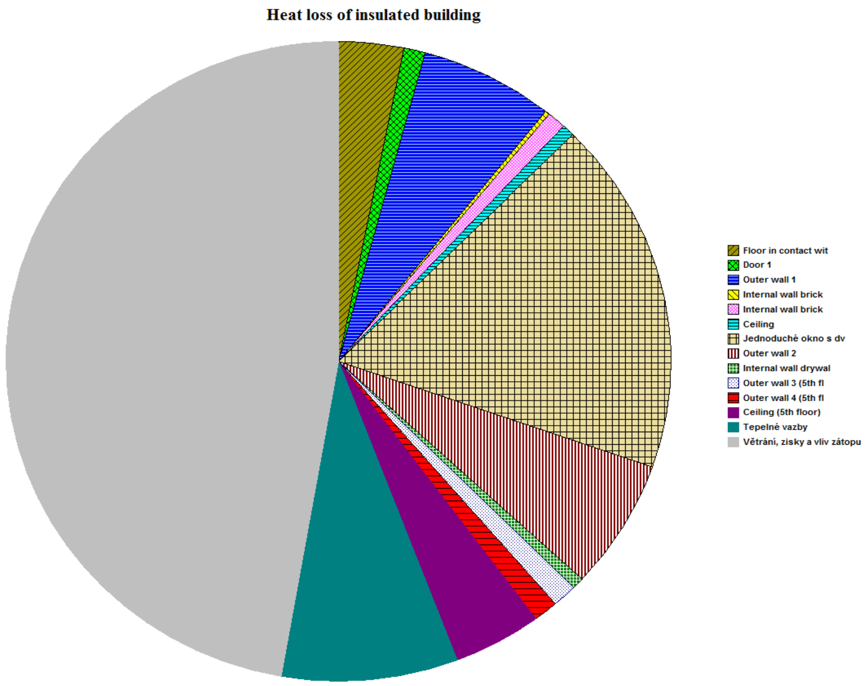


Fig. 31. Repartition of heat loss between insulated building structures

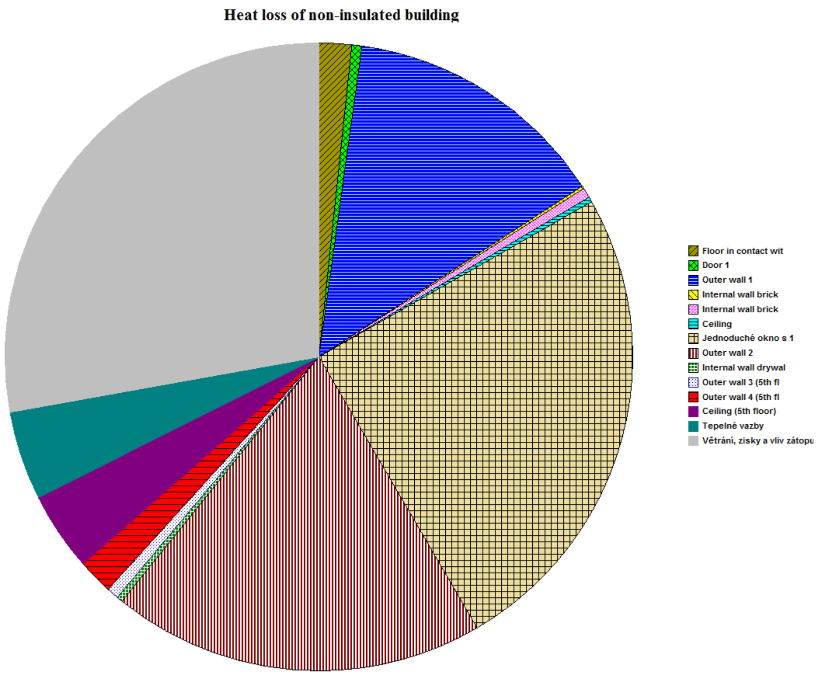


Fig. 32. Repartition of heat loss between non-insulated building structures

Zero value of necessary reheating power for some rooms is explained by the fact that they are not heated. Sufficient temperature in those areas is maintained by heat loss from surrounding areas and maintaining high temperature is not necessary in them.

Effects of insulation of the building structures can be seen by comparing heat loss repartition diagrams of insulated and non-insulated building (Fig. 31, Fig. 32). In non-insulated building, heat loss by ventilation account for around 26% of total loss. Another major factor of heat loss is windows, which is natural, considering relatively lower insulation properties of glass and big total area of windows (314 m^2).

Total heat loss of non-insulated building was 110207 W, which is 1.92 times higher than insulated building. Respectively, total heat loss was reduced by 48%.

Only installing the windows with higher insulation parameters results in a reduction of heat losses by 17040 W, by 15,5%.

Total required heat power of the building is 79.47 kW. Heating system shall be designed according to that value.

9.6 Heat gains

For assessment of system stability, critical from point of view of heat gains room is analyzed. It is considered the room on a higher floor, mostly exposed to sun radiation (south oriented). Room 5.4 was considered as critical for the stability. It is South-East oriented, has an area A = 20.1 m^2. Structures, which are in contact with external environment, are presented in the table (Tab. 31).

Tab. 31.. Structures in contact with environment of crtical room

Structure name	A [m^2]	R_{si} [m^{2}K/W]	U [W/(m^{2}K)]	R_{se} [m^{2}K/W]	Orientation	C [kJ/(m^{2}K)
Outer wall 4	18.69	0.13	0.29	0.08	N-E	110.687
Outer wall 3	5.71	0.13	0.23	0.08	S-E	31.338
Ceiling	20.1	0.1	0.54	0.1		23.972
Window 1	3.82	0.13	1	0.08	S-E	

Calculations were done using *Svoboda Software.* Biggest influence on heat gains is by solar irradiation during the hottest month. According to the standard, heat gains for one person in an office room is 80 W/person, with a total of 2 persons in the room. Heat gain value for lighting and office equipment is given for m^2. Heat gain for lighting is 12 W/m^2, for equipment – 7 W/m^2. Windows are shaded from outside with controlled blinds.

Heat gain characteristics of the room:

- Area of envelop A_t = 48.32 m^2;
- Thermal capacity of the room C_m = 2767.7 kJ/K;
- Equivalent accumulation area A_m = 31.07 m^2;
- Specific gain by internal convection and radiation H_{is} = 166.56 W/K;
- Specific gain through windows H_{es} = 5.44 W/K;
- Specific gain through massive construction H_{th} = 6.82 W/K;
- Heat transfer coefficient on the inner side H_{ms} = 282.77 W/K;
- Heat transfer coefficient on the outer side H_{em} = 6.98 W/K;

Determined temperature hourly distribution is given in figure x.

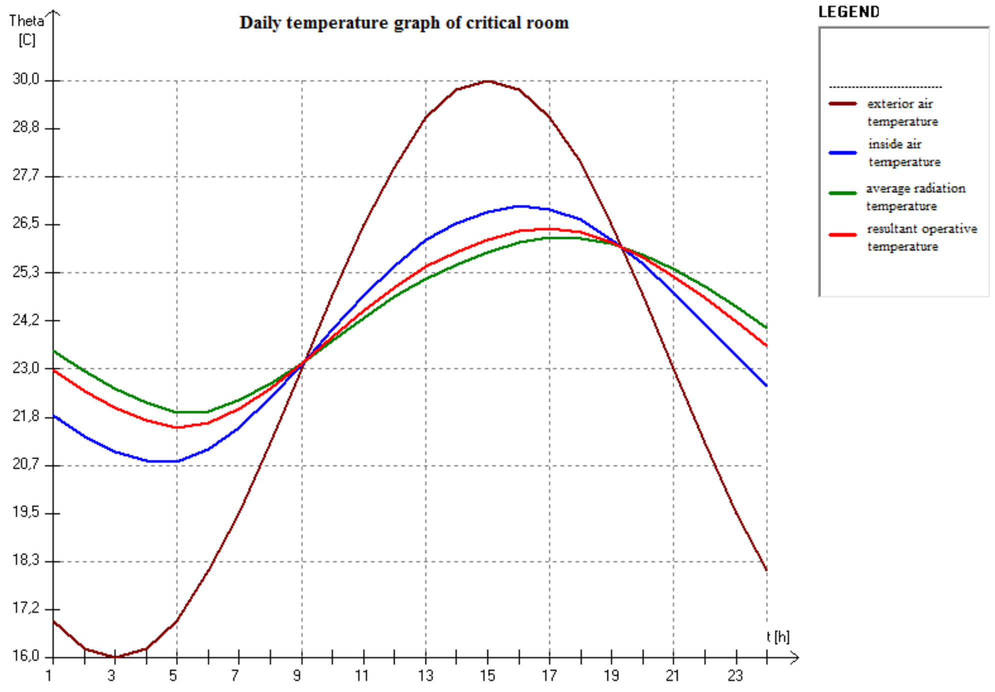


Fig. 33. Hourly temperature distribution

As it can be observed, highest internal value of internal temperature does not go over 27 ^{0}C. According to ČSN 730540-2 standard, maximally allowed temperature is 27 ^{0}C., although it can be exceeded for a short period of time for up to 2 ^{0}C. Therefore, the condition is meet and air conditioning system is not necessarily required.

10 HEATING SYSTEM DESIGN

10.1 Description of the heating system

In the past, the building was connected to the municipal central heating system. Due to years of downtime, it became operationally unfunctional. That, as well as disadvantageous tariffs of the central heating supplier and reconstruction, determined the decision of installing an autonomous heating system.

Taking into consideration both installation and operational costs, ease of maintenance and requirements of the owner, most advantageous heat source type is natural gas boiler. Designed heating system is a two-pipe horizontal heating system with bottom distribution and forced circulation of heating agent (water), closed and co-current. According to recommendations [40], chosen temperature drop of heating agent is 75/55 °C ($\Delta \boldsymbol{T}$ = 20 °C).

Boiler room is situated on the additional storey, constructed over the 5th floor. A standpipe leads from the boiler room down to the first floor. Each floor has a horizontal heating distribution system. Difference in the heating load of the 5 floors is the same, that allows us to use a parallel connection for the floors in one circulation segment [41]. Connection of the horizontal network to the standpipe on each floor is made through a manifold.

There are three circulation segments:

- Office heating segment;
- Stairs heating segment;
- Hot water preparation segment;

General heating system scheme is given in figure (Fig. 34). Primary circuit contains two gas boilers (B1.1 and B1.2) with safety valves, circulation pumps for each boiler (B2.1 and B2.2), screen filters for return water (F2 and F1). According to the recommendations, each pump in the circuit should be equipped with pressure gauges before and after, as well as anti-vibrational joints Danfoss ZKB (AV2, AV3, etc.) for absorbing expansion contractions, oscillations and vibrations caused by mechanic equipment. Thermometer is installed for temperature control on the boiler outlet.

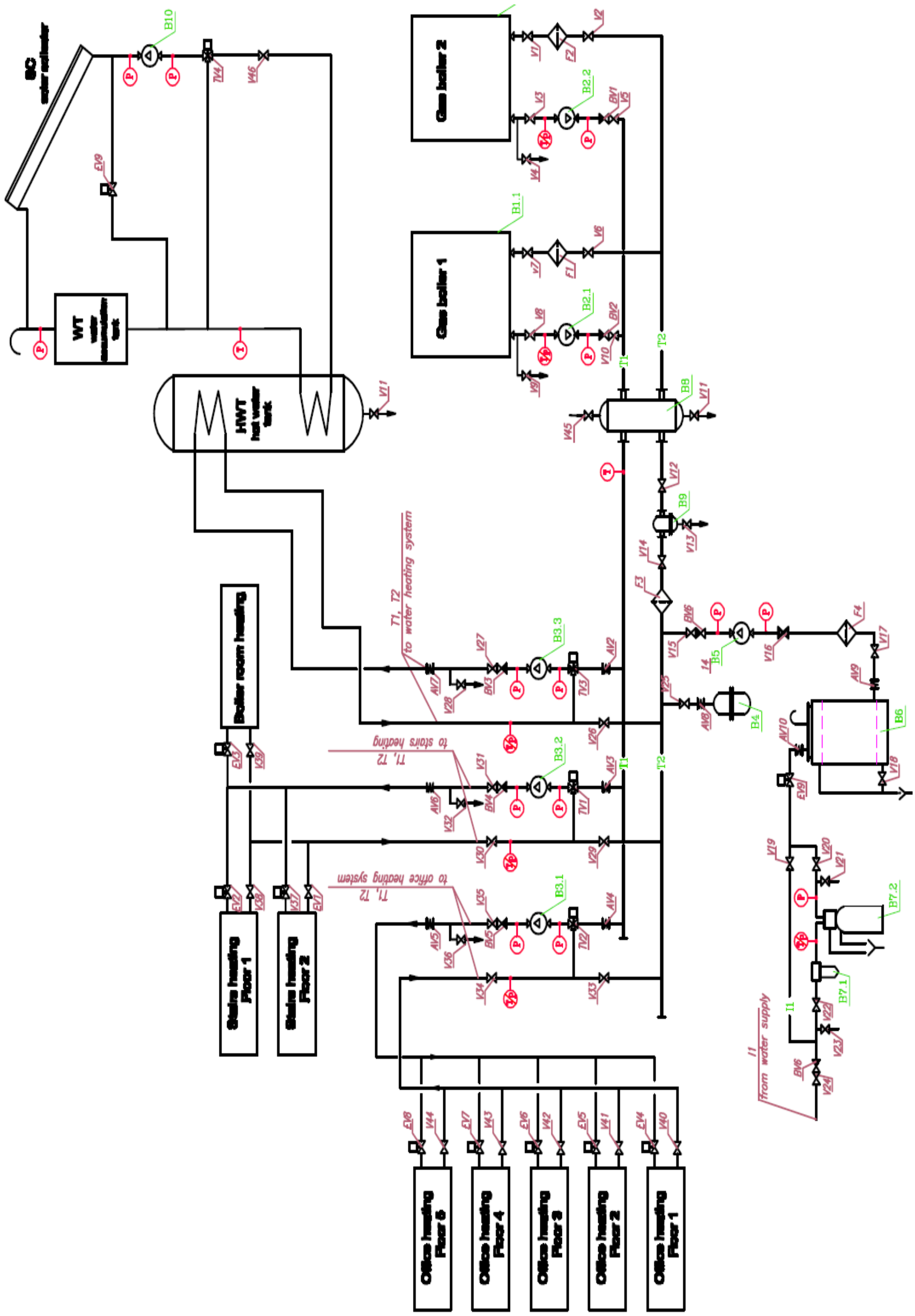


Fig. 34. General scheme of the heating system

For equalizing temperature and pressure and smoother operation of the boilers, a hydraulic separator (B8) is installed between primary and secondary circuits. It is equipped with automatic air vent (V45) on the top of and drainage valve (V11) for maintenance purposes.

For eliminating sludge in the return branch of the secondary circuit, a sludge separator is installed near the hydraulic separator (B9), Thermona Spirovent kal. By changing flow direction a few times inside the separator, velocity of the flow decreases and sludge settles down, being later eliminated through the valve in the bottom (V13). For protection of the closed heating system from excessive pressure an expansion tank is mounted (B4). Its pressurized air cushion prevents system from water hammer shock and excess of water pressure resulted from thermal expansion.

Every segment is equipped with three-way valve (TV1, TV2) for regulation of temperature by mixing supplied hot water with the returning one and a circulating pump. There is no necessity of mixing valve in the ventilation heating segment.

Water is fed from the central water supply system, and needs to pass specific treatment to correspond with allowable characteristics for heating equipment. In our case, it is filtered through a cyclone sand filter Depura Cyclon (B7.2). Later, it is softened by a water softening device Decalux Basic 25 ET (B7.1). It separates calcium and magnesium salts through ion exchange resins. Supply water availability is secured by storing it in a makeup water tank (B6).

Detailed selection of key components of and design will be discussed further.

10.2 Selection of heaters and design of heating segments

For convective heating of the spaces, VIADRUS THERMO 150/130 radiators (Fig. 35) were chosen. They are cast iron sectioned radiators, having many advantages:

- long lifespan (up to 50 years);
- relative unpretentiousness to heating agent quality;
- high corrosion resistance;
- possibility of regulating the installed power by choosing the number of sections;

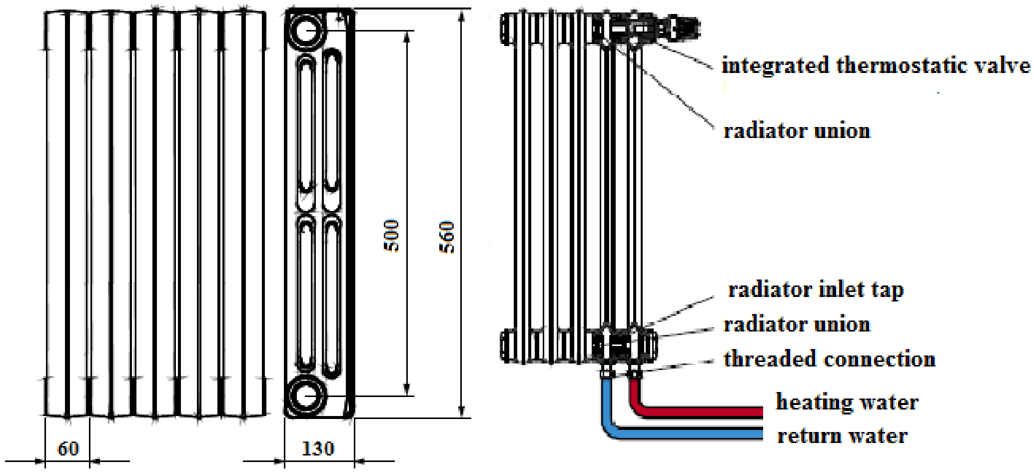


Fig. 35. Radiators VIADRUS THERMO 150/130

Tab. 32. Characteristics of VIADRUS THERMO 150/130 radiators

Distance between union axes, mm	**Total depth, mm**	**Total height, mm**	**Union thread, mm**	**Section mass, kg/pc**	**Section power, W/pc**	**Equivalent heating surface, m^3/pc**	**Section water volume, l/pc**
500	130	560	1	4.35	73.4	0.192	0.6

A variety of methods exists for simplified and fast calculation of required installed power of heaters. However, they don't take into consideration a multitude of building specifics, which vary from case to case and influence drastically heat consumption of the building (insulation of the building envelope, external environment, etc.). In order to design an efficient heating system, installed heating power is accepted according to previously determined value of total heat load for each room,Φ_{HL}. Installed heat power is taken with a 10% – 20% reserve toward total heat load.

Total installed power for each room is given in table (Tab. 33), as well as radiators dimensions, total nr of sections for each room and total water volume.

Tab. 33. Radiator parameters for each room (floor 4)

Nr.	**Description**	**Total heat load, [W]**	**Radiator dimensions, L*H*D, [m]**	**Nr. of radiators, [pcs]**	**P, [W]**	**Nr. of sections, [pcs]**	**V, [l]**
1.1	Hall	377,5	0,42*0,56*0,13	1	455	5	4
1.2	Shop	2201,6	0,78*0,56*0,13	2	2275	25	20
1.3	WC-f	245,4	0,18*0,56*0,13	1	273	3	2,4
1.4	WC-m	245,4	0,18*0,56*0,13	1	273	3	2,4
1.5	Cloakroom	336,9	0,24*0,56*0,13	1	364	4	3,2
1.6	Storage	1063,1	0,48*0,56*0,13	2	1092	12	9,6
1.8	Production space	10449,2	0,84*0,56*0,13	9	10465	115	92
			0,6*0,56*0,13	1			
St-1	Stairs	3772,6	1,14*0,56*0,13	2	3822	42	33,6
			0,72*0,56*0,13	2			
St-2	Stairs	2763	0,72*0,56*0,13	2	3458	38	30,4
			0,84*0,56*0,13	1			
	Total floor 1	**21454,7**			**22477**		
2.1	Tambour			0			
2.2	Conference hall	1952	0,36*0,56*0,13	3	2002	22	17,6
2.3	Office	11341,1	0,6*0,56*0,13	14	12740	140	112
2.4	Hall						
2.5	WC-f	302,7	0,24*0,56*0,13	1	364	4	3,2
2.6	WC-m	211,4	0,18*0,56*0,13	1	273	3	2,4
2.7	Archive	107,8	0,18*0,56*0,13	1	182	2	1,6
	Total floor 2	**13915**			**15561**		
3.1	Office	1933	0,48*0,56*0,13	3	2184	24	19,2
3.2	Hall						
3.3	WC-f	302,7	0,24*0,56*0,13	1	364	4	3,2
3.4	WC-m	239,4	0,18*0,56*0,13	1	273	3	2,4
3.5	Office	11774,8	0,6*0,56*0,13	14	12740	140	112
	Total floor 3	**14249,9**			**15561**		
4.1	Restroom	619,8	0,48*0,56*0,13	1	637	7	5,6
4.2	WC	227,1	0,18*0,56*0,13	1	273	3	2,4
4.3	Director's office	1603,9	0,6*0,56*0,13	2	1638	18	14,4

Nr.	Description	Total heat load, [W]	Radiator dimensions, L*H*D, [m]	Nr. of radiators, [pcs]	P, [W]	Nr. of sections, [pcs]	V, [l]
4.4	Reception	819,9	0,6*0,56*0,13	1	910	10	8
4.5	Office	819,9	0,6*0,56*0,13	1	910	10	8
4.6	Office	1613,4	0,6*0,56*0,13	2	1638	18	14,4
4.7	Office	2767,8	0,42*0,56*0,13	5	3185	35	28
4.8	Office	1170,1	0,3*0,56*0,13	3	1365	15	12
4.9	Hallway	646	0,48*0,56*0,13	2	728	8	6,4
4.10	Office	2321	0,84*0,56*0,13	2	2548	28	22,4
4.11	WC-f	334,7	0,24*0,56*0,13	1	364	4	3,2
4.12	WC-m	232,4	0,18*0,56*0,13	1	273	3	2,4
	Total floor 4	**13176**			**14469**		
5.1	Office	13678	0,84*0,56*0,13	13	16562	182	145,6
5.2	Hall	181,4	0,24*0,56*0,13	1	182	2	1,6
5.3	Hallway	432,9	0,54*0,56*0,13	1	455	5	4
5.4	Office	1350,3	0,54*0,56*0,13	2	1638	18	14,4
5.5	WC-f	429,8	0,36*0,56*0,13	1	455	5	4
5.6	WC-m	293,6	0,24*0,56*0,13	1	364	4	3,2
6.1	Boiler room	307,6	0,18*0,56*0,13	1	273	3	2,4
	Total floor 5	**16673,6**			**19929**		
	TOTAL	**79469,2**			**87997**		**773,6**

Each staircase is considered as one room. Because of big height (5 floors), and the propriety of hot air to move upwards, around 2/3 of heating power is installed on the level of first floor and 1/3 on the second.

Optimal place for installing radiators is under the windows, because windows is the main source of heat losses in the building. It compensates the heat loss and prevents condensation on the windows glass. Recommended installation height above the floor is 5-10 cm, 3-5 cm from windowsill and 3-5 cm from the wall. Inserting heat-reflecting material between wall and radiator lets reduce this distance and utilize generated heat more efficiently. Radiator should be mounted strictly at right angles, both horizontally and vertically. Any deviation leads to the accumulation of air, which leads to corrosion of the radiator.

10.3 Calculation of piping network hydraulic parameters

Before choosing the basic elements of the boiler room (pumps, valves, etc.), it is necessary to determine pressure losses of the basic circuit, in which critical heating element is located. Critical heating element is usually the one placed in most loaded pat of the system, at longest distance and height from the heat source.

Various options of pipe materials are available on the market: steel, PEX, polypropylene, metal PVC-coated, corrugated stainless and copper pipes. WICO copper pipes were chosen for our application due to its numerous advantages:

- Long lasting. It has excellent resistance to corrosion, high mechanical strength, high-temperature resistance and lifetime resistance to UV degradation;
- Ease of installation. Copper tube can be joined with capillary fittings. These fittings save material and make smooth, neat, strong and leak-proof joints. Because copper tube can be bent and formed, it is frequently possible to eliminate elbows and joints. Smooth bends permit the tube to follow contours and corners of almost any angle.
- Smaller internal diameter is needed to assure same flow and mechanical characteristics with the other types of pipes;

Although installation costs of copper tubing are high, general “price to quality” rate is the best, considering long-time fail-free operation.

For performing hydraulic calculations, piping system of each floor was separated in segments, as can be seen in figure (Fig. 36), on the example of fourth floor.

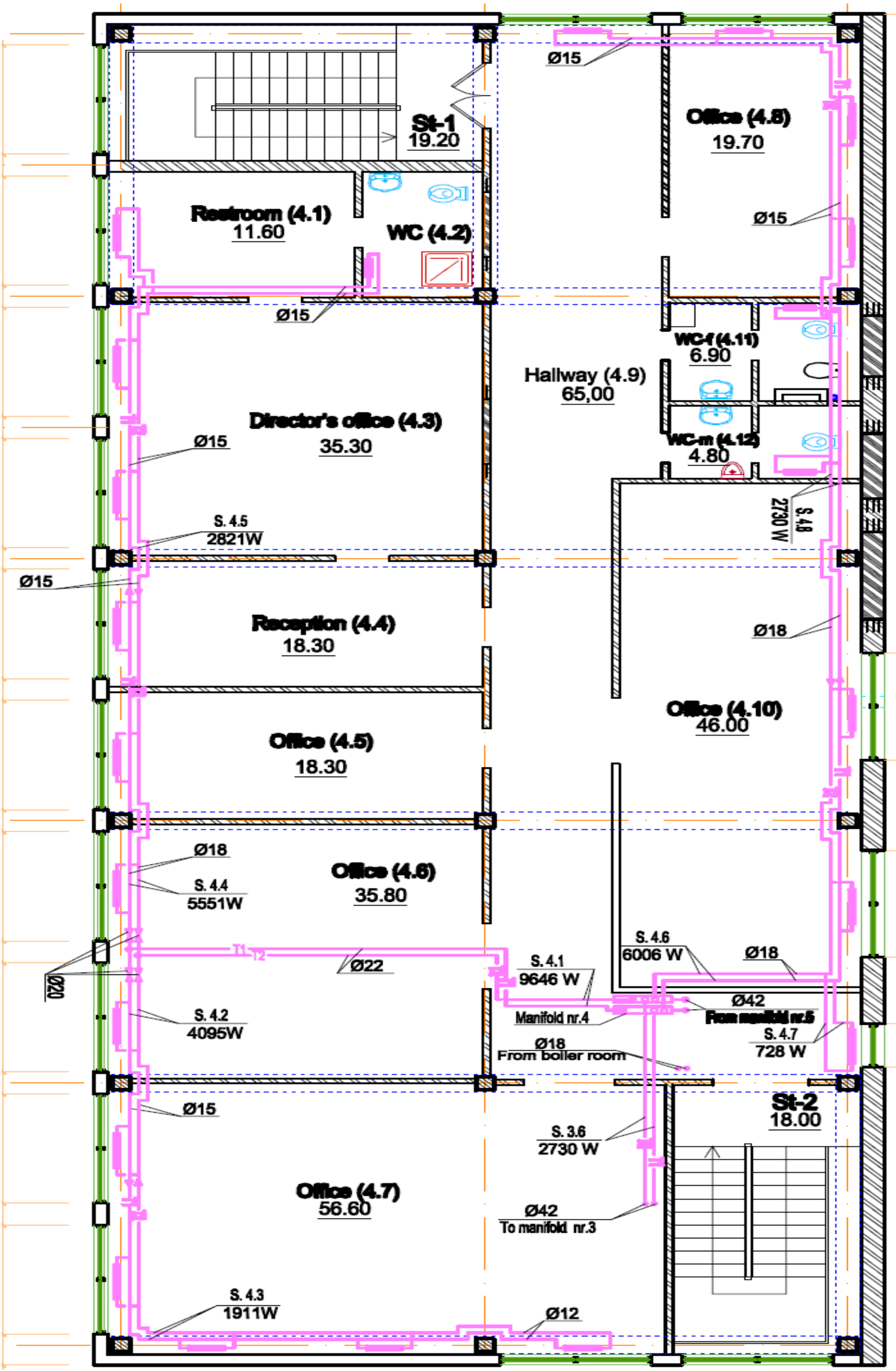


Fig. 36. Heating system of the fourth floor – layout view.

Figure below (Fig. 37), presents the schematic view of heating branches of the 4th floor. Every main branch is equipped with pressure balancing valves (BV). Radiators are equipped with thermostatic valves with flow regulation (TRV) on the inlet pipe and fittings for draining and filling the radiator (LV) with regulation possibility on the outlet. Connection to the standpipe is done through manifold.

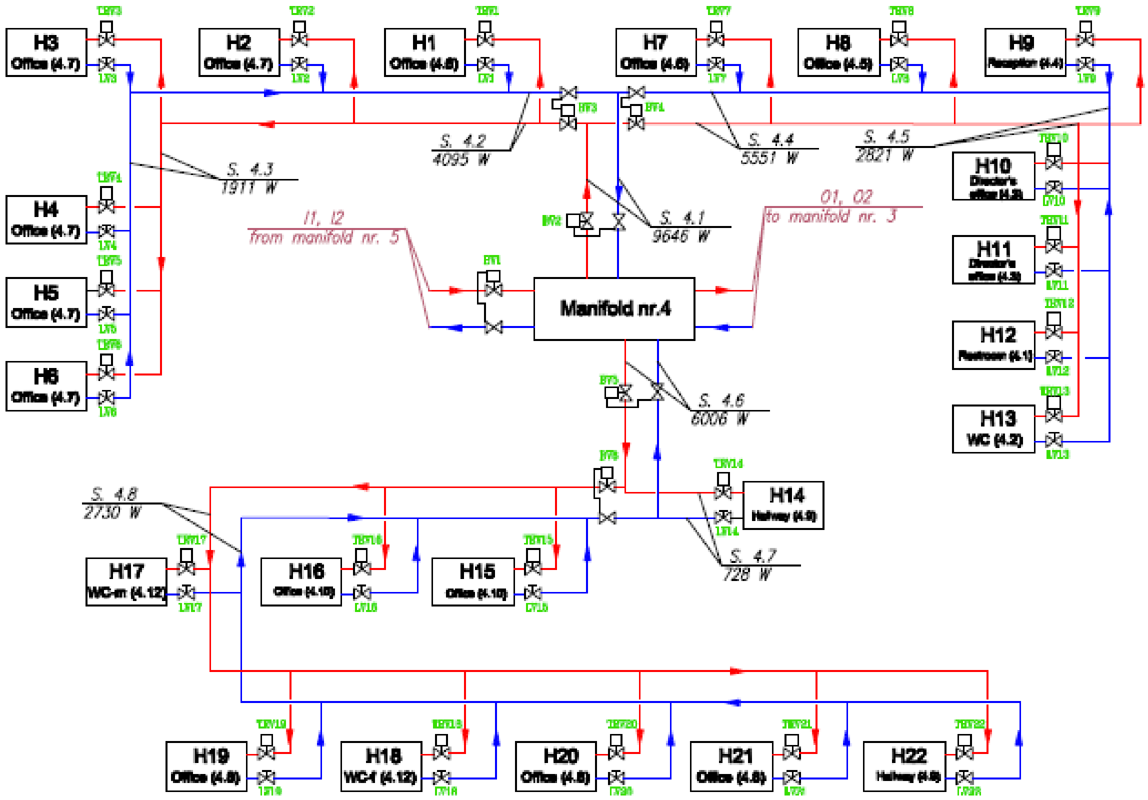


Fig. 37. Heating system of 4th floor – general scheme.

Manifold represents the connecting nod of the heating system of the floor. It consists of a system of hydraulic connections and equipment which allow the central connection of the heating branches to the central distribution pipe (standpipe). Designing a system using a manifold offers next advantages:

- It offers possibility of central control, allowing filling, isolation, hydraulic balancing, draining, flow and temperature control of each section separately.
- Maintenance and installation is simplier and costs are reduced;
- Higher safety, due to possibility of disconnecting problematic branches.

Simplified representation of the manifold for the input circuit of the first floor is given in figure (Fig. 38).

At the input of each manifold, a pressure gauge and temperature sensor are placed. Balancing valves before the distribution between the sections allows correction of pressure needed to provide a stable system operation at designed efficiency. For the same reasons balancing valves are equipped at the beginning of each branch.

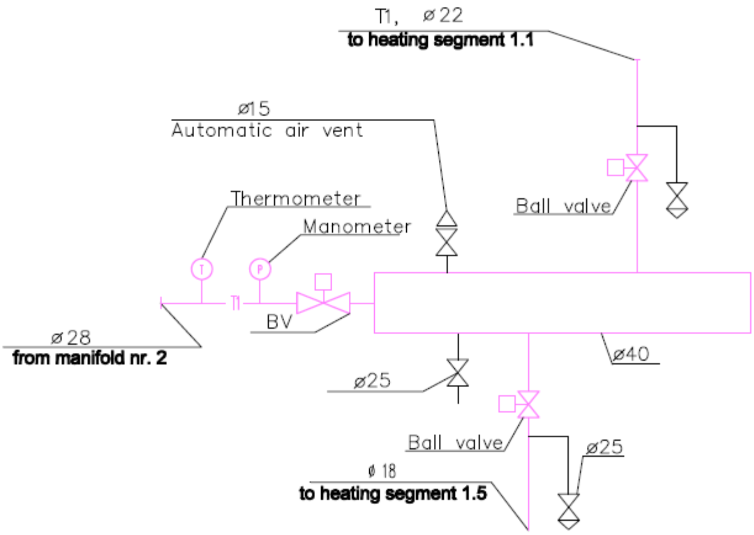


Figure 38. General scheme of input manifold at first floor

Being a closed-loop system, it can contain various amount of air. To eliminate it, sections are equipped with air vent valves. Not doing so may lead to negative consecuences:

- Flow stoppage in portions of the system due to air binding;
- Inefficient circulation because of the compressibility of water/air mixtures;
- Noise in the system due to water cascading in piping containing air;
- Internal corrosion of ferrous components due to dissolved oxygen in the water.

Pressure loss is separated in friction loss and local resistance loss.

Heating losses by friction Δp_λ [Pa] (27) appear on the entire section and length of the piping line.

$$R \cdot L = \Delta p_\lambda = \lambda \cdot \frac{l}{d} \cdot \frac{w^2}{2} \cdot \rho, \text{ [Pa]} \tag{27}$$

where:

R – specific loss by friction, value taken from table for copper tubes of known diameter and flow velocity [Pa/m];

l – length of the pipeline [m];

w – flow velocity of the thermal agent in the pipeline [m/s];

d – internal diameter of the pipe [m];

ρ – density of thermal agent [kg/m^3];

λ – friction coefficient.

Pressure loss by resistance ***Z*** [Pa] (28) is caused by swirling of the fluid in the points of change in flow direction or cross-section of the pipe.

$$Z = \Delta p_{\xi} = \sum \xi \cdot \frac{w^2}{2} \cdot \rho, \text{ [Pa]} \tag{28}$$

where:

ξ – coefficient of local resistance;

w - flow velocity of the thermal agent in the pipeline [m/s];

ρ – density of thermal agent [kg/m^3].

Design of the pipeline was performed using the method of optimal flow velocity. Piping characteristics may be selected according to the available engineering tables of computed using relations. According to this method, flow velocity must be selected as follows:

- inside the buildings, in the connecting branches of radiators – 0.15-0.6 m/s;
- inside the buildings, main horizontal distribution network – 0.6 -1 m/s.

Calculations are done considering the properties of thermal agent – water, at the average between two circuits temperature of 65 ^{0}C.

Initially knowing the heat load on each segment, mass flow ***M*** [kg/h] is determined by:

$$M_w = \frac{Q_w}{20} \cdot 0.86, \text{ [kg/h]} \tag{29}$$

where: $\boldsymbol{Q_w}$ – heat load [W];

Internal diameter of piping ***d*** is preliminary chosen. Having this data we can determine the flow velocity ***w*** on this segment:

$$w = \frac{4 \cdot \frac{M_w}{3600}}{\pi \cdot d^2 \cdot \rho}, \text{ [m/s]} \tag{30}$$

where: $\boldsymbol{M_w}$ – mass flow in the segment of piping [kg/h];

d – internal diameter of pipe [m];

ρ – density of thermal agent at operated temperature [kg/m^3] (ρ = 986 kg/m^3);

By adjusting value of internal diameter, desired velocity is chosen in the limits of recommendations. Specific loss by friction ***R*** is obtained using relation:

$$R = \lambda \cdot \frac{w^2}{2} \cdot \frac{\rho}{d}, \text{ [Pa]} \tag{31}$$

where: ***w*** – flow velocity [m/s];

ρ – density of water [kg/m^3];

d – internal diameter of pipe [m];

λ – friction coefficient.

Friction coefficient is a characteristic of flow, dependent on its type and is in correlation with the Reynold's number ***Re***:

$$\lambda = \frac{64 \cdot \eta}{w \cdot d \cdot \rho} = \frac{64}{\text{Re}} \tag{32}$$

where: ***η*** - dynamic viscosity, [kg/(m·s)];

w – flow velocity [m/s];

d – internal diameter of pipe [m];

ρ – density of water [kg/m^3];

Re – Reynolds number;

Reynold's number ***Re,*** is a dimensionless physical quantity, used for predicting flow pattern in various hydrodynamic conditions. There are three flow patterns, characterized by Reynold's number,:

- laminar - when ***Re*** < 2300. Friction coefficient is determined according to relation (32).
- transient - when 2300 < ***Re*** < 4000. The flow varies between laminar and turbulent flow and the friction coefficient is not possible to determine.
- turbulent - when ***Re*** > 4000. Friction coefficient is calculated using the Blasius correlation:

$$\lambda = \frac{0.316}{\mathrm{Re}^{1/4}} \tag{33}$$

Reynold's number can be expressed as a ratio of inertial forces to viscous forces:

$$\mathrm{Re} = \frac{w \cdot d \cdot \rho}{\eta} = \frac{w \cdot d}{\nu} \tag{34}$$

where: $\boldsymbol{\eta}$ - dynamic viscosity, [kg/(m·s)];

$\boldsymbol{\nu}$ – kinematic viscosity [m^2/s] (for t = 65 ^{0}C, $\nu = 4.44 \cdot 10^{-7}$ m^2/s);;

w **–** flow velocity [m/s];

d – characteristic linear dimension (internal diameter of pipe in our case) [m];

$\boldsymbol{\rho}$ – density of water [kg/m^3];

Total pressure loss on the section of pipeline $\Delta \boldsymbol{p_s}$ [Pa] is:

$$\Delta p_s = \Delta p_\lambda + \Delta p_\xi, \text{ [Pa]} \tag{35}$$

Pressure loss of basic circuit $\Delta \boldsymbol{p_{bc}}$ [Pa] is determined by sum of individual pressure loss segments:

$$\Delta p_{bc} = \sum (\Delta p_\lambda + \Delta p_\xi), \tag{36}$$

where: $\Delta \boldsymbol{p_\lambda}$ – pressure loss by friction [Pa];

$\Delta \boldsymbol{p_\xi}$ – pressure loss at local resistance [Pa].

Detailed data for pressure drop calculations in each section is given in table (Tab. 34). Sections marked with "St" belong to the branch of staircase heating, "p" symbolizes standpipe sections, "b.r." – boiler room heating.

As results from the calculation, difference in pressure drop of the office heating branch of each of 5 floors is negligible, and they can be connected in parallel.

Most important for further design is the pressure drop of the basic circuit for each of the heating branches. It is composed of the pressure drop on the first floor (as the most distanced from heating source) and in the standpipe (marked with "p" in table).

- For office heating: Δp_{bc} = 32848.8 Pa;
- For stairs heating: Δp_{bc} = 13493 Pa.

Tab. 34. Calculation of pressure loss in the heating pipeline

Section	Q [W]	Mw [kg/h]	l [m]	DN [mm]	v [m/s]	R [Pa/m]	∑ ξ	R*l	Z [Pa]	Δp_s [Pa]
1.1	11102	477	28.74	22	0.354	77.10	31.8	2215.87	1964.38	4180.25
1.2	6006	258	25.40	18	0.286	68.25	95.6	1733.51	3856.77	5590.29
1.3	5096	219	24.00	18	0.243	51.19	82.7	1228.66	2401.93	3630.59
1.4 St-1	3458	148	57.21	15	0.237	61.75	77.5	3532.61	2149.18	5681.79
1.5	5369	230	41.10	18	0.256	56.09	73.4	2305.28	2366.35	4671.63
1.6	3278	140	37.16	15	0.225	56.23	68.6	2089.64	1709.47	3799.12
1.7 St-2	2184	93	13.02	12	0.234	79.74	52.4	1038.26	1415.13	2453.39
1.8 (p)	16471	708	9.92	28	0.324	48.91	27	485.16	1399.13	1884.29
									∑	31891.34
2.1	10920	469	25.44	22	0.348	74.90	29.2	1905.52	1745.11	3650.63
2.2	5460	234	34.00	18	0.260	57.76	128.5	1963.97	4284.34	6248.31
2.3	5460	234	36.00	18	0.260	57.76	128.5	2079.50	4284.34	6363.84
2.4 St-1	2184	93	57.46	15	0.150	27.63	64.4	1587.59	712.38	2299.97
2.5	4823	207	38.24	18	0.230	46.49	60.9	1777.84	1584.34	3362.18
2.6	2821	121	38.50	15	0.193	43.24	86	1664.74	1587.18	3251.92
2.7 St-2	1274	54	6.00	1	0.197	73.82	42.4	442.91	807.96	1250.87
2.8 (p)	32214	1385	7.00	35	0.406	54.81	26	383.68	2110.94	2494.62
									∑	28922.33
3.1	10920	469	27.40	22	0.348	74.90	29.2	2052.32	1745.11	3797.44
3.2	5460	234	34	18	0.260	57.76	108.5	1963.97	3617.52	5581.49
3.3	5460	234	36.00	18	0.260	57.76	108.5	2079.50	3617.52	5697.02
3.4	4641	199	46.04	18	0.221	43.46	91.6	2001.13	2206.55	4207.68
3.5	2548	109	28	15	0.175	36.19	70.5	1013.18	1061.47	2074.65
3.6 (p)	47775	2054	16.1	42	0.418	45.95	26	739.79	2239.05	2978.83
									∑	24337.11
4.1	9646	414	18.28	22	0.308	60.29	29.2	1102.02	1361.67	2463.69
4.2	4095	176	17.6	15	0.281	83.01	68.7	1460.96	2671.68	4132.64
4.3	1911	82	16	12	0.205	63.13	47.4	1010.02	980.08	1990.10
4.4	5551	238	19.2	18	0.264	59.46	74.7	1141.62	2574.30	3715.91
4.5	2821	121	24.2	15	0.193	43.24	60.1	1046.41	1109.18	2155.59
4.6	6006	258	30.4	18	0.286	68.25	47.3	2074.76	1908.22	3982.97
4.7	728	31	4.34	08	0.176	80.01	13.6	347.26	206.60	553.86
4.8	2730	117	33	15	0.187	40.83	75.6	1347.34	1306.68	2654.02
4.9 (p)	63427	2727	6.7	42	0.555	75.45	26	505.52	3946.48	4452.00
									∑	26100.78

Section	Q [W]	Mw [kg/h]	l [m]	DN [mm]	v [m/s]	R [Pa/m]	∑ ξ	R*l	Z [Pa]	Δp_s [Pa]
5.1	14014	602	18.1	25	0.346	63.15	6	1143.04	354.16	1497.20
5.2	6370	273	18	18	0.303	75.65	69.3	1361.71	3144.91	4506.62
5.3	7644	328	20	22	0.244	40.13	74.7	802.50	2187.54	2990.05
5.4	2548	109	10	12	0.273	104.44	26.5	1044.36	974.10	2018.47
5.5	3822	164	16	15	0.262	73.57	47.4	1177.09	1605.76	2782.85
5.6	5915	254	43.32	18	0.282	66.45	71	2878.58	2778.20	5656.78
5.7	2457	105	20.08	15	0.169	33.95	42	681.79	588.00	1269.80
5.8	364	15	4.6	06	0.156	93.29	12.9	429.12	154.84	583.96
5.9 (p)	83356	3584	10.3	54	0.441	36.89	7	379.94	671.56	1051.50
5.10 St(p)	9373	403	17	18	0.446	148.72	28.8	2528.17	2829.73	5357.90
									∑	27715.12
6.1 (b.r.)	273	11	18.2	06	0.117	45.54	27.7	828.82	187.02	1015.84

10.4 Selection of three-way valves

In order to assure constant required temperature in heating circuit and more efficient use of generated heat, a three-way mixing valve is installed in each circuit, in between the distribution point (manifold) and pump. Exception is the circuit for ventilation heating, where it is not necessary to perform the mixing.

The purpose of a three-way control valve is to shut off water flow in one pipe while opening water flow in another pipe, to mix water from two different pipes into one pipe, or to separate water from one pipe into two different pipes.

Three-way valve is characterized by three ports A, B and C. The valve is normally defined by its flow coefficient $\boldsymbol{k_{vs}}$ [m^3/h] value, which expresses the volume of water that passes through the fully open valve in 1 hour with a pressure differential of 1 bar. It is normally provided with an electrical, pneumatic or thermal actuator.

As an example of three-way valve calculation, circuit of office heating is considered.

As initial data, next values are considered:

- Volume flow - $\boldsymbol{V}$ = 3.58 m^3/h;
- Pressure drop of basic circuit - $\Delta \boldsymbol{p_{bc}}$ = 32.85 kPa.

Basic characteristic of a control valve is authority. It expresses the ratio between pressure drop across the control valve compared to the total pressure drop across the whole circuit. By this parameter it is possible to assess suitability of specific chosen valve for the application. Authority of valve is defined by relation:

$$a = \frac{\Delta p_v}{\Delta p_{bc} + \Delta p_v} \tag{37}$$

where: $\Delta \boldsymbol{p_v}$ – pressure drop on the valve [bar];

$\Delta \boldsymbol{p_{bc}}$ - pressure drop in the basic circuit [bar];

Flow coefficient $\boldsymbol{k_v}$ [m^3/h] is given by formula:

$$k_v = \frac{V}{\sqrt{\Delta p_v}} = \frac{3.58}{\sqrt{32.85 \cdot 0.01}} = 6.25 \text{ m}^3/\text{h} \tag{38}$$

where: $\boldsymbol{V}$ – volume flow [m^3/h];

Nominal flow coefficient $\boldsymbol{k_{vs}}$ is chosen to be 1.1 – 1.3 times higher than calculated flow coefficient, due to safety considerations.

$$k_{vs} = k_{vs} \cdot (1.1 \text{ to } 1.3) = 6.25 \cdot (1.1 \text{ to } 1.3) = 6.87 \text{ to } 8.13 \text{ m}^3/\text{h} \tag{39}$$

Of the available product range of mixing valves, closest nominal $\boldsymbol{k_{vs}}$ value is 8 m^3/h, which corresponds to the diameter of DN 25.

Actual pressure loss of the selected valve $\boldsymbol{\Delta p_{v,H100}}$ [bar] at the full opening is:

$$\Delta p_{v,H100} = (\frac{V}{k_{vs}})^2 = (\frac{3.58}{8})^2 = 0.2 \text{ bar} \tag{40}$$

Knowing the value of $\boldsymbol{\Delta p_{v,H100}}$ it is possible to finally determine valve's authority:

$$a = \frac{\Delta p_v}{\Delta p_{bc} + \Delta p_v} = \frac{0.2}{0.33 + 0.2} = 0.38 \tag{41}$$

According to recommendations, valve is considered correctly designed if authority is in between 0.3 and 0.5. Chosen valve meet the requirements (Tab. 35).

Tab. 35. Selection of three-way mixing valves

Segment	Mass flow, M	Volume flow, V	DN	Total pressure loss, Δp_{bc}	Flow coeff., K_v	Nominal flow co-eff., K_{vs}	Total loss in valve, $\Delta p_{v,H100}$	Authority of valve, a
	[kg/h]	[m3/h]	[mm]	[kPa]	[m3/h]	[m3/h]	[bar]	
Office heating	3584.3	3.58	25	32.85	6.25	8.13	0.2	0.38
Stairs heating	403	0.40	15	12.96	1.12	1.46	0.06	0.33

With the consideration of design parameters, HYDRONICS CV 216/316 RGA 60-330-125 was chosen for office heating circuit and HYDRONICS CV 216/316 RGA 60-330-315 for stairs heating circuit.

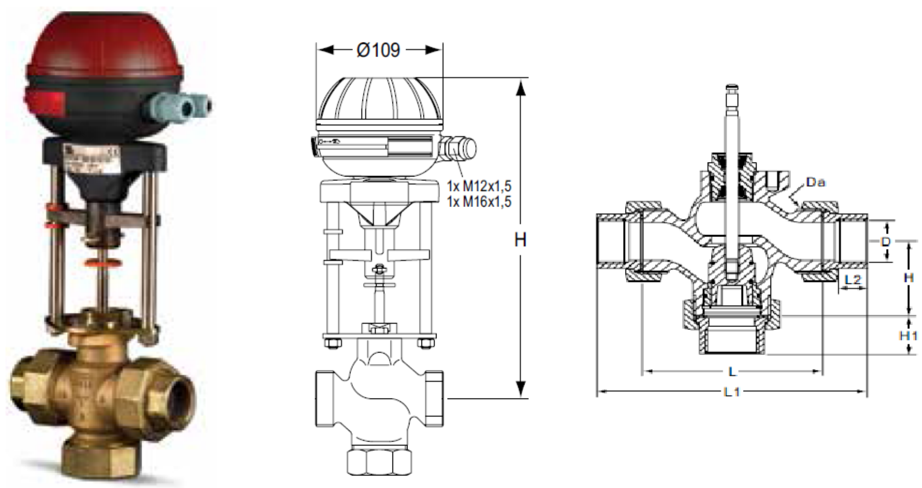


Fig. 39. Selected HYDRONICS CV 216/316 mixing valve.

Tab. 36. Selected HYDRONICS CV 216/316 mixing valve parameters

DN	D	Da	L [mm]	L1 [mm]	L2 [mm]	H [mm]	H1 [mm]	K_{vs}	M [kg]	Article nr.
25	Rp1	G1 ½	80	138	17	45	74	8	1.7	60-330-125
15	Rp1/2	G1	62	114	13	40	66	0.63	0.9	60-330-115

10.5 Selection of secondary circuit circulating pumps

Proper selection of circulating pump is critical for efficient and reliable operation of the system. In order to correctly select the pump it is necessary to determine the hydraulic head of the pump ***H*** [m]. It is calculated considering the transportation height and pressure drop along the system. In our case of the heating system, it is dealt with a closed system and therefore vertical transportation height value is annulated by return circuit to the pump from the highest point of the line.

As an example, selection of pump for office heating circuit is considered. Initially, we determine the hydraulic head, covering up all pressure losses in the circuit. Total pressure drop in the circuit Δp is 32848 Pa. From safety considerations, pressure drop is taken with a reserve coefficient of 1.4. Pressure drop Δp_v at the mixing valve of 20074 Pa is added to that value.

Relation for calculating hydraulic head of the pump is:

$$h = \frac{(\Delta p \cdot 1.4) + \Delta p_v}{\rho \cdot g} = \frac{(32848 \cdot 1.4) + 20074}{980 \cdot 9.81} = 6.872 \text{ m} \quad (42)$$

where: Δp – pressure drop in the circuit [Pa];

Δp_v – pressure drop on the mixing valve [Pa];

ρ – density of water at the operating temperature [kg/m^3];

g – gravity acceleration constant [m/s^2].

Second important parameter is volume flow in the segment, which equals to 3.58 m^3/h for office heating segment.

Tab. 37. Calculation of pump characteristics

Segment	Pressure loss in the segment, Δp	Total loss in valve, Δp_v	Head, h	Volume flow
	[Pa]	[Pa]	[m]	[m3/h]
Office heating	32848	20074,00	6,871497	3,584308
Stairs heating	12962	6344,00	2,547463	0,403

Having the values of two parameters listed above, it is possible to choose suitable pump from the available range of products. Each producer supplies pump characteristics graphs

(Fig. x), where operational point is specified as an intersection of pipeline and pump functions of head ***H*** and volume flow ***Q***, respectively.

For optimal pump selection, Grundfoss online selection application was used. Grundfoss MAGNA3 25-100 pump model was selected, being optimal for heating applications of required parameters. They are designed specifically for heating applications and offer a variety of functions for energy savings. Pump characteristics are represented in Fig. x. Operational point of considered application is noted by yellow point with the red dot.

Same procedure was performed for stairs heating circuit, selecting Grundfoss ALPHA2 25-50 180 pump.

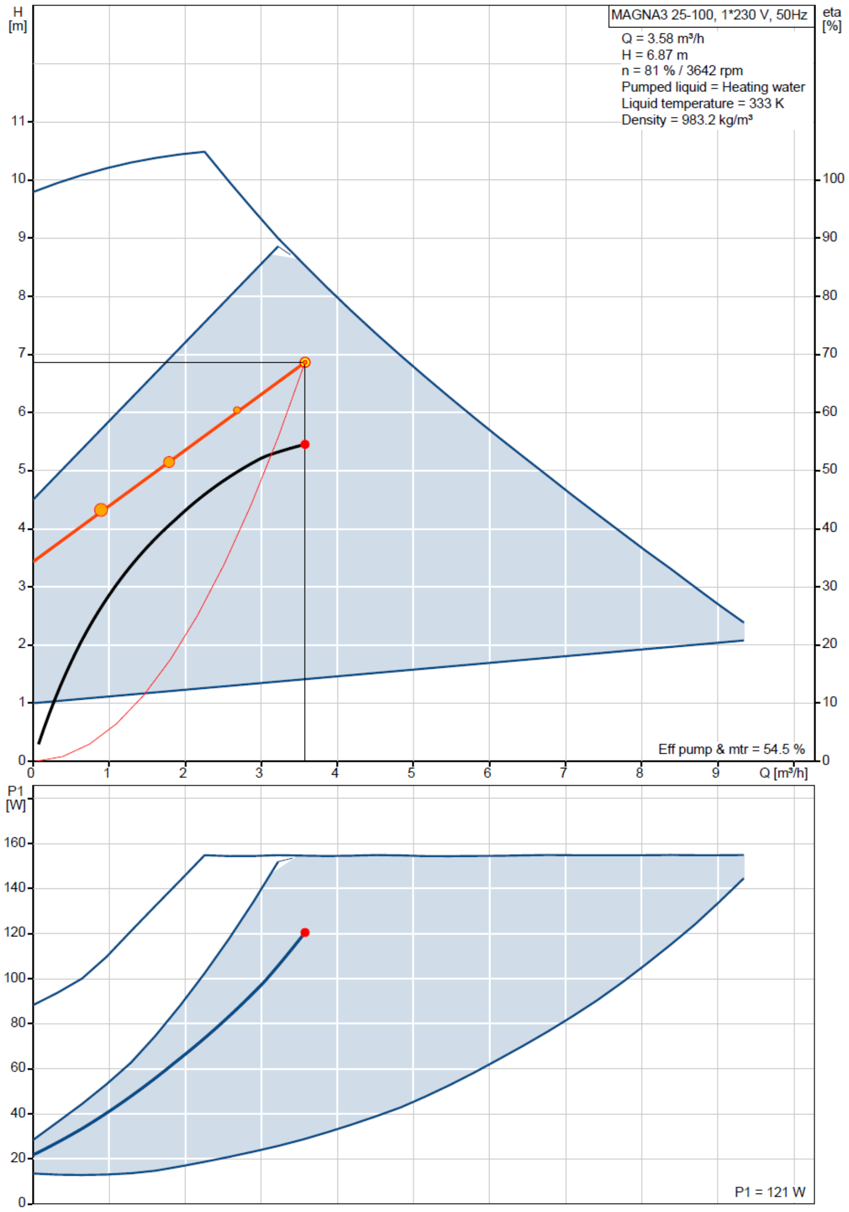


Fig. 40. Selected MAGNA3 25-100 pump characteristics.

10.6 Hot water preparation

10.6.1 Requirements for hot water preparation

A key point for evaluation of heat consumption and thermal efficiency of a building, and respectively correct design of heating installations, is precise determination of energy, required for hot water preparation.

Hot water preparation equipment should be designed in such a way, so that when fully opening a tap at the point of consumption, not later than after 30 s of flow water would reach temperature between 50 and 55 ^{0}C [41]. Water should be stored at a temperature of 60 ^{0}C to prevent spread of Legionella, a bacteria which causes acute respiratory infection.

Proper sizing of water heaters in requires an estimation of peak demand. Peak demand is defined as the highest amount of hot water being used simultaneously. Sizing methods factor the capacity of the hot water source, from either conventional storage tank or tankless water heaters, to the needs of the facility.

Water heating equipment, and similar appliances require the installation of backflow protection through either a backflow prevention assembly, backflow device or an air gap.

Requirements regarding hot water supply are given in *SNIP 2.04.01–85 "Internal water supply and sewerage of buildings*", valid in the Republic of Moldova.

Initial step in hot water supply design is average calculated daily hot water consumption in the building $\boldsymbol{V_{hw}}$ [m^3/day] [42]:

$$V_{hw} = (g_p \cdot n_p + g_s) \cdot 10^{-3}\ m^3/day \tag{43}$$

where: $\boldsymbol{g_p}$ – average hot water consumption by a person. According to valid regulations (*SNIP 2.04.01–85*) for administrative buildings, total average water consumption is 12 l/(pers·day), of which hot water is 5 l/day. In comparison, relevant Czech standard *ČSN 06 0320* requires 4 l/(pers·day). However, the legally valid value for Moldova is taken into consideration for calculations;

$\boldsymbol{g_s}$ – hot water consumption for production spaces per one shower, $\boldsymbol{g_s}$ = 500 l/day. It should be added to the total water consumption due to existing production space on the first floor;

$\boldsymbol{n_p}$ – number of people in the office part of the building. Maximal estimated value is $\boldsymbol{n_p}$ = 30 · 4 = 120 pers.

$$V_{hw} = (5 \cdot 120 + 500) \cdot 10^{-3} = 1.15\ m^3/day$$

V_{hw} = 1.15 m^3/day, of which 45.5% (0.5 m^3/day) is for production space hot water supply.

Average hourly heat consumption Q_{hw} [kW] for hot water preparation according to *SNIP 2.04.01–85* is:

$$Q_{hw} = \frac{V_{hw}(55 - t_{wc})(1 + k_{hl})\, p_w c_w}{3.6 \cdot 24} \qquad (44)$$

where: V_{hw} – average daily hot water consumption in the building [m^3/day]:

t_{wc} – temperature of cold water [^{o}C], t_{wc} = 5 ^{o}C;

k_{hl} – coefficient, considering heat loss in the hot water supply pipeline (k_{hl} =0.25, table x);

ρ_w – water density [kg/l], ρ_w = 1 kg/l;

c_w – specific heat capacity of water [J/(kg·^{o}C)], c_w = 4.2 J/(kg·^{o}C).

$$Q_{hw} = \frac{1.15(55-5)(1+0.25)\cdot 1 \cdot 4.2}{3.6 \cdot 24} = 3.494 \text{ kW}$$

Tab. 38. Values of k_{hl} coefficient, considering heat loss in hot water supply pipeline

Type of hot water supply system	**k_{hl} coefficient**	
	With hot water system after central heating point	**With no hot water distribution sys-**
With isolated standpipes with no towel warmers	0.15	0.1
Same with towel warmers	0.25	0.2
With uninsulated standpipes and no towel warmers	0.35	0.3

Heat power required by hot water preparation system during an year Q^y_{hw} [kWh], with consideration of maintenance interruption:

$$Q^y_{hw} = Q_{hw} \cdot 365 \cdot n_h = 3.494 \cdot 365 \cdot 8 = 10202 \text{ kWh/year} \qquad (45)$$

where: n_h – number of water heating system operation per day [h], n_h = 8 h.

Considering the limited needs of hot water due to office use of building and light character of manual work done in the assembly space, which we observe in practice, three main options of hot water preparations are available:

- gas boiler water heating installation;
- combined solar panel and gas boiler water heating installation;
- electrical boilers installed on each floor.

10.6.2 Combined gas boiler - solar collector system design

10.6.2.1 Overview of designed combined water heating system

Even in case of solar collector installation for preparing hot water, it is necessary to assure possibility of heating water by common gas heating system, because solar system cannot maintain a required temperature of around 60 ^{0}C in the hot water storage tank. For installation of combined gas boiler and solar collector system, heating circuit from Fig. x is added to general heating system, as well as a respective branch on the secondary circuit side after hydraulic separator with necessary equipment.

Hot water is prepared in hot water tank (HWT) by 2 heating circuits: from solar panel and from gas boiler.

Thermal solar collector is designed for heating hot water by efficient accumulation and conversion of solar energy to heat energy.

Designed system is an indirect active open water preparation system with forced circulation.

Latitude of designed installation in Chisinau, Central Moldova, is 48^0 North. Period of efficient operation, when collector is able to provide considerable output is between 1st March and 31st October. Solar collector will be installed on the side of the roof heading South.

10.6.2.2 Determining optimal inclination angles of solar collector and available solar energy

In order to assess future performance of the solar system it is necessary to determine available solar energy resource. Initially solar energy available at various angles in different periods of year is assessed [31].

Global irradiance on a tilted plane $\mathbf{G_\beta}$ [MJ/m^2] is equal to the summ of three components:

$$G_\beta = B_\beta + D_\beta + R_\beta \; [MJ/m^2] \tag{46}$$

where: B_β – direct solar irradiation on a tilted plane [MJ/m^2]:

$$B_\beta = R_b \cdot B \; [MJ/m^2] \tag{47}$$

where: B – direct solar radiation on a horizontal plane [MJ/m^2];

R_b – ratio between direct radiation on a tilted plane and on a horizontal one, is given in engineering tables (table x) [MJ/m^2];

D_β – diffused irradiation on a tilted plane [MJ/m^2];

R_β – reflected radiation on a tilted plane (component that is reflected from the ground) [MJ/m^2].

The integral of solar irradiance over a time period is called "solar exposure" or "insolation".

Primary data regarding solar irradiance on a horizontal plane, according to data supplied by Chisinau meteorology station, is given in table (Tab. 39).

Tab. 39. Average monthly values of direct irradiance B, diffuse irradiance Gd and global irradiance G, [MJ/m^2] [31]

Month	III	IV	V	VI	VII	VIII	IX	X
G	303	460	607	692	685	598	440	281
B	131	220	318	391	389	348	255	148
G_d =G - B	172	240	289	301	296	250	185	133

Tab. 40. Values of Rb(β) coefficient for latitude 48 ^{0}North (Chisinau, Moldova) [MJ/m^2]

Month		III	IV	V	VI	VII	VIII	IX	X
Rb	β								
	28	1.49	1.18	1.01	0.95	0.98	1.10	1.35	1.76
	33	1.54	1.19	0.99	0.92	0.96	1.09	1.38	1.85
	38	1.57	1.18	0.97	0.89	0.93	1.08	1.40	1.93
	43	1.60	1.17	0.94	0.85	0.89	1.06	1.40	1.99
	48	1.62	1.13	0.83	0.71	0.76	0.99	1.40	2.05
	53	1.62	1.12	0.85	0.76	0.80	0.99	1.36	2.08
	58	1.61	1.08	0.80	0.70	0.75	0.96	1.37	2.10
	63	1.59	1.03	0.75	0.64	0.69	0.90	1.34	2.10
	68	1.55	0.98	0.69	0.58	0.63	0.84	1.29	2.03

According to available meteorological data, all three types of solar irradiation values are computed for a diapason of angles from 28^0 to 68^0 with a 5^0 step.

Direct solar irradiation on a tilted plane is calculated according to (47) (Tab. 41).

Tab. 41. Values of direct solar irradiation on a tilted plane [MJ/m²]

Month		III	IV	V	VI	VII	VIII	IX	X
B_β	β								
	28	195.19	259.60	321.18	371.45	381.22	382.80	344.25	260.48
	33	201.74	261.80	314.82	359.72	373.44	379.32	351.90	273.80
	38	205.67	259.60	308.46	347.99	361.77	375.84	357.00	285.64
	43	209.60	257.40	298.92	332.35	346.21	368.88	357.00	294.52
	48	212.22	248.60	263.94	277.61	295.64	344.52	357.00	303.40
	53	212.22	246.40	270.30	297.16	311.20	344.52	346.80	307.84
	58	210.91	237.60	254.40	273.70	291.75	334.08	349.35	310.80
	63	208.29	226.60	238.50	250.24	268.41	313.20	341.70	310.80
	68	203.05	215.60	219.42	226.78	245.07	292.32	328.95	300.44

Diffuse irradiation on a tilted plane $\boldsymbol{D_\beta}$ is calculated for each angle value $\boldsymbol{\beta}$ and diffuse radiation on a horizontal plane $\boldsymbol{D}$ for each month:

$$D_\beta = 0.5 \cdot (1 + Cos\beta) \cdot D \qquad (48)$$

Where: $\boldsymbol{D}$ – diffuse radiation on a horizontal plane [MJ/m²];

$\boldsymbol{\beta}$ – angle of panel inclination [^{0}].

Tab. 42. Values of diffuse solar irradiation on a tilted plane [MJ/m²]

Month		III	IV	V	VI	VII	VIII	IX	X
Dβ	β								
	28	161.93	225.95	272.09	283.38	278.68	235.37	174.17	125.22
	33	158.13	220.64	265.69	276.72	272.12	229.83	170.08	122.27
	38	153.77	214.56	258.37	269.10	264.63	223.50	165.39	118.90
	43	148.90	207.76	250.18	260.57	256.24	216.42	160.15	115.14
	48	143.55	200.30	241.19	251.21	247.03	208.64	154.40	111.00
	53	137.76	192.22	231.47	241.08	237.07	200.23	148.17	106.52
	58	131.58	183.59	221.08	230.26	226.43	191.24	141.52	101.74
	63	125.05	174.48	210.11	218.83	215.19	181.75	134.50	96.69
	68	118.22	164.96	198.64	206.88	203.45	171.83	127.15	91.41

Reflected irradiation on a tilted pane $\boldsymbol{R_\beta}$:

$$R_\beta = 0.5 \cdot (1 - Cos\beta) \cdot \rho \cdot G \qquad (49)$$

where: $\boldsymbol{\rho}$ – reflection coefficient (Tab. 43);

G – global radiation on a horizontal plane [MJ/m^2];;

β – angle of panel inclination [^{0}].

Tab. 43. Values of reflection coefficient depending on the terrain

Terrain composition	**ρ**
Soil	0.2
Terrain covered with vegetation	0.3
Sand	0.4
Snow	0.7

Tab. 44. Values of reflected solar irradiation on a tilted plane [MJ/m^2]

Month		III	IV	V	VI	VII	VIII	IX	X
	β								
	28	5.32	8.08	10.66	12.15	12.03	10.50	7.73	4.93
	33	7.33	11.13	14.69	16.75	16.58	14.47	10.65	6.80
	38	9.63	14.63	19.30	22.00	21.78	19.01	13.99	8.93
	43	12.21	18.54	24.46	27.88	27.60	24.10	17.73	11.32
$R_β$	48	15.04	22.83	30.12	34.34	33.99	29.68	21.84	13.95
	53	18.10	27.47	36.25	41.33	40.91	35.72	26.28	16.78
	58	21.36	32.43	42.80	48.79	48.30	42.16	31.02	19.81
	63	24.81	37.67	49.71	56.67	56.10	48.97	36.03	23.01
	68	28.42	43.15	56.94	64.91	64.26	56.09	41.27	26.36

Global irradiation on a tilted panel $G_β$ is a sum of all three components:

Tab. 45. Values of global solar irradiation on a tilted plane [MJ/m^2]

Month		III	IV	V	VI	VII	VIII	IX	X
	β								
	28	362.44	493.63	603.92	666.98	671.92	628.67	526.15	390.63
	33	367.20	493.57	595.20	653.19	662.14	623.63	532.63	402.87
	38	369.07	488.79	586.13	639.09	648.18	618.36	536.38	413.48
	43	370.71	483.70	573.56	620.80	630.05	609.40	534.88	420.98
$G_β$	48	370.80	471.73	535.26	563.16	576.67	582.84	533.23	428.34
	53	368.07	466.09	538.02	579.57	589.18	580.46	521.25	431.14
	58	363.85	453.63	518.28	552.75	566.48	567.49	521.89	432.35
	63	358.15	438.75	498.32	525.74	539.70	543.93	512.23	430.51
	68	349.69	423.71	474.99	498.58	512.77	520.24	497.38	418.21
	0	303	460	607	692	685	598	440	281

For the convenience of modelling results perception, data reflecting the dependence of global solar radiation on a tilted plane $G_β$ on month and angle of inclination ***β*** is presented in figure (Fig. 41).

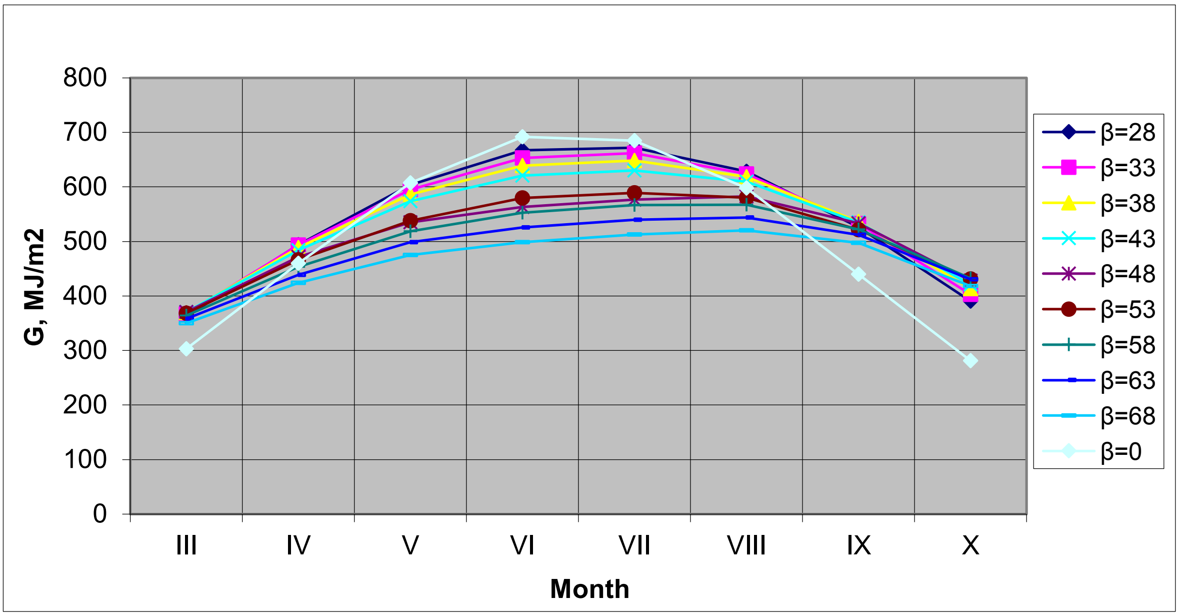


Fig. 41. Diagram of global solar radiation on a tilted plane on month and angle of inclination

It is observable on diagram that the peak of collected solar energy is obtained in June, specifically at $\beta=0^0$. In March and October gained energy is increasingly dropping down, falling lower than 300 MJ/m^2. Comparative energy loss and gain of inclined surface relative to horizontal surface is given in table (Tab. 46).

Tab. 46. Energy gain/loss in March, June and October relatively to horizontal surface [%]

	III	VI	X
β	%		
28	16.4	-3.8	28.1
33	17.5	-5.9	30.3
38	17.9	-8.3	32.0
43	18.3	-11.5	33.3
48	18.3	-22.9	34.4
53	17.7	-19.4	34.8
58	16.7	-25.2	35.0
63	15.4	-31.6	34.7
68	13.4	-38.8	32.8

Basing on the obtained data, it is obvious that optimal inclination angles of solar collector panels are:

- For March - $\beta=48^0$. Energy gain towards horizontal surface of 18.3 %;
- For June, $\beta=0^0$. Otherwise energy loss increases proportionally with inclination angle;

- For October, $\boldsymbol{\beta}$=59^0. Energy gain towards horizontal surface of 35%.

In case of installing solar collector without automated angle correction system, which is often justified considering high cost of automation devices, optimal constant angle of mounting is $\boldsymbol{\beta}$=48^0, being most equilibrated from the perspective of energy capturing.

10.6.2.3 Calculation of accumulation tank parameters

To correctly dimension the accumulation tank, it is necessary to know the consumption graph of hot water. Data regarding hot water consumption regime (Tab. 47) is provided by building administrator. Major part of hot water is consumed by shower unit in the production hall at the end of the working day, between 17:00 and 19:00 – 45%. In the lunch 2 hours, between 11:00 and 13:00 20% of total hot water consumption takes place.

Tab. 47. Hot water consumption distribution

Time interval	**HW consumption**	**Consumed water**	**Consumed energy**
[h]	[%]	[l]	[kWh]
0	0	0	0
7	0	0	0
11	10	115	2,8
13	35	402,5	9,8
17	40	460	11,2
19	100	1150	28
24	100	1150	28

Basing on available consumption distribution data, we can plot energy consumption graph, representing time distribution of produced, consumed and lost energy (Fig. 42).

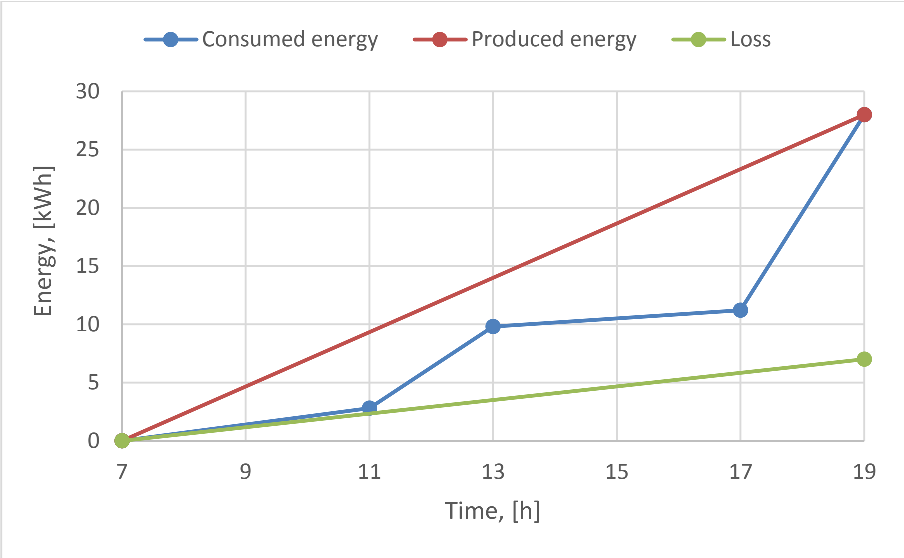


Fig. 42. Energy consumption distribution graph

Biggest difference between supplied and consumed energy $\Delta \boldsymbol{Q}_{max}$=16.8 kWh takes place at 17:00.

From the available data we can calculate required volume of accumulation tank $\boldsymbol{V}_{HWT}$ [l]:

$$V_{HWT} = \frac{\Delta Q_{\max}}{c(\theta_2 - \theta_1)} \text{ [l]} \tag{50}$$

where: $\Delta \boldsymbol{Q}_{max}$ – maximal difference between supplied and consumed energy [Wh];

$\boldsymbol{c}$ – specific heat capacity [kWh/(kg·K)], c = 1.161 kWh/(kg·K);

$\boldsymbol{\theta_2}$ – temperature of outlet water [°C], θ_2 = 55 °C;

$\boldsymbol{\theta_1}$ – temperature of inlet water [°C], θ_1 = 12 °C;

$$V_{HWT} = \frac{16800}{1.161(55-12)} = 336.5 \text{ l}$$

When selecting a hot water storage tank, a reserve coefficient of 1.4 is taken due to the requirement of hot water availability for more than a day. Therefore:

$$V_{HWT} = 336{,}5 \cdot 1.4 = 471 \text{ l}$$

OKC 500 NTRR/SOL hot water indirect heater was selected, with effective volume of 470 l (Fig. 43). It is designed specifically for preparation of hot service water by means of a solar system and is equipped with two heat exchangers for an optional combination of a solar system and an additional indirect circuit (gas boiler in our case). An electric heating element can be mounted as well.

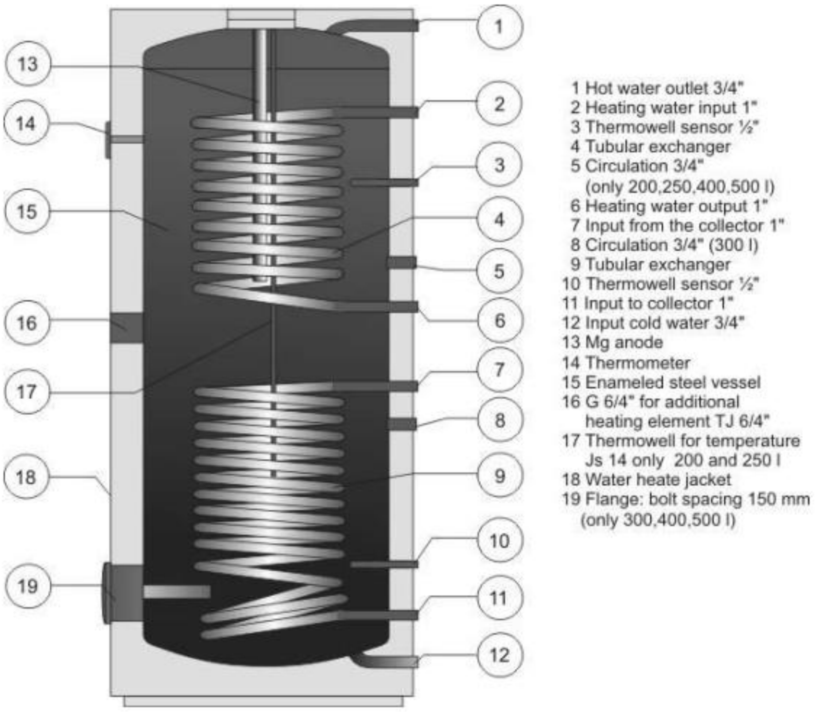


Fig. 43. OKC 500 NTRR/SOL water heater structure

10.6.2.4 Calculation of solar collector parameters

According to previous calculations, optimal constant angle **β**=28°. Daily global radiation available on the panel at this angle in different months is shown in table (Tab. 48).

Tab. 48. Daily globar radiation Gβ [MJ/m²] at β=28 ⁰

	III	IV	V	VI	VII	VIII	IX	X	Average
G_β	11.70	16.44	19.48	22.25	21.68	20.29	17.53	12.62	17.75

Necessary solar collector area $\boldsymbol{S_{col\_tot}}$ is determined by relation:

$$S_{col\_tot} = \frac{E_{req}}{\eta_{col} \cdot G_{\beta av}} \ [\text{m}^2] \qquad (51)$$

where: $\boldsymbol{\eta_{col}}$ – solar collector efficiency (for a closed active solar systém $\boldsymbol{\eta_{col}}$ ~ 0.55);

$\boldsymbol{E_{req}}$ – required energy [MJ/day], $\boldsymbol{E_{req}}$ = 28 kWh · 3.6 = 100.8 MJ/day;

$\boldsymbol{G_{\beta av}}$ – average daily global radiation [MJ/m²].

$$S_{col\_tot} = \frac{100.8}{0.55 \cdot 17.75} = 10.32 \text{ m}^2$$

Reflex RSK II 25 highly selective solar collector was selected as the heating installation. According to manufacturer's technical specifications, one panel has a total area of 2.51 m^2, effective area S_{col} of 2.19 m^2, volume of 1.7 l, optical efficiency – 78%, nominal flow – 25 l/(m^2h). Maximally allowed is a number of 6 collectors, serially connected.

Total required number of collectors $\boldsymbol{Nr_{col}}$:

$$Nr_{col} = S_{col\_tot} / S_{col} = 10.32 / 2.19 = 4.71 \approx 5 \text{ pcs} \quad (52)$$

Minimal output temperature of the solar collector in the coldest month of effective operation:

$$t_{HW} = t_{CW} + \frac{G_{\beta}^{III} \cdot S_{col\_tot} \cdot \eta_{col}}{c \cdot C_w} \; [^{\circ}C] \quad (53)$$

where: $\boldsymbol{t_{CW}}$ – temperature of cold water [°C], $\boldsymbol{t_{CW}}$ = 15 °C for warm period;

$\boldsymbol{G_{\beta}^{III}}$ – daily global radiation in March at certain angle (β=28°) [J/m^2],

$\boldsymbol{G_{\beta}^{III}}$ = 11.7 · 10^6 J/m^2;

c – specific heat capacity of water [J/(kg·°C)], c_w = 4.2 J/(kg·°C).

$\boldsymbol{C_w}$ – hot water daily consumption [l/day], C_w = 1150 l/day.

$$t_{HW} = 15 + \frac{11.7 \cdot 10^6 \cdot 10.95 \cdot 0.55}{4.173 \cdot 1150} = 29.7 \; ^{\circ}C$$

As we can see, minimal otput temperature in operated period is 29.7 °C. Gas boiler heating system has just to compensate the difference between solar collector output temperature and required temperature. Heating load of the gas boiler is reduced minimally by 48%.

Total heat energy $\boldsymbol{E_{tot}}$ [MJ] produced in operating period (March – October):

$$\boldsymbol{E_{tot}} = N_d \cdot G_{\beta av} \cdot S_{col\_tot} \cdot \eta_{col} \quad [MJ] \quad (54)$$

where: $\boldsymbol{N_d}$ – number of days in the operating period [days], N_d = 245 days.

$$E_{tot} = 245 \cdot 17.75 \cdot 10.95 \cdot 0.55 = 26190.34 \; MJ$$

10.6.2.5 Calculation of equalization tank parameters

Equalization tank volume depends on the total volume of liquid, circulating in the solar collector circuit and which needs to be stored when system is deactivated.

Calculation of total liquid volume in the system, as a sum of all hydraulic elements which are above the level of equalization tank, is given in table (Tab. 49).

Tab. 49. Volume of the hydraulic system above equalization type

Equipment type	Volume [l]	Quantity [pcs]	Total volume [l]
Solar collector - Reflex RSK II 25	1.7	5	8.5
Copper pipe – 18 x 1 mm	0.2	10	2
Total			**10.5**

Equalization tank should maintain a certain level of liquid even when the system is running. Therefore, a reserve coefficient of 20% is given for the liquid volume:

$$\boldsymbol{V_t} = 10.5 \cdot 1.2 = 12.6\ l$$

Expansion coefficient $\boldsymbol{c_{exp}}$ = 0.0849 in the limits of temperature variation has to be considered as well:

$$V_t = 12.6 + (12.6 \cdot 0.0849) = 13.67\ l$$

Reflex F 15 water tank, with volume of 15 l, designed specifically for solar panel applications fits all the requirements.

10.6.2.6 Other components of solar heating system

Besides the main components of the solar heating system, various supplementary elements are needed, which provide stable and reliable operation of the system.

Controller provides algorithm for system regulation and manages its optimal operation. For example, in case when temperature in solar collector is lower than in accumulation tank, water flow is redirected to prevent cooling of stored water.

Designed water heating system is an open one, what means that there is no need of safety equipment like expansion tank or safety pressure valve. Pressure is regulated by the system itself. One of the main conditions needed for installing an open system is that equalization tank should be installed on the highest point in the system, above all the other components.

This is easy realized in our case, because the boiler room is a roof type one, and installing equalization tank on a raised level in the boiler room is just enough.

Accumulation tank is placed in the boiler room, so the hydraulic head ***H*** is 5 m. Flow velocity **v** is selected to be 0.5 m/s or 1800 m/h. Thermal agent is a 70%-mixture of water with propylene glycol, which prevents it from freezing at low temperatures, with a density of 1028 kg/m^3.

Solar collector manufacturer provides diagram of pressure loss on the collector, depending on volume flow. Volume flow is calculated as follows:

$$V = m \cdot \rho = v \cdot S \cdot \rho = v \frac{\pi \cdot d^2}{4} = 1800 \cdot \frac{\pi \cdot 0.02^2}{4} \cdot 1028 = 113.7 \text{ l/h} \quad (55)$$

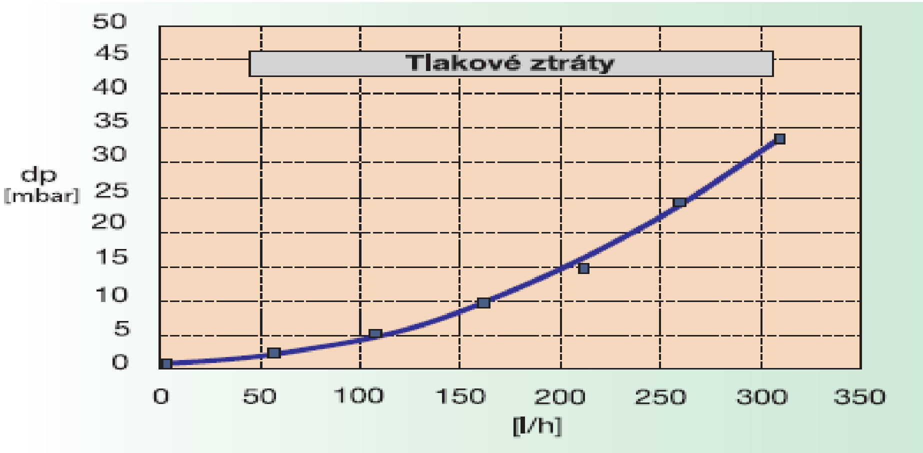


Fig. 44. Pressure loss graph for solar collector Reflex RSK II 25

According to the diagram of pressure loss on solar collector (Fig. 44), at volume flow of 114 l/h, pressure loss Δp_{col} = 5 mbar. Total pressure loss for 5 collectors will be Δp_{col} = 25 mbar. Pressure loss on the hydraulic circuit is 0.5 kPa. Total pressure loss will be Δp = 3 kPa.

For calculated value of pressure loss Δp = 3 kPa and ***v*** = 0.5 m/s, Grundfos Alpha2 25-40 circulating pump was selected.

10.6.3 Electrical hot water preparation system

Theoretical calculations assessing required hot water consumption were performed according to standards, and are very general. When designing an efficient system though, practical considerations should be an important point to consider. Real operational circumstances are the factors which define actual energy efficiency of the building.

In the case of analyzed building, theoretical design was done for the maximal load. Oversizing the equipment together with its high costs and long payback period might not be the best practical solution. This is conditioned by next factors:

- real hot water consumption per person is much lower than 5 l/day;
- production process mostly consists of light manual work of assembling electric cabinets, therefore the norm of 500 l per shower unit is excesive for every-day usage;
- declared number of people (30 per floor) is supposed for the future growth. Currently, many spaces of the building are empty, and number of employees in the whole building is 30 to 40 people.

With exposed considerations, an advantageous and efficient solution is hot water preparation using electric boilers. Electric boiler water preparation has a series of benefits:

- Lower heat loss. It does not require gas evacuation (flue), which is a source of heat loss in gas boilers;
- Due to compactness of water heating system, they can be fit anywhere according to the required power in the location. Transportation heat loss is diminished;
- Heat can be managed more efficiently, avoiding excesive heat generation. Water is being heated just in the location where it is needed and at required temperature;
- They are safer than combustion boilers. Expenses linked with safety requirements are avoided;
- Lower environmental impact due to absence of environment pollution at the place of heat generation. Environmental qualities can be raised by implementing environmental-friendly power generation sources.

According to these considerations, an alternative to the designed system would be installing Gorenje TGR 30 – 200 N electric boilers at each floor:

- 1st floor - Gorenje TGR 200 N to cover the high possible hot water consumption in the production space. Designed for 7 to 10 people consumption, heating time of 7 h;
- 4th floor - Gorenje TGR 100 N, to provide shower unit with water for 4 to 6 people, heating time of 4 h;
- 2nd, 3rd and 5th floors - Gorenje TGR 30 N, volume of 30 l of hot water being enough for office usage of hot water, heating time 1 h.

Selected boilers have a power of 2 kW each, heating time depending on the volume.

Electrical boiler can be connected to the water supply in two ways. The closed-circuit pressure system enables several points of use, while the open-circuit gravity system enables a single point of use only. In our case, every boiler prepares hot water for multiple points of use, and a closed system is needed (Fig. 45).

The closed-circuit pressure system requires the use of pressure mixer taps. For safety reasons the supply pipe must be fitted with a return safety valve (Fig. 45, 1) or alternatively, a valve of the safety class that prevents the pressure in the tank from exceeding the nominal pressure by more than 0.1 MPa. The outlet opening on the relief valve must be equipped with an outlet for atmospheric pressure (Fig. 45, 7).

The heating of water in the heater causes the pressure in the tank to increase to the level set by the safety valve. As the water cannot return to the water supply system, this can result in the dripping from the outlet of the safety valve. The drip can be piped to the drain by installing a catching unit just below the safety valve. The drain installed below the safety valve outlet must be piped down vertically and located in the environment that is free from the onset of freezing conditions.

The water heater may be connected to the water network in the house without reduction valve if the pressure in the network is lower than 0.5 MPa (5 bar). If the pressure exceeds 0.5 MPa, a reduction valve (Fig. 45, 4) must be installed. Non-return valve (Fig. 45, 3) needs to be installed in order to prevent the water from draining out of the tank in the event of the water supply running dry or being shut down. Closing valve (Fig. 45, 5) permits disconnection of the boiler from water feeding system.

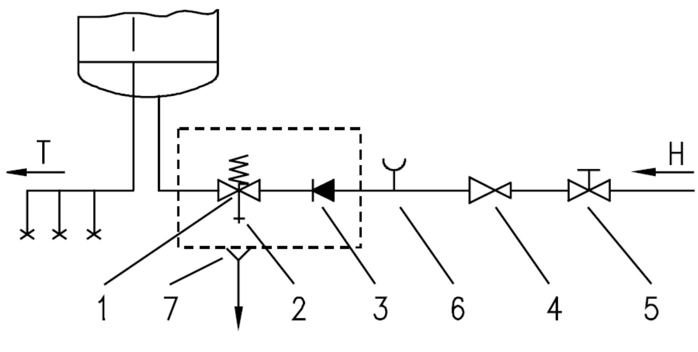


Fig. 45. Closed pressure electrical boiler system

A schematic layout of water distribution system is given in figure (Fig. 46).

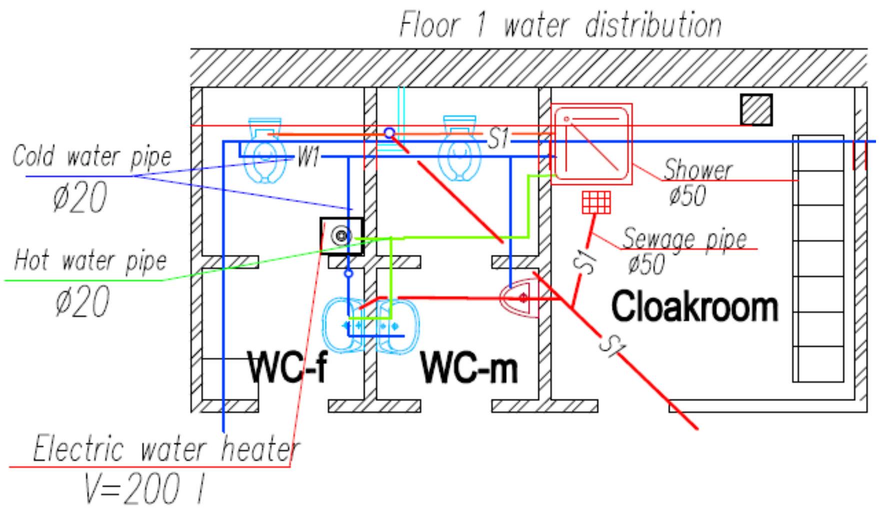


Fig. 46. Layout of water distribution system of first floor

10.7 Design of the boiler room

10.7.1 Design and selection of heat source

From the point of view of national legislation, aspects regulating the design of boiler equipment are described in the latest edition of *SNIP II-35-76 "Boiler installations".* It contains requirements and recommendations regarding: allowable types of used heat sources, fuel types and quality, gas circulation paths and chimneys, gas filtration, hydraulic equipment, water treatment, various aspects of operation, safety requirements, environmental impact, etc.

There is a variety of classification parameters, defined by the standards. Each of them has individual requirements:

- By location type - roof boiler room.
  It is erected on the roof level of the building, in a specially designed room. They can be stationary, as in analyzed case, (constructed together with the building construction) and modular (acquired in a pre-manufactured, ready-to-use state). This type was preferred because of ease of installation, low installation and operational costs, higher efficiency towards other options. Its disadvantages are linked with stricter regulations of installed equipment, allowable applications, higher safety standards, which do not affect the case of our building. Main requirements towards roof boiler rooms are:

1) For installation in roof boiler rooms, heat generators with water as heat agent are recommended, with temperature under 95 ^{0}C, pressure under 1 MPa and fully automated;
2) Boiler room has to have minimal dimensions: height – 2.65 m, width – 1 m, height of passage – 2.2 m;
3) Exit from the boiler room should lead directly to the roof level;
4) Roof boiler rooms are not allowed for heating of schools and kindergartens, medical institutions, production spaces with increased fire hazard;
5) Design of roof boiler rooms in the buildings, with height exceeding 26.5 m or 10 storeys needs to be coordinated with local Fire Department.

- By its intended purpose of heat load - heating boiler room, designed to provide heat for heating, ventilation, air conditioning and hot water.
- By reliability of heat supply to consumers – 1st category (Boilers, which are the only source of heat the heating system).
- By the type of exposure to fire and explosion hazard – category G.

By classification, given in Czech standard *ČSN 07 0703 “Gas boiler rooms”,* designed boiler room is of category III – “*Boiler-room with a rated output of one boiler from 50 kW to the nominal sum of heat output of boilers of 0.5 MW, including the case when the sum of the nominal heat output boilers is greater than 100 kW, although neither of them reaches heat output of 50 kW*”

Required heat output of the boiler $\boldsymbol{Q_{req}}$ [W] is equal to maximal heat load of the system determined in p. 10.2. summed with heat power for hot water preparation $\boldsymbol{Q_{hw}}$ [W] from p. 10.6.

Tab. 50. Selected boiler technical data

Parameter	Unit	Max value	Min value
Heating capacity (Net Heat Value)	kW	61.6	24.5
Available Heat Output 80°C - 60°C	kW	56	21.6
Max. working temperature	°C	95	
Working pressure in heating mode	bar	0.3	6
Boiler water content	litres	16.6	
Height	mm	850	
Width	mm	600	
Depth	mm	615	
Weight	kg	191	
Max. electrical absorption	W	15	
Electrical protection rating	IP	X0D	

Nominal heat power of the gas boiler $\boldsymbol{Q_{nom}}$ [W] is considered with a safety reserve of 20%.

$$Q_{nom} = (Q_{req} + Q_{hw}) \cdot 1.2 = (87997 + 3494) \cdot 1.2 = 109789.2\ W \tag{56}$$

According to considerations, expressed above and in p.5.1, two Ferolli Pegasus 56 gas boilers were selected. Boiler's technical parameters are given in TABLE (Tab. 50).

10.7.2 Selection of hydraulic separator

In a common circuit of boilers and heating circuits, interference between simultaneous circuits would occur, leading to problems in operation. This is prevented by installing a hydraulic separator (low-loss header), thus separating heating system in primary circuit of water heating and secondary circuit of heat distribution (Fig. 34, B8). By decoupling boiler and system circuits from each other, low-loss header increases operational efficiency and helps eliminate debris from the heating system.

Volume flow of primary circuit (boiler circuit) $\boldsymbol{V_b}$ [m^3/h] is considered from 1.2 to 1.5 times higher than the secondary circuit one $\boldsymbol{V_s}$ [m^3/h]. Total mass flow of the secondary circuit $\boldsymbol{M_s}$ is the sum of mass flow in all sections $\boldsymbol{M_i}$ of the system:

$$M_s = \sum M_i = 3987.3\ kg/h \Rightarrow V_s = 3.987\ m^3/h \tag{57}$$

$$V_b = (1.2\ to\ 1.5) \cdot V_s = (1.2\ to\ 1.5) \cdot 3.987 = 4.78\ to\ 5.98\ m^3/h \tag{58}$$

Basing on volume flow, cross-section of hydraulic separator can be determined. Cross-section ***D*** should be dimensioned in such a way, that flow velocity in the primary is kept in between 0.1 and 0.25 m/s. All other dimensions are linked to that parameter (Fig. 47).

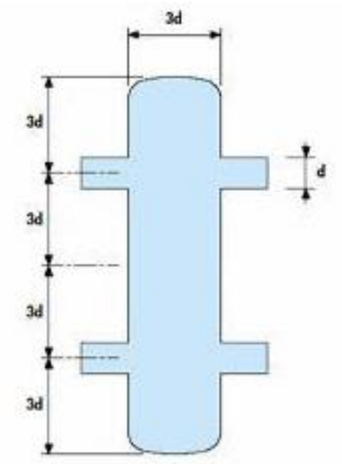


Fig. 47. General view of a hydraulic separator

Cross-section can be calculated by 2 methods:

1) Basing on maximal volume flow in the primary circuit $\boldsymbol{V_b}$:

$$D = 3 \cdot d = 1000 \cdot \sqrt{\frac{4 \cdot V_b}{\pi \cdot 3600 \cdot w}} = 18.8 \cdot \sqrt{\frac{V_b}{w}} \tag{59}$$

where: ***d*** – diameter of the connection [mm];

$\boldsymbol{V_b}$ **-** volume flow of primary circuit [m^3/h];

w – flow velocity [m/s].

$$D = 18.8 \cdot \sqrt{\frac{(4.78 \div 5.98}{0.2}} = 91.95 \div 102.81 \text{ mm}$$

2) Basing on temperature difference between heating and return branches $\Delta \boldsymbol{t}$:

$$D = 3 \cdot d = 1000 \cdot \sqrt{\frac{4 \cdot P}{\pi \cdot c \cdot w \cdot \Delta t}} = 17.4 \cdot \sqrt{\frac{P}{\Delta t}} \tag{60}$$

where: ***d*** – diameter of the connection [mm];

w – flow velocity [m/s];

P – boiler maximal power [kW];

Δ**t** – temperature difference between branches [^oC] **(**$\Delta \boldsymbol{t}$ = 20 ^oC).

$$D = 17.4 \cdot \sqrt{\frac{112}{20}} = 92.07 \text{ mm}$$

According to determined limits, Viessman 160/80 hydraulic separator was chosen. It is pre-equipped with necessary plumbing, air-vent and temperature sensor (Fig. 48).

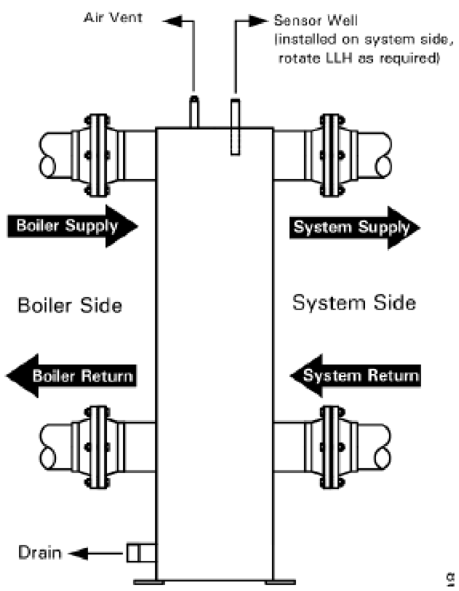


Fig. 48. Selected hydraulic separator Viessman 160/80

10.7.3 Design of safety equipment

10.7.3.1 Design of safety valves

Each heat source has to be equipped with a safety device, protecting it from exceeding maximal working overpressure, exceeding maximal temperature and lack of water in the system.

Minimal cross-section of the safety valve for water heating systems $\boldsymbol{S_o}$ is:

$$S_o \geq \frac{2 \cdot Q_p}{a_w \cdot \sqrt{p_{po}}}, \ [\text{mm}^2] \tag{61}$$

where: $\boldsymbol{Q_p}$ – locking power, according to *ČSN 06 0830* $\boldsymbol{Q_p} = 2\ \boldsymbol{Q_n}$ [kW];

$\boldsymbol{a_w}$ - guaranteed safety valve discharge coefficient;

$\boldsymbol{p_{po}}$ - opening overpressure of valve [kPa].

Discharge coefficient reflects pressure loss on the safety valve, which lower outflow velocity after safety valve. Depends on the design of valve and varies between 0.04 to 0.8.

For calculation of suitable safety valve online application was used, available on the webpage http://vytapeni.tzb-info.cz/tabulky-a-vypocty/43-vypocet-pojistneho-ventilu-pro-kotle-a-vymeniky-tepla. Calculation results are presented in table (Tab. 51).

Tab. 51. Calculation of safety valve characteristics

Parameter	**Unit**	**Value**
Opening pressure of safety valve, p_{ot}	kPa	250
Nominal power of heat source, Q_n	kW	56
Calculated minimal cross-section of valve	mm^2	22
Minimal inlet pipe cross-section	mm	15
Minimal outlet pipe cross-section	mm	15
Selected valve model	**Honeywell SM 120-1/2“**	

Honeywell SM 120-1/2 diaphragm safety valve was selected according with the requirements.

Dimensions of the valve (Fig. 49) are: $\boldsymbol{H}$=93 mm, $\boldsymbol{h}$=28 mm, $\boldsymbol{I}$=36 mm, $\boldsymbol{D_o}$=15 mm.

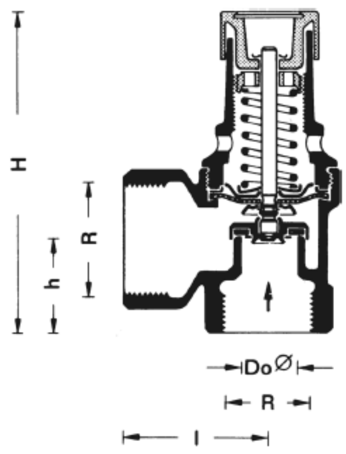


Fig. 49. Honeywell SM 120-1/2

10.7.3.2 Design of expansion tank

Expansion tank is a small tank used to protect closed water heating systems and domestic hot water systems from excessive pressure. The tank is partially filled with air, whose compressibility cushions shock caused by water hammer and absorbs excess water pressure caused by thermal expansion.

Expansion tank was selected with assistance of web application as well, located on the http://vytapeni.tzb-info.cz/tabulky-a-vypocty/60-tlakova-expanzni-nadoba web page.

Application screen with the input data, general scheme of the system for calculation and output results are presented in figure (Fig. 50).

Input data for calculation is:

- Power of heating source $\boldsymbol{Q_p}$ = 120 kW;
- Maximal temperature of heating water $\boldsymbol{t_{max}}$ = **75** ^{o}C;
- Highest point of heating system $\boldsymbol{h}$ = 6.9 m (water column between the neutral point NB and the highest point of the system B);
- Lowest operating overpressure of the system $\boldsymbol{p_d}$ = 80 kPa (in the case of rofftop boiler room, where overpressure of water column is not ensured, value of $\boldsymbol{p_d}$ is taken between 30 and 80 kPa);
- Maximal operating overpressure of the system $\boldsymbol{p_{h,dov}}$ = 250 kPa (opening pressure of the safety valve);
- Water volume of heating system $\boldsymbol{V}$ [l]:

$$V = V_k + V_p + V_{OT} + V_{ost} = 44 + 1171.7 + 818.4 + 4.5 = 2039\ l \qquad (61)$$

where: V_k – boiler volume [l];

V_p – pipeline volume [l];

V_{OT} – radiators volume [l];

V_{ost} – other equipment [l].

- volume increase factor n = 0.0253 (proportional increase in water volume when it is heated from a cold water temperature (10 °C) to the maximum temperature of heating water t_{max}).
- lowest system pressure $p_{d,dov}$, is the lowest system pressure at which system is filled completely with water and evaporation of water is prevented on the entire length of the system and at all operation conditions:

$$p_{d,dov} = \frac{1.1 \cdot h \cdot \rho \cdot g}{1000} = \frac{1.1 \cdot 6.9 \cdot 980 \cdot 9.81}{1000} = 73 \text{ kPa} \tag{62}$$

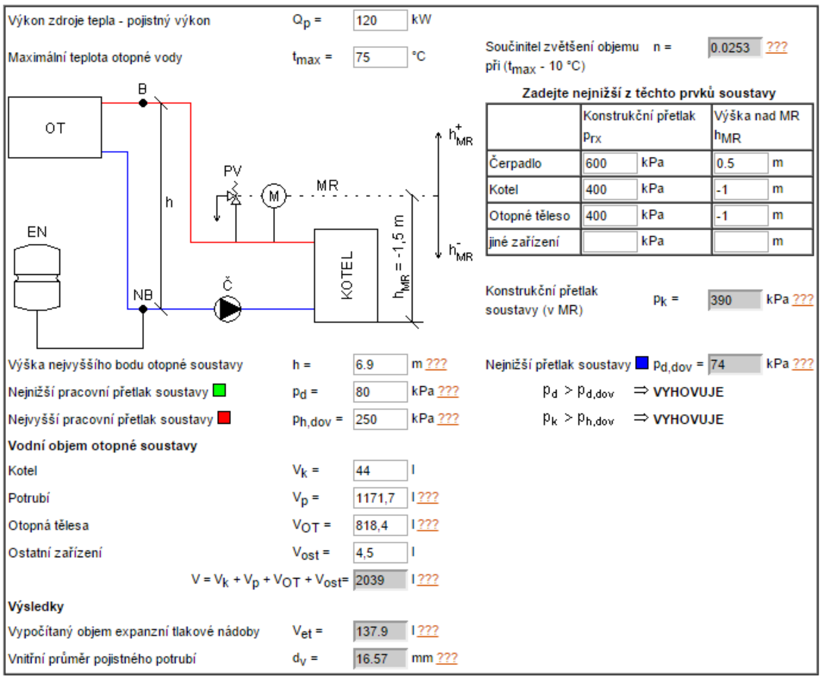


Fig. 50. Calculation of expansion tank parameters [44]

Required expansion tank should have a volume of 137.9 l and internal diameter of safety pipe of 16.6 mm. REFLEX NG 140 expansion tank was chosen (Fig. 51). Characteristics are given in table (Tab. 52).

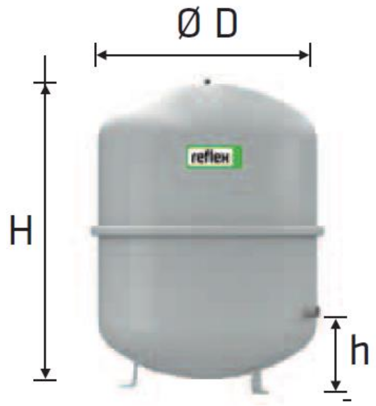


Fig. 51. Selected expansion
tank REFLEX NG 140

Tab. 52. REFLEX NG 140 expansion tank technical data

Type	Weight, kg	D, mm	H, mm	h, mm	Dim	Pre-set pressure, bar
140/6	14.5	480	912	175	R1	1.5

10.7.4 Design of piping system and pump selection for primary circuit

For design of primary circuit hydraulic system, same procedure as in p. 10.3 was used. Type of the pipes is similar, copper tubes with PVC insulation. Table (Tab. 53) shows the composition of total equivalent resistance of primary circuit.

Tab. 53. Equivalent resistance of primary circuit

Element name	**Quantity**	**Total equivalent resistance ξ**
Hydraulic separator inlet	1	0.5
Hydraulic separator outlet	1	1
Flow merging	1	0.4
Flow separation	1	1.3
90 degree elbow	2	2.6
Boiler inlet	2	2
Boiler outlet	2	1
Safety valves	2	2
Total		**28.8**

Additionally, to resistance loss it is necessary to add pressure loss in the boilers – 2060 Pa and hydraulic separator – 1176 Pa, both values taken from manufacturer’s documentation.

Mass flow in the primary circuit $\boldsymbol{M_{pc}}$ is 5220 kg/h, resulting in a volume flow $\boldsymbol{V_{pc}}$ of 5.22 m^3/h.

Tab. 54. Hydraulic parameters of primary circuit parameters

Section	Q [W]	M [kg/h]	l [m]	DN [mm]	v [m/s]	R [Pa/m]	$\sum \xi$	R*l	Z [Pa]	Δp_s [Pa]
Prim. c.	121400	5220	3,4	60	0,52	43,2	28,8	146.8	3845	7228

Calculated hydraulic head ***h***, with a reserve for pressure drop of 1.4, is:

$$h = \frac{(\Delta p \cdot 1.4)}{\rho \cdot g} = \frac{7228 \cdot 1.4}{980 \cdot 9.81} = 1.053 \text{ m}$$

Using the values of volume flow and hydraulic head, Grundfoss MAGNA1 25-40 pump was selected. Pump characteristic is shown in figure (Fig. 52).

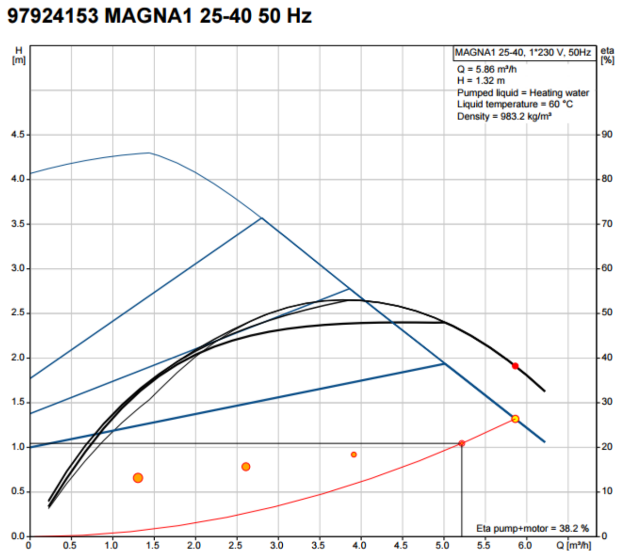


Fig. 52. Characteristics of primary circuit pump.

10.7.5 Ventilation of boiler room

Due to high safety requirements towards boiler rooms with gas boilers, being considered as space with high fire and explosion hazard, special attention has to be given to proper ventilation and fresh air supply of boilers. Specific requirements towards air flow are given in both *SNIP II-35-76 "Boiler installations*" and *ČSN 07 0703 "Gas boiler rooms".*

10.7.5.1 Air flow

Theoretical volume of combustion air, $\boldsymbol{V_{min}}$ [m^3/m^3] for combustion of 1 m^3 of fuel (at temperature of 20 °C and atmospheric pressure of 101.3 kPa):

$$V_{min} = 0.864 \cdot H - 0.25 = 0.864 \cdot 10.5 - 0.25 = 8.82\ m^3/m^3 \tag{63}$$

where: $\boldsymbol{H}$ – calorific value of fuel (natural gas – 10.5 kWh/m^3).

Actual volume of the combustion air $\boldsymbol{V_{act}}$ [m^3/m^3] is determined by formula:

$$V_{act} = V_{min} \cdot \lambda = 8.82 \cdot 1.3 = 11.46\ m^3/m^3 \tag{64}$$

where: $\boldsymbol{\lambda}$ – air excess coefficient for specific combustion type ($\boldsymbol{\lambda}$ = 1.1 to 1.3 at normal conditions).

Fuel need $\boldsymbol{F}$ [m^3/s]:

$$F = \frac{\Sigma Q}{3.6 \cdot \eta \cdot H} \cdot 10^3 = \frac{121.4}{3.6 \cdot 0.91 \cdot 10.5} \cdot 10^{-3} = 3.53 \cdot 10^{-3}\ \ \mathrm{m}^3/\mathrm{s} \tag{65}$$

where: $\boldsymbol{Q}$ – sum of boiler room equipment heat power [kW];

$\boldsymbol{\eta}$ – boiler efficiency ($\boldsymbol{\eta}$ = 0.91 according to specifications).

Combustion air flow $\boldsymbol{V_{ca}}$ [m^3/h]:

$$V_{ca} = V_{act} \cdot F = 11.46 \cdot 3.53 \cdot 10^{-3} = 0.0405\ m^3/s = 145.7\ m^3/h \tag{66}$$

10.7.5.2 Prescribed intensity of ventilation

Standards require all boiler rooms of actual category to have a minimal hourly air change intensity $\boldsymbol{n}$ of 0.5 l/h ensured, for all operating conditions.

Airflow for securing ventilation $\boldsymbol{V_i}$ [m^3/h]:

$$V_i = n \cdot V_{br} = 0.5 \cdot 45.717 = 22.85\ m^3/h \tag{67}$$

where: $\boldsymbol{V_{br}}$ – air volume of the boiler room [m^3].

Actual combustion air flow in the heating period exceeds the air flow for ventilation. The flow of combustion air is also involved in boiler room ventilation.

Ventilation intensity in the winter period $\boldsymbol{n_w}$ [l/h]:

$$n_w = \frac{V_{ca}}{V_{br}} = \frac{145.713}{45.17} = 3.19\ \mathrm{l/s} \tag{68}$$

10.7.5.3 Design of ventilation openings

Boiler room ventilation, as well as combustion air supply, is performed through special ventilation duct, covered with a rain louver from the outside. Air evacuation is don through a separate ventilation duct. Gas evacuation is done through exhaust chimney above the roof.

Cross-section of the rain louver $\boldsymbol{S_p}$ [m^2] for air supply duct is:

$$S_p = \frac{V_{ca}}{w_p} = \frac{0.0405}{1.5} = 2.69 \cdot 10^{-2} \text{ m}^2 \tag{69}$$

Wide variety of rain louvers is largely available in the market and can be acquired on demand.

Cross-section of the ventilation duct, $\boldsymbol{S_o}$ [m^2]:

$$S_o = \frac{V_i}{w_p} = \frac{22.85}{1.5 \cdot 3600} = 4.23 \cdot 10^{-3} \text{ m}^2 \tag{70}$$

Ducts are selected by their diameter $\boldsymbol{D_o}$ [mm]:

$$D_o = 10^3 \cdot 2 \cdot \sqrt{\frac{S_o}{\pi}} = 10^3 \cdot 2 \cdot \sqrt{\frac{4.23 \cdot 10^{-3}}{3.14}} = 73.4 \text{ mm} \tag{71}$$

Closest nominal diameter in the standard range of duct diameters is $\boldsymbol{D_0}$ = 80 mm.

10.7.5.4 Design of gas exhaust

Cross-section area of the chimney duct $\boldsymbol{S_c}$ [m^2] for two gas boilers with total power $\boldsymbol{Q_b}$ = 112 kW:

$$S_c = \frac{2.6 \cdot Q_b}{1800 \cdot \sqrt{h}} = \frac{2.6 \cdot 112}{1800 \cdot \sqrt{18}} = 0.0413 \text{ m}^2 \tag{72}$$

Calculated diameter of the chimney duct $\boldsymbol{D_c}$ [mm]:

$$D_c = 10^3 \cdot 2 \cdot \sqrt{\frac{0.0413}{3.14}} = 229 \text{ mm}$$

Corresponding nominal diameter of the cimney duct is $\boldsymbol{D_c}$ = 250 mm.

11 ELECTRICAL DESIGN

Electrical distribution system in the analyzed building has to be completely redesigned according to the current needs of the owner and valid technical standards.

Requirements to electrical installations for Moldova are given by code of practice in constructions *CP G.01.02:2014 "Design and installation of electrical installations in residential and public buildings. The design standards"*. It defines basic requirements for designing power distribution systems in the buildings, design guidelines for artificial lighting and power equipment.

Electrical design goes through several important stages of development. First, the designer must understand the scope of the project. Then, the designer defines and designs each component (such as general office areas, specialized machinery, and power distribution equipment) to recognized industry standards. Finally, these individual components are compiled to form the final presentation for the design.

Every electrical design has unique requirements, depending on the scope of the project. The project scope is determined by the customer's requirements and the type of structure that the customer will occupy. For example, if the project requires new electrical systems for an existing building, designer must evaluate the existing electrical system to ensure that existing electrical systems can accommodate new additional electrical loads that will be imposed on them. When the design is for a new proposed facility, then the scope of the project is much greater. Electrical designs for these types of projects require an entirely new electrical system design.

Generally accepted sequence of stages, related to design of electrical equipment in buildings, is as follows [45]:

1. Preparing the building and formulating the technical specifications. Is prepared together with the customer together with the analysis of conditions, necessary for creation of a new power distribution system. Necessary data for that include not only internal characteristics of the building, but its position towards the source of electric energy.
2. Project development:
    - preliminary calculations;
    - design of a one-line diagram of power distribution system;

- obtaining the power connection permission;
- selection of equipment;
- functionality test in nominal mode and in short-circuit mode;
- preparing the specifications of equipment;
- design of electrical lighting and socket schemes;
- preparing installation schemes.

3. Coordination of the project in local supervisory institutes.
4. Execution of electrical installation works.
5. Testing and commissioning.

Detailed rules and requirements of electrical installations are defined by *Regulations for Electrical Installation* (PUE).

11.1 Power distribution system

With regard to ensuring reliability of power supply, the electrical receivers of designed object belong to Category III (PUE). Devices and fire alarm system, emergency lighting – to first category.

Voltage in the power distribution network is 380/220V.

Municipal power distribution network offers a connection to its 10 kV line, therefore power supply of the building is realized through a cable line from a designed lowering transformer station, from 10 kV to 400 V.

Evidence of consumed electrical energy is done through an active and reactive energy electric meter, installed in a pre-assembled evidence distribution board of BZUM-TF type.

Main distribution board (MDB) of PR11 type is situated on the ground floor. Electrical circuits of each floor are connected to distribution boards which are installed on every floor (DB1, DB2, DB3, DB4, DB5 and DBboil), which are equipped with modular circuit breakers designed for the load current. Distribution boards should have separate neutral and protective ground bus.

Distribution networks are realized with PV1-450 cable (operating voltage – 450 V), hidden in unplasticized polyvinyl chloride pipes in the indent and the layer of plaster; VVG-660 cable in metal duct and plastic cable channel, laid on the walls. The height of the installation of metal ducts and plastic cable channel should be no less than 2.5 m from the finished floor level (ground level).

Connection plug sockets for cleaning mechanisms, hand dryers, portable electrical equipment, electrical equipment associated with wet process is provided through the RCD (residual current device) with a maximum trip current of 30 mA. In the zone of RCD operation, working neutral wire (N) shouldn’t have any connection to grounded elements and ground protection wire (PE).

Connecting sockets to the zero protective conductor should be performed by branches without crosscuts with subsequent isolation of the place of branching. It is very important to respect the color marking of the electrical wiring all over the system.

Regulations forbid installing any disconnecting devices in the circuits of protective wires, which simultaneously serve as neutral circuits. Connection of working and protective zero conductors should be done by pressing or soldering. All the metal objects of electrical equipment should be grounded by connecting them to zero (ground) protective wire of the network.

Grounding system is accepted according to TN-C-S [45] system (Fig. 53). It supposes combined PEN conductor from transformer to building distribution point, but separate PE and N conductors in fixed indoor wiring and flexible power cords.

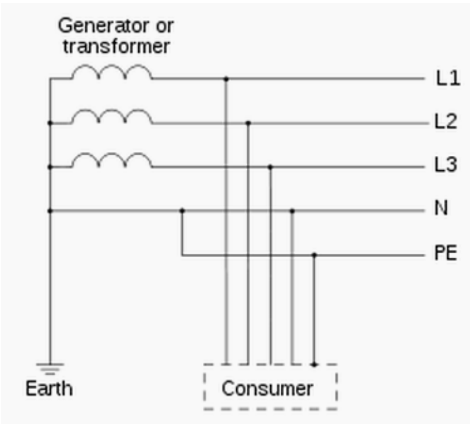


Fig. 53. TN-C-S grounding system

In the scope of equalizing potentials, metal parts of all structures and pipelines should be connected to the potential equalization system. Potential equalization system should be done by connecting next conductive parts:

a) main protective conductor;

b) main grounding conductor;
c) steel pipes of building communication systems;
d) metal parts of structures.

Mentioned conductive elements should be interconnected when entering the building and connected to the main grounding bus.

According to *RD 34.21.122-87 "Instructions for lightning protection of buildings and structures"*, building should be equipped with lighting protection of category III.

Primary data for designing a power distribution system of a building is the quantity and characteristics of potential electrical receivers, considering the possibility of growth.

Conditionally, all electrical consumers can be separated in 4 groups:

e) household electrical equipment of general purpose;
f) electrical equipment of special purpose;
g) informational equipment;
h) lighting equipment.

Another criteria is uniformity of electrical load distribution through feeding cables to the protective device.

Due to big scale of necessary work, in current thesis only the example of 4^{th} floor is analyzed. Fourth floor is the most complex and accounts for the biggest part of electrical power required.

Initial step is defining the load table (Tab. 55). Number of electrical appliances and their rated power $\boldsymbol{P_n}$ [kW] is determined for each circuit. Basing on this data and knowing the system voltage $\boldsymbol{U_n}$ = 220 V it is possible to determine the rated current of each circuit:

$$I_n = P_n / U_n \tag{72}$$

The entire load, provided by the disribution board, is not necessarily consumed at full rated power or simultaneously. It is a matter of common experience that the simultaneous operation of all installed loads of a given installation never occurs in practice, there is always some degree of diversity and this fact is taken into account for estimating purposes by the use of a simultaneity factor K_s. It is applied to each group of loads.

Tab. 55. Load table of the floor 4

Cir-cuit	**Room name**	**Electrical equipment**	**Qua ntity**	**Sock ets**	**P_n [kW]**	**$P_{n,tot}$ [kW]**
c.4.1	Hallway (4.9)	Cleaning devices (c/d)	3	3	2	6
c.4.2	Office (4.8)	Personal computer (p/c)	4	8	0.4	1.6
c.4.3	Office (4.8)	Mobile electric equipment	5	5	0.2	1
c.4.4	WC-f (4.11)	Hand dryer (h/d)	1	1	1	1
	WC-m (4.12)	Hand dryer (h/d)	1	1	1	1
c.4.5	Office (4.10)	Mobile electric equipment	8	8	0.2	1.6
c.4.6	Office (4.10)	Personal computer (p/c)	8	16	0.4	3.2
c.4.7	Office (4.6)	Personal computer (p/c)	6	12	0.4	2.4
	Office (4.5)	Personal computer (p/c)	3	6	0.4	1.2
c.4.8	Office (4.6)	Mobile electric equipment	6	6	0.2	1.2
	Office (4.5)	Mobile electric equipment	5	5	0.2	1
c.4.9	Reception (4.4)	Personal computer (p/c)	1	2	0.4	0.4
	Director office (4.3)	Personal computer (p/c)	1	2	0.4	0.4
c.4.10	Reception (4.4)	Mobile electric equipment	4	4	0.2	0.8
	Director office (4.3)	Mobile electric equipment	5	5	0.2	1
	Restroom (4.1)	Mobile electric equipment	3	3	0.2	0.6
c.4.11	WC (4.2)	Hand dryer (h/d)	1	1	2	2
c.4.12	WC (4.2)	Electric heater (e/h)	1	1	1	1
c.4.13	Office (4.7)	Mobile electric equipment	8	8	0.2	1.6
c.4.14	Office (4.7)	Personal computer (p/c)	8	10	0.4	3.2
c.4.15	Office (4.5) Office (4.6)	Lighting equipment				0.864
c.4.16	Restroom (4.1) WC (4.2) Director office (4.3) Reception (4.4)	Lighting equipment				1.184
c.4.17	Hallway (4.9) WC-f (4.11) WC-m (4.12) Stairs St-1 Stairs St-1	Lighting equipment				1.032
c.4.18	Office (4.8)	Lighting equipment				0.58
c.4.19	Office (4.10)	Lighting equipment				1.08
c.4.20	Office (4.7)	Lighting equipment				1.08
		TOTAL				**37.9**

Hypothetical values of K_s, generally accepted for a distribution board supplying a number of circuits for which there is no indication of the manner in which the total load divides between them, are given in table (Tab. 56). They are similar in both GOST R 51628-2000 and IEC 60439.

Tab. 56. Factor of simultaneity for distribution boards

Number of circuits	Factor of simultaneity (ks)
Assemblies entirely tested 2 and 3	0.9
4 and 5	0.8
6 to 9	0.7
10 and more	0.6
Assemblies partially tested in every case choose	1.0

Factor of simultaneity is considered when calculating the minimal cross-section of conductors ***S*** [m^2]. As an example, we can determine the cross section of the feeding conductor for distribution board of floor 4 (DB4), knowing total rated power of the circuits in the floor. Electrical distribution board is placed in the staircase St-2. Power is supplied from the distribution board of the third floor. Relation for calculating is:

$$S = \frac{P_n \cdot K_s \cdot \rho \cdot l}{U_n \cdot u \cdot \cos\varphi} \ [\mathrm{m}^2] \tag{73}$$

where: $\boldsymbol{P_n}$ – rated power of the circuit [W];

$\boldsymbol{\rho}$ – specific resistance of the conductive material of wire [Ωm] (for copper - $\boldsymbol{\rho}$ = 0.01748 · m^{-6} Ωm;

$\boldsymbol{l}$ – length of the wire from the supply [m] ($\boldsymbol{l}$ = 3 m);

$\boldsymbol{K_s}$ - factor of load simultaneity, according to table x ($\boldsymbol{K_s}$ = 0.7).

$\boldsymbol{U_n}$ – phase voltage of the system [V] ($\boldsymbol{U_n}$ = 230 V);

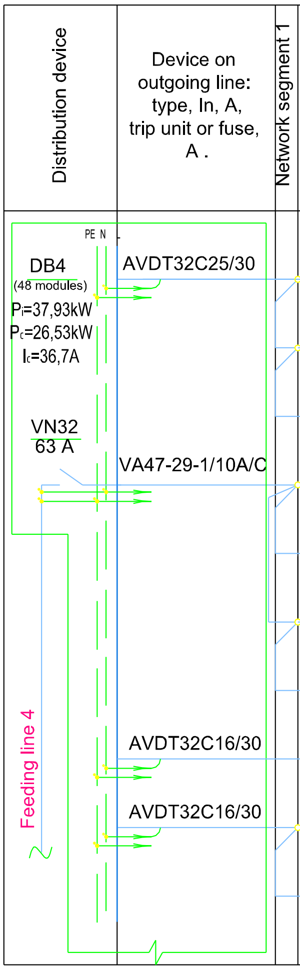
$\boldsymbol{u}$ – voltage loss in the connection point [V]. Usually accounts for 1% from the effective value of voltage ($\boldsymbol{u}$ = U_n · 0.01 = 2.3 V);

cosφ – network efficiency rate (***cosφ*** = 0.9).

$$S = \frac{37944 \cdot 0.7 \cdot 3 \cdot 10^{-6}}{230 \cdot 2.3 \cdot 0.9} = 3.97 \cdot 10^{-6}\mathrm{m}^2 = 2.97\ \mathrm{mm}^2$$

Although the minimal calculated cross-section is 3.97 mm^2. According to PUE, minimal required cross section of insulated wires for stationary electrical wiring, for wires connected to screw terminal is 1 mm^2, so the condition is met.

A portion of general diagram of group distribution board DB4, with the indicated rated power, current, selected cable and circuit breaker for each branch is presented in figure (Fig.54).



Starting unit: type, In, A, trip unit or fuse, A.	Network segment	Cables and wires: Notation	Type	Quantity, number of wires and cross-section	Length, m	Electric consumer: Notation	Pn, kW	In, A	Name, type
ES220V IP20	1	c.4.1	H07V-U	3(1x2,5)	8	c/d	2,0	9,1	Cleaning devices
	2								
ES220V IP20	1	c.4.1	H07V-U	3(1x2,5)	8	c/d	2,0	9,1	Cleaning devices
	2								
ES220V IP20	1	c.4.1	H07V-U	3(1x2,5)	8	c/d	2,0	9,1	Cleaning devices
	2								
Block of 2 ES220V IP20	1	c.4.2	H07V-U	3(1x1,5)	25	p/c	0,4	1,8	Personal computer (room 4.8)
	2								
Block of 2 ES220V IP20	1	c.4.2	H07V-U	3(1x1,5)	3	p/c	0,4	1,8	Personal computer (room 4.8)
	2								
Block of 2 ES220V IP20	1	c.4.2	H07V-U	3(1x1,5)	3	p/c	0,4	1,8	Personal computer (room 4.8)
	2								
Block of 2 ES220V IP20	1	c.4.2	H07V-U	3(1x1,5)	3	p/c	0,4	1,8	Personal computer (room 4.8)
	2								
ES220V IP20 5pcs.	1	c.4.3	H07V-U	3(1x2,5)	35		1,0	4,5	Mobile electric equipment (room 4.8)
	2								
ES220V IP20	1	c.4.4	H07V-U	3(1x1,5)	20	h/d	1,0	4,5	Hand dryer (WC-m)
	2								
ES220V IP20	1		H07V-U	3(1x1,5)	1		1,0	4,5	Hand dryer (WC-f)
	2								

Fig. 54. General diagram of outler circuits connection in DB4

11.2 Outlet circuit diagram

Conditionally it is accepted that all power supply circuits are divided in lighting circuits and outlet circuits. And within each circuit individual groups of energy consumers are defined, that require individual power supply circuit and protection.

Outlet circuit receive the main load. Part of outlet circuits feeds low power electrical receivers (television, personal computers, coffee machines, etc.) and can be connected to one socket circuit. Separate socket circuits are reserved for higher power consuming equipment:

a) equipment used in bathrooms (like water heaters). In our case, electric boiler in room 4.12 is separated in its own circuit;
b) electrical cookers;
c) air conditioning units;
d) stationary air heaters, etc.

Fire alarm and security system can be connected in a separate circuit as well, for providing necessary voltage and secure supply.

Separation of socket chains into individual groups, on the one hand, improves the reliability of power supply to consumers, on the other - allows to create back-up power supply circuit, what improves the quality of power supply of consumers.

Outlet scheme for the 4th floor is given in figure (Fig. 55). Consumers in the scheme are separated in 15 circuits in total, according to two criterion:

e) Type of electrical load. Mobile electrical devices suppose occasional electrical equipment which might be connected to these universal socket (phone chargers, table lamps, radio, etc.). Each outlet is designed for a rated power of 200 W. Circuits for connecting personal computers (PC) of employees are separated as well, each PC is rated at 400 W, according to IEC 60439. Heating equipment, like electrical boiler of 2 kW in room 4.2 (WC) and hand dryers in toilets (1 kW), are connected separately as well.
f) Location. Circuits are grouped by rooms in order to achieve logical and balanced architecture and optimal usage of wiring.

CEE 7/4 "Schuko" electrical outlet was selected for installation in the building.

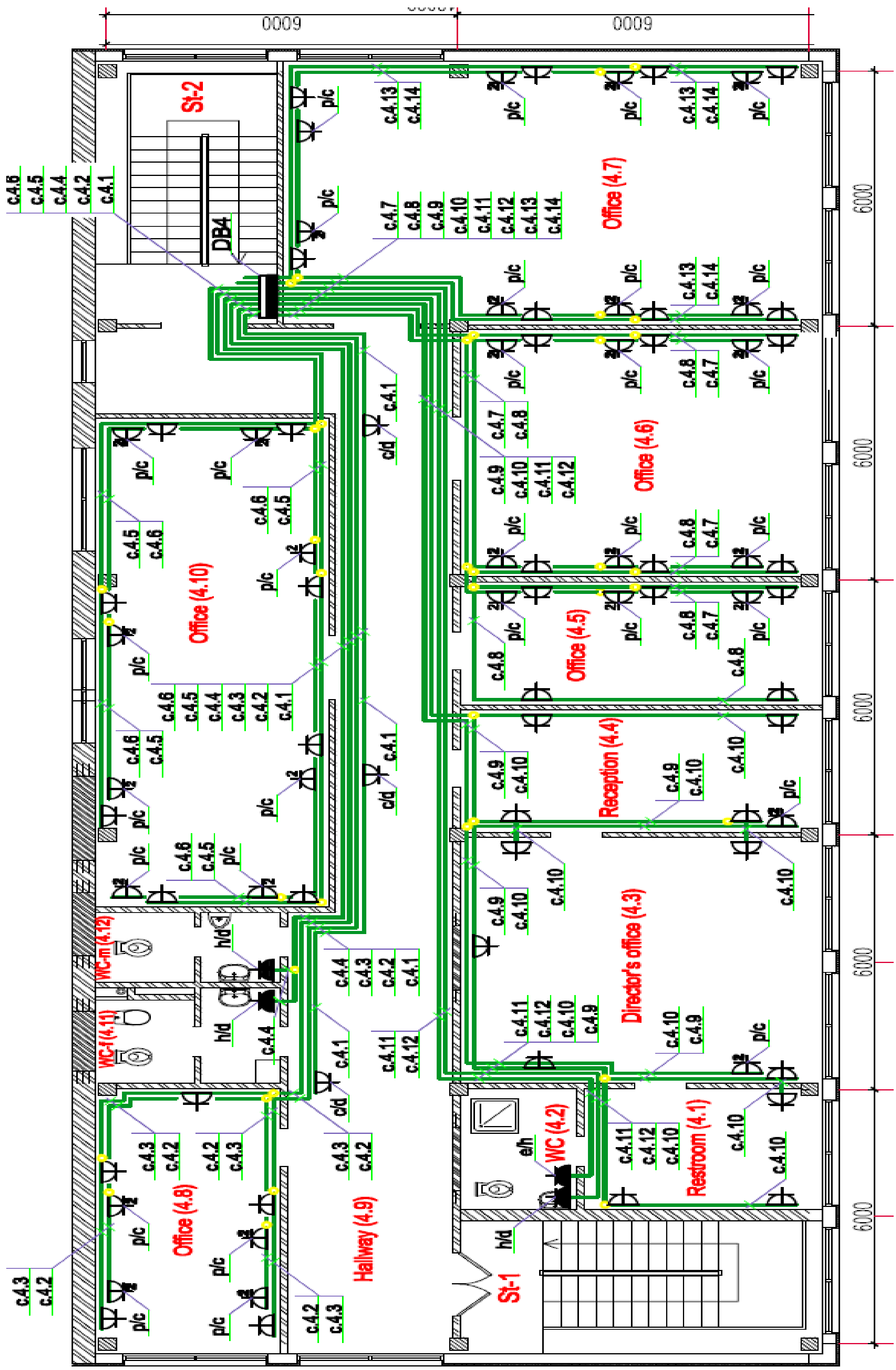


Fig. 55. Layout of power distribution system at floor 4

11.3 Lighting system

Crucial for securing comfort and productivity, lighting accounts usually for up to 40% of electrical consumption of the buildings. Quality of lighting depends on the power supply quality of the lighting equipment. Important criterions are light stability and continuity of service).

Initial data for lighting system design [46]:

Room characteristics:

- $\boldsymbol{l}$ – length [m], $\boldsymbol{w}$ – width [m], $\boldsymbol{h_1}$ – height [m] ($\boldsymbol{h}$= 3 m);
- Reflectance coefficients of surfaces $\boldsymbol{c_r}$, dependent of the materials and color of surface ($c_{r,wall}$ = 30, $c_{r,ceiling}$ = 30, $c_{r,floor}$ = 10);

Lighting fixtures:

- Coefficient of utilization of fixture $\boldsymbol{K_u}$;
- Designed height $\boldsymbol{h_2}$ (distance between the table and working surface $\boldsymbol{h_2}$ = 0.8 m);

Lamps:

- Type of the lamp;
- Power $\boldsymbol{P}$ [W];
- Luminous flux $\boldsymbol{\Phi_l}$ [lm].

Fixtures, selected for installing in appropriate rooms are given in table (Tab. 57).

Tab. 57. Installed lighting fixtures

Lighting fixture model	**IP**	**Nr of lamps**	**P_{lamp} [W]**	**$\Phi_{l,lamp}$ [lm]**	**Total number**	**Rooms**
PRBLUX 418	IP20	4	18	1150	64	4.1, 4.3, 4.6, 4.7, 4.8, 4.9, 4.10
PRBLUX 436	IP20	4	36	2500	6	4.4, 4.5
Navigator LPO-MS1-E218-G13	IP20	2	18	827	4	St-1, St-2
Gauss LED 6W IP44	IP44	1	6	600	6	4.2, 4.11, 4.12

Norms:

- Minimal illumination level $\boldsymbol{E_n}$ [lx], set by *SNIP 23-05-95* for each type of room. Standard defines next critical values for working height of 0.8 m:
    - Offices, places of operation with computer displays – 400 lx;
    - Halls, lobbies, foye – 150 lx;
    - Toiles, bathrooms – 50 lx;
    - Stairs – 20 lx.

Necessary number of lighting fixtures ***N*** is determined by the coefficients method:

$$N = \frac{E_n \cdot S \cdot 100 \cdot K_r}{K_U \cdot n \cdot \Phi_l} \tag{74}$$

where: $\boldsymbol{E_n}$ - required illumination level [lx];

$\boldsymbol{S}$ – area of the room [m^2];

$\boldsymbol{K_r}$ – reserve coefficient (for office spaces $\boldsymbol{K_r}$ = 1.25);

$\boldsymbol{n}$ – number of lamps in one fixture;

$\boldsymbol{\Phi_l}$ - luminous flux of the lamp [lm];

$\boldsymbol{K_U}$ – coefficient of utilization, which characterizes effective usage of the device in the room. For its determination it is necessary to know index of the room φ and reflection coefficients of internal surfaces of the structures.

Room index is determined by next relation:

$$\varphi = \frac{S}{(h_1 - h_2) \cdot (\mathrm{w} + l)} \tag{75}$$

where: $\boldsymbol{h_1}$ – room height [m];

$\boldsymbol{h_2}$ – height of the working surface [m];

$\boldsymbol{w}$ – room width [m];

$\boldsymbol{l}$ – room length [m].

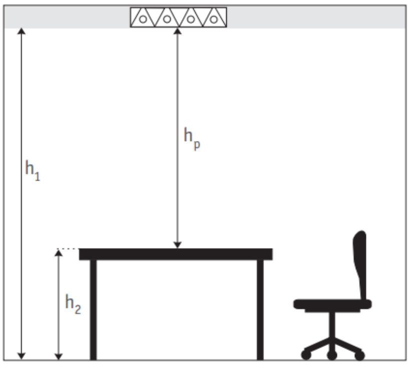


Fig. 56. Height values, used in lighting design

Having determined room index, and knowing the reflectance values, coefficient of utilization K_u is obtained from the table (Tab. 58).

Tab. 58. Coefficient of lighting utilization Ku

CEILING	80	80	80	70	50	50	30	0
WALLS	80	50	30	50	50	30	30	0
FLOOR	**30**	**30**	**10**	**20**	**10**	**10**	**10**	**0**
0,6	53	38	32	37	35	31	31	27
0,8	60	45	38	44	41	38	37	34
1	65	51	43	49	46	43	42	38
1,25	70	57	49	54	51	48	47	44
1,5	72	61	52	57	54	51	51	47
2	76	66	56	61	57	55	54	51
2,5	78	70	59	64	60	58	57	54
3	80	73	62	67	62	60	59	57
4	81	76	64	69	63	62	61	58
5	82	78	65	70	65	64	62	60

Calculated number of lighting fixtures is rounded up. Fixtures may be added with considerations of providing lighting uniformity.

Calculation of necessary lighting fixtures number is given in table (Tab. 59).

Lighting circuits are drafted according to location, in order to easily control it, and to normalize the load. Every circuit is protected by an accordingly selected circuit breaker.

Tab. 59. Required minimal number of fixtures

Room nr.	Room name	S [m^2]	l [m]	w [m]	E_n [lx]	Index	K_u	Required nr.
4.1	Restroom	11.6	3.04	4.26	150	0.72	37	1.8
4.2	WC	5.7	3.04	2.12	50	0.50	31	1.9
4.3	Director of-fice	35.3	6.38	6	400	1.30	45	8.5
4.4	Reception	18.3	6.38	3	400	0.89	39	2.3
4.5	Office	18.3	6.38	3	400	0.89	39	2.3
4.6	Office	35.8	6.38	6	400	1.31	47	8.3
4.7	Office	56.6	9.4	6	400	1.67	52	13.6
4.8	Office	19.7	3.4	6.43	400	0.91	39	7.0
4.9	Hallway	65	30	2.15	150	0.92	39	7.8
4.10	Office	46	11.6	4.25	400	1.32	48	12.6
4.11	WC-f	6.9	3.3	2.44	50	0.55	31	2.3
4.12	WC-m	4.8	3.3	1.66	50	0.44	28	1.8
St-1	Stairs	19.2	3.2	6.45	20	0.90	39	1.5
St-2	Stairs	18	3.35	6.44	20	0.84	37	1.5

General diagram of lighting circuits in distribution board DB4, with the indicated rated power, current, selected cable and circuit breaker is presented in figure (Fig. 57).

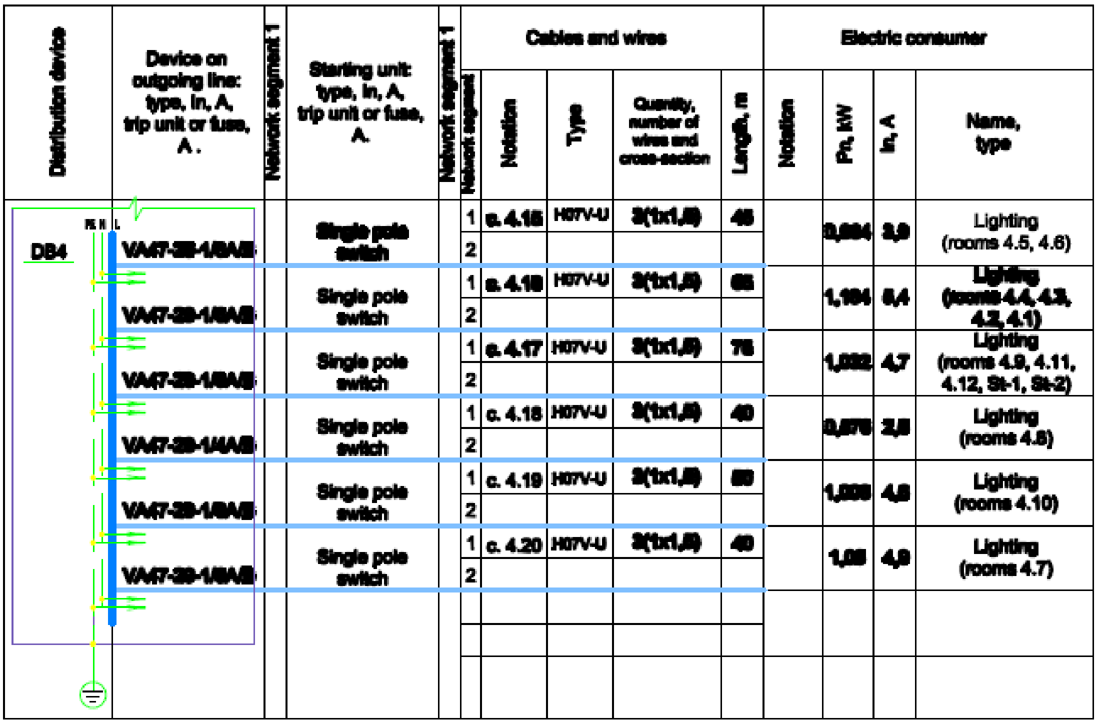


Fig. 57. General diagram of lighting circuits in DB4

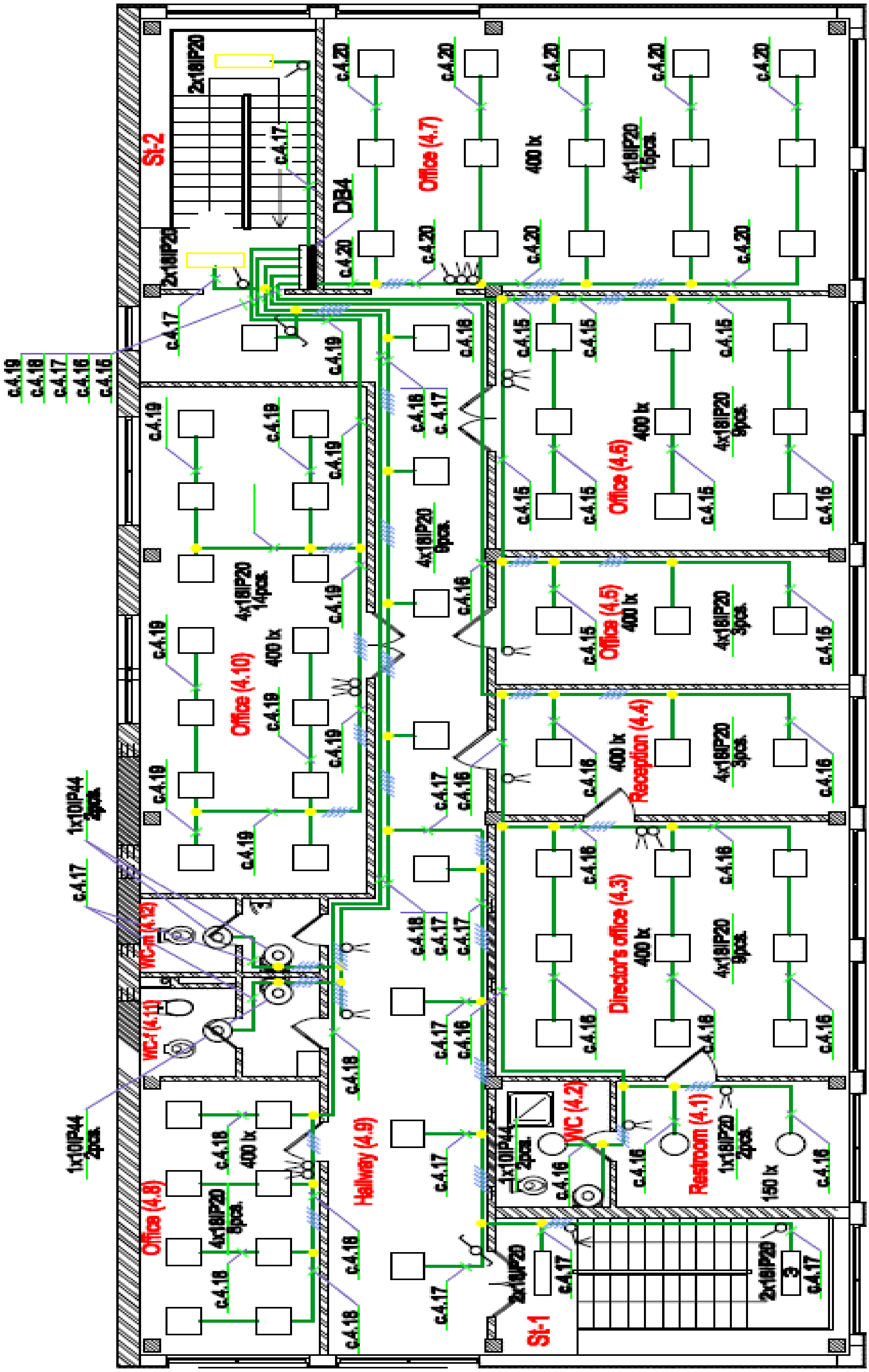


Fig. 58. Layout of lighting system of floor 4

12 PHOTOVOLTAIC SYSTEM

From the variety of types, present on the market, monocrystalline Yingli Panda 48 solar modules were chosen, due to their advanteageous price and good characteristics (Tab. 60).

Tab. 60. Technical characteristics of chosen module

Electrical parameters at Standard Test Conditions (STC)							
Module type			YLxxxC-24b (xxx=P_{max})				
Power output	P_{max}	W	225	220	215	210	205
Power output tolerances	ΔP_{max}	W	0 / + 5				
Module efficiency	η_m	%	17.1	16.7	16.3	15.9	15.6
Voltage at P_{max}	V_{mpp}	V	24.8	24.6	24.4	24.2	23.9
Current at P_{max}	I_{mpp}	A	9.06	8.94	8.81	8.69	8.57
Open-circuit voltage	V_{oc}	V	31.4	31.1	30.9	30.7	30.5
Short-circuit current	I_{sc}	A	9.55	9.48	9.41	9.34	9.27

STC: 1000W/m² irradiance, 25°C cell temperature, AM1.5g spectrum according to EN 60904-3.
Average relative efficiency reduction of 3.5% at 200W/m² according to EN 60904-1.

12.1 Characteristics of a PV module

Functional characteristics of used modules are determined by variation of voltage and current according to ambient conditions and radiation. To analyze this variation, data supplied by the manufacturer can be used. Characteristics were calculated according to the method described in p.6.2 [31].

Characteristics at standard conditions:

- Power of the module, P_m = 225 W;
- Voltage U_m = 29.5 V;
- Current I_m = 7.63 A;
- Open circuit voltage U_0 = 36.5 V;
- Short-circuit current I_{sc} = 8.28 A;
- Number of cells n_c = 60;
- Nominal Operating Cell Temperature, ***NOCT*** = 45 °C.

Nominal Operating Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module under the conditions as listed below:

- Irradiance on cell surface = 800 W/m^2;
- Air temperature = 20 °C;
- Wind velocity = 1 m/s;
- Mounting = open back side.

Data regarding variation of basic characteristics together with temperature variation is obtained by manufacturer in testing laboratories, and is provided in table (Tab. 61).

Tab. 61. Variation of characteristics with change of ambient temperature

I_{sc}	U_0	I_m	U_m
% / ˚C			
0.06	-0.37	0.06	-0.37

To obtain representative data, characteristics will be determined for 3 ambient modes:

- Global radiation ***G*** = 800 W/m^2, ambient average temperature ***t*** = 35 ˚C;
- Global radiation ***G*** = 500 W/m^2, ambient average temperature ***t*** = 20 ˚C;
- Global radiation ***G*** = 300 W/m^2, ambient average temperature ***t*** = 0 ˚C.

Calculation of PV module characteristics are given in table (Tab. 62).

Tab. 62. Calculation of PV module characteristics for various radiation and temperature

Parameter	**Unit**	**Values**		
G	W/m^2	800	500	300
t_a	˚C	35	20	0
I_{sc}	A	7.64	4.78	2.87
t_c	˚C	60.00	35.63	9.38
U_0	V	24.05	29.17	34.68
I_M	A	7.25	4.53	2.72
U_M	V	17.66	22.63	27.99
FF	-	0.74		
P_c	W	137.87	104.51	74.55

Structured values of characteristics, are given in table (Tab. 63) for short-circuit (SC), operation point (M) and open circuit (OC).

Tab. 63. PV module characteristics

G [W/m^2]	**Characteristic**	**SC**	**M**	**OC**
1000	U [V]	0	24.80	31.40
	I [A]	9.55	9.06	0
800	U [V]	0	17.66	24.05
	I [A]	7.64	7.25	0
500	U [V]	0	22.63	29.17
	I [A]	4.78	4.53	0
300	U [V]	0	27.99	34.68
	I[A]	2.87	2.72	0

Graphically, power - voltage characteristic is represented in figure (Fig. 59), and current – voltage characteristic in figure (Fig. 60). Basing on the resulted data, we can observe that short-circuit current and power are directly proportional to incident radiation.

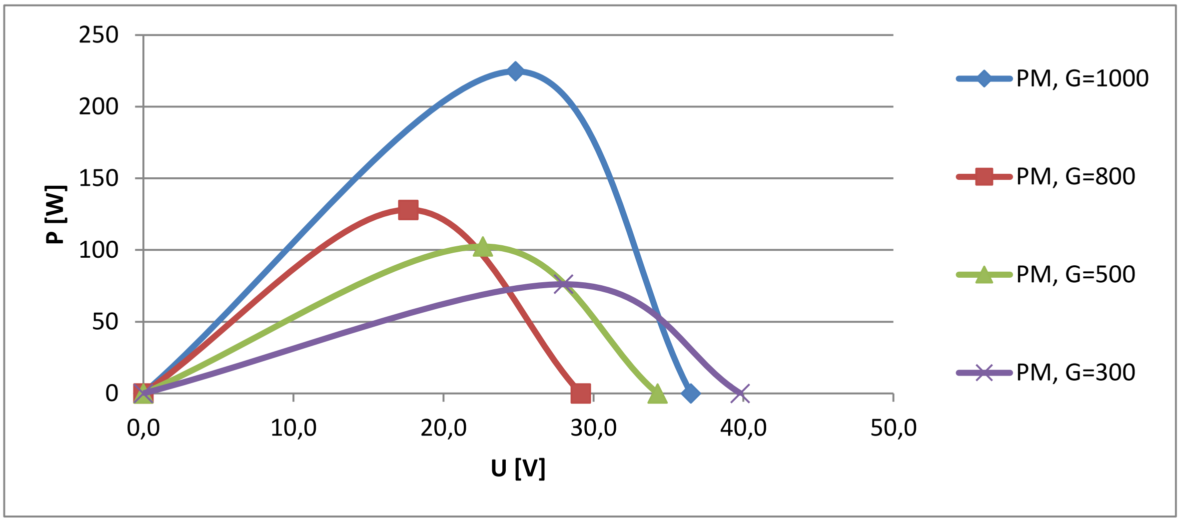


Fig. 59. P(U) function for various radiation values

However, voltage is inverse proportional to cell temperature (at 0 ˚C U_0=39.78 V, while at at 35 ˚C U_0=29.15 V). Maximal power output is reached in operating (M) point at U_M and I_M.

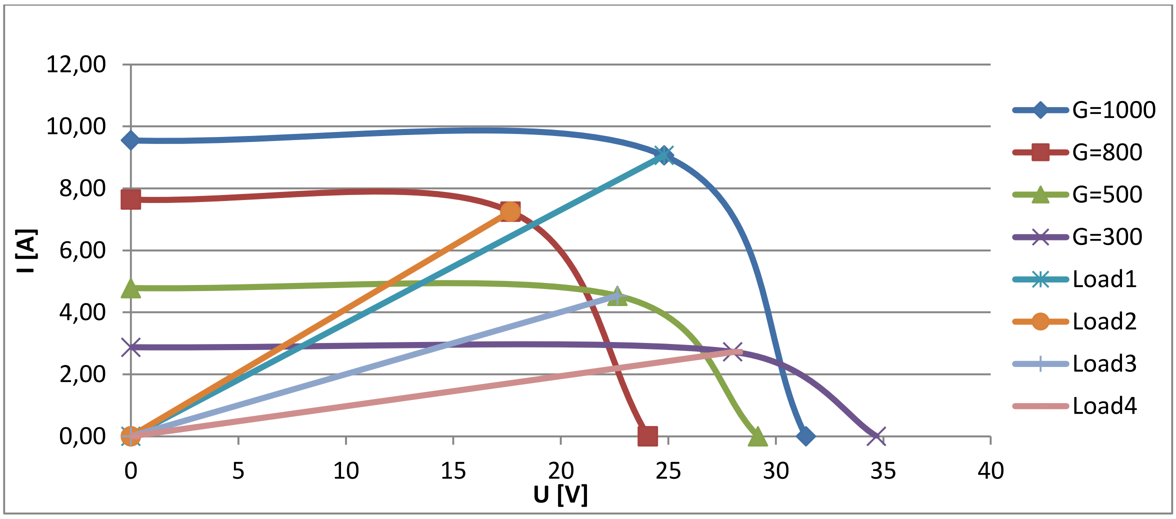


Fig. 60. I(U) function for various radiation values

Respectively, an ideal load should be passing through all M points. When that is not possible, it is advisable to regulate load of the module which does not correspond with M point, according with solar radiation. Difference between open circuit voltage depends on the number of cells in the module. Higher the number of cells, higher is the difference between the voltage at various radiation.

12.2 Design of photovoltaic system

Prior to designing the PV system itself, available for installation area should be determined. For photovoltaic panels efficient use, installation is recommended on the southern side of the roof, in case of angled roof. Inclination of the roof in our case is in south-eastern direction, this half allows panel installation.

Total area of the half of the roof which allows access, is $\boldsymbol{A_{tot}}$ = 200 m^2. Available area is the difference between total area of the south-eastern side and area of solar collector panels. Area of solar collector is $\boldsymbol{A_{col}}$ = 11 m^2. Considering the necessity of assuring access to all panels and not blocking technical elements on the roof, effective area for installation is 75% of the available area:

$$A_{PV} = (A_{tot} - A_{col}) \cdot 0.8 = (200 - 11) \cdot 0.75 = 141.75\ m^2 \tag{76}$$

When the decision of PV system installation has been made, maximal available space should be used, because scale rules apply to the costs, solar panels accounting for 60% of the total cost. Installation costs per installed 1 W are inversely propotial with the area of panels.

Chosen photovoltaic models have an area of 1.317 m^2 each.

$$N_{PV} = A_{PV} / A_{module} = 141.75 / 1.317 = 107.6 \tag{77}$$

Therefore, 107 modules can be installed from the area point of view. Consulting with structural engineers is required, regarding the mass of the installed systém, which is 14.9 kg per module, and corrections should be made. Total mass of the systém, together with mounting installations (10% of modules mass):

$$m_{PV} = m_{module} \cdot N_{PV} \cdot 1.1 = 107 \cdot 14.9 \cdot 1.1 = 1753.7\ kg \tag{78}$$

Nomnial peak power of a module is P_{peak_mod} = 225 W. Total nominal peak power of the systém:

$$P_{peak} = P_{peak\_mod} \cdot N_{PV} = 225 \cdot 107 = 24075\ W = 24.075\ kW \tag{79}$$

For estimating electricity production possibilities during the year, Photovoltaic Geographical Information System (PVGIS) software, available online, was used. It was implemented by Joint Reseach Center (JRC) from the European Commission's in-house science services.

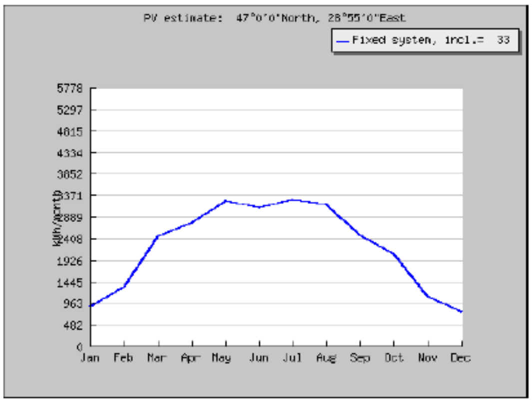
Program uses a similar algorithm to the one presented before. It outputs average daily $\boldsymbol{E_d}$ [kWh] and monthly $\boldsymbol{E_m}$ [kWh] electricity production from the system, average daily $\boldsymbol{H_d}$

[kWh/m²] and monthly $\boldsymbol{H_m}$ [kWh/m²] sum of global irradiation per square meter received by the modules of the system. Output data is presented in table (Tab. 64).

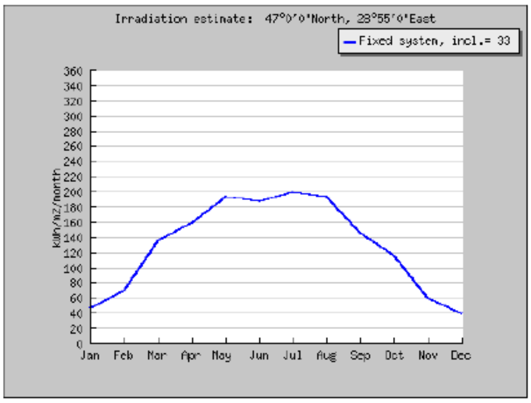
Tab. 64. Electricity production by designed photo-voltaic system

Month	Ed	Em	Hd	Hm
Jan	28.90	897	1.49	46.2
Feb	48.60	1360	2.49	69.8
Mar	81.40	2520	4.37	135
Apr	94.90	2850	5.30	159
May	107.00	3320	6.21	193
Jun	106.00	3180	6.21	186
Jul	108.00	3350	6.40	198
Aug	105.00	3260	6.24	193
Sep	85.10	2550	4.86	146
Oct	68.20	2120	3.73	116
Nov	37.70	1130	2.00	59.9
Dec	24.90	773	1.28	39.6
Year	74.80	2280	4.22	128
Total for year		27300		1540

Annual electricity production $\boldsymbol{E_a}$ [kWh] is estimated to 27300 kWh. Distribution by months is shown in figure (Fig. 61).



Monthly energy output from fixed-angle PV system



Monthly in-plane irradiation for fixed angle

Fig. 61. Estimated electrical energy generation

12.3 PV system connection

From the existing architectures of PV systems, most suitable for our application is a grid-connected PV system. PV solar system connected to the local switch board enables self-consumption of PV solar electricity. Surplus of PV electricity will be transfered into the local grid. They have a number of advantages, important in our conditions [29]:

- Reducing the energy bill from electric distribution system, as it is possible to sell surplus of electricity produced to the electricity supplier. Energy is not wasted in vain;
- Grid-connected PV system have much lower installation costs, as they do not require battery systems, which lose their workin
- Grid interconnection of PV power generation systems results in an effective utilization of produced power because no storage losses occur.
- It has better carbon negative factor over its lifespan, as any energy produced over and above that to build the panel initially offsets the need for burning fossil fuels. Installation gives a reasonably predictable average reduction in carbon consumption at any amount of solar irradiation.

Connection diagram of a grid-connected PV system is given in figure (Fig. 62).

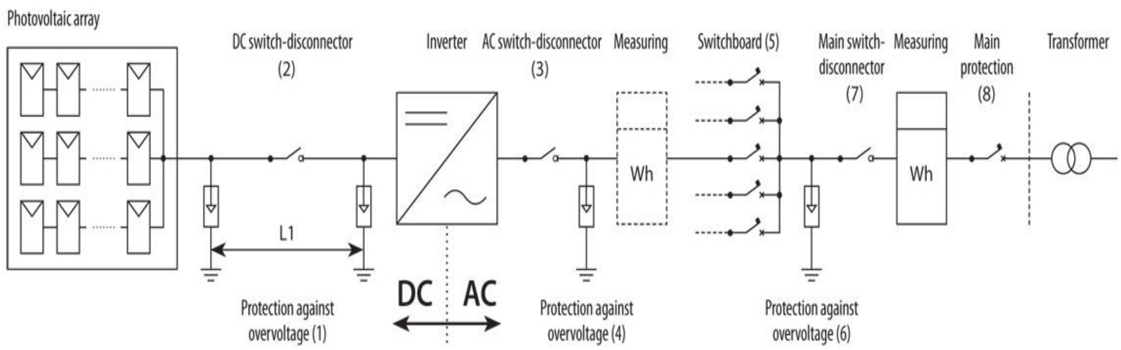


Fig. 62. Connection diagram of PV power system working in parallel with distribution

In case of a high number of strings connected in parallel it is necessary to ensure protection of PV panels against reverse currents, and overcurrent protection of cables of PV array. In presented scheme, overvoltage protection is provided through surge voltage arresters (1). In case of a longer line between the PV array and the inverter it is appropriate to use them both at the inverter and close to PV arrays. To ensure maintenance of the inverter, it is necessary to meet the requirement for its possible disconnection from both a.c. and d.c. side; therefore d.c. disconnector (2) and a.c. disconnector (3) are installed at the inverter. In case that it is functionally ensured that switching the d.c. side off/on always takes place without load, i.e. the a.c. side will be switched off sooner and switched on later, it is possible to use also a disconnector on the d.c. side.

Downstream of the a.c. disconnector there is a surge voltage arrester (4) installed; it is above all recommended if a long line is after it. Furthermore, it is possible to connect local meter of electrical energy generated by PV source, which is connected through a protective device to the switchboard (5).

In case of high-capacity PV source individual parallel line of the PV source is connected via protective devices to the switchboard. The switchboard and downstream wiring is protected by a surge voltage arrester (6) on the side of connection to the distribution network.

The meter of the supplied and consumed energy (generation and consumption on site – green bonus) or only of supplied energy (only generation without consumption) is preceded by the main disconnector (7) of the switchboard. The switchboard, disconnector and the line to the distribution system are protected against overload and short-circuit by the main protective device (8).

Protection of strings from overcurrent by fuses on each line is omitted to reduce its cost, because short-circuit current $\boldsymbol{I_{sc}}$ of the PV panel is only by 10 to 20 % higher than its rated operating current. In case of application with maximum 3 strings there is no risk of panel damage by reverse current induced by short-circuit.

The risk of thermal overload of cables due to the short-circuit can be dealt with by their appropriate overrating. In a higher number of parallel strings it is necessary to take into account the value of possible reverse current with regard to maximum allowable reverse current of the PV panel.

13 CONTROL SYSTEM DESIGN

In order to simplify the operation and control of technical systems in the building, and to provide flexibility of their usage, an intelligent centralized control system was proposed. Control system offers a possibility of simple and user-friendly control of internal environmental parameters in the building. Any person without specific technical knowledge can manipulate it, by simply setting parameters (temperature, lighting, etc.) through control point (touch panel or PC).

Control system was realized using KNX building automation technologies. Being a universally accepted building automation protocol, it offers a broad variety of hardware suppliers, which can be combined in the optimal way from financial and functional points of view. Besides, a KNX system may be controlled by any functional control device, from microcontroller to a PC, depending on the scale of the project [32]. An important advantage is flexibility of KNX system. Architecture can be easily modified, elements can be added or removed without affecting the whole system. It is a low voltage system of 30 V DC and current of 25 mA. Control bus is routed in parallel with 230V power supply circuit.

Automation was done for heating and lighting control in the building. All active control elements are placed in the electric distribution boards. Control elements of the boiler room heating equipment are in distribution board DBboil and is the “heart of the system”. Lighting control devices for each floor are placed in correspondent distribution boards (DB1-DB5).

13.1 Heating system control

Primary application of KNX control system is in the field of room-oriented temperature regulation. Control is realized by detecting an actual temperature value in the room and comparing it to a reference value, set in thermostat. Thermostat sends a respective control signal to the actuator through digital input and output devices, which controls heating unit of the room. Temperature is controlled by actuating thermoelecric valve drives, thus varying the flow.

Initial step in design of a control system is defining the equipment which is involved in control process. It gives a possibility to define the table of inputs and outputs, their control characteristics and serves as basis for selection of equipment.

Control system connections of heating and hot water preparation systems in the boiler room is presented in figure (Fig. 63).

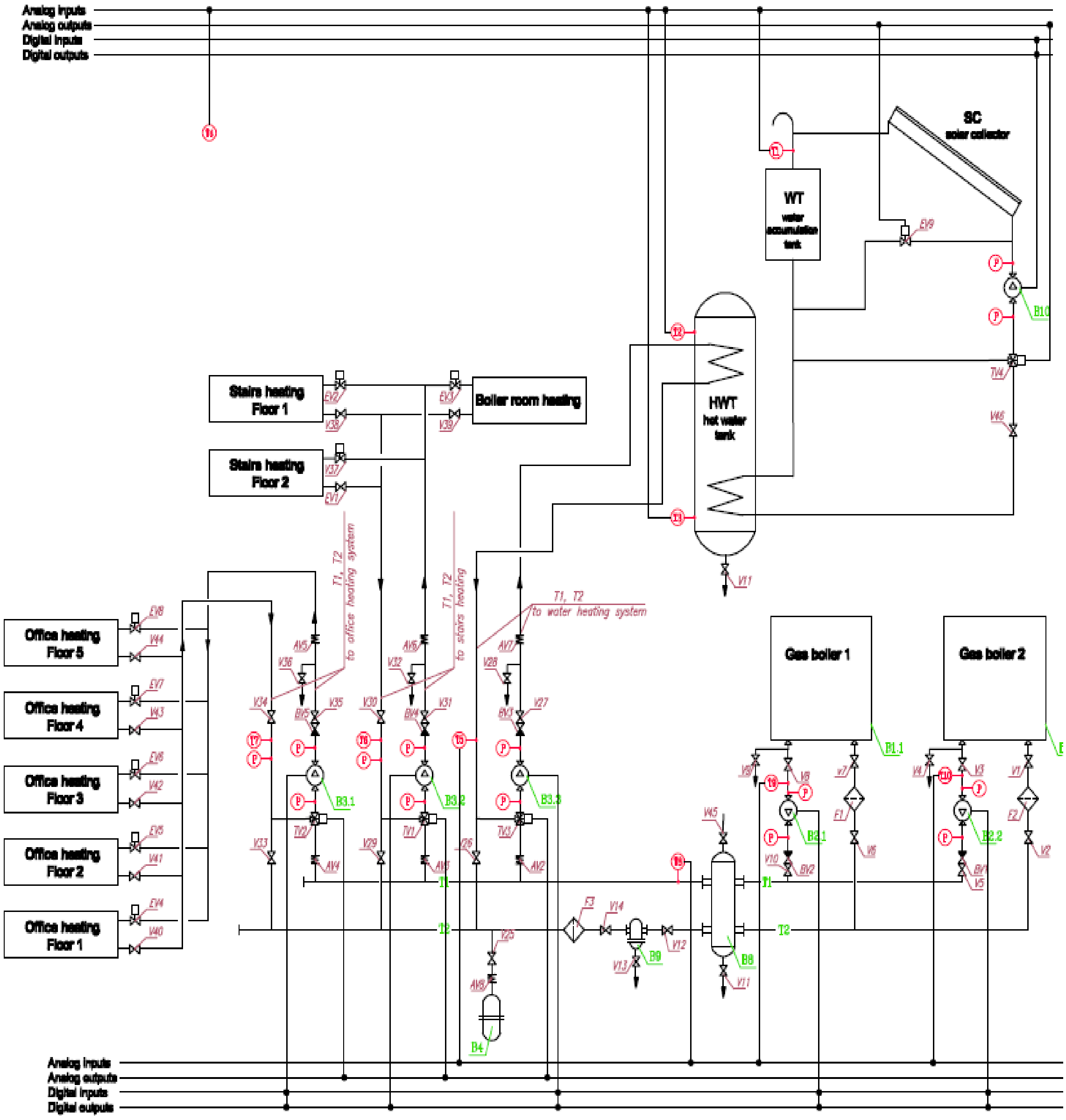


Fig. 63. Connections of heating and hot water preparation system

Main inputs are temperature values obtained from temperature sensors with a 4-20 mA transducer. This current range is used both for the control and power of the sensor.

Controlled equipment consists of:

- Servo drives for controlling three-way or two-way control valves. Supplied heat volume is regulated by changing the position of the spool, thus regulating the flow of hot water. Control signal is an analogue one, of 0-10V or 4-20 mA;

- Variable speed drives of pumps, which control the speed of pump's motor by alternating frequency of supplied current. Current value of shaft speed is measured by potentiometer or Hall sensor and supplied as an output of the pump. Both inputs and outputs are digital.

System settings and control is realized from a central touch panel, situated near the door of the Boiler room. From this panel it is possible to set a general temperature for each section through controlling a three-way valve and for each secondary branch of the section (like floor circuits) through two-way controlled valves.

Temperature in specific rooms can be controlled by conventional thermostats accordingly installed in them. They are advantageous from the point of view of price and can be included in KNX system through a binary input module. In that case thermostat sends a control signal through binary input to the electronic switch actuator of electrothermal valve drive, which controls the valve. Control is performed Phase Wide Modulation (PWM) or two-step control.

Electrothermal valve drive consists of a thermal expansion element, which heats and expands when electric voltage is applied. After switching off the voltage, expansion element will contract. Valve is opened or closed, changing the flow of water. Time of valve actuation is around two to three minutes. System inertia gives a possibility to operate valve in a partly open position through PWM. It is realized through electronic switch actuator.

Control principle diagram of a normally closed (NC) electrothermal valve drive with travel distance of 4 mm is represented in figure x.

Multi-boiler system offers a possibility of maximally efficient usage of the boiler efficiency, depending on the demand for hot water in the heating system. Gas boilers output power is controlled by analogue input signal from the control system of 0-10 V. If the required heat power can be handled by one boiler, another one is in stand-by mode. Second boiler is activated only when heat demand is higher than the first boiler can handle. Main control criteria is the output temperature of 75 ^{0}C at the outlet of hydraulic separator.

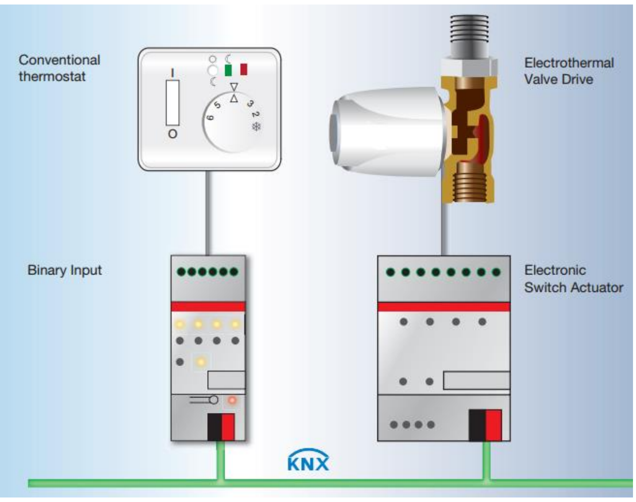


Fig. 64. Room temperature control system devices

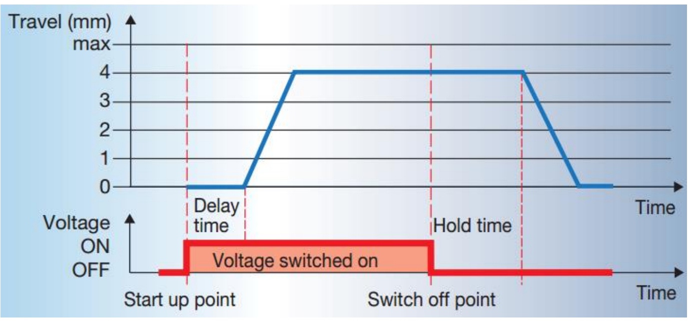


Fig. 65. Characteristic of a NC electrothermal valve drive

Secondary heating circuits are each controlled through flow rate regulation by controlling the speed of pumps B3.1, B3.2, B3.3 and temperature regulation by mixing supplied water with the return water in three-way valves TV1, TV2 and TV3. Pumps are be disconnected when a respective three-way valve is closed.

13.1.1 Solar collector control

Solar collector control system is realized by pump B10, three-way valve TV4 and two-way valve EV9, both equipped with servo drives.

In order to keep the water in the collector from freezing and damaging the system, solar collector heating system is working until the external air temperature, measured by T4 sensor, is over 5 ^{0}C. Besides the external temperature T1, collector is controlled in correspondence with temperature of the water in lower part of hot water tank (HWT), measured by T3 and temperature of the water coming from the collector T1.

In case if external temperature drops below 5 ^{0}C, pump B10 is stopped, valve is closed and the water from the collector is drained to water accumulation tank WT in the boiler room.

During operation, pump B10 is controlled through comparison of temperature of water coming from the collector T1 with temperature of the water in lower part of HWT T3. If T1 < T3, three way valve TV4 is closed in such a way that water is circulating only in the solar collector circuit, accumulating solar energy and heating up continuously. This allows a more efficient use of accumulated energy and faster heating up of the agent. As well as usage of collector, when external temperature is lower than the required one. When T1 > T3, pump is working at nominal rate and three-way valve TV4 is open so that the heating agent circulates through heat exchanger of HWT, heating the water, while the condition is fulfilled.

If temperature T1 doesn't rise during an hour of pump operation, pump is shut down, valve EV9 is open and circulation is restored not earlier than in 1 hour and only if the external temperature rises with at least 2 ^{0}C. Same mode of operation is set for the period in between 8 PM and 7 AM, when hot water is not required and during the night. Opening EV9 valve allows water drainage from collector and pipes situated in unheated space to accumulation tank WT.

In case when the water is heated by collector more than 55 ^{0}C, it is mixed by three-way valve with the return water. Once in a week water should be heated to a temperature of 70 ^{0}C for sanitary reason of bacteria elimination.

13.1.2 Hot water preparation circuit control

In case if the heat supplied by solar collector is not enough to heat the water to the required value, a heating circuit of the central heating system of the building heats it additionally.

It is controlled using temperature sensor from the top of the hot water tank (HWT) T2, B3.3 pump and TV3 three-way valve.

When temperature T2 is lower than the required temperature of 50 ^{0}C, TV3 valve is open in such a way to allow circulation of the heating agent from secondary circuit of gas boiler system through heat exchanger of HWT.

Fresh water to HWT is supplied by EV10 valve.

13.2 Lighting automation

For the office buildings segment, lighting control is most cheap and accessible measure of energy savings in the terms of operational costs. Lighting can constitute 35-40% of total office energy consumption [47]. Although implementation of energy efficient lamps and lighting fixtures can drastically reduce energy usage through efficiency of light source, implementing proper control algorithms increases effectiveness of entire system usage.

In implementing lighting control system it is necessary to keep a compromise between avoiding socially and commercially unacceptable excessive usage of lighting and keeping the required amount of light to provide social security and comfortable conditions.

In case of KNX system implementation, KNX compatible switches are installed. Switches and fixtures of each branch are connected in a common circuit through load actuators. Each of the system elements has its address. Changing the logic of system or redesigning it in these conditions can be done without physical intervention, just by reprogramming it.

Complex integration offers us a possibility of combining multiple system in order to provide optimal functionality, in our case combining blinds control with lighting control.

Lighting in staircases and other areas with rare and short-time access is controlled automatically using combined motion and ambient lighting sensors. They analyze the actual value of natural illumination, and send a control signal to actuator, proportional to the required value of lighting. Dimming actuator powers the lighting source with the needed voltage. In case if lighting fixtures are not dimmable, a relay actuator will be installed, providing just on/off control. Lighting in the restrooms is controlled solely by PIR detector.

Lighting and blinds in office rooms has 2 control modes, which can be changed from central touch panel:

- Manually from a push-button switch with 4 buttons. Top two buttons are programmed to switch on and off 2 groups of lighting fixtures. Intensity is controlled through time of button pressing. Short press leads to change of on/off state, while longer pressing modifies the intensity. Other 2 buttons control the blinds. Left button for gradually closing, right for gradually opening.
- Automatic regulation using mixed motion and daylight sensors. Having a preset luminosity value, sensors communicate required control signal to the dimming actuator.

Lighting and blinds control can be preprogrammed through central touch panel, defining various scenes, which are activated by preset time or on demand from the panel.

Daily preset lighting cycle can be set in next way:

- 6 AM – System warm-up. Blinds are 100% open, lighting in main lobbies and hallways turned on to 80%;
- 7:30 AM – Office start. Daylight sensors in working areas are activated.
- 2 PM – Afternoon adjustment. West blinds are dropped to 60% to reduce sun glare.
- 5 PM - Sunset adjustment. West blinds area closed. Daylight sensors are disabled. Lighting is set to 90%.
- 7:30 PM – Shut-down mode initiation. All blinds are closed for thermal insulation. Motion timer is set to 15 minutes for more strict energy saving program. In case if no motion is detected for 15 minutes, lights are switched off.
- 8:30 PM - Testing for after-hours mode. Lighting is flashed to indicate that the lighting is going to shut down. Lighting mode can be extended from the touch panel for a specific area.
- 9:45 PM – Afterhours mode. Lighting is shut down in the areas where it was not extended. Presence sensors are adjusted to 5 min time-out. Areas with extended operation are retested every 30 minutes until all of them are shut down.
- 10:20 PM – Shut-down. All corridor lighting is shut down 10 minutes after all the office areas where shutdown.

13.3 SCADA visualization system

Main goal of SCADA system is real-time monitoring of technical systems in the building. Key element of the SCADA system is the Schneider Electric 7’ touch panel. Communication with KNX system is realized through a KNX to IP conversion module. Touch panel can be controlled on distance by connecting it to a LAN network through Ethernet port, in the same way SCADA system can be operated at a PC, connected to it.

SCADA system was realized in Reliance 4 software due to its availability in a free trial version. Although it allows a limited number of tags, it is enough for demonstration of visualization principles.

The main window of the program (Fig. 66) contains elements for control of the entire system state, as well as of the entire floors. It allows a quick view on the system operation in complex. Systems which can be manipulated are: heating system (shutting it down stops the hot water preparation system and solar collector system as well), solar collector water heating, hot water preparation system, lighting and blinds control.

Three scene buttons allow choosing the executable scenario:

- Night mode – when activated, all the lighting in the building is disconnected in 15 minutes, heating is lowered down by 3 ^{0}C until 5 AM of the next morning or Mon day, if night mode was activated on Friday evening;

- Day automated mode – when activated, a preprogrammed algorithm controls lighting and blinds. It may be the algorithm defined in 13.2, as well as any other logic, set by the user;

- Day manual mode – normal functioning mode, lighting in the offices is controlled from push-switches. In staircases, restrooms and some other areas – by mixed PIR-PE sensor control. In case if heating has not been risen automatically at 5 AM (for example, if day mode was activated on Saturday) it is done at the moment of mode activation.

Besides switching systems on or off in the entire building, it is possible to control them for separate floors from the main screen.

Indicators on the left show the power output of boilers, measured in percent, ambient temperature transmitted from exterior temperature sensor and outside air humidity. Menu on the top allows central switching of the entire systems: heating, hot water preparation, solar collector, lighting and blinds closing.

In the menu on the lower right it is possible to switch on or off heating and lighting systems for separate floors, as well as close or open the blinds. When a total system control of the system is enabled in the main menu, switching that system for the floors control menu is disabled.

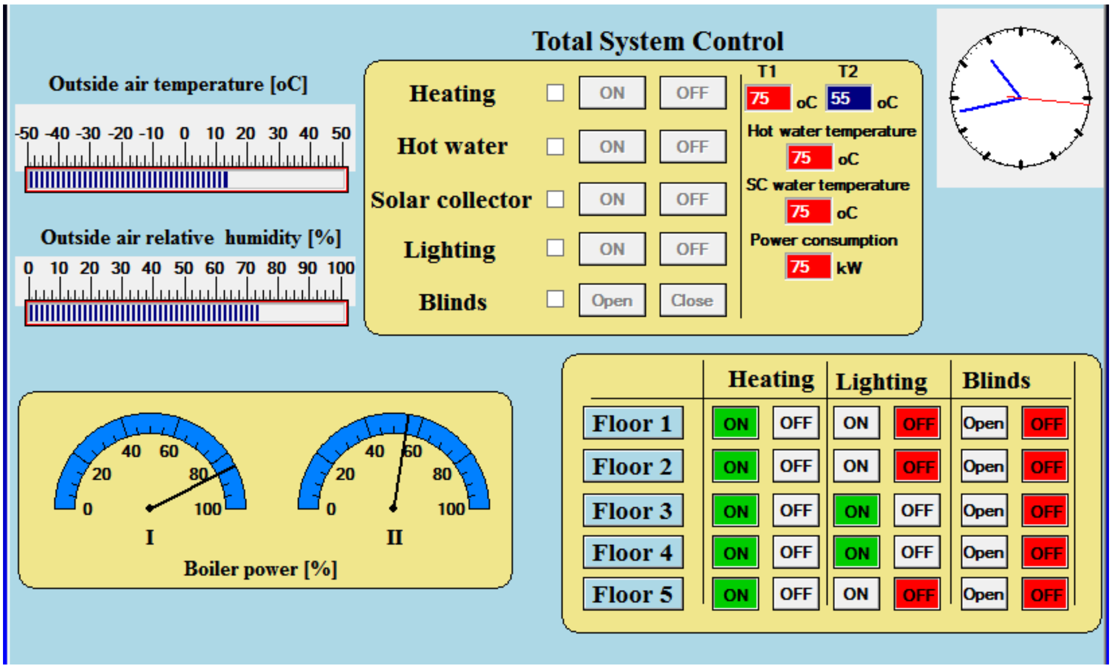


Fig. 66. Main screen of SCADA system

Pressing one of the buttons with the floor name opens the control window of selected floor. There are two control windows for each floor, switched by buttons in the lower left corner. Both windows represent the graphical representation of floor layout with specified control elements for each room:

a. Heating monitoring and control (Fig. 67).

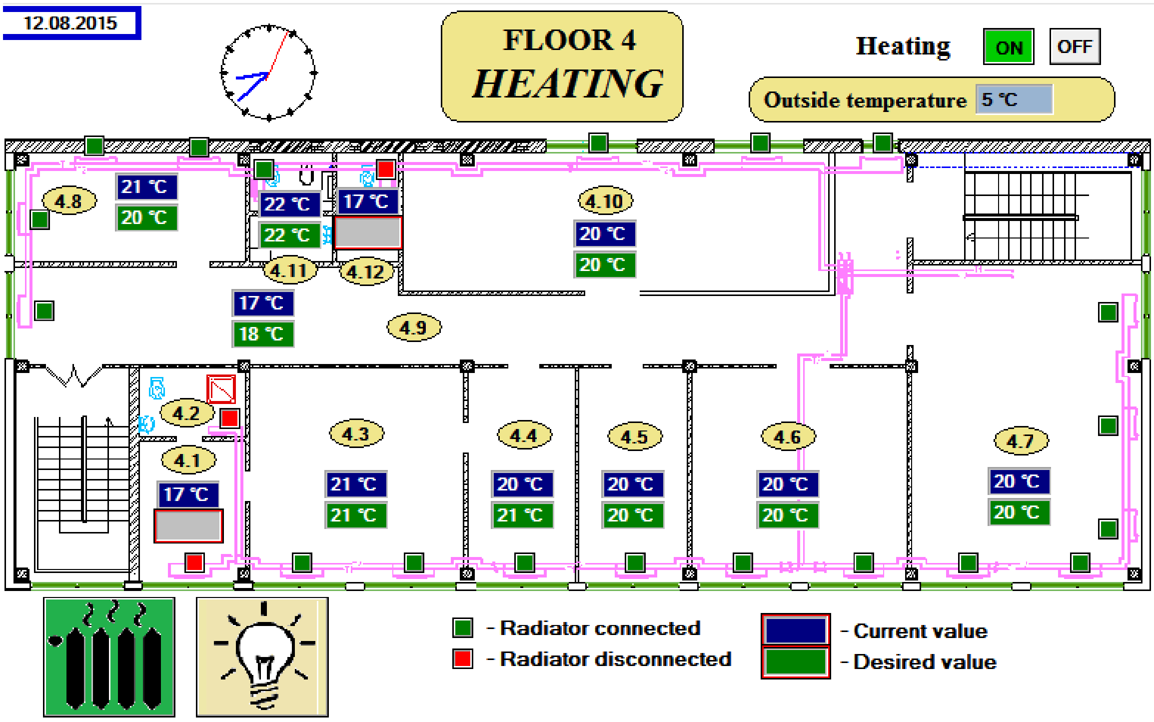


Fig. 67. Floor heating control system

Heating control window allows room-oriented temperature regulation and monitoring. Current temperature for a room is shown in the blue text box. Desired value can be set in the green input field. Radiators with installed thermoelectric valve drives can be disconnected or connected by clicking on the button near them (green – Open, red – Closed). When radiator valves in the entire room are closed, temperature regulation for that room is blocked (input box is gray – disabled).

b. Lighting and blinds monitoring and control (Fig. 68).

Current illumination value is shown in the yellow box of each room. Lighting in each room can be disconnected by clicking the button in desired room (green – ON, yellow – OFF). When selecting a room by clicking on its number (changes color from khaki to dark orange), control slider for lighting power and blinds opening is displayed.

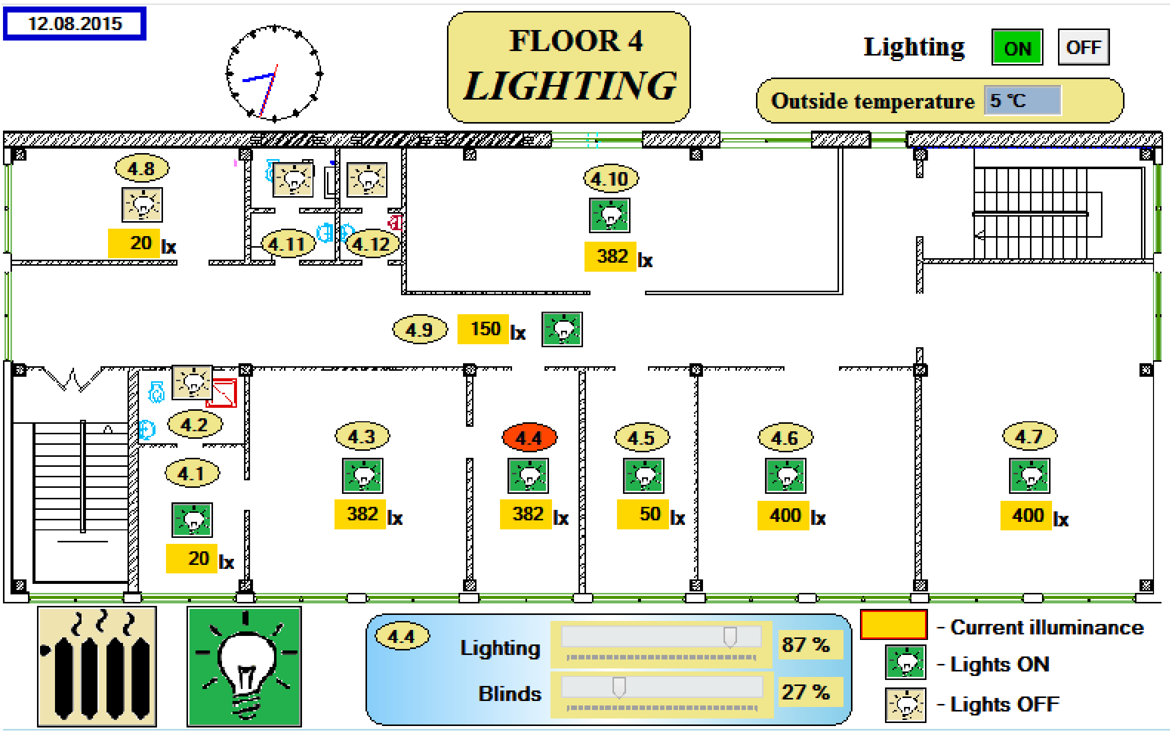


Fig. 68. Floor lighting and control system

14 ECONOMICAL EVALUATION

The goal of economical analysis of the project is providing judgement information to responsible persons. This data is one of the most importnat decision-making criteria of the potential investors. Basing on economical analysis, project can be even revisioned towards possible alternatives to proposed technologies or changing level of implemented technologies. The most complete analysis of investments in a project requires analysis of investments during each year of system's life, considering direct, indirect and overhead costs, taxes and returns on investment plus any external factors, like environmental impacts which may affect the decision.

Implemented measures can be divided in tow groups:

- Measures which have improvement of energy efficiency characteristics of the building and result in operational savings during lifetime: insulation of building envelope, solar collector, photovoltaic systems. Their payback period can be calculated basing on savings resulted.
- Systems required for providing human comfort and proper operation of the building: heating, electrical installations, control system. Payback period is not determined for these systems.

14.1 Fuel demand for heating

In order to perceive a complex image of the operational aspects of heating system it is necessary to find out the fuel demand for the annual heating season. This steps gives as well a possibility of assessment of general efficiency of the heating system, economical value and benefits of implemented measures.

Calculation of fuel demand for heating is based on external climatic conditions and internal environment requirements described in p. 9.1.1, and on data regarding heat loss of the building after insulation works have been made [48].

Initial data for fuel demand calculation through the degree-days method is:

- Heating season duration z_{ht} = 162 days;
- Air temperature of coldest 5 days t_{ext} = -17 ^{0}C;
- Average temperature of inside air t_{int} = 20 ^{0}C;
- Average outside temperature during heating season, t_{ht} = 0.6 °C;

- Total heat loss of the insulated building Q_{ins} = 57465 W;
- Total heat loss of the non-insulated building Q_{n_ins} = 110207 W.
- Total heat loss of the non-insulated building with new windows installed $Q_{n\_ins\_w}$ = 93167 W;
- Annual heat power required for hot water preparation Q^{y}_{hw} = 10202 kWh/year.

Heating degree-days value is determined D_d [K · days] :

$$D_d = (t_{int} - t_{ht}) \cdot z_{ht} = (20-0.6) \cdot 162 = 3142.8\ K \cdot days \quad (80)$$

There is a need of introducing an adjustment factor $\mathcal{E}$ which will consider external influences on heating process:

$$\mathcal{E} = e_i \cdot e_t \cdot e_d = 0.8 \cdot 0.8 \cdot 0.8 = 0.512 \quad (81)$$

where: e_i – reflects asynchronism of infiltration heat loss and convection heat loss (because heat loss by infiltration usually account for 10-20% of the total heat loss, it is chosen in the range 0.8 to 0.9);

e_t – reflects decrease of the temperature in the room during the day/night (selected in the range from 0.8 for half-day use up to 1.0 for a building with a 100% performance of the heating system 24 hours a day);

e_d – reflects shortening of heating of the building with operational interruptions. For seven-day per week operation building is equal to 1.

Annual need of heating power $Q_{h,an}$ [kWh/year]:

$$Q_{h,an} = \frac{\varepsilon}{\eta_0 \cdot \eta_r} \cdot \frac{24 \cdot Q \cdot D}{t_{int} - t_{ext}} \text{ [kWh/year]} \quad (82)$$

where: η_0 – effectiveness of the operator or control system (selected in the range from 0.9 for solid fuel boiler up to 1.0 for boiler with gas heating system divided into sections);

η_0 – efficiency of heating distribution (chosen in between 0.95 and 0.98 depending on design).

According to (83), annual need of heating power for the

- non-insulated building Q_{h,an,n_ins}:

$$Q_{h,an,n\_ins\_w} = \frac{0.512}{0.95 \cdot 0.98} \cdot \frac{24 \cdot 110207 \cdot 3142.8}{20+17} = 127455 \text{ [kWh/year]}$$

- non-insulated building with new windows installed $\boldsymbol{Q_{h,an,n\_in\_w}}$:

$$Q_{h,an,n\_ins\_w} = \frac{0.512}{0.95 \cdot 0.98} \cdot \frac{24 \cdot 93167 \cdot 3142.8}{20+17} = 107748 \text{ [kWh/year]}$$

- insulated building $\boldsymbol{Q_{h,an,n\_ins}}$:

$$Q_{h,an,n\_ins} = \frac{0.512}{0.95 \cdot 0.98} \cdot \frac{24 \cdot 57465 \cdot 3142.8}{20+17} = 66458 \text{ [kWh/year]}$$

Knowing calorific value ***H*** of used fuel (natural gas – 10.5 kWh/m^3), we can obtain annual volume of needed gas $\boldsymbol{V_{an}}$ [m^3/year]:

$$V_{an} = (Q_{h,an} + Q^y_{hw}) / H \; [m^3/year] \quad (83)$$

Annual fuel cost $\boldsymbol{C_{an}}$ [MDL/year] is calculated with consideration of current gas tariffs for final consumers in Moldova, $\boldsymbol{c_{gas}}$ = 5.96 MDL/m^3, although it is expected an increase in the price to 6.33 MDL/m^3.

$$C_{an} = V_{an} \cdot c_{gas} \; [MDL/year] \quad (84)$$

Tab. 65. Fuel necessity for various types of building insulation

Insulation	$Q_{h,an}$	Q^y_{hw}	V_{an}	c_{gas}	C_{an}	C_{an_exp}
	[kWh/year]		[m^3/year]	[MDL/m^3]	[MDL/year]	
Non-insulated	127455		13110.25		78137.1	82988
Non-insulated with windows replaced	107748	10202	11233.4	5.96	66951.1	71107
Insulated	66458		7301.05		43514.27	46215

14.2 Building envelope insulation

Entry data for economical evaluation is obtained by determining the installation (initial) and operational costs of the system as well as savings obtained as a result of its implementation.

Savings obtained by insulation of the building envelope result from reduction of fuel consumption during the year. Besides, an important factor to consider is reducing solar heat gains inside the buildings in the summer. Interior temperature does not rise above 27 °C during summer, eliminating by that the strict necessity of implementing air conditioning system.

14.2.1 Windows initital cost

Total area of windows of the building is 314.8 m^2. As it was mentioned in p. 9.3, triple-glazed windows of the type 4M1-10Ar-4M1-10Ar-4M1(i) were chosen. Price for acquirement, transport and installation of this type of windows, considered various required sizes, can be accepted as 500 MDL per m^2. Total cost will be:

$$IC_{win} = 500 \cdot 314.8 = 157400\ MDL.$$

14.2.2 Thermal insulation initial cost

Required amount of thermal insulation materials is calculated basing on data from Chapter 9, according to area and material consumption per m^2, specified by manufacturer. Prices are retrieved from suppliers and contractors accessible on-site in Chisinau. Calculation of required materials is given in table (Tab. 66).

Tab. 66. Calculation of building insulation cost

Material	Depth [m]	Area [m^2]	Price per m^2 [MDL/m^2]	Total price [MDL]
Baumit adhesive mortar	0,003	880,8	36	31708,8
Isover Fassil mineral wool boards	0,1	805,9	185	149091,5
Isover Fassil mineral wool boards	0,8	74,9	150	11235
Isover Fassil mineral wool boards	0,6	356,4	106	37778,4
Baumit silicate plaster	0,003	880,8	61	53728,8
Baumit silicate paint	0,0002	880,8	9	7927,2
Webe.dur 130 light base coat	0,003	880,8	43	37874,4
Installation costs				32370
TOTAL				**361714,1**

Total expenses for thermal insulation works are 361714 MDL.

14.2.3 Economic feasibility of building insulation

Quick assessment of economic feasibility can be done by calculating payback period ***P*** [years] basing just on initial cost ***IC*** [MDL] and annual return ***AR*** [MDL]:

$$P = IC / AR\ [years] \tag{85}$$

All other factors being equal, the better investment is the one with the shortest payback period. But this method does not consider benefits which can occur after payback period and ignores the money time value, thus it can't be considered as a good reflexion of profitability.

In order to provide a more detailed view over economic efficiency, discounted payback period $\boldsymbol{P_d}$ [years] is used:

$$P_d = \frac{\ln[1 + \frac{IC}{AR} \cdot (\alpha - r)]}{\ln \frac{1+\alpha}{1+r}} \text{ [years]} \tag{86}$$

where: - $\boldsymbol{\alpha}$ – inflation rate (considered as 2%);

- $\boldsymbol{r}$ – discount rate (considered as 5%).

Knowing discounted payback period, it is possible to evaluate the benefit and cost cash flow, by calculating net present value ***NPV*** [MDL]. It represents the sum of present values of outgoing and incoming cash flows over a certain time domain. ***NPV*** is determined by calculating the negative and positive cash flows for each year of an investment. After the cash flow for each year is calculated, the present value ***PV*** [MDL] of each one is achieved by discounting its future value at a periodic rate of return.

$$NPV = AR \cdot \frac{(1 + r - \alpha)^t - 1}{(r - \alpha) \cdot (1 + r - \alpha)^t} - IC \text{ [MDL]} \tag{87}$$

where: - $\boldsymbol{t}$ – lifetime of the project [years];

Another indicator, Internal Return Rate ***IRR*** [%], equals the net present value of all cash flows from the analyzed project to zero. To calculate ***IRR***, we set ***NPV*** equal to zero and solve the relation for discount rate $\boldsymbol{r}$. Accumulated over the lifetime period $\boldsymbol{t}$ net cash inflow, represented by annual return is calculated for that. The higher is ***IRR***, the more profitable is the project over its lifetime.

$$\sum_{i=1}^{t} \frac{AR}{(1 + IRR)^t} - IC = 0$$

Calculation of economic indicators, exposed above for building insulation works and windows is given in table (Tab. 67). Annual return rate is the difference of annually consumed fuel cost for the case of insulated and uninsulated building, determined in p.14.1.

Tab. 67. Economic feasibility of building insulation improvement

	Self financing		Gas price increase		20% grant	
Project	Building insulation	Windows	Building insulation	Windows	Building insulation	Windows
Initial cost **IC** [MDL]	361714,1	157400	361714,10	157400	289371,28	125920,00
Annual return **AR** [MDL]	23437	11186	24892	11880,4	23437,00	11186
Inflation **α** [-]	0,02	0,02	0,02	0,02	0,02	0,02
Discount **r** [-]	0,05	0,05	0,05	0,05	0,05	0,05
Lifetime of project **t** [year]	25	25	25	25	25	25
Simple pay-back **P** [year]	15,43	14,07	14,53	13,25	12,35	11,26
Discounted payback **Pd** [year]	21,45	18,92	19,75	17,48	15,96	14,21
Net present value **NPV** [MDL]	46397,84	37383,47	71733,97	49475,16	118740,66	68863,47
Internal rate of return **IRR** [%]	6.1	7	6.7	7.6	8.4	9.4

In case of self-funding of entire project, discounted payback period is 85.8% (21.45 years) of total lifetime of the system for building insulation, and 75.7% (18.92 years) for windows. Although this can be considered a long payback time, project presents considerable financial benefits, considering its usage after the payback period. Internal return rate indicates that 6.1% of initial cost will return in form of the benefit from building insulation and 7% from windows. This equals to 22064 MDL for building insulation and 11018 MDL for windows replacement.

Expected gas price increase to 6.33 MDL/m^3 will lead to shortening the payback period with 1.7 years for building insulation and 1.44 years for windows replacement. Internal return rate is increased by 0.6% (24234 and 11962 MDL).

It is possible to obtain a grant, covering 20% of initial cost of the project, from MOSEEF. In that case, payback period is reduced to 64% (15.96 years) and 56.84 % (14.21 years) from system lifetime. Internal return rate increases by 2.3% comparing with the self-funding case.

Therefore, from financial point of view, building insulation is a profitable investition, although a long-term one especially when making use of external funding possibilities. An important factor is savings resulted from increasing solar heat gains during the summer. Considering elimination of necessity in cooling system installation, or diminishing its required power, economic impact of building thermal insulation is even higher. Another source of possible increasing economic effect is the expectable jump in gas prices, which will result in increasing heating expenses. Expected rise of gas prices cannot be included in the analysis though, due to lack of precise information.

Besides financial factor, certain benefits are presented by lowering the environmental impact and improving the image of the company, which is especially important in the case of engineering company.

14.3 Water heating system

As it was determined in p.10.6.2.4, designed solar collector with the area of 10.95 m^2 is able to generate energy ***E*** = 26190 MJ = 7275 kWh per year. Volume of annually consumed gas for the same amou nt of energy would be:

$$V_{an} = 7275 / 10.5 = 692.8\ m^3/year$$

Annual return at current gas price of 5.96 MDL/m^3 and expected rise to 6.33 MDL/m^3 is:

$$AR_{5.96} = 692.8 \cdot 5.96 = 4129\ MDL$$

$$AR_{6.33} = 692.8 \cdot 6.33 = 4385.5\ MDL$$

In calculating initial cost of solar collector system, we ignor the elements of gas boiler water heating system (like hot water tank and secondary heating circuit), as they are considered as a separate possible solution.

Operational costs, such as electrical energy needed for pump operation and maintenance were ignored, due to their low relative value to the obtained savings.

Tab. 68. Calculation of solar collector initial cost

Equipment	**Price**
Solar collector Reflex RSK II 25 - 5 pcs	50600
Equalization tank Reflex F 15	2014
Grundfos Alpha2 25-40	2330
Control system	3115
Piping	840
Valves	2740
Installation works	11750
TOTAL	73389

Tab. 69. Economic feasibility of solar collector system

	Self financing	**Gas price increase**	**20% grant**
Initial cost **IC** [MDL]	73389,00	73389,00	58711,20
Annual return **AR** [MDL]	4129,00	4385,50	4129,00
Inflation **α** [-]	0,02	0,02	0,02
Discount **r** [-]	0,05	0,05	0,05
Lifetime of project **t** [year]	25,00	25,00	25,00
Simple payback **P** [year]	17,77	16,73	14,22
Discounted payback **Pd** [year]	26,28	24,05	19,19
Net present value **NPV** [MDL]	-1490,11	2976,36	13187,69
Internal rate of return **IRR** [%]	4.8	5.4	6.9

Calculations show that solely from financial perspective, implementing solar collector system proves to be unfeasible solution in the case of self-funding. Payback period is bigger than system lifetime and net present value accounts to -1490 MDL. System moves on the edge of profitability after possible increase of gas prices to 6.33 MDL/m^3 lowering its payback period to 24 years. Economic feasibility will be improved in case if hot water cossumption rises. However, considering that hot water necessity, used during design is a maximally possible one in theory, given by the general standard, implementation of solar collector is not reasonable in analyzed application. Instead, more flexible and cheap on the initial costs options should be considered, such as electrical boilers installed at separate floors.

Implementing solar collector proves to be reasonable only in the case of obtaining a 20% grant from such organizations as MOSEFF. In that case, system starts to run in profit after 19.2 years of operation.

14.4 Photovoltaic panels

Economical feasibility of photovoltaic panels is completely dependent on energy policy in the region. Electrical energy price, feed-in tarrifs, possible tax reductions and supporting grants are vital to the development of solar energy technologies.

In the circumstances of harsh economical situation, Moldovan government does not have any possibilities of supporting investments in solar energy sector. In the same time, Moldovan energy industry is in a critical situation because of technological running out of power generation and distribution equipment and lack of investment possibilities.

Privatization of governmentally controlled energy distribution companies by „RED UNION FENOSA" in 2000 gave a boost to technical improvements in the industry, but today it suffers a deep crisis due to a number of reasons, which are out of the competence of the current study. Therefore it is hard to assess the future financial perspectives of solar energy technologies in Moldova. Power distribution company currently is not willing to contribute to stimulation of alternative energy sector.

Today, there are 5 companies in Moldova, which implemented photovoltaic panels. Only one of them is selling the harvested energy to the distribution network. Other four are using all the collected energy in their production activity. In each of these cases, an individual agreement for feed-in tariffs was negotiated with the power distribution company in the form of exception, after a long-term struggle and with intervention of governmental institutions.

Regular procurement rate c_e of electrical energy in Chisinau area is 1.58 MDL/kWh. In case of feed-in tarrifs, it was secured at 1.9 MDL/kWh.

Price of PANDA 48 Cell modules is 160 EUR per unit. Corresponding to currency exchange rate of 20 MDL to 1 EUR, 1 module is 3350 MDL. Total price of the modules will be 3350 MDL * 107 units = 358450 MDL. Other related costs as transportation and taxes can be estimated in 30000 MDL. General calculation of installation cost ***IC*** [MDL] is given in table (Tab. 70).

Tab. 70. Calculation of initial cost of PV system

Element	Price [MDL]
Photovoltaic modules - PANDA 48 Cell	358450
Invertor – Panpower SSI3-15KW	53350
Distribution panel	42400
Construction design and manufacturing	21200
Installation works	18000
Other costs	30000
Total	**523400**

Annual income from selling generated energy will be:

$$V_{PV,year} = E_a \cdot c_e = 27300 \cdot 1.58 = 43134\ MDL$$

where: $\boldsymbol{E_a}$ – annual electricity production from PV the system [kWh].

Tab. 71. Economic feasibility of photovoltaic system

Project	Self financing	Electricity price increase	20% grant
Initial cost **IC** [MDL]	523400	523400	418720
Annual return **AR** [MDL]	43134	52416	43134
Inflation **α** [-]	0,02	0,02	0,02
Discount **r** [-]	0,05	0,05	0,05
Lifetime of project **t** [year]	25	25	25
Simple payback **P** [year]	12,13	9,99	9,71
Discounted payback **Pd** [year]	15,61	12,28	11,87
Net present value **NPV** [MDL]	227698,71	389327,55	332378,71
Internal return rate **IRR** [%]	8.6	10.8	11.1

Payback period in case of individual funding is 15.6 years with 8.6% internal return rate. It results in 45012 MDL of net profit over the lifespan on the project. Being an acceptable rate for a photovoltaic panel system, it will improve at expected increase of electrical energy price or obtaining a guaranted feed-in tarrif from energy supplier and completely selling it at 1,9 MDL/kWh. It will increase net profit to 56527 MDL and reduce payback period to 12.3 years.

Obtaining a grant for implementing renewable energy technologies, offered by MOSEFF, in the value of 20% of installation costs, improves by itself the financial indicators: net present value from 227699 MDL to 332379 MDL, payback period to 11.9 years and internal revenue rate to 11.1%.

Implementing a PV system proves to be profitable and is highly recommended.

CONCLUSION

The main scope of the Thesis was study and analysis of renovation of old buildings in Moldova, with consideration of energy efficient measures and intelligent building design, according to valid regulations. Taking into account current on-going transition of Moldovan technical standards to EU energy norms and regulations, another goal was to provide a short insight in the energy saving possibilities using EU standards for Moldova. During design process, a compromise between national regulations and efficient energy-saving measures should be found.

Besides, study pays special attention to perspectives of implementation of renewable sources in buildings in Moldova, and the importance of supportive funding in the development of energy efficiency sector. Intelligent KNX system was proposed for thermal comfort provision and energy management.

This goal was achieved through a practical design example of a renovated 5-storey office building in the center of Chisinau.

Thesis is structured in two major parts: theory and analysis. Theoretical part presents a complex description of energy efficient building technologies and their legislative aspects, while practical part is focused on actual design of the object and analysis of implemented measures.

First chapter of theoretical part presents the current situation in the housing sector in Moldova, its current condition, improvement possibilities and barriers that stand in front of them. Residential sector accounts for 48.7% and commerce for 21.5% of total energy consumption. Given data makes it evident that investing in building energy efficiency has a high energy saving potential and is the shortest way to increasing overall condition of energy sector in Moldova. Analysis of energy tariffs shows that energy prices in Moldova are highest between EaP members. A presentation of legislative field presents current efforts in transition to EU energy standards, last one being the adoption of Energy Performance in Buildings Law.

Second chapter presents the specific aspects of energy efficiency measures in commercial office buildings. It describes possible measures for energy savings in office buildings and types of low-energy buildings.

Third and fourth chapters describe the requirements towards inner environment and building physics. A parallel is drawn between EU and current Moldovan legislation. It is evident that current Moldovan legislation is out-of-date, when referring to modern energy saving approach. Following requirements of EU norms is highly advised. However, this is not possible in practice in the fields, linked with sanitary norms, like lighting, acoustics or some aspects of hot water supply.

Last three chapters of theory part deal with description of specific technologies, used for inner microclimate formation and energy saving.

Analysis part of the Thesis starts with the description of analyzed object, its background and properties. Structural design of the building is presented, including its orientation and floors layout. Presented layout is the one accepted for reconstruction.

In Chapter 9, existing building physics state is evaluated, by performing thermal analysis of the structure. Structure analysis and heat loss calculations proved that existing state is extremely inefficient from energy performance perspective, being of “F” class according to Energy Performance Rating. Through individual approach to each structure, optimal thermal insulation was proposed, finding compromise between energy efficiency improvement and potential investment possibilities, increasing overall energy performance class to “C”.

Basing on thermal calculations, a proper heating and hot water preparation system was designed in Chapter 10. Gas boiler was selected as the main heat source, because of low initial investment and affordable gas prices in Moldova. Hot water preparation system is a combined solar collector and gas heating one.

Knowing the purpose of the spaces in the building, electrical design was done in Chapter 11. Electrical distribution network was calculated and designed according to electrical load of used appliances and lighting. Lighting was designed to conform with national norms for illumination.

Of all renewable sources, sun is the most accessible and has highest potential in Moldova. Chapter 12 contains the design of photovoltaic panels, which should be installed on the south-eastern side of the roof. PV system is a grid-connected one, without storing energy in batteries. Due to complexity and high cost of automatic positioning equipment, an optimal angle for solar panels inclination was calculated. Calculations were based on available data of global sun radiation at the latitude of Chisinau. Electrical U-I characteristics of the chosen modules were determined for conditions of Chisinau, being the base for electrical load control for maintaining optimal operation characteristics. Expected electricity production from PV system is 27300 kWh per year.

In order to provide proper control of building management systems, a KNX control and visualization system was proposed in Chapter 13. A complex and integrated system allows control of heating, hot water preparation, lighting and blinds control from central touch panel or PC station. Individual thermal comfort values can be set on a room-oriented basis centrally or from local switch panels as well. System allows pre-setting of automated control of equipment. Energy savings in that case are achieved by: automatic artificial lighting control according to daylight level and presence, blinds control to limit unwanted heat loss or gains, automatic heating regulation according to outside temperature and pre-set temperature in the rooms, automatic heating turndown during periods when building is unused (nights, weekends).

Last chapter deals with economical evaluation of offered system in the context of current energy prices and financing opportunities. All of the offered energy-saving measures are long-term investments, with payback period ranging from 15.6 years (PV system) to 26 years (solar collector). Internal return rate is above 6.1% for all systems, besides the solar collector.

Study proves the crucial role of subsidizing energy saving measures by governmental funds. Currently, subsidies for building energy efficiency in the value of up to 20% are available through MOSEFF fund, financed by EBRD. Covering 20% of installation cost result in reducing the payback period by 25% in our case (up to 5 years). This factor can directly influence the investor’s decision of installing a system. Profitability of the system increases by that as well. Some systems are profitable just with the condition of external funding, like solar collector.

Another stimulating factor is the possibility of obtaining feed-in tariffs for PV energy, which can improve PV system payback period from 15.6% to 12.3%. Expected increase in energy prices would increase competitiveness of energy efficient solutions as well.

BIBLIOGRAPHY

[1] Economic Commission for Europe. *Country Profiles on The Housing Sector, Republic of Moldova.* 2002. Available from: http://www.unece.org/housing-and-land-management/housingareas-of-work/housingcountry-profiles/country-profile-studies/republic-of-moldova-2002.html

[2] ŢULEANU C., BINZARI A., NICOLAV E. Analiza performanţelor energetice ale clădirilor din Republica Moldova, un deziderat important în contextul actual al reducerii consumurilor de resurse energetice şi a impactului asupra mediului înconjurător. In*: Revista Română de Inginerie Civilă*. 2013. Volume 4. Bucharest.

[3] *International Monetary Fund, World Economic Outlook Database*. IMF. 2014 [cit. 2015-02-21]. Available from: https://www.imf.org/external/ns/cs.aspx?id=28.

[4] CITRUS PARTNERS LLP. *Moldova. Study into improving the energy efficiency of residential buildings.* 2011. Available from: http://www.unece.org/fileadmin/DAM/hlm/prgm/cph/experts/moldova/housing_info/energy_efficiency_study.pdf

[5] INOGATE. *A Review of Energy Tariffs in INOGATE Partner Countries*. 2015. Available from: http://www.inogate.org/documents/A_Review_of_Energy_Tariffs_in_INOGATE_Partner_Countries.pdf

[6] BÎNZARI A., A. and C. ŢULEANU. The current state in the field of energy efficiency in the Republic of Moldova. In: XIV-th International Multidisciplinary Conference “Professor Dorin Pavel – Founder of Romanian Hydroenegretics”. Sebes, 2014.

[7] National Bureau of Statistics of Republic of Moldova. *Energy Balance of the Republic of Moldova. Statistics Collection. 2013.* Chisinau. 2014. Available from: http://www.statistica.md/public/files/publicatii_electronice/balanta_energetica/BE_2014_rom.pdf

[8] *Energy Strategy of the Republic of Moldova until year 2030*. Approved by Government Decision no. 102 of February 5, 2013. Available from: http://lex.justice.md/md/346670/

[9] Reports: Energy use in homes. *Building Research Establishment* [online]. 2007 [cit. 2015-03-20]. Available from: http://www.bre.co.uk/page.jsp?id=1753

[10] HASTINGS S., *Passive Solar, Commercial And Institutional Buildings*. Chichester: John Wiley & Sons, 1994.

[11] KOK H., HOLTZ M., *Passive And Hybrid Solar Low Energy Buildings*. Paris: International Energy Agency, 1990.

[12] ČSN EN 15251. *Vstupní parametry vnitřního prostředí pro návrh a posouzení energetické náročnosti budov s ohledem na kvalitu vnitřního vzduchu, tepelného prostře-dí, osvětlení a akustiky.* Praha: Úřad pro technickou normalizaci, metrologii a státní zkušebnictví, 2011.

[13] ASHRAE. *2013 ASHRAE Handbook*. Atlanta, GA: Ashrae, 2013. ASHRAE Terminology. ISBN 19-138-6273.

[14] ČSN EN ISO 7730. *Ergonomie tepelného prostředí – Analytické stanovení a interpretace tepelného komfortu pomocí výpočtu ukazatelů PMV a PPD a kritéria místní-ho tepelného komfortu.* Praha: Český normalizační institut, 2006.

[14] ASHRAE. *2013 ASHRAE Handbook*. Atlanta, GA: Ashrae, 2013. Thermal Comfort. ISBN 19-138-6273.

[15] FANGER P. *Thermal Comfort: Analysis And Applications In Environmental Engineering*. New York: McGraw-Hill, 1972.

[16] JENSEN K., and E. ARENS. Acoustic Quality in Office Workstations, as Assessed by Occupant Surveys. In: *Proceedings, Indoor Air 2004*. Beijing, China. 2005.

[17] NCM E.04.02-2006. *"Protectia contra zgomotului*". Chisinau: Agentia constructii si dezvoltare a teritotiului Republicii Moldova, 2007.

[18] NCM C.04.02-2005. *Iluminatul natural şi artificial (exigenţe funcţionale. Instalaţii electrice)*. Chisinau: Agentia constructii si dezvoltare a teritotiului Republicii Moldova, 2006.

[19] HENS H. *Building Physics--Heat, Air And Moisture*. Berlin: Ernst & Sohn, 2007. ISBN: 978-3-433-03027-1.

[20] ČSN 730540-2. *Tepelná ochrana budov*: Část 2. Praha: Úřad pro technickou normalizaci, 2011.

[21] СНиП 23-02-2003. "*Тепловая защита зданий*". Moscow: State Committee for Construction of Russian Federation, 2003.

[22] ČSN EN 12831. *Tepelné soustavy v budovách: Výpočet tepelného výkonu*. Praha: Český normalizační institut, 2005.

[23] SPITLER J. *Load Calculation Applications Manual*. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2009. ISBN 978-193-1862-974.

[24] GREENWALD M. *Residential Hot Water And Steam Heating*. Englewood Cliffs, N.J.: Prentice-Hall, 1987.

[25] KAVANAUGH S. *HVAC Simplified*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2006. ISBN 978-193-1862-974.

[26] МДС 41-2.2000. *Инструкция по размещению тепловых агрегатов, предназначенных для отопления и горячего водоснабжения одноквартирных или блокированных жилых домов.* Moscow: Russian Ministry of Construction, 2000.

[27] NORTON B. *Harnessing Solar Heat.* Springer, 2003. ISBN 978-94-007-7275-5.

[28] WALKER N. *Harnessing Power From The Sun*. New York: Crabtree Pub. Co, 2007.

[29] DUNLOP J. *Photovoltaic Systems*. Orland Park, Ill.: American Technical Publishers, Inc, 2010.

[30] BOSTAN I., GHEORGHE A., SOBOR I. *Resilient Energy Systems for Renewables: Wind, Solar, Hydro.* Springer, 2012.

[31] BOSTAN I., DULGHERU V., SOBOR I. *Sisteme de Conversie a Energiilor Regenerabile*. Chisinau: “Bons Offices” SRL, 2007.

[32] KNX. 2014. *KNX* [online]. [cit. 2015-06-13]. Available from: http://www.knx.org/knx-en/index.php

[33] KNX System Architecture. *Konnex Association [online]*. 2004 [cit. 2015-07-20] Available from: http://paginas.fe.up.pt/~ee07367/wordpress/wp-content/uploads/2013/03/KNX%20System%20Architecture.pdf

[34] СНИП 23-01-99. “*Строительная климатология*”. Moscow: State Committee for Construction of Russian Federation, 2000.

[35] CP E.04.05-2006. *Proiectarea protectiei termice a cladirilor.* Chisinau: Agentia constructii si dezvoltare a teritotiului Republicii Moldova, 2006.

[36] *ГОСТ 11024-84 "Панели стеновые наружные бетонные и железобетонные для жилых и общественных зданий. Общие технические условия.* Moscow: State Committee for Construction, 1985.

[37] СНИП 2.03.13-88. "Полы. Толщина, покрытия полов, прослойка, стяжка и подстилающие слои полов". Moscow: State Committee for Construction, 1989.

[38] MILLER M, MILLER R. *Complete Building Construction*. Indianapolis, Ind.: Wiley, 2004.

[39] ГОСТ 30674-99. *"Блоки оконные из поливинилхлоридных профилей".* Moscow: State Committee for Construction, 1989.

[40] CHECHETKIN A. *High temperature heat carriers*. New York: Octavo, 1963. ISBN 978-0080098982.

[41] HANSEN E. *Hydronic System Design And Operation*. New York: McGraw-Hill, 1985. ISBN 978-0070260658.

[42] СНиП 2.04.01-85. "*Внутренний водопровод и канализация зданий*". Moscow: State Committee for Construction, 1986.

[43] LADD G, HARRISON J. *Electric Water Heating For Single-Family Residences*. Palo Alto, Calif.: Electric Power Research Institute, 1985.

[44] Tlaková expanzní nádoba. 2011. *TZB-info* [online]. [cit. 2015-05-25]. Available from: http://vytapeni.tzb-info.cz/tabulky-a-vypocty/60-tlakova-expanzni-nadoba

[45] TROST J. *Design Of Mechanical And Electrical Systems In Buildings*. Upper Saddle River, N.J.: Pearson/Prentice Hall, 2004.

[46] Brandi U, Geissmar C. *Lightbook: The Practice of Lighting Design*. Basel: Birkhäuser, 2001. ISBN 978-3764363031

[47] MCDOWALL R. *Fundamentals Of HVAC Control Systems*. Amsterdam: Elsevier, 2009. ISBN: 978-0080552330.

[48] SHORT W. *A Manual For The Economic Evaluation Of Energy Efficiency And Renewable Energy Technologies*. Honolulu, Hawaii: University Press of the Pacific, 2005.

LIST OF ABBREVIATIONS

EaP	Eastern Partnership
GDP	Gross Domestic Product
USD	United States Dollar
IMF	International Monetary Fund
ENTSO-E	European Network of Transmission System Operators for Electricity
ANRE	National Agency for Energy Regulation
EEA	Agency for Energy Efficiency
EEF	Energy Efficiency Fund
CEN	European Committee for Standardization
PMV	Predicted Mean Vote index
PPD	Predicted Percentage of Dissatisfied
PD	Predicted Percentage Dissatisfied due to draft
DR	Draft rate
PV	Photovoltaic
DC	Direct current
EHS	European Home Systems Protocol
HVAC	Heating, ventilating, and air conditioning
BRE	Building Research Establishment
UK	United Kingdom
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
KNX	Konnex – OSI based network communications protocol
EPC	Energy Performance Certificate
etc.	Abbreviation of expressions such as: and so forth, and so on
MDL	Moldovan Lei

IRR	Internal Rate of Return
PIR	Passive InfraRed sensor
MOSEFF	Moldovan Sustainable Energy Financing Facility
EBRD	European Bank for Reconstruction and Development
GOST	State Union Standard
SNIP	Construction Codes and Regulations (Stroitelnye Normy i Pravila)

LIST OF FIGURES

LIST OF TABLES

APPENDICES

A I Building facade

A II Floor layout plans

A III Heating system floor layout plans

A IV Heating system general scheme

A V Electrical distribution layout scheme

A VI Electrical lighting layout scheme

A VII Electric circuit general diagrams

A VIII Doors and windows

Appendices are attached in the CD, togethere with an electronic version of the work.