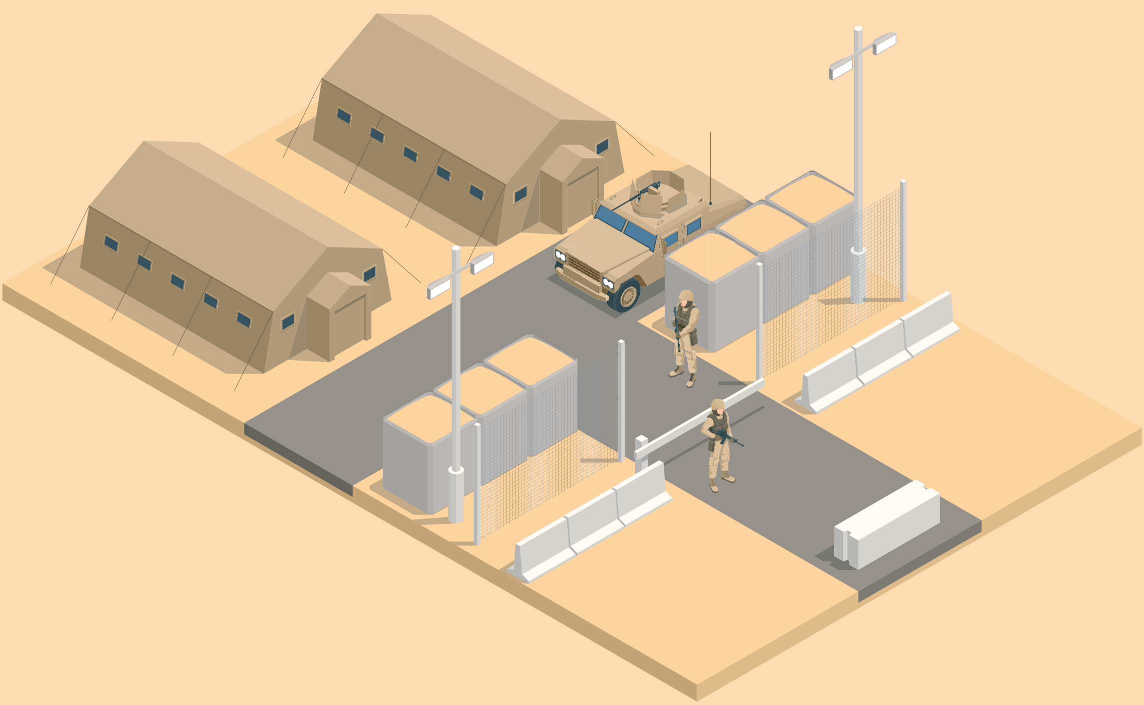
RIGA TECHNICAL UNIVERSITY

Aleksandrs Geikins

METHODOLOGY FOR EVALUATION OF ENERGY EFFICIENCY OF UNCLASSIFIED BUILDINGS

Summary of the Doctoral Thesis



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RIGA TECHNICAL UNIVERSITY
Faculty of Civil Engineering
Institute of Heat, Gas and Water Technology

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Summary of the Doctoral Thesis

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defense at the open meeting of RTU Promotion Council on 11 October 2022 13:00 at the Faculty of Civil Engineering of Riga Technical University, Kipsalas Street 6A, Room 546.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Aleksandrs Geikins ……………………………. (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction, 5 chapters, Conclusions, 85 figures, 30 tables; the total number of pages is 130. The Bibliography contains 104 titles.

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INTRODUCTION

According to the International Energy Agency (IEA) report, energy consumption in 2018 grew at the fastest rate in the last decade, and CO_2 emissions rose to a record high level. Total global final energy consumption in the building sector in 2019 (compared to 2018) remained stable at around 35–40 % [1], while CO_2 emissions from buildings peaked at around 28 % of total global energy-related CO_2 emissions [2].

The Covid-19 pandemic was the biggest shock to the global energy system, with energy consumption falling by almost 8 % in 2020, the lowest level since 2010. At the beginning of 2022, the global energy system was shaken by the geopolitical situation in the world. Of course, changes in the energy balance can already be observed, but real data have not yet been processed for analysis, therefore, the Thesis is based on real available data from the IEA, EUROSTAT and the Central Statistical Bureau of Latvia for 2021.

In 2021, economic activity and energy use recovered in countries around the world, and global energy demand increased by 4.6 %, driven by a strong global economy and increased heating and cooling needs. Almost 70 % of global energy demand growth is in emerging markets and developing countries, where demand rose to 3.4 % above 2019 levels. Demand for all fuels increased, led by natural gas, coal, even as solar and wind posted double-digit growth. Higher electricity demand was responsible for over half of the growth in energy needs. Energy efficiency saw lackluster improvement.

Energy efficiency across the global economy continued to improve, with global primary energy intensity falling by 1.3 %. But this was lower than improvement rates seen in recent years. Energy efficiency trends are expected to return to a ten-year average after the worst year in ten years. However, the level of improvement needs to double compared to the current level to be in line with the IEA's net zero emissions scenario by 2050.

Today only around one-third of final energy use is covered by mandatory energy efficiency policies, such as codes and standards, with only marginal coverage growth in recent years. Efforts to strengthen existing energy efficiency policies also remained weak in 2021. Increasing the coverage and strength of codes and standards is a key lever of energy efficiency gains.

The report of the International Energy Agency (IEA) notes the lack of a regulatory framework in the field of energy efficiency, which reaffirms the topicality and relevance of the theme chosen for this Thesis.

Currently, no specific energy audit methodology for unclassified buildings is available in Latvia.

Uncertainty, lack of specialized regulations governing operational characteristics and, as a result, lack of existing regulatory framework; application of civil engineering norms which do not specify the criteria to be taken into account in making calculations and specific technical decisions to determine unclassified buildings energy efficiency – all of this leads to a decrease in the energy efficiency of unclassified buildings, an increase in operating costs, and the emergence of significant discrepancies between theoretical (calculated) and practical data, resulting in a distortion of the values of the planned and obtained results.

Topicality of the Thesis

The lack of a direct regulatory framework and a limited amount of specialized publications and statistics do not allow clear, consolidated decisions to be made when planning the potential economic and energy costs of unclassified building energy efficiency projects or energy stagnation in the face of constantly increasing energy demand.

There is a lack of empirical research in nowadays literature which would allow to test the proposed theoretical concepts, thus, this Thesis in order to confirm the irreversible need for energy efficiency improvement, systematisation and improvement of calculation values in the existing regulatory framework, as well as the use of computer modeling solutions and the application of typical design with technical solutions in the construction or renovation of unclassified buildings, applies 1) analytical type of research that includes statistical data collection; 2) research of the European Union and United States of America legislation; 3) research on missing technical values in the Republic of Latvia laboratory and field research; 3) mathematical and thermodynamic, theoretical and practical calculations, taking into account the specifics of the use and application of the web-modeling tool, as well as the calculation of potential economic impacts.

The aim and tasks of the Thesis

The aim of the Thesis is to develop an energy audit methodology for unclassified buildings with guidelines for technical inspection of unclassified buildings with a focus on the development of common renovation and power supply solutions that will ensure high quality of work and minimize the number of stakeholders in the renovation process, in order to achieve and introduce possible improvements to reduce energy consumption.

To achieve this goal, the following **tasks** were set:

1. To study the existing strategic goals and directions of action of the European Union and the Republic of Latvia in energy efficiency, their tendencies and challenges. To examine existing legislation with possible application in the context of unclassified buildings.
2. To summarize, analyze and draw conclusions on the existing energy consumption statistics of unclassified buildings and the practical indicators received on the researched objects. The Thesis looks at the portfolio of unclassified buildings in Latvia, namely, comparing the age of buildings within different services.
3. To perform an initial analysis and classification of building sets according to typology.
4. To systematize unclassified buildings according to their functional, constructive, and other features to implement standard energy efficiency solutions that can subsequently be replicated to similar buildings and in case of further modelling it would be possible to analyze the impact of energy efficiency improvement measures on the overall energy performance of buildings without attaching it to a specific address.
5. To conduct a study on the limit values for the data to be entered in the energy audit.
6. To develop a methodology for evaluation of energy efficiency of unclassified buildings, taking into account the specific values of factors, calculation methods, and regulatory requirements.

Hypothesis of the Thesis

A methodology for evaluation of energy efficiency of unclassified buildings has been developed, which includes guidelines for the technical inspection of unclassified buildings, the main purpose of which is to establish a common energy performance assessment considering the specifics of unclassified buildings and enable ensuring of the development of sustainable renovation and energy supply solutions for unclassified buildings.

Methodology of research

To achieve the aim, it was necessary to conduct a research that provides a full empirical cycle – from facts, data collection, grouping, and forming a hypothesis to testing the hypothesis with new empirical material, as well as validation of research results, i.e. a set of complex measures to prove the reliability of research data and justification of data readiness.

The researched criteria, which have been used during the development of the methodology for reducing the energy consumption of unclassified buildings, are shown in Fig. 1.

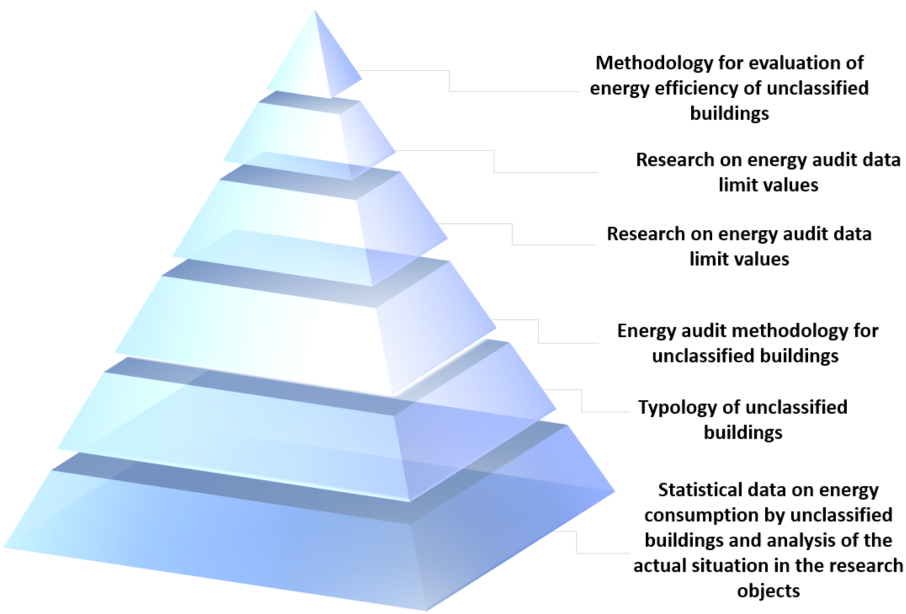

Fig. 1. Researched criteria used during the development of the methodology for evaluation of energy efficiency of unclassified buildings.

Scientific significance of the Thesis

Currently, no specific methodology for evaluation of energy efficiency of unclassified buildings is available in Latvia, including a methodology for determining the energy efficiency of buildings, which is directly addressed to temporary structures and permanently located unclassified buildings.

Practical significance of the Thesis

The develop methodology for evaluation of energy efficiency of unclassified buildings and planning tool with a detailed study of energy consumption and ongoing processes to increase energy efficiency in existing and projected unclassified buildings due to projected climate change will undoubtedly reduce total primary energy consumption, reduce greenhouse gases emissions and at the same time will affect the overall efficiency and management costs of the types of buildings studied. Therefore, the existence of an energy consumption forecasting methodology and assessment tool that will take these future trends into account in the long-term development planning phase is important for different development scenarios.

Structure and description of the Doctoral Thesis

The Thesis is organized in 5 chapters.

Chapter 1 analyzes the current situation in the field of energy efficiency of unclassified buildings: the common strategic goals of the European Union and the Republic of Latvia (LR) are considered; the average specific energy consumption of the buildings owned by the Ministry of Defense (MoD) and the Ministry of the Interior (MoI) of the Republic of Latvia has been assessed. An extensive study of the proposed energy consumption forecasting methodology was carried out.

In Chapter 2, the classification of unclassified buildings according to various parameters was performed: functional purposes, number of stores, durability, wall materials and wall constructions.

Chapter 3 describes the development of the methodology for determining the energy performance of unclassified buildings. Factors influencing the energy efficiency of buildings are studied. The developed research methodology is described, as well as the model for determining the heat loss of buildings and tents is developed. An analysis of the requirements of the current legislation and their adaptation to unclassified buildings has been performed.

Chapter 4 describes the study on the limit values of the data to be entered in the energy audit; it is based on surveys on indoor comfort in a military facility and summaries of results and indoor air quality (IAQ) measurements in different types of unclassified buildings (barracks, administrative buildings, canteens, fire stations, etc.). The amount of air exchange in unclassified buildings has been determined and a specific study directly related to the topic of the Thesis has been performed – the effect of uniform on thermal comfort.

Chapter 5 describes the validation of results for practical use and the development of renovation scenarios for unclassified buildings. A modular ballistic-resistant wooden frame insulation solution has been developed and simulated and its use in the renovation of unclassified buildings has been considered. The potential for the use of solar energy in existing unclassified buildings has been calculated. Possible economic impact by implementing energy efficiency improvement programs for unclassified buildings has been calculated, which allows the author to draw final conclusions of the Thesis.

Approbation of the Thesis

The results of the Doctoral Thesis have been presented at 5 international conferences and in 12 scientific articles (11 articles are indexed in SCOPUS database):

1. **Geikins, A.,** Borodinecs, A., Jacnevs, V. Estimation of Energy Profile and Possible Energy Savings of Unclassified Buildings. Buildings. 2022, 12(7): 974. https://doi.org/10.3390/buildings12070974 (SCOPUS).
2. Borodinecs, A., **Geikins, A.,** Barone, E., Jacnevs, V., Prozuments, A. Solution of Bullet Proof Wooden Frame Construction Panel with a Built-In Air Duct. Buildings, 2022, 12(1), 30. DOI: 10.3390/buildings12010030 (SCOPUS).
3. Zemitis, J., Borodinecs, A., Bogdanovics, R., **Geikins, A**. A case study of thermal comfort in a temporary shelter. Journal of Sustainable Architecture and Civil Engineering, 2021, 29(2), pp. 139–149. DOI: 10.5755/j01.sace.29.2.29240 (SCOPUS).
4. Borodinecs, A., **Geikins, A.,** Prozuments, A. Energy consumption and retrofitting potential of Latvian unclassified buildings. Smart Innovation, Systems and Technologies, 2020, 163, pp. 319–326. DOI: 10.1007/978-981-32-9868-2_27 (SCOPUS).
5. Borodiņecs, A., **Geikins, A.,** Smirnovs, S. Energy Performance of Temporary Shelters. IOP Conference Series: Materials Science and Engineering, 2019, 660(1), 012017. DOI:10.1088/1757-899X/660/1/012017. (SCOPUS).
6. **Geikins, A**., Borodinecs, A., Daksa, G., Bogdanovics, R., Zajecs, D. Typology of Unclassified Buildings and Specifics of Input Parameters for Energy Audits in Latvia. IOP Conference Series: Earth and Environmental Science, 2019, 290(1), 012131 DOI: 10.1088/1755-1315/290/1/012131 (SCOPUS).
7. Borodiņecs, A., **Geikins, A.,** Zemītis, J. Life-Cycle Assessment of Apartment Building Renovation in Latvia. ASHRAE Transaction, 2018, 1, pp. 1–9. ISSN 2378-2129.
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9. Tumanova, K., Borodiņecs, A., **Geikins, A.** The Analysis of the Hot Water Consumption and Energy Performance before and after Renovation in Multi-Apartment Buildings. IOP Conference Series: Materials Science and Engineering, 2017, 251(1), 012058. DOI:10.1088/1757-899X/251/1/012058; (SCOPUS).
10. Borodiņecs, A., Zemītis, J., Dobelis, M., Kaļinka, M., **Geikins, A.** Development of Prefabricated Modular Retrofitting Solution for Post-World War II Buildings. 10th International Conference on Environmental Engineering, ICEE 2017, 2017, enviro.2017.252. DOI:10.3846/enviro.2017.252; (SCOPUS).
11. Zemītis, J., Borodiņecs, A., **Geikins, A.,** Kalames, T., Kuusk, K. Ventilation System Design in Three European Geo Cluster. Energy Procedia, 2016, Vol. 96, pp. 285–293. ISSN 1876-6102. DOI: 10.1016/j.egypro.2016.09.15. (SCOPUS).
12. Borodiņecs, A., Zemītis, J., Millers, R., Tumanova, K., **Geikins, A**., Nefedova, A. Specifics of Multi-Apartment Building Deep Complex Retrofitting. CESB 2016 – Central Europe Towards Sustainable Building *2016*: Innovations for Sustainable Future, 2016, pp. 49–55. DOI: 10.1016/j.egypro. 2016.09.151 (SCOPUS).

1. ANALYSIS OF THE CURRENT SITUATION IN THE FIELD OF ENERGY EFFICIENCY OF UNCLASSIFIED BUILDINGS

1.1. Common objectives and energy efficiency action plans of the European Union and the Republic of Latvia

The issues of climate change, including the reduction of greenhouse gas (GHG) emissions and attracting carbon dioxide (CO_2), are at the center of attention in the European Union (EU) and are also very important to Latvia. Latvia has ratified the United Nations (UN) Framework Convention on Climate Change, its Kyoto Protocol and the Doha Amendment, as well as the Paris Agreement. The Sustainable Development Strategy of Latvia until 2030 (Latvia 2030) states: "Latvia is our home, it is a green and clean, creative and easily accessible place in the global space, and we are responsible to future generations for its sustainable development". According to the Latvian National Energy and Climate Plan (NEPP), it is necessary to reduce the total Latvian GHG emissions by 60 % by 2030 compared to the total Latvian GHG emissions in 1990.

EU energy efficiency Directive 2012/27/EU [3] and EU Directive 2010/31/EU on the energy performance of buildings [4] encourage to act immediately to decrease carbon dioxide emissions and increase the proportion of renewable sources used. The proposal to amend Directive 2012/27/EU sets an obligation to achieve new annual energy end-use savings of 0.8 % over the period 2021–2030.

The National Development Plan (NDP 2027) also determines an action plan for energy efficiency, energy production; and its objective is to ensure sustainable use of the energy resources necessary for the national economy by promoting the availability of resource markets, ensure a decrease of energy intensity and emission intensity in the sectors as well as decrease of the proportion of local renewable resources in the total amount consumed.

The tasks to be performed in the framework of the action plan:

- ✓ Energy efficiency programs in the state and municipal public building sector.
- ✓ Support for innovative energy and energy efficiency technology projects.
- ✓ The use of renewable energy resources in energy production, thus decreasing dependence on fossil energy resources, and the promotion of energy efficiency in district heating.

As stated in Energy Efficiency Directive 2012/27/EU, the EU member states, including Latvia, have decided to take various measures to improve the efficiency of energy production and supply, as well as consumption. The Directive also provides for a mandatory objective – every state, every year has to ensure customer energy efficiency measures that would allow saving 1.5 % of the total energy supplied to customers in the state.

The concept offers a solution for the fulfilment of this obligation that provides, starting from 2014, for the renovation of 3 % of the **buildings belonging to the state** every year, **including** unclassified buildings, such as military buildings, police buildings, and fire stations common areas used for performing the functions of direct administration.

As stated in Directive 2012/27/EU on energy efficiency, one of the largest potential fields for the improvement of energy efficiency is city buildings where particular attention is given to the **buildings owned by the state and municipalities which should serve as an example for the rest of society** [5].

In accordance with the requirements of Article 5, member states, by 31 December 2013, shall establish and make publicly available an inventory of heated and/or cooled central government buildings with a total useful floor area over 500 m^2 and, as of 9 July 2015, over 250 m^2, excluding buildings to which an exemption applies. The requirements of the Directive do not apply to buildings that are cultural and historical monuments, buildings used as places of worship or serving national defense purposes.

In accordance with the requirements provided for in Article 5 of Directive 2012/27/EU, the Ministry of Economics of the Republic of Latvia (MOE) delegated the task to the maintainers of the state and municipal buildings to prepare and provide to MOE information on energy consumption by real property subordinate to them (RPEC) for further processing.
Regardless of the possible easements provided for in Directive 2012/27/EU and following the common climate change concept adopted by the UN, EU, and the Republic of Latvia, the Ministry of Defense of the Republic of Latvia (MOD) has prepared and submitted to MOE for processing the RPEC information requested in the Directive and designed an energy resource consumption reduction program for 2012–2020 which defines the "urgent" and "required" measures.

The urgent measures include the maintenance/repair of damaged roofing, window replacement, replacement of indoor heating elements, and the preparation of an annual report on the consumption of electricity and other energy resources.

Whereas the measures required include **energy audits**, replacement of boilers (coal or liquid fossil fuel), replacement of asbestos cement roofing (European Council Directive 87/217/EEC) by 2020, **measures for the improvement of energy efficiency of buildings** (heat insulation), reduction of electricity consumption, education of the staff working in the buildings owned by MOD, and control of the fulfilment of the energy resource consumption reduction program.

1.2. Average specific energy consumption of buildings owned by the Ministry of Defense (MoD) of the Republic of Latvia

The major part of unclassified buildings has been constructed before the 1990s typical Soviet construction projects. Mainly brick external walls and unheated attics with very minimal attic slab thermal insulation was used due to low energy prices and limited availability of thermal insulation. One-pipe heating systems and natural ventilation are the most common technical solutions in all types of unclassified buildings except some very specific buildings such as garages, ammunition rooms, indoor shooting ranges, etc. In addition to initial poor technical conditions, unclassified buildings have not undergone proper energy management or energy audits due to the data privacy and limited access to such buildings.

According to the data of the Latvian Ministry of Economy the average total annual energy consumption of military buildings is 212 kWh/m^2 for buildings built before the 1990s. The measured data for unclassified buildings with variable construction dates has been collected and is shown in Figs. 1.1 and 1.2. The measurement process was performed in two different periods. The first time the measurements were done was in the time period 2011– 2014 and the second time was in 2014–2016. Also, for some of the buildings the calculation of theoretical energy consumption was done according to local regulations.

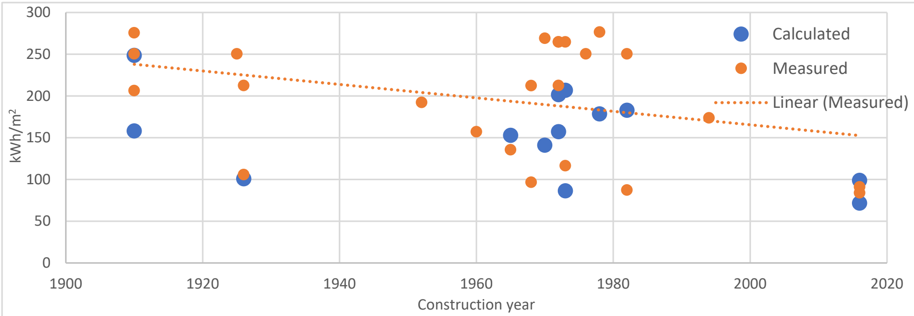


Fig. 1.1. Calculated and measured total annual energy consumption of military buildings with various construction year. Calculation period: 2014–2016.

Figures 1.1 and 1.2 show that the average energy consumption slightly reduces as the building's construction date increases. Total average annual measured energy consumption of military buildings is 230 kWh/m^2 for the measurements performed in years 2011–2014 (Fig. 1.2). The calculated values are obtained according to Latvian official calculation procedure Regulation No. 348 "Methodology for Calculating the Energy Performance of a Building". This procedure is mainly based on EN ISO 13790:2009 L data.

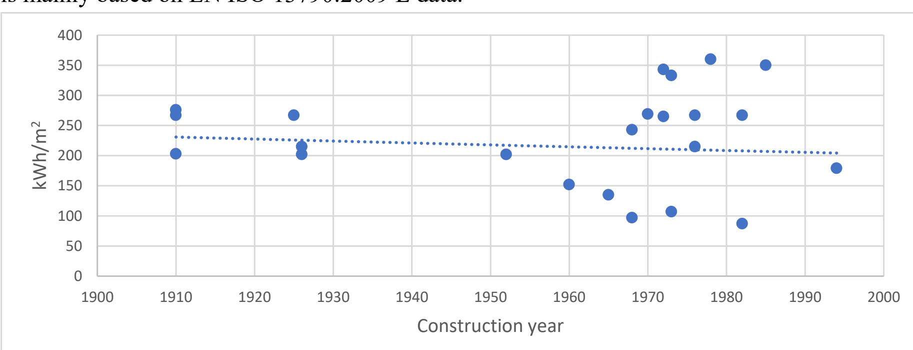


Fig. 1.2. Calculated total annual energy consumption of military buildings. Calculation period: 2011–2014.

The measurements of the same buildings were repeated a couple of years later to see if there are any changes as during the last year's active information campaigns and EU directives on energy efficiency have started. However, the results showed that although there had been slight reduction in energy consumption, the changes were negligible.

The measured energy consumption performed both times is significantly higher than theoretically estimated values. Average theoretical energy consumption estimated by energy auditors for analyzed buildings is 153 kWh/m^2, which is by 39 % lower than measured during the years 2014–2016. Such difference can occur due to improper definition of such initial set-up values as hot water consumption, indoor temperature, supply air exchange, airtightness of building envelope, etc. These values are defined by local norms for apartment buildings and office buildings. The data for unclassified buildings is not strictly defined by local norms, and energy auditors usually take into consideration data for civil buildings.

1.3. Average specific energy consumption of buildings owned by the Ministry of the Interior (MoI) of the Republic of Latvia (fire and police departments)

Similar situation is noticed also for police and fire departments where specifics of hot water consumption and ventilation rates should be taken into account. It should be noted that heat energy storage for buildings is very important, as it influences the final installed capacity of energy production units. It is time and experience tested conclusion that thermal "batteries" can be more effective and significantly less costly than traditional electric batteries in storing bulk energy. Electric batteries and thermal energy storage both have a role to play in stabilizing electricity grid. Thermal energy storage, as well as batteries, should be an integral part of the future energy infrastructure [6].

The measured average annual energy consumption of police departments is 252 kWh/m^2 while for fire departments 317 kWh/m^2. The increased energy consumption of fire department buildings could be explained by more strict requirements for ventilation rates and introduction of new technological devices like dedicated ventilation system from firefighting truck exhaust pipes (Fig. 1.3).

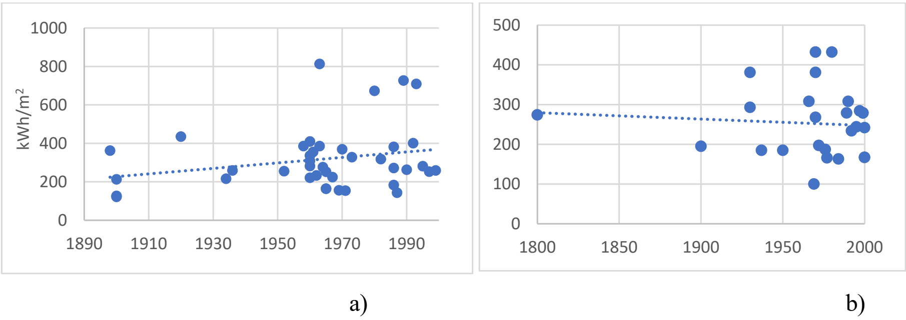


Fig. 1.3. Measured average total annual energy consumption of (a) fire and (b) police departments in measurement period 2011–2014.

The measured energy consumption of above-mentioned buildings significantly exceeds the energy consumption of apartment buildings. Typical Latvian multi apartment building annually consumes 190 kWh/m^2 for heating and hot water preparation [7], [8].

1.4. Review of energy consumption for hot water preparation

Hot water consumption of modern, low energy consuming buildings, accounts for a significant part of buildings total energy consumption profile, as the water amount can only marginally be influenced by technological or occupant driven saving methods. In order to make precise energy audits, the initial set-up values should be precisely predefined taking into account national requirements as well as accounting for local user behavior, applied technical solutions, maintenance procedures, etc.

The unclassified buildings include buildings like barracks and fire departments which mainly have shared bathrooms and kitchens. Hot water consumption of these types of building **is similar to dormitories**. However, differences in hot water consumption should be carefully evaluated in further studies. The main differences in hot water consumption between dormitories and unclassified buildings with shared showers could be more active shower use in unclassified buildings due to higher working and training loads, clothing type, different food preparation principles, room cleaning requirements, etc.

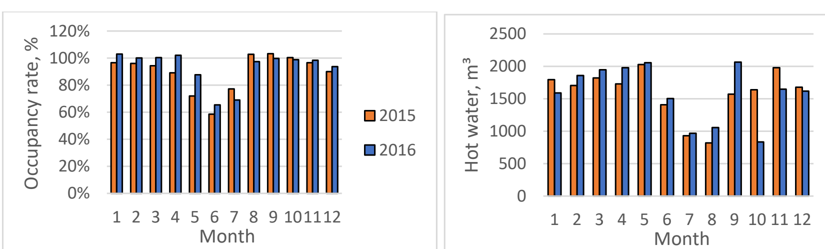
According to the Latvian Construction Regulations (LBN 221, 2015), standard hot water consumption per person is 105 l/day in apartment building, 80 l/day for dormitories with shared kitchens and showers on each floor, and 180 l/day in hotel rooms with individual showers. However, previously performed analysis [9] of real measured hot water consumption shows significantly lower consumption values.

Table 1.1

Average Hot Water Consumption in Apartment Buildings (l/d per person)

Observation year			Average
2013	2014	2015	
43.6	40.9	41.4	42.0

Given that the consumption of hot water is directly related to the number of people in the building, this value was first determined and compared with the consumption of water by months (see Fig. 1.4).



a) b)

Fig. 1.4. Dormitory occupancy (a) and measured hot water consumption per month (b).

The total average occupancy of dormitory was 765 persons with a maximum value of 880 in September and a minimum value of 499 in June. The total average hot water consumption in both dormitories in 2016 was 64.9 m^3/person and in 2015 – 67.2 m^3/person, which is 17 % less than specified in the Latvian Construction Standard. Hot water consumption in July and August is also almost 27 % lower than in the winter season. This can be explained by the fact that people stay in dormitories less in summer, thus reducing water consumption through less dishwashing, general cleaning and showering, as people often spend time outdoors and at natural water sources.

1.5. Heat energy consumption of special purpose buildings

For the analysis of total heat energy consumption of unclassified buildings, set of police departments, fire departments and **military buildings** (special purpose campus) were selected. Mostly these buildings are administrative, office buildings for duty units and teams performing operational work, barracks and canteens. Heat energy consumption includes heat energy for the heating and hot water preparation.

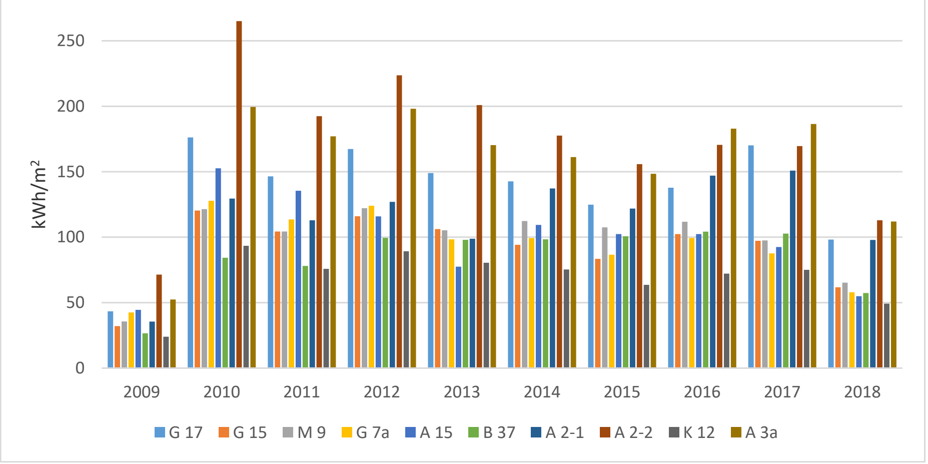


Fig. 1.5. Annual heat energy consumption by police departments (address information is deliberately hidden).

As it can be seen, heat energy consumption differs from year to year for each building and this represents one of the mostly important characteristics of special purpose buildings, as heat energy consumption is strongly influenced not only by the function of building's thermal performance and outside air temperature but also by user behavior which varies and depends on the task assigned to operational personnel and other human factors.

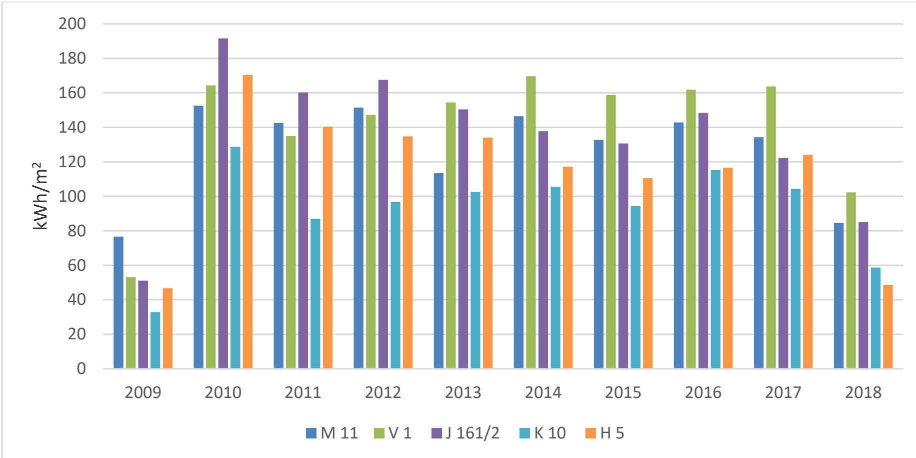


Fig. 1.6. Annual heat energy consumption of fire departments (address information is deliberately hidden).

Investigated buildings have poor thermal performance, which is explained by the fact that buildings were built before 1990 when the normative values for *U*-values for different dwelling elements in national building norms were defined much higher that it is now. The average annual heat consumption of police departments is calculated 112 kWh/m^2 and for fire departments 121 kWh/m^2.

Heat energy consumption of special purpose campus

For the analysis of total heat energy consumption of unclassified buildings, a campus of 15 special purpose buildings was selected and analyzed. Total area of the campus is 190 th.m^2, of which approximately ~100 th.m^2 are occupied by the unclassified special purpose buildings which are connected to the district heating networks (dormitories, warehouses, study rooms, sports facilities, swimming pool, bedrooms, common areas). Location of the campus is presented in Fig. 1.7.

Fig. 1.7. Location of the campus buildings.

Campus buildings were investigated and purpose of each of them was defined. District heating network scheme was carefully studied and the location of heating networks was established. After detailed survey, diameters and length of the pipelines were defined for further research. Buildings are marked with numbers from 1 to 15 without certain definition of their purpose, since this information is considered as highly sensitive. During the survey it was concluded that majority of the buildings have unevenly distributed heat energy consumption, which is explained by purpose of the building and random use (only when it is necessary). Some of buildings are used as warehouses for very different purposes and have special thermal requirements, which sometimes do not need additional heat supply.

At the inspection of all buildings, it was found that only 5 buildings are equipped with thermal energy meter. Heat energy meters were installed only in the buildings where heat energy consumption was constant or regular. Heat energy mostly is needed in buildings which are used by people or local staff, such as gym, swimming pool, dormitories, study rooms, etc.

Fig. 1.8 presents heat energy consumption of unclassified special purpose buildings for the last 7 years.

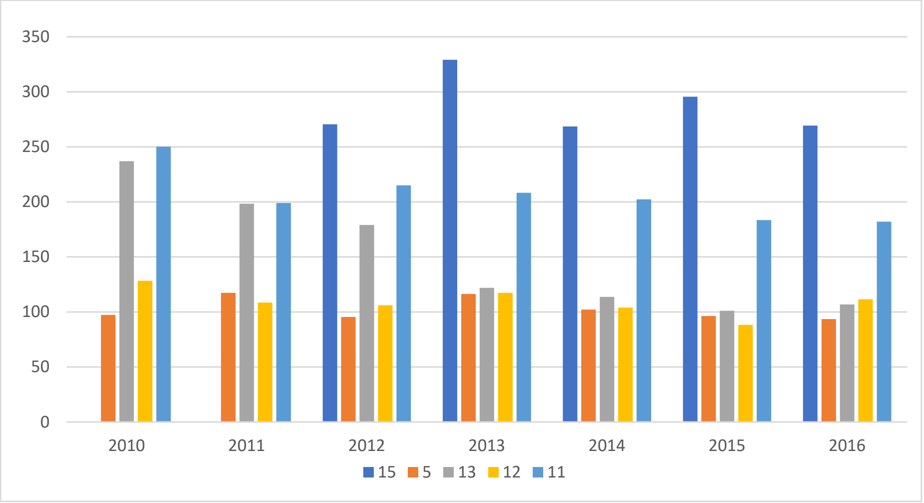


Fig. 1.8. Heat energy consumption of unclassified special purpose buildings (address information is deliberately hidden).

Heat energy consumption is given in MWh/m^2 without corrections by heating degree days, since internal temperature settings are not strictly defined for special purpose buildings. Outside temperatures have certain influence on the heat energy consumption of any building but in this case, occupancy profile and envelopes thermal performance has a decisive influence. As it can be seen, Building 13 has a significantly lower heat energy consumption since 2013, this is due to the building's renovation measures which were performed in 2012. Average heat energy consumption before the renovation activities was 204 kWh/m^2 but after refurbishment heat consumption reduced by more than one half and averaged at 110 kWh/m^2. For the remaining values, the average absolute deviation is within 7.92 %. Heat consumption of Building 15 is much higher because of its purpose, which is connected with high demand water activities, Building 15 has been open since 2012.

In To conclude, the energy efficiency of unclassified buildings could and should be improved. Improvements in energy efficiency can be achieved through systematisation of data, regulatory changes, different requirements, technological changes, management and organizational improvements of publicly owned buildings (unclassified buildings), and changes of individual consumer behavior through consumer education, not forgetting about the specifics of the sector under the study.

2. SYSTEMATISATION OF UNCLASSIFIED BUILDINGS

Energy efficiency solutions for unclassified buildings is a crucial issue, especially due to the fact that great part of unclassified buildings is being maintained by using public funding.

Systematisation of unclassified buildings is necessary to be able to perform analysis in the future on the effect of energy efficiency improvement measures on overall energy efficiency of buildings without linking it to a specific address and location. This will ensure the protection of limited access data before taking a final decision and inviting specialists for inspection of the buildings on site.

The parameters relevant for energy efficiency improvements are functional, structural, and space types, indoor environment quality levels, and others.

When buildings are classified, it is possible to develop standard solutions that can be replicated for similar buildings of the same type.

Systematisation of unclassified buildings allows beginning work on the creation of standard models in the future.

Developing of standard solutions becomes easier when modeling tools are used. By using some of the unified formats, for example *.ifc it is possible to use different tools for the analysis of energy consumption.

In addition, the development of standard models helps to assess the impact of thermal bridges and to prepare a catalog of standard solutions, thus ensuring a uniform approach to energy auditing, regardless of the experience of the selected contractor. For temporary buildings, for example, tents, there is a potential for energy efficiency improvements as well. This research work provides an overview of the principles for systematising tents as well as measures to be undertaken for energy efficiency improvements.

This work provides an overview of the portfolio of unclassified buildings in Latvia by comparing the age of buildings within portfolios of different departments.

The US army uses standard design for buildings allowing to evaluate the usefulness and energy efficiency of different complex renovation measures. The use of a standard building model allows ensuring confidentiality and data protection before taking final decisions.

2.1. Necessity for systematisation of unclassified buildings

Systematisation of unclassified buildings is necessary to be able to perform analysis in the future on the effect of energy efficiency improvement measures on overall energy efficiency of buildings without linking it to a specific address and location. This will ensure the protection of limited access data before taking a final decision and inviting specialists for inspection of the buildings on site.

One of the aims of this Thesis is to systematise unclassified buildings according to different functional, structural, and other features.

Systematisation of unclassified buildings allows beginning work on the creation of standard models in the future.

2.2. Systematisation principles of unclassified buildings

Buildings can be systematised according to several parameters. There are performance characteristics, layout parameters, functional purpose, etc.

The following important parameters which affect the choice of power supply solutions, the creation of a standardised model, and the design of standard energy efficiency measures were selected for research: functionality, number of floors, lifespan, materials, and construction year. In addition, layout parameters can also be used in systematisation of buildings: layout plans, functional zoning of buildings, etc.

2.3. Classification of use of unclassified building premises

In order to correctly determine the indoor temperature regime during the year and choose the amount of air exchange required, as well as determine the thermal properties of building envelopes, it is necessary to determine the specific service properties of unclassified building premises.

Mostly, the specific service properties of premises correspond to office and public building needs. The main difference to be taken into account when designing energy audits is the higher intensity of harmful emissions and heat emissions.

Table 2.1

Specific characteristics of unclassified building premises

Type of premises	Public buildings	Specific characteristics of unclassified buildings
Administrative premises	Office rooms and related auxiliary rooms	Specialised clothes, higher CLO value of the uniform, limited opportunities for the use of passive ventilation and cooling solutions
Warehouses	Office supplies, inventory, office equipment	Explosive materials, ammunition, food stuff
Garages	Cars	Heavy and armoured cars; car repair workshops (limited opportunities for performing repairs in civil repair shops), painting workshops
Canteen	Various food, steady flow of visitors	Large number of visitors at the same time, strict dietary requirements; higher air exchange and water consumption
Hotels and dormitories	Predictable and steady water consumption	Higher hot water consumption due to higher work, exercise and training loads; higher population density in barracks.
Shooting galleries	Civil shooting gallery – use of small calibres	Use of large calibres, active load

2.4. Systematisation of tents

Considering that during the research it is planned to design mobile power supply solutions for tents, tents are systematised as well. Primarily the tents intended for accommodation of people are reviewed. A systematisation example has been prepared during the research on the basis of buildings for the defence forces, which is why military tents are reviewed in more detail. Buildings for the defence forces are barracks, teaching premises, office buildings, shooting-galleries, garages, dormitories, warehouses, ammunition storages, canteens, gyms, medical premises, etc. Residential buildings are barracks and dormitories, whereas teaching premises, office buildings, warehouses, canteens, and gyms are public buildings.

Military tent is a collapsible temporary building that has to be put up fast. The tent is intended for protection from unfavourable weather conditions and temporary accommodation of people and for living, working, and household needs, as well as for storing various materials in the field.

According to **functional purposes,** military tents can be divided into

- ✓ trekking tents,
- ✓ encampment tents.

According to **structure,** tents can be

- ✓ with a frame,
- ✓ frameless,
- ✓ inflatable.

2.5. Division of Latvian police, fire service buildings and the Latvian defense force buildings according to construction year

During the research information was prepared on the following basis:

1. Buildings owned or possessed and used by the state authorities with the total area over 250 m^2 as of 09.07.2015 in accordance with Article 5(5) of Directive 2010/27/EU of the European Parliament and the Council on energy efficiency (prepared in accordance with the information provided by the state authorities).
2. Buildings owned or possessed and used by the state authorities with the total area over 250 m^2 as of 09.07.2017 in accordance with Article 5(5) of Directive 2010/27/EU of the European Parliament and the Council on energy efficiency (prepared in accordance with the information provided by the state authorities).

Considering the development of the construction industry on the territory of Latvia, four time periods can be singled out, and the buildings can be divided according to these periods. The first category is pre-war buildings (buildings constructed before 1940); the second category includes buildings constructed from 1945 until 1970. The third category includes buildings constructed from 1971 until 1990. Buildings constructed after 1991 shall be included in the fourth category.

A total of 92 buildings were reviewed, 27 of which are police service buildings and 40 are fire service buildings and 25 buildings of the Latvian Defense Forces. The distribution of service buildings by years of construction is shown in Fig. 2.1.

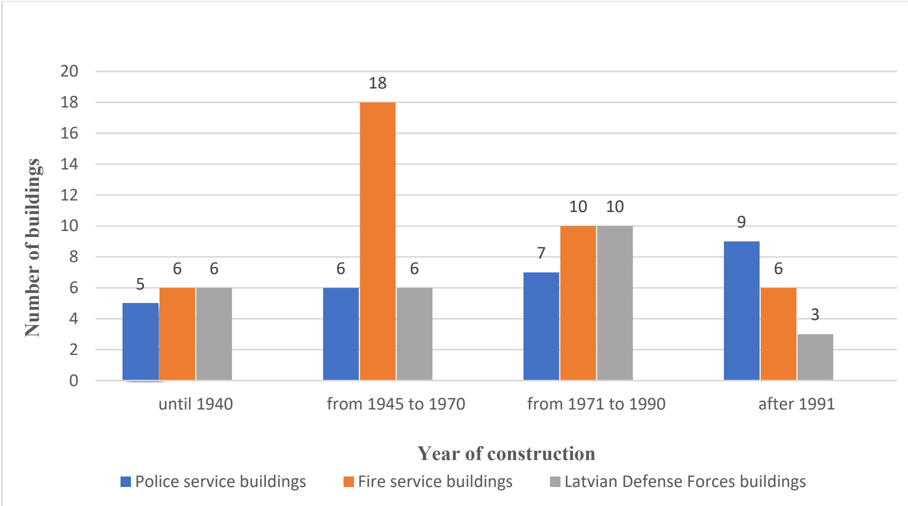


Fig. 2.1. Distribution of researched service buildings by years of construction.

Distribution of the buildings according to their mean age can also be viewed according to services. The data are summarised in Table 2.2.

Table 2.2.

Distribution of buildings according to mean age

Service	Number of buildings	Mean age (years)	Number of buildings younger than the mean age	Number of buildings older than the mean age
Police service	27	49.7	20 (74 %)	7 (26 %)
Fire service	40	55	22 (55 %)	18 (45 %)
Defence forces	25	54.8	17 (68 %)	8 (32 %)
Total	92	53.4	59 (64.1 %)	33 (35.9 %)

3. METHODOLOGY FOR EVALUATION OF ENERGY EFFICIENCY OF UNCLASSIFIED BUILDINGS

The aim of the Thesis is to develop a methodology for evaluation of energy efficiency for reducing the energy consumption of unclassified buildings and recommendations for their technical inspection. The recommendations are aimed at the development of unified solutions for renovation and energy supply while ensuring the high quality of the work to be performed, provided that a minimum number of staff is involved in the reconstruction of this type of buildings.

To achieve the goal of the Thesis, it was necessary to conduct research, providing a full empirical cycle, from gathering facts, data, grouping and hypothesis testing to hypothesis testing from new empirical material, as well as validation of research results, i.e. a set of complex measures to prove the reliability of the data obtained and the justification for the readiness of the data.

Generally, the energy required for heating or cooling for a reference period is calculated as the difference between heat emissions and heat loss in the reference period:

$$Q_h = Q_l - \eta_u \cdot Q_e, \quad (3.1)$$

where: Q_h – energy required for heating (Wh);

Q_l – total heat loss for heating (Wh);

Q_e – total heat emissions in heating mode (Wh);

η_u – heat emissions utilisation factor.

$$Q_c = Q_{em} - \eta_u \cdot Q_{hf}, \quad (3.2)$$

where: Q_c – energy required for cooling (Wh);

Q_{em} – total heat emissions (Wh);

Q_{hf} – total heat flux (Wh);

η_u – heat loss utilisation factor.

To calculate specific annual energy consumption, we need to take into account all the possible separate types of energy consumption, which can be divided into heat loss, electricity consumption and hot water consumption. Subtract internal heat gain which originates from the sun, as well as various other heat sources – people, appliances, lighting, hot water pipes. Figure 3.1 shows a summary of all the factors that affect the total energy consumption of a building and need to be taken into account when designing energy audits. The specific factors characteristic of unclassified buildings in particular are marked separately.

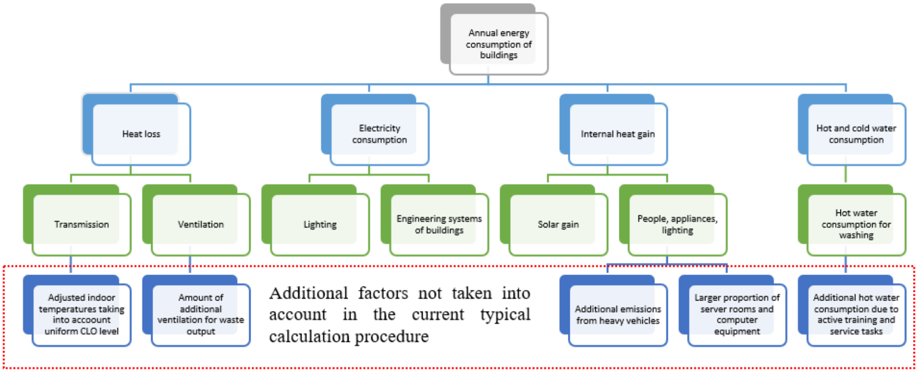


Fig. 3.1. Factors affecting energy efficiency of buildings.

The influence of mutual processes of the work and the structure of the work are shown in Figs. 3.2–3.4.

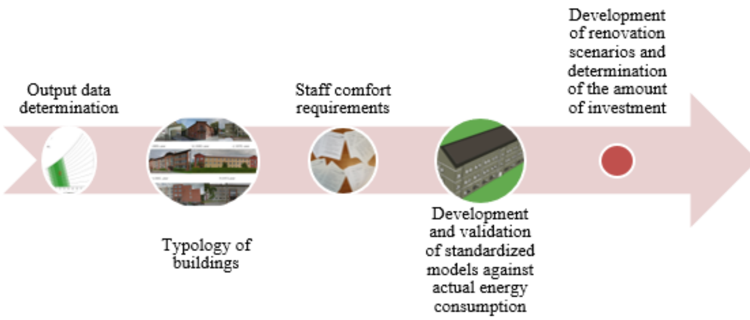


Fig. 3.2. Influence of the mutual processes of the work.

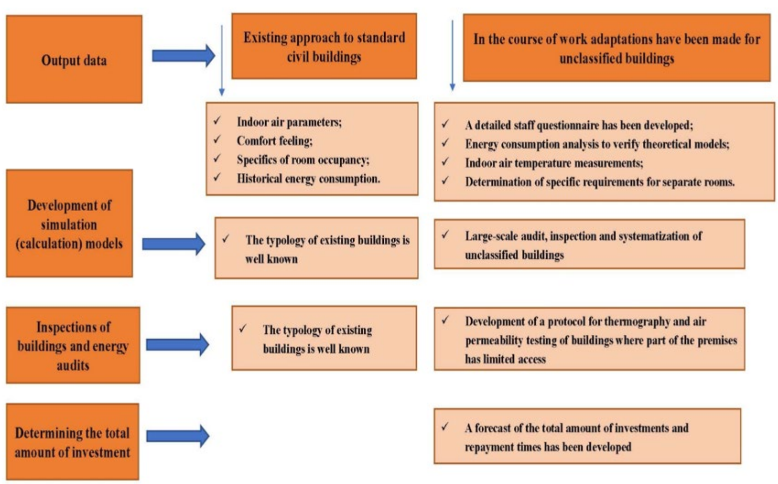


Fig. 3.3. Structure of the work.

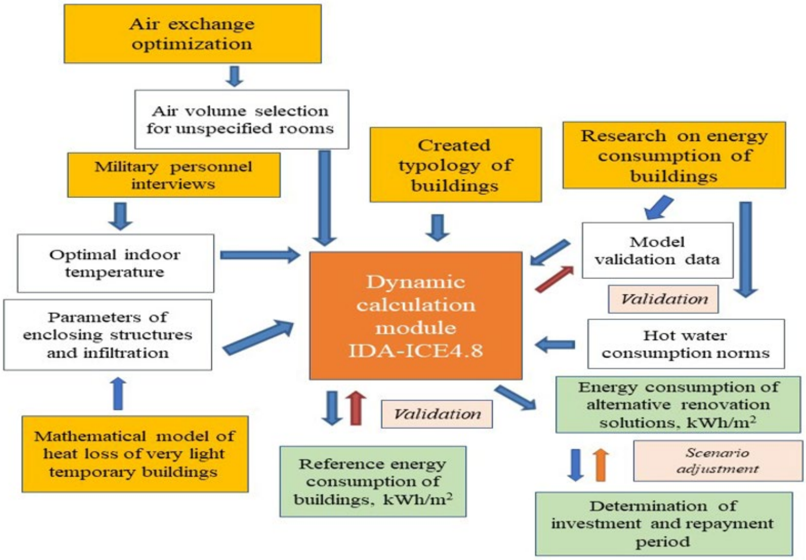


Fig. 3.4. Structure of the work.

3.1. Energy performance in unclassified buildings

As there is no publicly available database containing construction data and performance characteristics of each individual unclassified building, thorough and detailed prototype models had to be developed that would represent a typical military, police and fire station building. Furthermore, the building prototype models are necessary to perform thermal energy consumption calculation for the selected buildings, as each of the unclassified building subcategory may have different structural characteristics and requirements with regards to building design, materials, heat transfer coefficients, indoor comfort level and other thermal parameters. The standardized heat transfer coefficients of building construction elements largely define the thermal energy consumption of a building and, therefore, are at the base of the thermal energy consumption equation. These coefficients are defined by the Latvian Construction Standard LBN 002-19 [10] "Thermotechnics of Building Envelopes" (Normative Values of Heat Transmittance Coefficients).

The required annual thermal energy (kWh/m^2) for the prototype was calculated in accordance with Cabinet Regulation No. 222 "Methods for calculating the energy performance of buildings and rules for the energy certification of buildings" [11] which is referred to in LBN 002-19. The annual thermal energy consumption (kWh) across the given timeline for each building category (residential, public, industrial) was determined by calculating specific thermal energy consumption (kWh/m^2) and compiling data on the floor area of the respective building stock (m^2). Thus, the annual thermal energy demand for a prototype building (kWh/m^2) can be determined by Equation (3.3):

$$E_{annual} = \frac{\Sigma UiAi + \Sigma \psi jlj + \Sigma \chi k + (V_{air} \cdot c) \cdot 24 \cdot Dheat \cdot (Tin - Tout)}{1000 \cdot A} - \eta \cdot (Qint + Qsol). \quad (3.3)$$

Military buildings

To compare the actual energy consumption versus theoretical energy consumption, energy auditing and measurements were conducted in the same set of military buildings throughout 2011–2016. The energy consumption reduces in line with the building construction date, indicating the gradual improvement in the implementation of better building thermal performance practices as the time progresses. Some of the buildings may have undergone energy retrofits that eventually resulted in better thermal energy performance (Fig. 3.5) [12].

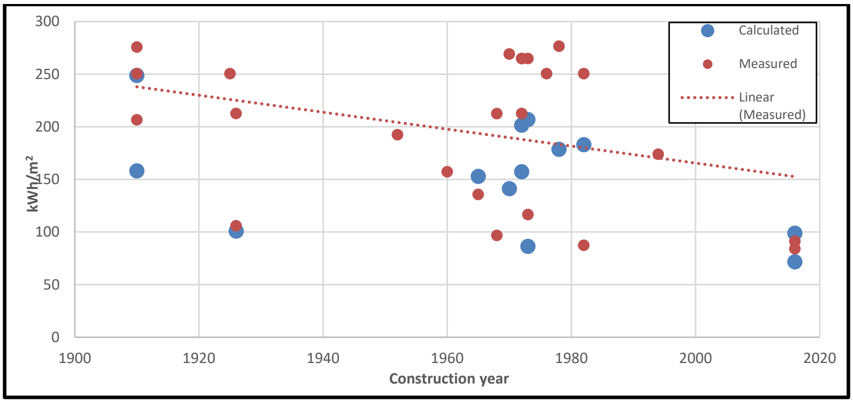


Fig. 3.5. Calculated and measured annual energy consumption of studied military buildings (kWh/m^2).

As it is seen in the graph, the total average measured annual energy consumption of military buildings was 230 kWh/m^2, while the average calculated (theoretical) energy consumption values for military buildings was 153 kWh/m^2 (33 % lower than measured).

This discrepancy clearly indicated the poor actual performance of the military buildings in reference against the theoretically acceptable energy performance that is based on the currently effective building energy efficiency requirements.

Another factor of the high degree of discrepancy between the actual (measured) and theoretical (calculated) energy consumption results is probable deviation of the input values from actual values (hot water consumption, indoor temperature, supply air exchange rate, airtightness of the building envelope etc.).

Since the input data for unclassified buildings is not defined by local norms, energy auditors typically take into consideration simplified input data that is used for civil (residential and/or public) buildings, which may result in high degree of mismatch between actual and theoretical performance.

Police departments and fire stations

The energy profile in police station buildings followed a similar trend as in military buildings (energy consumption decreased with the year of construction). In turn, the analyzed fire depot buildings showed a slightly opposite trend – with a slight increase in energy consumption for space heating and hot water in later years of construction. This is probably due to the fact that recently built fire depots are larger and, therefore, create higher energy demand due to their higher capacity and load (number of fire trucks, number of staff, etc.). Average measured annual energy consumption of police stations is 252 kWh/m^2 but by fire stations – 317 kWh/m^2.

3.2. Heat loss calculation model for buildings and tents

This chapter contains a review of heat loss calculation methods for tents with the aim to decrease energy consumption for heating and improve comfort.

Each calculation method is based on an irreversible process – heat exchange, which can consist of three separate types of thermal energy transfer (heat conduction, thermal convection, radiation) in different combinations.

The work is structured as follows: first, there is a brief review of different theoretical facts on heat exchange [13], [14] which is later used in the calculations. Then, heat loss calculation methods for tents are described and a specific calculation example is provided. Finally, the calculated data are compared with the values obtained using measuring instruments [15], [16] and some coefficients are adjusted.

Energy consumption analyses and energy audits of buildings are performed based on the heat balance of the premises (3.4) and the heat balance of the human body (3.5):

$$L = \frac{\frac{\Sigma}{n}(Q_C)n + Q_A}{\Delta T} = \sum_n (h_t\ A)n + pcV_a\ , \tag{3.4}$$

$$\dot{Q}_{con} + \dot{Q}_{rad} = A_{cl} \cdot h_{c+r}\left(T_{cl} - T_{op}\right). \tag{3.5}$$

There is currently no specific methodology for energy audit of unclassified buildings in Latvia, and ordinary calculation methods are used.

To perform correct evaluation of energy consumption of unclassified buildings, extensive energy audits of such buildings are required, considering their specific purpose.

As the comparison of the energy audit results of unclassified buildings with the actual measurement data shows, the results differ significantly, which can be explained by the specific nature of unclassified buildings and by the fact that energy assessment of such buildings requires **specific raw data** – amount of heat emissions, humidity mode, air exchange value, hot water consumption, etc.

3.3. Adapting the requirements of applicable legislation

The legislation applicable in the Republic of Latvia does not directly prescribe the data to be used in energy audits of unclassified buildings when choosing calculation temperatures, air exchange values, heat emissions, operation modes, energy consumption for lighting, hot water consumption, etc.

Thus, already existing data need to be used, and these need to be adapted for specific needs. Table 3.1 shows a review of the standards applicable in the Republic of Latvia and their application for unclassified buildings. Full version of Table 3.1 can be found in full text of the Thesis.

Table 3.1

Review of the standards applicable to the calculation of energy consumption

Title of the norm	The norm set in regulation	Applied for unclassified buildings
LBN 002-19 "Thermotechnics of building envelopes"	Normative Tables 1–4.2 determine the heat engineering indicators of the building envelope and their values. Article IV of the Standard determines the air permeability and energy efficiency of buildings.	Barracks can be considered as residential buildings. Administrative buildings, head-quarters, canteens and teaching premises can be considered as public buildings. Garages, repair workshops can be considered as production buildings.
LVS CR 1752:2008 "Ventilation of buildings – indoor environment design criteria"	The Standard prescribes the necessary room temperatures, amounts of ventilation air, airflow speeds in the working area, and the permissible noise level. It also provides guidelines on the amount of metabolic heat emissions from a person, and the dressing level depending on the clothes put on.	Table 1 of the Standard can be used for determining the required air amounts in the teaching premises, cafeteria, and barracks of unclassified buildings, equating these with office buildings.
LVS EN ISO 7730:2006 "Ergonomics of the thermal environment - analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria"	The Standard prescribes how to characterize and determine the thermal comfort level of people depending on the room air temperature, radiation temperature, air flow spend, and air humidity.	The Standard can be used for all unclassified buildings to predict or describe the indoor thermal comfort level.

4. RESEARCH ON ENERGY AUDIT DATA LIMIT VALUES

4.1. Methodology

When assessing the energy performance characteristics of unclassified buildings, attention should also be paid to indoor air quality and indoor comfort (IAQ). Therefore, in order to objectively determine the level of satisfaction/dissatisfaction of the deployed contingent with the IAQ in military facilities (special purpose campuses), a written survey of soldiers on indoor comfort is provided and long-term monitoring of indoor air quality, relative humidity and temperature of the studied buildings is ensured. Indoor air quality parameters are evaluated in administrative building, barracks and canteens. Measurements are made during the heating season. Sensors are placed in rooms with the highest concentration of service staff and are left indoors for at least a month. Reading of the real values of the studied air parameters is provided by the sensor settings and is performed at a frequency of 5 minutes.

4.2. Determination of the amount of air exchange in unclassified buildings

One of the basic tasks for performing energy audits is to determine the exact heat energy losses. Typically, this process consists of two parts – the calculation of the heat loss that occurs through the enclosing structures and the energy consumption that is lost due to building ventilation. If the first of these is relatively easy to calculate because it is only necessary to know the specific areas and thermal conductivity coefficients of the enclosing structures, then the second one is more complicated. This is due to the fact that in order to determine energy loss through ventilation systems during a year, it is necessary to know a number of parameters that may change dynamically and are not constant not only for two similar buildings, but also for one particular building during its life cycle. These parameters are: the expected volume of ventilation air, the operation regime of the ventilation equipment, the efficiency of the heat recovery of the ventilation equipment, as well as the overall air permeability of the building, which affects the amount of uncontrolled infiltrated air.

The definition of unclassified buildings includes buildings with a wide variety of uses, which means that their ventilation air volumes can be very different. It should be noted that many unclassified buildings consist of premises with a local source of air pollution, such as garages, ammunition repositories, warehouses, shooting ranges, industrial workshops, etc.

In the energy consumption balance of buildings, ventilation air heating and electricity for transporting it constitute a very important part, especially for buildings with good thermal insulation. Data on the volume of ventilation air should be taken into account in the energy audit of such buildings or in the assessment of the energy performance of the building.

Taking into account that Latvian construction norms do not indicate the required minimum amounts of ventilation air or the amount that should be adopted, the regulations of other countries should be applied.

The full text of the Thesis reflects the amounts of ventilation air according to the type of use of the premises and the applied norm. Based on them, it is possible to estimate the amount of air exchange in unclassified buildings such as fire stations or garages for military equipment.

In order to show the significance of the total energy consumption ventilation system, the amount of air exchange for shooting ranges was calculated and a basic ventilation system scheme was developed within the framework of the Thesis.

4.3. Impact of the uniform on thermal comfort

To determine the heat loss that occurs during transmission, it is necessary to know the areas of the boundary structures and the coefficients of thermal transmittance for them. The outside air temperature and the set air temperature must therefore be taken into account. Since it is not possible to influence the outdoor air temperature, the indoor temperature can be set according to the type of use of the building and the level of thermal insulation of the peoples' clothing.

The main parameters that influence thermal comfort are the environmental parameters and individual parameters of the human. If an employee has a constant feeling of heat, it is more difficult to concentrate on work and perform his/her duties qualitatively.

Nowadays it is widely proven that the employee's productivity is much higher in comfortable conditions. On the other hand, in buildings where employees are required to wear uniforms with a higher degree of thermal insulation, **it may not be necessary to maintain standard air temperature**. The comfort level of employees can also remain optimum at the indoor air temperature, which is 2–3 degrees lower, saving money at the expense of heat. Theoretically, this has two positive effects – improved employee performance and productivity, as well as savings on heating.

The opposite effect could occur if the buildings were equipped with air conditioning and in the summer the room would need additional cooling. The facts mentioned above are more relevant to the headquarters' staff who need to spend most of their day indoors. It is important to pay attention to the clothing equipment of soldiers who spend a long time outside with varying physical loads. Here too, thermal insulation of clothing has a direct impact on human's work ability and performance. In the full text of the Thesis, this section of the research deals in detail with the impact of uniforms on thermal comfort, human wellbeing and energy efficiency of a building. Table 4.1 provides information on comfort levels and their comparison in different states.

Table 4.1

Comfort evaluation and the corresponding temperature sensations

VOTE		TEMPERATURE SENSATION	$ET^{*(4)}$	COMFORT SENSATION	$\bar{T}_s^{(5)}$	% $A_{sw}^{(6)}$
		1 – very cold	10 °C	Uncomfortable	30 °C	
1	−3	2 – cold	15 °C		30.5 °C	
2	−2	3 – cool	20 °C	Slightly uncomfortable	32 °C	
3	–1	4 – slightly cool	25 °C	Comfortable	32.5 °C	
4	0	5 – neutral	30 °C	lightly uncomfortable	34 °C	6
5	+1	6 – slightly warm	35 °C	Very uncomfortable	35 °C	
6	+2	7 – warm			-	20
7	+3	8 – hot	40 °C		-	40
						60
		9 – very hot	45 °C		-	80
				Limited	$(T_{core} - \bar{T}_s)$	100

4.4. Thermal insulation of military uniforms and their components. Theoretical assessment of thermal comfort. Thermal balance of the human body

Considering that military clothing is specific and very different from civilian clothing, the calculations require specific CLO values for this type of garments. In the Thesis, thermal insulation data are collected for typical army uniform components in different conditions in order to get a rough idea of the total level of thermal insulation in different combinations. Pictures of several levels of clothing for the soldiers of the National Armed Forces of the Republic of Latvia are shown below. Gloves, headgear and footwear are not listed here.

Table 4.2

Elements of Uniform

	Level 1 underwear Consists of: T shirt, short pants (boxer shorts) Main fabric properties: * removes and repels moisture * does not irritate the skin * fast drying * protects against UV radiation * antibacterial Intended: as underwear under other layers of field uniform
	Level 2 underwear Consists of: long sleeve shirt, long underpants Main fabric properties: * removes and repels moisture * does not irritate the skin * fast drying * protects against UV radiation * antibacterial Intended: as underwear under other layers of field uniform
	Level 3 underwear Consists of: thick shirt (with zipper) with long sleeves, thick long pants Main fabric properties: * removes and repels moisture * does not irritate the skin * fast drying * protects against UV radiation, * keeps the body warm Intended: as underwear under the rest of the field uniforms layers
	Cool weather costume Consists of: jacket, pants Main fabric properties: * keeps body heat * good air permeability * flexibility * protects against UV radiation Intended: as a separate field uniform, worn with other layers of field uniform
	Field uniform Consists of: hat, jacket, trousers Key features: * serves as a basic combat uniform * with a unified camouflage pattern * provides visual camouflage and indicates affiliation to LR at close distance * provides camouflage in the NIR range * The fabric is impregnated for protection against insects (for international operations in Afghanistan) Intended: as a separate basic field uniform, along with other layers of field uniforms

Table 4.2 continued

	Rain Costume Consists of: jacket, pants Key features: * waterproof fabric * good air permeability * protects from wind * with a unified camouflage pattern * provides visual camouflage and indicates affiliation to LR at close distance * provides camouflage in the NIR range Intended: as a separate basic field uniform, along with other layers of field uniforms
	Winter jacket Consists of: jacket Key features: * keeps body heat * protects against rain and snow * protects from wind Intended: as a separate layer of field uniform, along with other layers of field uniform
	Particularly cold weather costume Consists of: jacket, pants Key features: * keeps body heat * protects against rain and snow * protects from wind Intended: as a separate field uniform, with other layers of field uniform

Under normal circumstances, the outfit of a soldier working indoors basically consists of Level 1 underwear and battlefield uniform.

Fig. 4.1. Clothing of an indoors working soldier.

To assess the thermal comfort of military personnel in office conditions, the specifics of military clothing and CLO values should be taken into account. For this purpose, battlefield uniforms of soldiers of the National Armed Forces of the Republic of Latvia can be compared with the US soldiers' uniform which has an approximate CLO value of 1.4

Using Thermal Comfort Calculator, developed by the University of California (Berkeley), it is possible to determine if the indoor climate and clothing insulation correspond to ASHRAE 55/2020 [17] and EN-15251 Indoor Environmental Criteria [18]. Adopting an indoor air temperature of 25 °C and a CLO value of 1.4 shows that the given criteria are outside the comfort zone (see Fig. 4.2). ASHRAE 55/2020 and EN-15251 Indoor Environmental Criteria requirements are met if indoor air temperature is reduced to 20 °C (see Fig. 4.3).

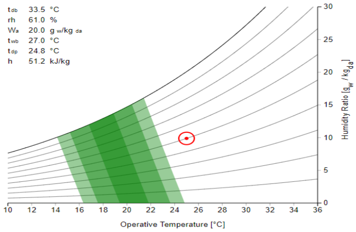


Fig. 4.2. Comfort zone in military clothing at indoor air temperature 25 °C, relative humidity 50 % and clothing CLO value 1.4.

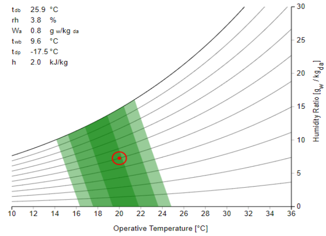


Fig. 4.3. Comfort zone in military clothing at indoor air temperature 20 °C, relative humidity 50 % and clothing CLO value 1.4.

Heat loss from the human body is a complex problem in transient heat transfer, involving radiation, convection, conduction and evaporation, along with many other variables, from the wetness of the skin to the composition of the clothing. The Thesis deals with such processes as the total rate of energy production in the body, the rate of metabolism during various activities, and heat loss from the body's radiation.

4.5. Research on indoor air quality (IAQ) in unclassified buildings

In order to monitor diurnal changes of various parameters, in this case – indoor air temperature, relative humidity and CO_2 concentration, and characterize the conditions of indoor environment, a series of measurements were performed.

Two buildings (Nos. 6 and 9) were selected from the barracks of the special center (see Fig. 1.6). Barrack No. 9 was built during the period of the first free state of the Republic of Latvia. The number of above-ground floors is 3, the number of underground floors is 1. The total area of the building is 2388 m^2, construction volume –11 530 m^3. There is no mechanical supply-exhaust ventilation in the building.

Barrack No. 6 was built in 1910. The number of above-ground floors is 3, the number of underground floors is 1. The total area of the building is 2387 m^2, construction volume – 11 990 m^3. During the partial renovation of the building, the building's enclosing structures were insulated, and a mechanical supply-exhaust ventilation system was installed. Heating for both buildings is provided by connecting the heating units of the buildings to the district heating system.

For one barrack, measurements were taken in two different rooms, one of which is a guard room and the other a meeting room on the third floor. For the second barrack, measurements were taken in three different rooms: in the training center on the second floor, and on the third floor – in the bedroom and the common office. The inspections took place in January, February, and March.

The results showing the changes in the parameters of the internal environment of the guard room and the meeting room during the day can be seen in Figs. 4.4 and 4.5.

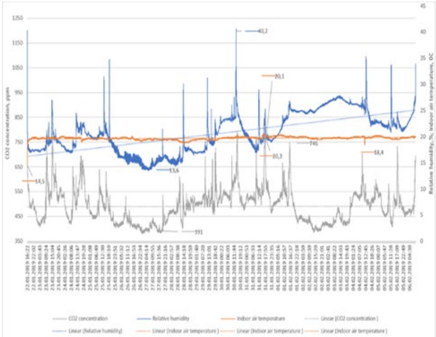


Fig. 4.4. Indoor air temperature, relative humidity and carbon dioxide concentration measurements for the guard room.

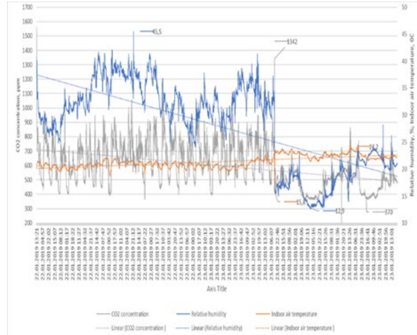


Fig. 4.5. Indoor air temperature, relative humidity and carbon dioxide concentration measurements for the third-floor meeting room.

The measurement results, which show the changes in the environmental parameters of the training center and sleeping area during the day, are shown in Fig. 4.6 and Fig 4.7.

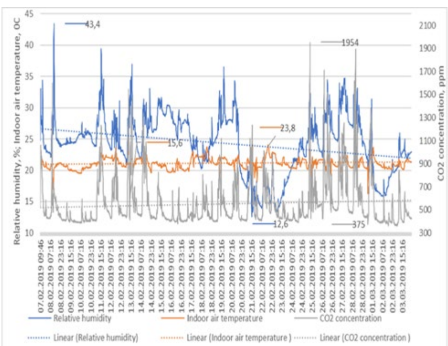


Fig. 4.6. Indoor air temperature, relative humidity and carbon dioxide concentration measurements for the second-floor training center.

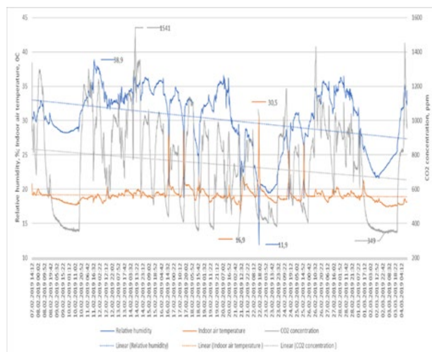


Fig 4.7. Indoor air temperature, relative humidity and carbon dioxide concentration measurements for the third-floor sleeping area.

Indoor temperature, relative humidity and air quality measurements were performed in the canteen building of the special purpose center, where universal sensors for measuring air parameters were installed – temperature and humidity sensors and carbon dioxide concentration sensors.

The canteen building was put into operation in 1960. It is a two-story brick construction with reinforced concrete flooring. The building volume is 5274 m^3. The building was partially renovated – the windows were replaced; the facade of the building was insulated with stone wool and tin-plated; mechanical supply and exhaust ventilation was installed. The building is operated in 5/12 regime. The heating of the building is provided by connecting the building's heating unit to the district heating system. The measurement results, which show the changes in the parameters of the indoor environment of the canteen building during the day, are shown in Fig. 4.8 and Fig. 4.9.

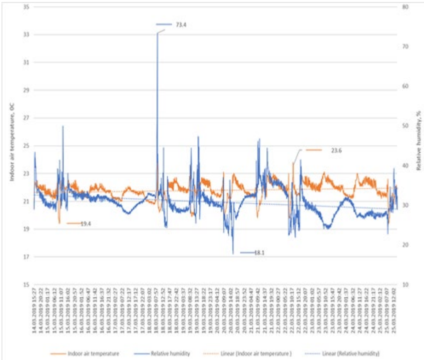


Fig. 4.8. Indoor air temperature and relative humidity measurements for the cooking room.

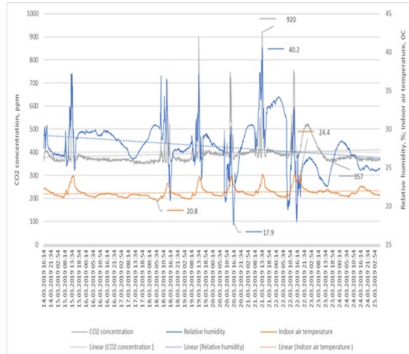


Fig. 4.9. Indoor air temperature, relative humidity and CO_2 concentration measurements for the dining room.

Within the framework of the research, as additional questionnaire was conducted and universal sensors for measuring air parameters – temperature, humidity and carbon dioxide concentration – were installed in one of the administrative buildings of the special purpose center.

A two-story building, built in 1977, with a building volume of 3666 m^3 was chosen from the administrative buildings of the special purpose center. The building has not been previously renovated. The building is in operation round-the-clock. There is no mechanical supply-exhaust ventilation in the building. Heating of the building is provided by connecting the building's heating unit to the district's heating system. Measuring devices for air parameters were installed on the first and second floors of the building, in work areas, and in the lounge. Measurements were made between December 2018 and February 2019 (including). The daily measured parameters of humidity, air temperature, and carbon dioxide concentration of the first-floor work areas are shown in Fig. 4.10, while the second-floor lounge area IAQ parameters are shown in Fig. 4.11.

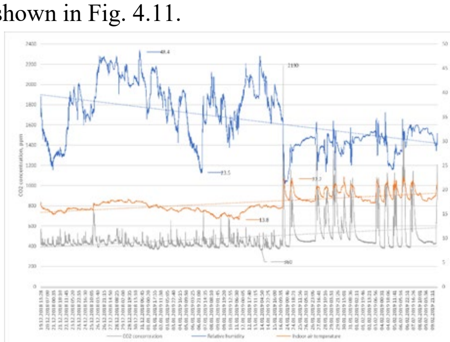


Fig. 4.10. Humidity, air temperature, and carbon dioxide concentration (IAQ) of the first-floor work areas of the administrative building.

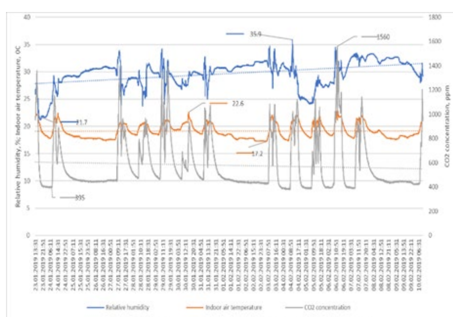


Fig. 4.11. Humidity, air temperature, and carbon dioxide concentration (IAQ) of the second-floor work areas of the administrative building.

Measurements of indoor air parameters in barracks (built before 1960 and in the mid-1970s) were performed in the Thesis. They are characterized by a low level of occupancy – few staff and very large premises. More than 1,000,000 measurements were made during the study, and the location of the barracks and the dates of the measurements were deliberately hidden. Measurement data are summarized in Table 4.3.

Table 4.3

Average data

	Indoor temperature (*t*, °C)	Relative humidity (%)	Indoor CO_2 concentration (PPM)
Barrack 006_01	19.8	32.6	586
Barrack 006_02	20.1	25.6	778
Barrack 4_01	18.5	37.5	739
Barrack 4_02	21.0	35.2	560
Barrack 4_03	19.3	41.7	-
Barrack 2_01	17.3	34.6	487
Barrack 2_02	19.8	-	-
Barrack 2_03	17.3	32.6	587
Barrack 3_01	18.4	30.3	753
Barrack 3_02	20.1	24.3	550
Barrack 3_03	19.0	29.2	564
Barrack 3_04	17.6	24.3	551
Barrack 5_01 (kitchen)	20.3	19.2	-
Barrack 5_02 (kitchen at the entrance)	19.5	25.7	394
Barrack 5_03 (upon receiving the cargo)	18.9	23.6	374

When analyzing the data, it was concluded that the average data of the indoor air of the barracks are: relative humidity 29.7 %, indoor temperature 19.1 °C, and indoor CO_2 concentration 576.9 PPM.

4.6. Survey on indoor comfort in a building at a military site and summary of its results

73 respondents of different age and gender participated in the survey, either in their workplaces or while performing their daily duties. Three groups of buildings were surveyed.

Respondents were advised to fill in a questionnaire by answering questions that could generally help to describe the interior comfort of the building being studied (see Fig. 4.12).

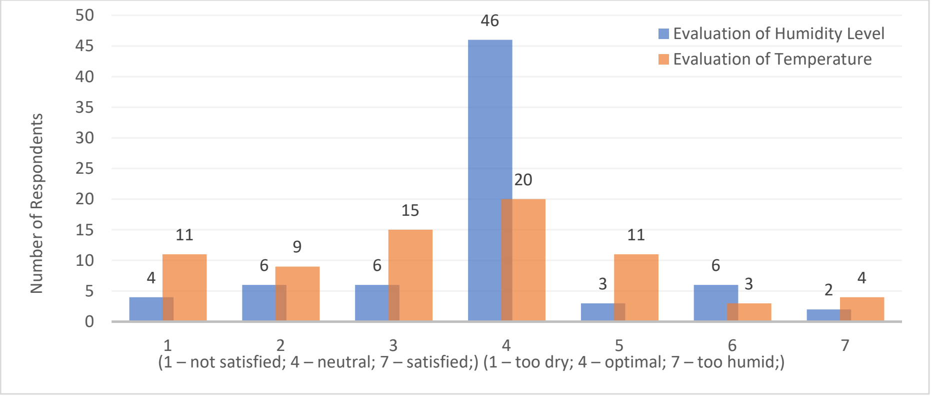


Fig. 4.12. Survey “On Interior Comfort” of a military object respondents’ satisfaction indicator of interior temperature.

The analysis of the survey schedules illustrates the problem of indoor comfort in the studied buildings. Most respondents give negative ratings to indoor air temperature, relative humidity and air quality. The responses of the respondents about the acoustic situation and the perceptible odor in the interior are not illustrated graphically in the paper, but the written answers of the survey largely reflect dissatisfaction of the respondents.

5. VALIDATION OF RESULTS IN PRACTICAL APPLICATION

5.1. Estimation of energy consumption of unclassified buildings in different Latvian cities

Theoretical estimation of energy consumption was performed for Latvian climatic conditions, which is similar in the Baltic region and in Western regions of Russian Federation, in order validate dynamic energy calculations and to evaluate different retrofitting scenarios. For this purpose, a typical Latvian fire station was selected. A typical fire station is a low-rise building. There are several cost optimal solutions for the construction and retrofitting of low-rise buildings which can be easily applied to fire stations. However, retrofitting of the fire stations is more complicated in comparison to residential and public buildings. This type of buildings has specific requirements on ventilation due to fire-fighting truck exhaust pipes and hot water consumption pattern that has explicit peak loads on staff shifts change.

As a first step, a non-renovated building was analyzed. Table 5.1 presents data on energy consumption of non-renovated buildings with the activity level of 2.0MET, 1.4CLO in garage and 1.2 MET, 0.85 CLO in office. The energy consumption for hot tap water was not taken into consideration.

Table 5.1

Energy consumption of non-renovated buildings, kWh/m^2

	Riga	Liepaja	Gulbene	Daugavpils
HVAC electricity	0	0	0	0
District heating	136.2	123.2	160.7	151.5

In the scope of this study three retrofitting scenarios were analysed. Scenario 1 “basic” includes thermal insulation of building envelope in accordance with Latvian legislation and installation of mechanical ventilation system without exhaust air heat recovery. Scenario 2 is similar to scenario 1, however, it is enhanced by the installation of the exhaust air heat recovery unit. Scenario 3 is a deep retrofitting approach which is suitable for Latvian climatic conditions. It includes installation of more efficient exhaust air heat recovery unit, better airtightness of building envelope and an extra thermal insulation that meets the passive house standard requirements.

The results of this study indicate that an installation of mechanical ventilation system without exhaust air heat recovery unit significantly increases energy consumption even for a well-insulated building. Installation of an exhaust air heat recovery unit, on the other hand, ensures a reduction of thermal energy consumption by 165.8 kWh/m^2 or by 72 %. However, there is a significant increase in electricity consumption to run an air handling unit which on average adds 25 kWh/m^2.

5.2. Development of renovation scenarios for unclassified buildings

All in all, the measured energy consumption of the selected unclassified buildings is significantly higher than the energy consumption of civil buildings (residential and public), where the combined energy consumption for heating and hot water preparation is 190 kWh/m^2. This report aims to define the main parameters of unclassified buildings in order to develop guidance for refurbishment of unclassified buildings in regions with space heating demand. Based on the typology of unclassified buildings, a standardised model was developed (Fig. 5.1).

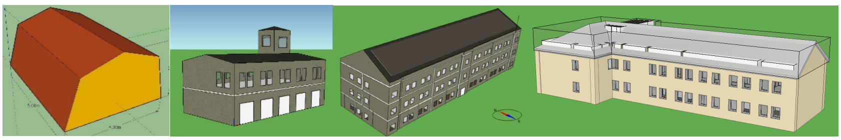


Fig. 5.1. Standardised model developed for unclassified buildings.

Based on the performed measurements and questionnaires, standard exit data were set for each type of building: indoor temperature, number of people and the specifics of their stay, air permeability of the enclosing structures.

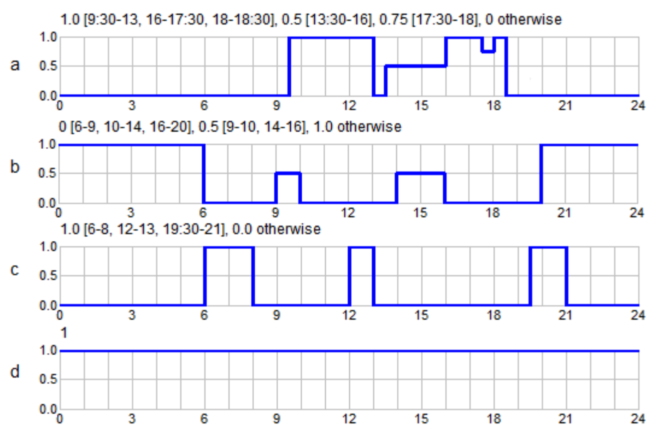
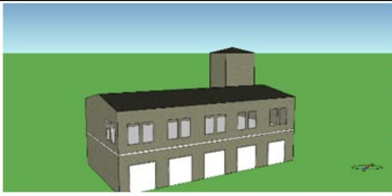


Fig. 5.2. Load and lighting schedules.

A study on energy consumption of non-renovated fire station buildings was conducted to showcase the impact of renovation measures (2 simulation scenarios). In scenario 1, the retrofit package included replacement of windows and an application of additional thermal insulation layer (+50 mm). In scenario 2, the retrofit package included scenario 1 with an exhaust air heat recovery system for ventilation through a rotary heat exchanger with a temperature efficiency of 86 %. Air infiltration rate for retrofitted buildings: 1.5 m^3/h × m^2; U-value of external building envelope: 0.29 W/(m$^2 \cdot$ K); mechanical ventilation rate: n – 1 =2 without recovery.

SCENARIO 1: Façade retrofit w/o heat recovery system

SCENARIO 2: Façade retrofit with exhaust air heat recovery system for ventilation



Model floor area	552.0 m^2
Model volume	2531.9 m^3
Model ground area	276.0 m^2
Model envelope area	1245.8 m^2
Window/Envelope	4.0 %

a) fire station model for calculation

b) typical Latvian fire station

Fig. 5.3. Fire station prototype model developed by IDA-ICE v4.8 software.

The simulation for the 2 scenarios was conducted by IDA-ICE v4.8 software based on the developed prototype model representing a typical fire station. A typology of the 40 analyzed fire depots indicates common construction principles, namely, the ground floor is used for parking fire-fighting vehicles, whereas the second floor is used for staff needs and administration. Majority of fire stations have a similar floor layout and occupancy specifics.

Within the framework of Thesis, a study was conducted to model and compare the effects of different renovation/retrofitting measures in military barracks. Simulation of annual weather conditions in dynamic simulation model was performed using the climate file for 3 cities: DAUGAVPILS (WMO: 265440), RIGA (WMO: 264220) and LIEPAJA (WMO: 264060).

A single model of a building was used for all simulations (Fig. 5.4), it has a floor area of 618.0 m^2 and volume of 1936.1 m^3. The model's envelope area is 1254.1m^2, 7.0 % of which is window area. All zones have identical temperature set points of 21 °C as minimum and 25 °C as maximum. Descriptions of scenario simulations and their results can be seen in Table 5.2.

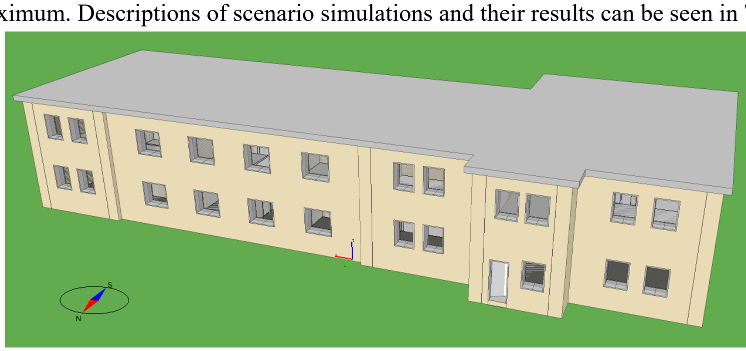


Fig. 5.4. Model of a building – barracks in Latvia.

Table 5.2

Description of retrofitting scenarios and their results

	U-values, $W/(m^2 \cdot K)$	Air flow of wind dependent infiltration at pressure difference 50 Pa, $m^3/(h \times m^2$ ext.surf.)	Exhaust air heat recovery, %	Air exchange rate, ACH	Location	HVAC electricity, kWh/m^2	District heating, kWh/m^2
Scenario 1	Windows – 2.6 Walls – 0.9 Floor – 0.8 Roof – 0.9	4	0	0.5	Daugavpils	0	222.7
					Riga	0	201.4
					Liepaja	0	190.5
Scenario 2	Windows – 1.1 Walls – 0.16 Floor – 0.16 Roof – 0.10	1.5	0	0.5	Daugavpils	0	94.4
					Riga	0	85.3
					Liepaja	0	79.5
Scenario 3	Windows – 1.1 Walls – 0.16 Floor – 0.16 Roof – 0.10	1.5	80	0.5	Daugavpils	6.2	50
					Riga	6.2	43.7
					Liepaja	6.2	39.4
Scenario 4	Windows – 1.1 Walls – 0.16 Floor – 0.16 Roof – 0.10	1.5	80	0.5*	Daugavpils	13.0	72
					Riga	13.0	63.4
					Liepaja	13.0	58.8

**In this scenario eight living rooms in the barrack have increased air exchange rate, which is 2.5* $l/(s \times m^2)$ *according to D2 national building code of Finland.*

The results showed that there is a 30 % of savings potential with façade retrofit only, and up to 83 % of savings potential if deep energy retrofit intervention is carried out in the form of equipping the building with an exhaust air heat recovery ventilation system. Another study conducted to simulate and compare the impact of different renovation measures in military barracks showed that significant savings can be achieved by a combination of energy efficiency measures (presented in Table 5.3).

Table 5.3

Renovation potential in military barracks (case study)

Infiltration, m^3	System description	Energy consumption, kWh/m^2	
		Heating	Electricity
1.5	With ventilation + heat recovery	86.5	5.1
4.0	With ventilation + heat recovery + windows *U*-value 1.1	79.8	5.1
1.5	With ventilation + heat recovery + windows *U*-value 1.1	76.3	5.1

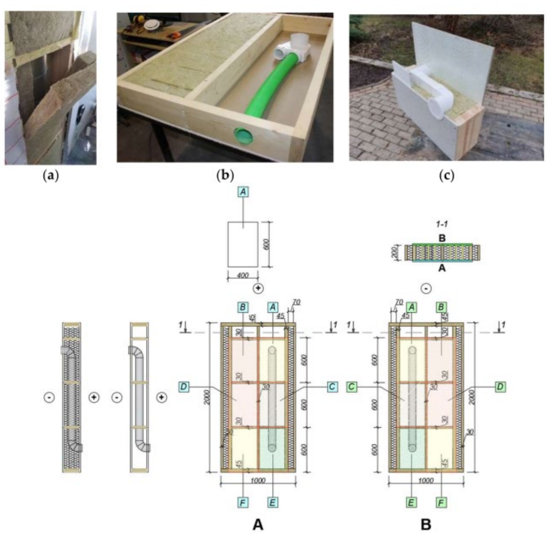
Table 5.3 continued

1.5	With ventilation + heat recovery + windows *U*-value 1.1 / walls *U*-value 0.17	25.5	5.1
1.5	With ventilation + no heat recovery + windows *U*-value 1.1 / walls *U*-value 017	58.1	5.1

5.3. Development of a solution for modular bulletproof wooden frame insulation

The safety of personnel is a top priority in unclassified buildings, especially military buildings. However, indoor air quality and thermal comfort has a direct impact on personnel's productivity and ability to concentrate on duties and affect the decision making in stress conditions [19]. The use of wooden structures and wooden frame structures for the construction of new buildings as well as for the retrofitting/renovation of existing buildings is becoming more common in the construction of buildings. The modular timber frame construction perfectly meets the needs of unclassified buildings, allowing a significant reduction in construction time and the integration of various active and passive elements, such as fresh air supply ducts. As part of the Thesis, a study of a 12 mm thick aramid ballistic panel was conducted. Solutions of various modular external walls were modeled, a ballistic wooden construction panel with an integrated air duct was analyzed, and their thermal conductivity was tested. The main advantage of the proposed technology is the fast and high-quality construction of unclassified building modules, which meets all modern requirements not only for safety, but also for energy efficiency and indoor air quality.

In the course of the research, separate demonstration walls with built-in channels were made (see Fig. 5.5). This allowed the overall efficiency of the wall mounting to be tested and the additional integration of ballistic protection to be assessed. Different ventilation ducts were considered. The main goal was to create a layout that would prevent the bullet from penetrating.



(a) (b) (c)

(d)

Fig. 5.5. Wooded frame test construction: (a) steel duct; (b) flexible plastic duct; (c) plastic ducts; (d) test wall dimensions.

Research has shown that bulletproof wooden frame constructions can provide protection for people in the event of an accidental fire or attack, as well as ensure the energy efficiency of the entire building. Simulations have shown that the built-in air duct has no negative effect on the wall heat transfer coefficient. However, the circulating air temperature must not be lower than +20 ºC. The heat transfer coefficient decreases to 0.346 W/(m^2·K) when the air temperature drops to –5 ºC. This solution can be used in combination with mechanical ventilation equipped with a recuperation unit. In other cases, it can be used as a local outdoor air outlet with a length of 0.5 m or less.

The bulletproof panel can only be placed on one side, which significantly reduces construction costs while slightly compromising ballistic safety. An additional aramid backing reduces this risk. The layout of the room must take into account possible accidents and prevent work tables from being placed close to the ventilation openings. A safe place to install such local ventilation openings is under the ceiling. A lightweight wooden frame construction with ballistic protection may be recommended for use in temporary military or other towns, thus ensuring energy efficiency and human safety in the event of an accidental fire.

5.4. Potential assessment of solar energy for integration in buildings energy system

One of the main priorities of NECP 2021-2030 is the implementation of energy efficiency measures in buildings and the integration of renewable energy (RES) technologies in buildings. The potential of energy production (using solar energy) to increase the energy efficiency of unclassified buildings was calculated in the Thesis. In order to increase the energy efficiency of unclassified buildings, scenarios for on-site energy production using renewable energy sources – solar collectors and panels – were considered.

Scenario 1: Solar collectors for heat and hot water. A real building is modeled and simulated (see Fig. 5.6), its parameters are given in Table 5.4, and solar collector parameters in Table 5.4. Given that this is a town and each building is located differently (see Fig. 1.7), different simulations were performed for different building orientations (towards the sky), the solar collector orientation was simulated for the whole sky, this was done to determine the highest solar collector performance.

Scenario 2: PV for electricity generation. All building parameters are similar to scenario 1 (see Table 5.4).

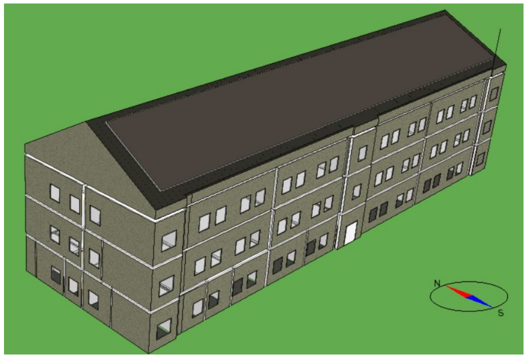


Fig. 5.6. Model of the building.

Table 5.4

Modeled building parameters

Building parameters	
Location	Riga
Floor area	3297.2 m^2
Volume	11664.5 m^3
Land area	832.1 m^2
Window / ratio of enclosing structures	6.4 %
Average U-value	0.9682 $W/(m^2 \cdot K)$
Roof side area	504 m^2
Slope of the roof	30°
Scenario 1: Solar collectors	
Collectors area	385 m^2
Collectors number	180
Area occupied by collectors	76 %
Scenario 2: PV	
Number of PV panels	32
Rated capacity	576 W
MPP voltage	132 V
MPP current	4.37 A
Total capacity	18.43 kW_p
PV area	371.2 m^2

The results of the simulation can be used to develop energy supply solutions for military self-sufficient communities (military towns, military bases, etc.), for example, estimating the amount of energy produced during the day and matching it to the energy use profile.

5.5. Calculation of the potential economic impact of implementing energy efficiency improvement programs for unclassified buildings

Nowadays, due to the increasing moral and physical depreciation of the outdated stock of unclassified buildings, there is an urgent need for their renovation. The purpose of the renovation is to bring the existing morally and physically outdated stock into compliance with social and technical norms, standards and conditions of temporary presence or residence in these buildings. An alternative to reconstructing the outdated stock of unclassified buildings is de-construction and construction of a new building in the cleared area. However, due to the fact that at the moment there is lack of sufficient technical and material resources to develop the unclassified buildings, renovation is the only way to maintain and increase the existing stock. Renovation of buildings is mainly focused on improving their energy efficiency [20]. Significant energy savings include increasing of the insulation of the building envelope, instalation of supply and exhaust ventilation with air heat recuperator, which allows to reduce the heating load of the building, modernization of the heating system, installation of energy efficient lighting, as well as using of solar thermal energy equipment – solar collectors. The automation of work control processes of the engineering systems and devices mentioned above also play an important role in saving energy.

The potential economic impact of implementing energy efficiency improvement programs for unclassified buildings was based on the renovation project of an administrative building consisting of two adjacent buildings, the main and the newly built building, implemented in November 2019. In 1930, the foundation was laid for the building – one two-story brick building with a ground floor. In 1989, a new building – a three-story brick building with a basement was added. The total usable area of the administrative building is 2288.10 m^2.

In order to reduce heat loss through the facade of the building, the design documentation provided for complex thermal insulation of the buildings using 150 mm thick insulation material and a specific thermal conductivity of 0.036 $W/(m^2 \cdot K)$.

In the design of the attic roof insulation it was planned to use 350 mm thick thermal insulation material with specific thermal conductivity of 0.035 $W/(m^2 \cdot K)$. Also, during the project implementation the roofing of the renovated buildings was completely replaced and the foundation of the building was insulated.

The one-pipe heating system was replaced by a two-pipe heating system. New radiators with regulation fixtures were installed in all rooms of the building. Partial reconstruction of the building's heating unit was carried out.

Supply and exhaust ventilation were completely reconstructed. A ventilation system with exhaust air heat recovery (85 % efficiency) was installed.

A solar collector system was also installed to provide pre-heating of the cold water used in the hot water supply system. LED fixtures were installed throughout the building. Control and management processes of installed engineering systems with online monitoring capability were automated.

During the construction all basic methods were implemented, which allowed to minimize energy consumption, improve thermal comfort and air quality, as well as the overall technical condition of the renovated building, which, in turn, may be the minimum necessary measures to be taken when implementing energy efficiency projects in unclassified buildings and determining (calculating) the likely economic impact. The total cost of the project was EUR 308.93 / m^2.

Of course, given the geopolitical situation in the world, there is already a rise in construction prices, but this is a temporary phenomenon, therefore calculation of the Thesis is based on data from the 2018 INK ANALYTICS Scientific Statistics Survey commissioned by the Ministry of Economics of the Republic of Latvia "Study on Projected Changes in Labour and Building Material Costs in the Construction Sector in Latvia from 2018 to 2022".

In total, 92 unclassified buildings, of which 27 are owned by the State Police (VP), 40 are owned by the National Fire and Rescue Service (VUGD) and 25 are under the control of the Ministry of Defence (AM) of the Republic of Latvia, were considered in this research. The total usable area (S∑) of the analysed buildings was 127,466.9 м^2.

According to the values indicated in the scientific work, average specific energy consumption of buildings owned by the Ministry of Defence (AM) of the Republic of Latvia is 230 kWh/m^2 per year; average specific consumption of energy of buildings owned by the Ministry of Interior (IeM) of the Republic of Latvia consists of average annual energy consumption measured in police stations – 252 kWh/m^2 and in fire stations – 317 kWh/m^2. In order to determine the expected economic impact, the arithmetic average value of the energy consumption of unclassified buildings shall be taken into account:

$Q_{vid.\ AM,\ IeM}$ = (230 kWh/m^2+252 kWh/m^2+317 kWh/m^2) / 3 = 266.33 kWh/m^2 per year

Knowing $Q_{vid.\ AM,\ IeM}$, C_{2019} and S∑ values, we can determine the possible total cost of heating services ($C_{total\ 2019}$) for unclassified buildings in 2019:

$C_{total\ 2019}$ = (Qvid. AM, IeM × C_{2019}) × S∑ = (266.33 kWh/m^2 × 0.058 EUR/kWh) ×127,466.9m^2 = 1,968, 999.05 EUR per year.

Assuming that after the renovation of unclassified buildings energy efficiency performance can be improved and energy costs reduced by 54.59 %, we achieve a total potential cost savings of EUR 1,074,876.58 per year or 8.43 EUR/m^2.

CONCLUSIONS

In the initial phase of the Thesis, detailed analysis of energy consumption data of the unclassified buildings segment and practical indicators received by the researched subjects clearly pointed out the topicality of the issues discussed in the Thesis, relevance of the research topic and possible future economic benefits.

1. Climate change issues, including the reduction of greenhouse gas (GHG) emissions and the capture of carbon dioxide (CO_2), are at the center of attention of the European Union (EU) and are very important for Latvia as well. Latvia's Sustainable Development Strategy 2030 “Latvia 2030” states that "Latvia is our home – a green and tidy, creative and easy-to-reach place in the global space for which we are responsible to future generations."
2. With the adoption of the Energy Efficiency Directive 2012/27/EU, the European Union countries, including Latvia, have decided to take various measures to improve the efficiency of energy production, supply and consumption. The directive also sets a mandatory target for each country to provide end-users with energy efficiency measures that would save 1.5 % of the total energy supplied to end-users in the country.
3. According to the Energy Efficiency Directive, from 2014 onwards, Member States are required to renovate 3 % of their state-owned buildings each year, including non-classified buildings such as military buildings, police buildings and fire stations. Summarizing the research carried out in the Thesis, it was concluded that the energy efficiency of unclassified buildings could and should be improved. Improvements in energy efficiency can be achieved through systematisation of data, regulatory changes, different requirements, technological changes, management and organizational improvements of publicly owned buildings (unclassified buildings),

and changes in individual consumer behaviour through consumer education and information, not forgetting about the specifics of the sector under the study.

4. This work provides an overview of the portfolio of the unclassified buildings in Latvia by comparing the age of buildings within portfolios of different departments. Based on the research results, the most optimal methodology for determining the energy efficiency of buildings was proposed. The methodology is based on statistical and machine learning methods – hybrid methods involve a combination of both engineering and statistical models and use the output from engineering models as an input to statistical models. The purpose of these models is to offset some of the constraints involved in physical modelling (such as the inability to model every building in a district) with the flexibility of statistical approaches. Workflows of model development are designed for individual buildings require a level of effort that would be time and cost prohibitive to apply to campuses which often include hundreds of diverse-use buildings. While smaller campuses can effectively utilize the traditional BEM approach to study retrofit scenarios, this option is, therefore, not feasible for larger campuses. A combination of statistical and spreadsheet models which may not fully capture the unique architectural features, programmatic requirements, and systems configurations of individual campus buildings still can be used for accurate predictions of savings from implementing a variety of retrofitting measures. For the research of unclassified buildings located mostly in northern climate, energy consumption is mostly related to the heating, cooling and hot water preparation purposes. Energy consumption for artificial lighting can be assumed by average values for public buildings depending on human activities and necessary illuminance emittance in lux, given in European and national standards and building codes. Considering energy source, it is important to highlight that energy source (fossil or renewable fuel) for heating, cooling and hot water preparation for unclassified buildings can be chosen based on existing needs and possibilities, depending on building type (stationary or mobile) and other different technical-economical parameters.
5. Based on the obtained real physical and economic data, a possible economic effect was calculated, which can be obtained provided that 54.59 % of energy efficiency programs are implemented in unclassified buildings, thus achieving a total potential cost savings of EUR 1,074,876.58 per year or 8.43 EUR/m^2.
6. Energy efficiency solutions for unclassified buildings are a pressing issue, especially since a large proportion of unclassified buildings are maintained at public expense and the reduction in the cost of living enables the redistribution and redirection of savings for the development of unclassified building segments and to support our efforts to tackle climate change.

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