Construction of Unique Buildings and Structures
journal homepage: www.unistroy.spbstu.ru`

doi: 10.18720/CUBS.66.4

Energy-efficient construction in the climatic conditions of Latvia

Энергоэффективное строительство в климатических условиях Латвии

А. Бородинец [1], Ю. Земитис [2], А. Геикинс [3], Ю.В. Быкова [4]*, А.В. Нефедова [5], С.В. Купавых [6]

[1-3] Рижский технический университет, LV-1658, Латвия, Рига, ул. Калькю, 1

[4,5] Санкт-Петербургский политехнический университет Петра Великого, 195251, Россия, г. Санкт-Петербург, Политехническая ул., 29.

[6] Санкт-Петербургский горный университет, 199106, Россия, г. Санкт-Петербург, Васильевский остров, 21 линия д.2.

A. Borodinecs [1], J. Zemitis [2], A. Geikins [3], I.V. Bykova [4]*, A.V. Nefedova [5], S.V. Kupavykh [6]

[1-3] Riga Technical University, 1 Kalku Street, Riga LV-1658, Latvia

[4,5] Peter the Great St. Petersburg Polytechnic University,29 Politechnicheskaya St., St. Petersburg, 195251, Russia

[6] Saint-Petersburg Mining University, 2, line 21 V.O., St. Petersburg, 199106, Russia

КЛЮЧЕВЫЕ СЛОВА

энергоэффективное строительство;
инсоляция;
климат;
Латвия;
ограждающие конструкции;

KEYWORDS

zero energy house;
insulation;
climate;
Latvia;
feasibility;

ИСТОРИЯ

Подана в редакцию: 17.02.2018
Принята: 02.05.2018

ARTICLE HISTORY

Submitted: 17.02.2018
Accepted: 02.05.2018

АННОТАЦИЯ

Низкое энергопотребление может быть достигнуто за счет внедрения энергоэффективных ограждающих конструкций, а также энергоэффективных систем отопления и вентиляции. Кроме того, использование возобновляемых источников энергии позволяет достичь требований nZEB и ZEB. В этой статье дается расчетный подход и выводы о необходимой толщине изоляции для непрозрачных элементов. Кроме того, в этом исследовании оцениваются оптимальные размеры окон, их ориентация и тепловые свойства для достижения стандартов низкоэнергетических зданий в латвийском климате. Расчеты были проведены для жилого дома для одной семьи. В исследовании учтены особенности зданий с низким потреблением энергии для пяти крупнейших городов Латвии, расположенных в местах с максимально разнообразными климатическими условиями. В статье представлены расчеты экономичности и окупаемости низкоэнергетических строительных конструкций и систем ОВК в Латвии.

ABSTRACT

The low energy building can be achieved by implementation of energy efficient building envelope as well as energy efficient heating and ventilation systems. In addition use of renewable energy sources allows reach nZEB and ZEB requirements. This paper provides calculation approach and conclusions on necessary insulation thickness for opaque elements. In addition optimal windows sizes, their orientation and thermal properties to achieve low energy buildings standards in Latvian climate is evaluated in this study. This has been done for single family house. Study takes into account specifics of low energy consumption buildings for five largest cities of Latvia located at places with maximally diverse climatic conditions. The paper presents economical and payback time calculations of low energy building constructions and HVAC systems in Latvia.

Содержание

1. Introduction

From the year 2021 all new buildings will need to be zero energy buildings. Increased attention should be paid to technical solutions in order to reduce the energy consumption of the buildings. The zero energy level can be achieved by very small amount of consumed energy for heating, ventilation, electricity and hot water [1-3]. Modern energy efficient buildings should produce necessary energy by renewable energy sources [4-7]. Therefore, these buildings will be similar to today's buildings of passive house standard. As seen from the experience of these type of buildings the needed low level of energy consumption can only be achieved by complex solutions including - increased building envelopes thermal resistance by applying thicker insulation, usage of low-e coated passive windows, utilizing passive solar energy, increasing air tightness to reduce air infiltration, applying ventilation system with heat recovery [8-10], preheating ventilation air through earth heat exchanger and other energy saving methods [11-13] . However increased attention needs to be addressed regarding indoor air quality which can suffer if not enough ventilation is ensured [14]. The necessary surplus energy will be provided by renewable sources therefore making the buildings zero energy.

The exact U-values of the building envelopes will vary in each case depending on several factors like parameters of outside air during heating season, size and type of building, architecture and availability of energy resources. The optimal insulation thicknesses must be calculated for each region to make the building zero energy at the same time ensuring the economic feasibility. In fact, one of the major influences to choose zero energy buildings over standard ones would come in case if they would not only be environmentally friendly but also economically beneficial.

Nowadays in Latvia there are houses, who have been planned as low-energy buildings, have come close to reaching the needed low levels of energy consumption. It is necessary to develop technical solutions to build zero energy buildings and to compare results with other countries [15]. In addition, the costs analysis of these building must be done.

2. Methods

The most common definition of passive building describes it as building with low energy consumption where, for the most part of year, usage of supplementary heating system is not necessary. The necessary heat in passive houses is provided using existing internal heat sources, solar energy and ventilation system [16-20]. The passive house standard states that total energy consumption for heating should be less than 15 kWh/m^2/year or design heating energy no more than 10 W/m^2. This is calculated assuming that the maximal allowed supply air temperature must not exceed +50 °C due to hygienic reasons, the ventilation air supply is 30 m^3/h/pers. and one person has 30 m2 of living space. This max peak heating load value therefore is not dependent on placement of building and can be used as design parameter calculated by Eq.1.

$$Q_{max} = (V\,(T_{supply} - T_{room})\,c_p\,\rho) / A_{room} \qquad (1)$$

Q_{max} – desing heating capcity (kJ/(h·m^2)),

V – infiltration air volume (m^3/h),

T_{supply} – supply air temperature (oC),

T_{room} – indoor air temp. (oC),

c_p – specific heat capacity (kJ/(kg·K)),

ρ – air density (kg/m^3),

A_{room} – heated area (m^2).

Each building is unique by its location energy use profile as owner life style etc. Methodology

To determine what should be the optimal orientation of windows and the minimal U-values of opaque building elements in each of previously mentioned Latvian cities a case building was chosen and analyzed for different outside air parameters [21].

The building is assumed to be a one story single family house. Total heated floor area is 180 m^2 and room height is 2.50 m. The total area of windows is 15% of floor area and the area of all external walls 140 m^2. The wall height is 3.0 m.

Бородинец А., Земитис Ю., Геикинс А., Быкова В.И., Нефедова А.В., Купавых С.В., Энергоэффективное строительство в климатических условиях Латвии, Строительство уникальных зданий и сооружений, 2018, №3(66). С. 41-48.

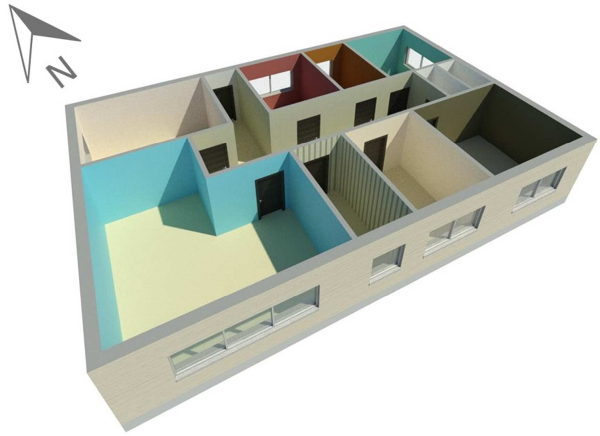

Figure 1. Floor plan of building with optimal orientation of windows

Prior to determining the optimal thermal transmittance values of building envelope a study on the best orientation of windows was performed. This was done in WinDesign software and data regarding the necessary yearly heating demand as well as days of overheating was compared. For given case building the best results were obtained with maximum window area facing the south and minimal to north. In comparison if most of the windows would be orientated to west and north side's the yearly energy demand would rise by 20-25% and also by moving a window from north to east facades reduction in energy is about 10%. Also in cases when larger window areas where facing west compared to south led to twice as many hours of overheating and larger demand of heating during winter by 10%.

The optimal air supply rate was calculated according to the national standards [22] and for exhaust air was calculated as 230 m^3/h and supply air - 285 m^3/h. The larger value was taken as design value and expressed as air exchange rate 0.62 h-1. The desing heating peak for ventilation is calculated using equation 1, 15.6 W/m^2 or 2800 W.

Knowing this value, it is possible to calculate the minimal U-values of building envelope elements in case of each city. However theoretically there are infinite number of possible combinations between the different types of building elements – walls, roof, ground slab and windows that could fulfill the set requirements. Therefore, assumption that U-values for walls, roof and ground slab should be similar is made as well as approximate thermal transmittance for windows should be in range of 0.6 to 1.1 W/(m2·K) while for entrance doors around 1.0-1.3 W/(m^2·K). This is the usual practice in passive houses to avoid discomfort from cold radiation caused by low temperatures on internal surfaces. Also the thermal bridges where assumed to be none changing and set to 0.01 W/(m·K) as well as infiltration air volume would be limited to 0.03 h-1 or 13.5 m^3/h.

The peak design heat loses for building was calculated for the different outside design temperatures according to building placement and assuming +20 °C for inside air:

$$Q_{design} = Q_{envel.} + Q_{bridges} + Q_{infilt.} + Q_{vent} \quad (2)$$

where

Q_{design} – peak design heat loses (W),

$Q_{envel.}$ – heat loses through building envelope (W),

$Q_{bridges}$ – heat loses through thermal bridges (W),

$Q_{infilt.}$ – heat loses through infiltration (W),

$Q_{vent.}$ – heat loses through ventilation (W).

The heat loses through ventilation was calculated assuming that the efficiency of air exchanger would be 90%. This was determined to be threshold value under which it becomes almost impossible to reach the needed low energy consumption and raises the construction costs dramatically.

Simultaneously with peak design heat loses calculation the yearly energy consumption in kWh/m2 for whole building was determined. For this the Eq.3 was used.

$$Q_{yearly} = (D_{heat} \cdot 24 \cdot (Q_{envel.} + Q_{bridges} + Q_{infil.} + Q_{vent.}) - Q_{solar} – Q_{int.}) / A \quad (3)$$

where

D_{heat} – number of days of the heating period.

Borodinecs A., Zemitis J., Geikins A., Bykova I.V., Nefedova A.V., Kupavykh S.V., Energy-efficient construction in the climatic conditions of Latvia, Construction of Unique Buildings and Structures. 2018. No. 3 (66). Pp. 41-48.

For yearly heating energy calculations, the yearly average heating seasons outside temperature is used, the inside temperature is assumed to be +20 oC. The internal heat gains are defined as 2.1 W/m^2 as it is recommended in PHPP calculation tool.

The passive solar energy gains are calculated taking into account the average yearly solar radiation dependent on window orientation in region of Latvia. For south it its 318 kWh/m^2, north 54 kWh/m^2, east 85 kWh/m^2 and west 255 kWh/m^2. The g-value of windows is set to 0.54 as this represents the average shading coefficient for passive house windows available in market.

3. Results and Discussion

3.1 Results

The obtained results of performed calculations to achieve the passive house level are shown in Table 1.

Table 1. Calculated U-vlaue W/(m2·K) of building envelope for different construction

Building element	City of Riga	City of Daugavpils	City of Liepaja	City of Aluksne	City of Ainazi
Exterior walls	0.075	0.07	0.09	0.06	0.07
Ground slab	0.08	0.07	0.08	0.07	0.07
Roof	0.07	0.06	0.075	0.06	0.065
Doors	1.1	1.1	1.1	1.1	1.1
Windows	0.65	0.65	0.7	0.65	0.65
Peak heat load	16 W/m2	16 W/m2	15.5W/m2	15.5 W/m2	15.5 W/m2
Yearly heating energy consum. kWh/m2/year	15.9	15.9	15.9	17.0	15.2

As seen from the result in the Latvia to achieve the low level of heat loses so they can be compensated using only ventilation is possible. At the same time in none of the case the yearly heating energy consumption was calculated to be less than 15 kWh/m2/year. However, as the main purpose of passive house is to provide the necessary indoor temperature during winter without additional active heating system, peak heating load is the indicator with most importance. Also the annual heating demand is dependent on more factors that can vary e.g. the actual shading coefficient of windows, ventilations heat recovery efficiency and internal gains which can be up to three times higher. [23, 24]

It should be pointed out that the chosen case study building represents hard to achieve passive house standard type of building do to the high ratio of surface to volume. In case if the building had more floors or would be different type the low levels of energy consumption would be more easily achievable.

To further analyze the heating energy balance of buildings a figure showing heat gains and losses for case of building in Riga was developed. (see Fig. 2.)

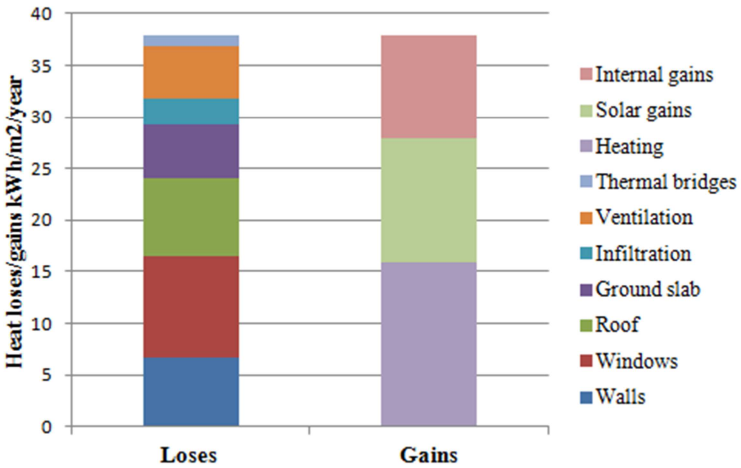

Figure 2. Buildings energy balance (Location City of Riga)

The analysis of energy balance in this case shows that about 75% - 78% of energy losses occur through opaque elements while the rest are associated with ventilation and thermal bridges. However, this may slightly vary in each case depending on the placement of the building, specific area of windows, geometry of building, available sunlight, etc. The heat gains are distributed evenly between solar, internal and heating gains. This shows that the assumptions of internal heat gains have large affect on total calculated heating energy.

3.2. Discussion

One of the most motivating factors to build passive houses would be their economic feasibility. As the existing experience of built passive houses shows their construction costs are on average 5-15% higher compared to standard type building which are in accordance with local regulations. The payback period of these buildings vary from 15 to 25 years, the large the built area the shorter the period. [24]

To verify this calculation for a case building which compiles the passive building standard in area of Riga was done. The previously determined insulation thicknesses where used and the economical comparison was done in retrospect to building which would be designed to comply with local regulations [25]. This building would need wall insulation of 150 mm; roof insulation of 200 mm, ground slab insulation of 70 mm and windows with U-value of 1.8 W/(m^2·K). The yearly heating energy consumption for this building would be 118 kWh/m^2/year or 21.2 MWh.

The additional costs of passive house would include paying for extra insulation (~5600 €), windows (~5400 €), installing a ventilation system (~5500 €) and electricity for ventilator (~100 €/year). However, it would save on not having radiators (~1500 €) and less use of heating fuel (1200 €/year). The price for heating are take 55 €/MWh for heating and for electricity - 162 €/MWh. Therefore, it can be calculated that the passive house will repay in 13 years. The time period will be longer in case the necessary money for initial investments will be taken on mortgage. At the same time it can shorten due to increasing fuel costs.

The predicted economic feasibility of zero energy houses would be expected to be longer. This is caused by the high renewable energy source installation costs and the fact that there would be only small amount of additional heating energy to save. However, it would be technically easily possible to achieve zero energy level from passive houses by implementing renewable energy sources like solar thermal energy, PV panels, geothermal energy, wind power, tidal power or other type of renewable energy. The optimal choice would strongly differ depending on local building site and the possible solutions.

A strong option would be utilization of solar energy both for generating solar thermal and electrical power. The Table 2 shows the solar radiation on horizontal plate in kWh/m2 for each month for city of Riga. However, the actual obtained energy of solar collectors is depend on their orientation, shading from trees as well as efficiency of the system. The data on how the efficiency changes depending on inclination angle and orientation if located at Riga is shown in Tables 3.

Table 2. Volume of solar radiation and average temperatures by months in City of Riga [26]

Location	January	February	March	April	May	June	July	August	September	October	November	December	Per year
Solar radiation kWh/m^2	12.1	28.6	79.1	120	170.3	206.3	192	146.5	87.0	43.3	15.4	9.1	1109
Average temperature, ^{o}C	-4.7	-4.3	-0.6	5.1	11.4	15.4	16.9	16.2	11.9	7.2	2.1	-2.3	6.2

Table 3. Optimal inclination angle of solar thermal collector for heating and hot water supply systems [27]

Inclination angle to the horizontal	0°	15°	30°	45°	60°	75°	90°
Heating loads	0.71	0.85	0.94	1.00	1.00	0.98	0.88
Heating and hot water supply	0.59	0.74	0.89	1.00	1.06	1.06	0.97

Taking into account that the heating season in Latvia on average is lasting from October until May, the total solar energy production during the heating season is 310 kWh/m^2. Maximal energy produced by solar panels can reach 185 kWh/m^2. Meaning that for our studied case building about 15.5 m^2 of solar panels would be necessary to generate energy needed for heating. However, some kind of heat accumulation must be applied to store the heat for prolonged periods of especially low outdoor temperatures. Importance of efficient renewable energy use also was considered in studies [28-31].

In addition to energy efficient building envelope, use of solar thermal energy the heat pump and PV panels can be used as well. In optimistic scenarios the COP of heat pumps can be assumed as 4.5 to 5. In that case the electrical consumption for yearly heating needs would be 570 kWh/year. The efficiency of PV panel systems is about 18% - 20%. It means that 1 m^2 of PV panel can produce 55 kWh during the heating season. In addition to all before mentioned measure the efficient pumps should be used in modern low energy buildings, that ensure the reduction of annual electricity consumption up to 48% [32].

4. Conclusions

This study provides calculations of required U-values of building elements for different cities of Latvia. The optimal insulation thicknesses must be calculated for each region to make the building zero energy. The results show that it is possible to achieve low-energy buildings requirements in cold Latvian climate. Implementation of highly insulated building envelope allows use of renewable to partly cover heat consumption. In addition to energy efficient building envelope use of solar thermal energy, the heat pump and PV panels can be used as well.

Results indicate that it is economically feasible to build low-energy houses in c Latvian climatic conditions. It can be calculated for a case building which compiles the passive building standard in area of Riga that the passive house will repay in 13 years. This leads to believe that the set goal that from year 2021 all new buildings must be zero energy is reachable. Such low energy buildings with efficient ventilation systems have added good indoor environment, long lifetime, higher market value as well as they are environmentally friendly.

5. Acknowledgements

This study was supported by European Regional Development Fund project «NEARLY ZERO ENERGY SOLUTIONS FOR UNCLASSIFIED BUILDINGS» Nr. 1.1.1.116A048.

Литература

[1]. Korniyenko S. V. (2013). Settlement and experimental control of energy saving for buildings. Magazine of Civil Engineering. Vol. 8. pp. 24–30

[2]. Афанасьев В., Ковалев В., Тарасов В., Тарасова В., Федоров Д. (2014) Исследование расхода тепловой энергии на отопление зданий. Вестник Чувашского университета. Vol. 2. pp. 10-18

[3]. Гагарин В.Г., Пастушков П.П. (2014) Об оценке энергетической эффективности энергосберегающих мероприятий. Инженерные системы. АВОК-СЕВЕРО-ЗАПАД. No. 2. c. 26–29

[4]. Murgul V. (2014) Solar Energy systems in the reconstruction of heritage historical buildings of the northern towns. (for example Saint-Petersburg). Journal of Applied Engineering Science. Vol. 12 (2). pp. 121-128

[5]. Aronova E., Radovic G., Murgul V., Vatin N. (2014) Solar Power Opportunities in Northern Cities (Case Study of Saint-Petersburg). Applied Mechanics and Materials, 587-589, pp. 348-354

[6]. Badescu V. (2007) Economic aspects of using ground thermal energy for passive house heating. Renewable Energy. No 32. Pp. 895–903

[7]. Недвига П.Н. (2010) Возможности использования тепловых аккумуляторов и низкопотенциального тепла земли при отоплении индивидуальных домов. Инжнерно-строительный журнал. No. 3. c. 11–14.

[8]. Nemova D. (2012). Ventilation systems in residential buildings as means of increase of power efficiency. Construction of Unique Buildings and Structures. No. 3.

References

[1]. Korniyenko S. V. (2013). Settlement and experimental control of energy saving for buildings. Magazine of Civil Engineering. Vol. 8. pp. 24–30

[2]. Afanas'ev V., Kovalev V., Tarasov V., Tarasova V., Fedorov D. (2014) Issledovanie rashoda teplovoj jenergii na otoplenie zdanij [Statistical analysis of the heat flow in heating]. Vestnik chuvashskogo universiteta. Vol. 2. pp. 10-18 (rus)

[3]. Gagarin V.G., Pastushkov P.P. (2014) Ob otsenke energeticheskoy effektivnosti energosberegayuschih meropriyatiy [About an Assessment of Power Efficiency of Energy Saving Actions]. Engineering systems. AVOK NORTH-WEST. No. 2. pp. 26–29 (rus)

[4]. Murgul V. (2014) Solar Energy systems in the reconstruction of heritage historical buildings of the northern towns. (for example Saint-Petersburg). Journal of Applied Engineering Science. Vol. 12 (2). pp. 121-128

[5]. Aronova E., Radovic G., Murgul V., Vatin N. (2014) Solar Power Opportunities in Northern Cities (Case Study of Saint-Petersburg). Applied Mechanics and Materials, 587-589, pp. 348-354

[6]. Badescu V. (2007) Economic aspects of using ground thermal energy for passive house heating. Renewable Energy. No 32. Pp. 895–903

[7]. Nedviga P.N. (2010) Vozmozhnosti ispol'zovanija teplovyh akkumuljatorov i nizkopotencial'nogo tepla zemli pri otoplenii individual'nyh domov [The possibility of using thermal accumulators and low-grade heat of the earth for heating of individual houses]. Magazine of Civil Engineering. No. 3. Pp. 11-14. (rus)

[8]. Nemova D. (2012). Ventilation systems in residential buildings as means of increase of power efficiency. Construction of Unique

pp. 83-86

[9]. Petritchenko M.R., Nemova D.V., Kotov E.V., Tarasova D.S., Sergeev V.V. (2018) Ventilated facade integrated with the HVAC system for cold climate. Magazine of Civil Engineering. No. 1. pp. 47–58

[10]. Petritchenko M.R., Kotov E.V., Nemova D.V., Tarasova D.S., Sergeev V.V. (2018) Numerical simulation of ventilated facades under extreme climate conditions. Magazine of Civil Engineering. No. 1. pp. 130–140

[11]. Табунщиков Ю.А., Бродач М.М. (2002) Математическое моделирование и оптимизация тепловой эффективности зданий. М.: АВОК-ПРЕСС. p. 194

[12]. Корниенко С.В., Попова Е.Д. (2017) "Зеленое" строительство в России и зарубежом. Строительство уникальных зданий и сооруженийs. № 4(55). с. 67-93

[13]. Ватин Н.И., Горшков А.С., Немова Д.В. (2013) Энергоэффективность ограждающих конструкций при капитальном ремонте. Строительство уникальных зданий и сооружений. № 3(8). с. 1-11

[14]. Dimdina I., Lešinskis A., Krumiņš E., Krumiņš V., Šnidere L., Zagorskis V. (2011) Indoor air quality and energy efficiency in multi-apartment buildings before and after renovation: A case study of two buildings in Riga. Paper presented at the Civil Engineering '11 - 3rd International Scientific Conference, Proceedings. pp. 236-241.

[15]. Nieminen J., Holopainen R., Lylykangas K. (2008) Passive House for a cold climate. Nordic Symposium on Building Physics, Copenhagen 2008. pp. 1-8

[16]. Harmati, N., Jakšić, Z., Vatin, N. (2015) Energy consumption modelling via heat balance method for energy performance of a building. Procedia Engineering, 117 (1), pp. 791-799

[17]. Gorshkov, A., Vatin, N., Nemova, D., Shabaldin, A., Melnikova, L., Kirill, P. (2015) Using life-cycle analysis to assess energy savings delivered by building insulation. Procedia Engineering, 117 (1), pp. 1085-1094

[18]. Аникина И.Д., Поршнев Г.П., Сергеев В.В. (2012) Тепловизионное обследование зданий. Научно-технические ведомости Санкт-Петербургского государственного политехнического университета. № 147-1. с. 94-98)

[19]. Аникина И.Д., Сергеев В.В., Амосов Н.Т., Лучко М.Г. (2016) Использование тепловых насосов в технологических схемах генерации тепловой энергии ТЭЦ. Международный научный журнал Альтернативная энергетика и экология. № 3-4 (191-192). с. 39-49

[20]. Постных Ж.В., Сергеев В.В. (2014) Оценка эффективности применения качественно-количественного регулирования в системе теплоснабжения города. В сборнике: Неделя Науки СПбГПУ Материалы научно-практической конференции с международным участием. Институт энергетики и транспортных систем. с. 141-143

[21]. Isaev, S.A., Vatin, N.I., Guvernyuk, S.V., Gagarin, V.G., Basok, B.I., Zhukova, Y.V. (2015) Drag reduction of energy-efficient buildings and wind energy extraction due to bleeding effect. High Temperature, 53 (6), pp. 873-876

[22]. LBN (Latvian Building Code 003-15. Building climatology [in Latvian].

[23]. Moutzouri E. (2011) Comparison between PHPP and SAP & Elaboration of monitored data for two dwellings with different insulation levels, United Kingdom. pp. 1-79

[24]. Audenaert A., S.H. De Cleyn (2010) Economic viability of passive houses and low-energy houses. Proceedings of the 3rd WSEAS International Conference on Urban Rehabilitation and Sustainability URES'10, Faro. pp. 29-35

[25]. LBN (Latvian Building Code) 002-15. Thermal performance

Buildings and Structures. 3. pp. 83-86

[9]. Petritchenko M.R., Nemova D.V., Kotov E.V., Tarasova D.S., Sergeev V.V. (2018) Ventilated facade integrated with the HVAC system for cold climate. Magazine of Civil Engineering. No. 1. pp. 47–58

[10]. Petritchenko M.R., Kotov E.V., Nemova D.V., Tarasova D.S., Sergeev V.V. (2018) Numerical simulation of ventilated facades under extreme climate conditions. Magazine of Civil Engineering. No. 1. pp. 130–140

[11]. Tabunshhikov Ju.A., Brodach M.M. (2002) Matematicheskoe modelirovanie i optimizacija teplovoj jeffektivnosti zdanij (Mathematical modeling and optimization of thermal efficiency of buildings). M.: ABOK-PRESS. p. 194 (rus)

[12]. Korniyenko S.V., Popova E.D. (2017) "Zelenoe" stroitel'stvo v Rossii i zarubezhom («Green» construction in Russia and other countries). Construction of Unique Buildings and Structures. No. 4(55). pp. 67-93 (rus)

[13]. Vatin N.I.., Gorshkov A.S.., Nemova D.V. (2013) Jenergojeffektivnost' ograzhdajushhih konstrukcij pri kapital'nom remonte (Energy efficiency of envelopes at major repairs). Construction of Unique Buildings and Structures. No. 3(8). pp. 1-11 (rus)

[14]. Dimdina I., Lešinskis A., Krumiņš E., Krumiņš V., Šnidere L., Zagorskis V. (2011) Indoor air quality and energy efficiency in multi-apartment buildings before and after renovation: A case study of two buildings in Riga. Paper presented at the Civil Engineering '11 - 3rd International Scientific Conference, Proceedings. pp. 236-241.

[15]. Nieminen J., Holopainen R., Lylykangas K. (2008) Passive House for a cold climate. Nordic Symposium on Building Physics, Copenhagen 2008. pp. 1-8

[16]. Harmati, N., Jakšić, Z., Vatin, N. (2015) Energy consumption modelling via heat balance method for energy performance of a building. Procedia Engineering, 117 (1), pp. 791-799

[17]. Gorshkov, A., Vatin, N., Nemova, D., Shabaldin, A., Melnikova, L., Kirill, P. (2015) Using life-cycle analysis to assess energy savings delivered by building insulation. Procedia Engineering, 117 (1), pp. 1085-1094

[18]. Anikina I.D., Porshnev G.P., Sergeev V.V. (2012) Teplovizionnoe obsledovanie zdanij (Thermal imaging of buildings). St. Petersburg Polytechnic University Journal of Engineering Science and Technology. № 147-1. pp. 94-98 (rus)

[19]. Anikina I.D., Sergeev V.V., Amosov N.T., Luchko M.G. (2016Ispol'zovanie teplovyh nasosov v tehnologicheskih shemah generacii teplovoj jenergii TJeC (The use of heat pumps in technological schemes for generating thermal energy of CHPP). International Scientific Journal for Alternative Energy and Ecology. No. 3-4 (191-192). pp. 39-49 (rus)

[20]. Postnyh Zh.V., Sergeev V.V. (2014) Ocenka jeffektivnosti primenenija kachestvenno-kolichestvennogo regulirovanija v sisteme teplosnabzhenija goroda (Assessment of the effectiveness of the application of qualitative and quantitative regulation in the heat supply system of the city) International Week of Science SPbSTU proceedings. Institute of Energy and Transport Systems. pp. 141-143 (rus)

[21]. Isaev, S.A., Vatin, N.I., Guvernyuk, S.V., Gagarin, V.G., Basok, B.I., Zhukova, Y.V. (2015) Drag reduction of energy-efficient buildings and wind energy extraction due to bleeding effect. High Temperature, 53 (6), pp. 873-876

[22]. LBN (Latvian Building Code 003-15. Building climatology [in Latvian].

[23]. Moutzouri E. (2011) Comparison between PHPP and SAP & Elaboration of monitored data for two dwellings with different insulation levels, United Kingdom. pp. 1-79

[24]. Audenaert A., S.H. De Cleyn (2010) Economic viability of passive houses and low-energy houses. Proceedings of the 3rd WSEAS International Conference on Urban Rehabilitation and

of building envelope [in Latvian].

[26]. Shipkovs P., Vasilevska L., Lebedeva K., Pankars M., Snegirjovs A. (2010) Modeling of Solar Heating Systems in Latvia. Proceedings of 10th REHVA World Congress on Sustainable Energy Use in Buildings "CLIMA 2010", Antalya. pp. 1-8

[27]. Shipkovs P., Snegirjovs A., Kashkarova G., Shipkovs J. (2014) Potential of solar cooling in latvian conditions. Paper presented at the Energy Procedia. 57 2629-2635.

[28]. Vatin, N., Gamayunova O., Nemova D. (2015) An energy audit of kindergartens to improve their energy efficiency. Paper presented at the Advances in Civil Engineering and Building Materials IV - Selected and Peer Reviewed Papers from the 2014 4th International Conference on Civil Engineering and Building Materials CEBM 2014. pp. 305-308

[29]. Нефедова А., Чернышев Д.., Цейтин Д. (2014) Анализ проекта мультикомфортного дома ISOVER. Строительство уникальных зданий и сооружений. Vol. 10(25). с. 73–87

[30]. Bazhenova E., Bykova J., Bryus D., Tseytin D. (2015) Results of Multi Comfort Building Designing. Applied Mechanics and Materials. Vol. 725-726. pp. 1445-1456

[31]. Lapinskiene V., Paulauskaite S., Motuziene V. (2011) The analysis of the efficiency of passive energy saving measures in office buildings. Papers of the 8th International Conference Environmental Engineering. Vilnius, 2011. pp. 769–775

[32]. Dzelzitis E., Pilscikovs D. (2014) Efficiency evaluation of proportional pressure control for centrifugal pumps with variable-speed motors. Paper presented at the ASHRAE Transactions 2014. 120(PART 1). pp. 382-385

Sustainability URES'10, Faro. pp. 29-35

[25]. LBN (Latvian Building Code) 002-15. Thermal performance of building envelope [in Latvian].

[26]. Shipkovs P., Vasilevska L., Lebedeva K., Pankars M., Snegirjovs A. (2010) Modeling of Solar Heating Systems in Latvia. Proceedings of 10th REHVA World Congress on Sustainable Energy Use in Buildings "CLIMA 2010", Antalya. pp. 1-8

[27]. Shipkovs P., Snegirjovs A., Kashkarova G., Shipkovs J. (2014) Potential of solar cooling in latvian conditions. Paper presented at the Energy Procedia. 57 2629-2635. doi:10.1016/j.egypro.2014.10.274.

[28]. Vatin, N., Gamayunova O., Nemova D. (2015) An energy audit of kindergartens to improve their energy efficiency. Paper presented at the Advances in Civil Engineering and Building Materials IV - Selected and Peer Reviewed Papers from the 2014 4th International Conference on Civil Engineering and Building Materials CEBM 2014. pp. 305-308

[29]. Nefedova A., Chernyshev D., Tseytin D. (2014) Analiz proekta mul'tikomfortnogo doma ISOVER [Analysis of the project of Multi-Comfort House ISOVER]. Construction of Unique Buildings and Structures. Vol. 10(25). pp. 73–87 (rus)

[30]. Bazhenova E., Bykova J., Bryus D., Tseytin D. (2015) Results of Multi Comfort Building Designing. Applied Mechanics and Materials. Vol. 725-726. pp. 1445-1456

[31]. Lapinskiene V., Paulauskaite S., Motuziene V. (2011) The analysis of the efficiency of passive energy saving measures in office buildings. Papers of the 8th International Conference Environmental Engineering. Vilnius, 2011. pp. 769–775

[32]. Dzelzitis E., Pilscikovs D. (2014) Efficiency evaluation of proportional pressure control for centrifugal pumps with variable-speed motors. Paper presented at the ASHRAE Transactions 2014. 120(PART 1). pp. 382-385

Контактная информация

1. +37126079655, anatolijs.borodinecs@rtu.lv (Бородинец Анатолий, д.т.н., Профессор)
2. +37167089333, jurgis.zemitis@rtu.lv (Земитис Юргис , д.т.н., доцент)
3. +37167089333, aleksandrs.geikins@rtu.lv (Геикинс Александрс , научный сотрудник)

4*. +7(904)5517433, y.b.v.9464@gmail.com (Быкова Юлия Викторовна, студент)

5. +7(931)36-93-893, anyanefedova94@mail.ru (Нефедова Анна Владимировна, студента)
6. +7(812)3288674; Siniavina_SV@pers.spmi.ru (Купавых Светлана Викторовна, к.т.н., ведущий инженер)

Contact information

1. +37126079655, anatolijs.borodinecs@rtu.lv (Anatolijs Borodinecs, Ph.D., Professor)
2. +37167089333, jurgis.zemitis@rtu.lv (Jurgis Zemitis, Ph.D., Researcher)
3. +37167089333, aleksandrs.geikins@rtu.lv (Aleksandrs Geikins, Researcher)

4*. +7(904)5517433, y.b.v.9464@gmail.com (Iuliia Bykova, Student)

5. +7(931)3693893, anyanefedova94@mail.ru (Anna Nefedova, Student)
6. +7(812)3288674; Siniavina_SV@pers.spmi.ru (Svetlana Kupavykh, Ph.D., Leading engineer)