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AN ENERGETIC ANALYSIS OF A MULTIFUNCTIONAL FAÇADE SYSTEM FOR ENERGY EFFICIENT RETROFITTING OF RESIDENTIAL BUILDINGS IN COLD CLIMATES OF FINLAND AND RUSSIA

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ABSTRACT

Retrofitting of external walls and building facades of residential buildings is often considered as the most energy efficient renovation measure. This paper presents a multifunctional energy efficient façade system for multi-family apartment building retrofitting, the “Meefs” system which is still under development in a concept phase, and analyses its energetic features based on building typologies to cold climate apartment buildings in Finland and in Russia.

Both in Finland and in Russia, the majorities of the apartment building stocks were built after the II World War. Major capital repairs are needed in both building stocks in the coming years. At the same time, energy efficiency of buildings could be improved which would make them more sustainable. The apartment building stocks in both countries consist of typical buildings of this construction period. Therefore prefabricated facade products, such as the “Meefs” system, could beneficially be adapted to retrofit them. In addition, as shown in this paper, the Meefs system would provide considerable energy savings.

However, adapting the system to Russian buildings would require changes to building energy systems as well.

KEYWORDS

energy renovation, façade renovation, residential buildings, cold climate

1. INTRODUCTION

In view of climate change, aging housing stocks and heavy energy consumption, it is important to promote integrated retrofit of residential areas, and to understand the importance of efficient modernisation, deployment of new technology and use of renewable energy resources (Raslanas et al., 2011). Energy retrofit of buildings represents an important sector for mobilizing investments to address carbon mitigation of cities (Mastrucci et al., 2014). For developed countries, such as EU-15, the technical greenhouse gas (GHG) reduction potential for the building stock in 2020 ranges between 21-54% of the national baseline. For economies in transition, such as Russia, this value ranges between 26 and 47% of the national baseline, for the building stock in 2030 (Ürge-Vorsatz & Novikova, 2008). For both markets, building envelop retrofits, including insulation, are estimated as measures with the largest potential. The integration of new technologies for renewable-based energy production, into building envelop retrofitting measures, can significantly reduce GHG emissions.

Most national building regulations that mandate thermal insulation of building envelopes were introduced after the 1970s following the energy crisis (Balaras et al., 2005). In addition, compared to current regulations the first thermal insulation requirements were quite moderate. So, the energy saving potential is the largest in the oldest non-retrofitted buildings.

About 60% of Russia’s total multi-family apartment buildings are in need of extensive capital repair, rising to 93–95% in those apartment blocks with an average age of less than 25 years (IFC & EBRD, 2012). The need for renovation and modernization of housing properties in Finland mainly concerns apartment buildings built in 1960s and 1970s (Lindtsedt et al., 2011). A major issue in renovation projects is to minimize living interferences and the duration of renovation works cost-effectively.

There is an urgent need for development of efficient and low cost (prefabricated) solutions that are modular, customizable, prefabricated and industrially marketable. These will allow systemic retrofitting that can easily be applied in buildings and affordably maintained with minimum disturbances to end-users (Meno et al., 2012). Industrialization does not necessarily imply the use of new materials, but new forms of application or combination of materials, and manufacturing construction components in facilities outside the place of the final assembly.

This paper introduces a multifunctional energy efficient façade system for multi-family apartment building retrofitting under development in a EC FP7 project Meefs: Multifunctional Energy Efficient Facade System for Building Retrofitting hereafter referred as the “Meefs” system. The Meefs system is still in the concept phase. We analyse the energetic aspect of the system to energy renovations in cold climate apartment buildings, classified by a building typology, and could it improve energy efficiency in these buildings. The analyses are based on case studies in two cold climate locations, namely Helsinki, Finland and Moscow, Russia. We also estimate the potential use of the solution as a part of holistic district renovations relevant in Russia.

2. Literature review

There are many aspects relevant to the scope of this paper. These include the climatic indicators used in energy calculations, methods to classify existing apartment buildings stock, and potentials and solutions for improving its energy-efficiency especially by means of façade retrofitting. This section will briefly review relevant information, on these themes, available on literature, to provide support and background for the further analysis.

The most widely used general climate classification is the Köppen-Geiger system (Kottek et al., 2006). In this system, major areas of both Finland and Russia are placed to the cold and snow climate (Peel et al., 2007; Kottek et al. 2006), meaning that the climate in large areas of both countries is quite similar. The most important indicator for the climate zones are heating degree days (HDDs) describing the typical useful energy demand to heat buildings (Lechtenböhmer & Schüring, 2011) even though there are country related differences in calculating these values. In Russia, HDDs are not typically calculated. However, Matrosov et al. (2007) give Moscow the value 4943. For Helsinki, the average HDD is 3878, but for the city of Vantaa locating only about twenty kilometers North of downtown Helsinki the HDD is already 4097 (Finnish Meteorological Institute, 2014). These values place both Helsinki and Moscow to the cold climate zone. Lechtenböhmer & Schüring (2011) provide a description and results of a detailed bottom-up model of the current and future residential building stock in the EU. Based on this model, different scenarios on the potentials for energy efficiency coupled with the refurbishment of existing buildings are presented. The technical potential available would allow to reduce the useful energy demand of existing buildings to about two third of the current level by 2030. The estimate covers only the energetic characteristics of the building shells. Other factors were not incorporated.

Mastrucci et al. (2014) introduce a bottom-up statistical methodology based on a Geographical Information System (GIS) to estimate the energy consumption of residential stocks across an entire city. The adoption of a multiple linear regression model allows the downscaling of measured natural gas and electricity consumption from the aggregated post-code level to single dwellings, based on several descriptors, such as dwelling type, period of construction, floor surface and number of occupants. The energy consumption is apportioned to different end-uses and corrected for weather, and then the energy savings potential is estimated by accounting for the implementation of typical refurbishment measures. The study provides results to prioritize the implementation of energy retrofit measures for the residential stock of Rotterdam city, consisting of about 300,000 dwellings.

Corgnati et al. (2013) introduce a concept for reference buildings and a state of art at an international level. In particular, a general methodology for the creation of reference buildings is illustrated. Three methodologies to define a reference building models (example, real and theoretical) are also defined. The recommended methodology describes what data are required and how to collect and gather them into different categories.

Ballarini et al. (2014) present a methodology for the identification of reference buildings, according to the TABULA project (2009–12). The term “building typology” refers to a systematic description of the criteria for the definition of typical buildings as well as to the set of building types itself. The building typology is classified according to three specific parameters: location (related to the climatic area), construction period (related to the constructive principles and materials), and building size and shape. The building typologies were used to evaluate the potentialities of energy savings and CO_2 emission reductions achievable through retrofit actions addressed to the building envelope and the space heating and domestic hot water systems from present state to a renovated state for some European countries. Ballarini et al. (2014) present results for the Italian approach, Dascalaki et al. (2013) for the Greek approach, and Kragh & Wittchen (2014) for the Danish approach.

Dall’O’ et al. (2012) detected the characteristics of the Milanese building stock, and based on that were able to analyze which energy retrofit interventions are feasible there from a technical, legal and economic point of view. Wittchen et al. (2012) describe the building stocks in Denmark, Norway, Finland and Sweden as part of a joint Nordic project MECOREN (Methods and Concepts for sustainable Renovation). In addition, the energy saving potentials within the building stocks are evaluated.

As one of the very few Russian related studies Nizovtsev et al. (2014) describe a new thermal-insulating facade system for newly constructed and renovated buildings, based on heat-insulating panels with ventilated channels. The calculated data on thermal resistances of heat-insulating panels and on the reduced thermal resistances of brick walls with an external facade system are reported as a function of panel thickness. The calculations also prove that the examined configuration of ventilated channels is capable of providing low moisture content and good heat-insulating properties of the walls. The thermal insulating facade systems based on the ventilated channels panels were installed on more than ten new and renovated buildings in Novosibirsk and Novosibirsk Region, in Russia. The experience gained in installation of the new facade system on renovated buildings proved the possibility of performing efficient, good-quality installation works. Thermal imaging confirmed high efficiency of the panels with ventilated channels used for heat insulation of reconstructed buildings.

SUSREF (Sustainable refurbishment of exterior walls and building facades) project developed sustainable concepts and technologies for the refurbishment of building facades and external walls. Häkkinen (2012) presents the methodological issues used in the project, while Vares et al. (2012) present generic refurbishment concepts for building facades and external walls. Peuhkuri et al. (2012) introduce specific refurbishment concepts, some of them also targeted to Eastern European and Russian markets. In addition, based on the work done in Susref, Hradil et al. (2014) analyze the durability of refurbished outdoor walls on the bases of building-physical analyses and estimate the benefits of refurbishment on concrete façade in Nordic conditions when an exterior insulation layer is added. The major part of building envelope failures was caused by excessive moisture content of building materials.

Hachem et al. (2014) provide an analysis of energy consumption and energy generation of multistory residential buildings and investigate various methods to increase energy generation potential to match consumption in the cold climate of Montreal, Canada. Results indicate the potential benefits in investing in exploitation of façades for electricity generation. Energy generation by façades can be further enhanced through geometric manipulations of the façades to increase their effective surface areas and optimize their tilt and orientation angles.

Building integrated photovoltaics are among the best methods for generating power using solar energy. To promote and respond to the concept of BIPVs, Young et al. (2014) present a type of multi-functional heat insulation solar glass (HISG) that differs from traditional transparent PV modules, providing functions such as heat insulation and self-cleaning in addition to power generation. The study verifies and compares the energy efficiencies of HISG and ordinary glass in a subtropical zone but the ideas could be extended to other climate zones as well.

Lindstedt et al. (2011) outline three renovation concepts for procurement methods which can be utilized in various types of renovation projects. The concepts are meant for renovation of one building component, of an entire building, and of residential areas.

Heikkinen et al. (2009) describe a façade renovation method (TES method) and define basic principles for the energetic modernization of the building envelope using prefabricated large-sized timber frame elements. The basis for the use of prefabricated retrofit building elements is a frictionless digital workflow from survey, planning, off site production and mounting on site based on a precise initial 3D measurement. The properties of the application of TES EnergyFacade are: precision and quality of an ecological building system, predictable pricing and reduction of work on-site, reduction of noise and disruption of the inhabitants, application of a great variety of cladding materials, integration of load bearing elements, integration of HVAC and solar-active components, and spatial intervention or expansion (modules) in the same system.

Cronhjort (2011) presents a pilot project where the prefabricated TES EnergyFacades were utilized for the first time in Finland. In this Innova project, the prefabricated elements included extra insulations, claddings, windows and ventilation ducts. The TES approach requires a detailed and precise documentation of the as-built/as-maintained conditions of the existing façade. Larsen et al. (2011) discuss the surveying and documentation of a building's existing state and the need to establish a continuous digital chain that encompasses the various project stages from the survey to the site assembly of the elements.

ETICS (External Thermal Insulation Composite System) are a set of construction elements consisting of certain prefabricated components being applied directly to the façade (EAE, 2014). They are utilized widely in facade renovations in many countries (e.g., Künzel et al., 2006; Amaro et al., 2014). The ETICS are installed tightly against the external building façade. They are not ventilated which may prevent drying incase moisture enters the structure. In case of damage, all parts need to be fixed. The system is not modular, it cannot be modified or parts of it changed. Basically, it includes only an extra insulation layer, thus improving the façade U-value, but without any other issues improving the building energy performance.

The literature review shows that it is relevant to analyze energetic features of an energy efficient renovation system in Finland and Russia since the major parts of the both countries are located in cold climates. In addition, it shows that building stock properties and building typologies, such as the approach in this paper, are commonly utilized in such analyses. Further, different façade solutions are being developed for renovation, especially due to their considerable energy saving potential. New façade solutions may also contain various additional technologies for building services. It is also addressed that prefabrication is considered as one important opportunity to speed up renovations.

3. THE MULTIFUNCTIONAL ENERGY EFFICIENT FAÇADE SYSTEM FOR BUILDING RETROFITTING (THE MEEFS SYSTEM)

Figure 1 shows the core idea of the Meefs system, i.e., it is an energy efficient non-intrusive façade concept based on multi-module technology components that will allow integrating both active and passive technologies in the façade. The retrofitting facade will be based on a combination of advanced active solutions with efficient passive design and materials as well as efficient energy management system. Every module will represent different energy efficient innovative solutions, and packaged into easy to install panels (Capeluto & Ochoa, 2013).

The system will highly rely on industrialized production always using standardized panels, easy to be assembled and technological modules, still allowing personalized configurations for each façade typology, orientation and local climate conditions.

The façade system will be composed by the structure and an anchorage system for fixing the structural panels to the existing facade; technological modules and an intelligent Control System. The project work includes the development of the

MEEFS Architectural & Structural System Design taking into account technical and aesthetical criteria. This will be based on building information model (BIM) design tools.

The following describes these main building blocks of the Meefs system and comments on their overall application for cold climates. The following sections of this publication will focus on the energetic assessment of these issues for the cold climates.

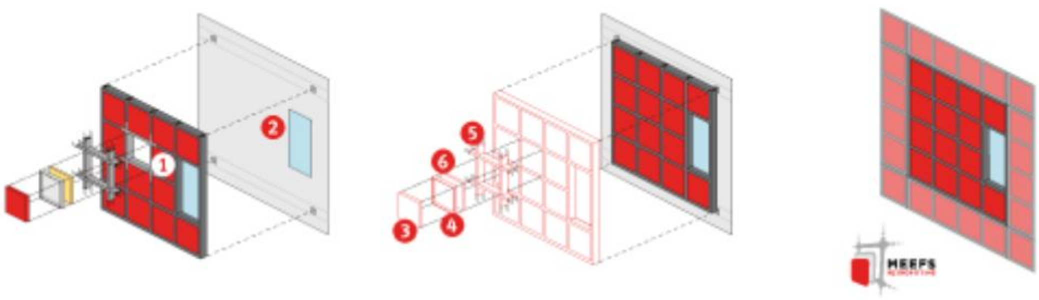

Figure 1. MeeFS Façade System Constructive Process. 1)Multifuntional panel, 2) Existing façade 3) Technological unit 4) Structural module 5) Structural panel 6) Thermal insulation 2+4) Technological module 3+4+5) Multifuntional panel

The façade system will be composed by:

The structure (Figure 1, 4+5): Meefs system structure will be based on lightweight and cost-effective structural panels, and an anchorage system for fixing these structural panels to the existing façade. The structural panels (or the "frames") are made of composite materials FRP - Fibre Reinforced Polymer. The structural application of FRP in cold climates is feasible. However testing should be done for deterioration and durability as the freezing and thawing dynamics might affect the structure. This is even more important when considering that the FRP structure hosts all the installations.

Operating Control System: the façade integrates an intelligent control system for energy management and control of all the mobile elements. This will be integrated in the building energy system. The connections and installations (electrical and hydraulic installations) will be integrated in the structural frame. For the cold climates further system development will be needed to ensure a proper insulation of controls and equipment's and a new frame design should be considered.

Technological modules consisting of structural module and technological units (Figure 1, 3+4+5). All the modules integrated in the façade will include a particular technology or flexible combinations of technologies allowing the reduction of the primary energy either reducing energy demand of the building or for supplying energy by means of renewable energy sources (RES). All opaque technological modules will incorporate thermal insulation. Most of the modules will include existing technologies already proven to be cost effective and energy efficient. Two innovative modules will be developed within the MEEFS development process: advanced Passive Solar Protector and Energy Absorption Unit; and Advanced Passive Solar Collector and Ventilation Unit[1].

Back layer insulation: The continuous back insulation layer is formed by rigid insulation panels fixed mechanically to the back part of the composite structural

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[1] [1] Technological units developed and patented by Tecnalia and Acciona. http://www.meefs-retrofitting.eu/project/products-under-development/technological-units.html

profiles of the multifunctional panels. The boards have the same dimensions as the multifunctional panel to create this continuous insulation layer. As it is fixed to the multifunctional panel (not to the existing building) the complete façade system is fastened to the building in one single step. It allows restricting the effect of the thermal bridges of the structural frame and modules and also takes into consideration the cases where the MEEFS façade consists mainly of technological units with limited insulation properties. For the cold climates special consideration should be given to this layer due to its needed thickness. In addition, in cold climates, as the water vapor moves from inside to outside the building special considerations should be given to this layer, and to the structural elements to avoid accumulation of moisture and consequent mold problems.

The technological units, in the Meefs system, will cover the traditional building envelope main functions and also add new functionalities as energy production and its flows management. Table 1 lists the state-of-art different technologies and solutions that can be integrated into the technological unit of the Meefs building façade system and comments on specificities for cold climate. It will be decided case by case which actually technologies will be integrated to the system. Section 5 will describe and analyze, from the energetic perspective, the new breakthrough units being developed with the system.

Table 1. State-of-the-art technologies in the Meefs system and their applications in cold climates.

Main technologies groups	Cold climates applications
Building integrated Photovoltaic systems (BIPV) and Solar thermal collectors.	The potential for solar systems is smaller than in warmer climates. However, can still produce part of the energy need especially in low-energy buildings.
Insulation	Most used is mineral wool in both countries which market share is 45% in Russia (Matrosov et al., 2007). For the cold climates the thickness/weight should be considered as modules might become too heavy. The application of e.g. vacuum insulated panels (VIPs) raise cost-effectiveness questions. The across Europe energy strategy developed in Meefs project proposes to use polyisocyanurate foam both for the back layer insulation (140mm) and for the technological unit (60 mm).
Glazing units and Windows	The most used glazing in the Nordic market are double and triple glazings depending on the year of construction. In Meefs system the glazing technological units cover the existing windows which makes it feasible to use single and double glazing.
The green façade	Would improve air quality and increase well-being. However, applicable only during the summer periods and would require extensive design.
Solar protectors/solar shades	Reduce cooling loads during the summer time. Since mechanical cooling is rare in cold climates would improve indoor conditions during the warmest periods.
Phase-change material (PCM)	Needs careful design, has not worked in some trial tests.
Ventilation units including Air filtration and cleaning	Natural ventilation dominates in Russian apartment buildings while mechanical exhaust is the most common solution in Finnish apartment buildings. In Riihimäki TES case a ventilation unit was integrated into the panels for each apartment (Cronhjort, 2011)
Heating technologies	Both in Finland and in Russia most apartment buildings are connected to district heating though system structures differ considerably.
Cooling technologies	Mechanical cooling is not common in cold climate apartment buildings. Often solutions reducing solar gains improve indoor conditions enough.

4. BUILDING TYPOLOGIES APPLIED

It is of vital importance to analyze which kinds of buildings and façade configurations exist in the targeted market areas. These form the bases on which the product development leans. In the following, we describe the properties of typical apartment buildings in Finland and Russia based on literature.

4.1. The Finnish apartment buildings

At the end of 2012, 44 per cent of all dwellings in Finland were in blocks of flats (Statistics Finland, 2013). In Figure 2, there is shown the Finnish multi-family apartment building stock at the end of 2012 divided based on the construction year (Statistics Finland, 2014). In total, there are almost 58.000 apartment buildings in Finland with the total gross floor area about 92.5 million m^2. The majority of these buildings were built in the 1960s, 1970s and 1980s.

Typically, the Finnish apartment buildings are not very tall. 70% of the apartment buildings have 3-9 storeys, and 29% have 1-2 storeys (Statistics Finland, 2014). Recessed balconies are common in Finnish apartment buildings built during 1960-1975, excluding the smallest apartments (Neuvonen, 2009). Often, the balconies are glazed afterwards. In the suburbs, the apartment buildings are not connected to each other.

In 2012, the average floor area of a dwelling in a block of flats was 56.5 m^2 and on average 2.06 persons lived in a dwelling. Most of the dwellings are owner-occupied. Buildings with 3-storeys, or less, typically do not have lifts. 14% of the apartment buildings with more than three storeys did not have lifts in 2012. The level of amenities is good. Practically every dwelling has sewer, piped water, flush toilet, warm water, bathing facilities and central heating. A Finnish speciality is that over 50% of the dwellings include saunas. (Statistics Finland, 2013)

About 44.500 (77%) of the apartment buildings are connected to district heating (Statistics Finland, 2014). Natural ventilation is dominating in apartment buildings built before 1970s, since then mechanical exhaust ventilation became most common (Litiu, 2012).

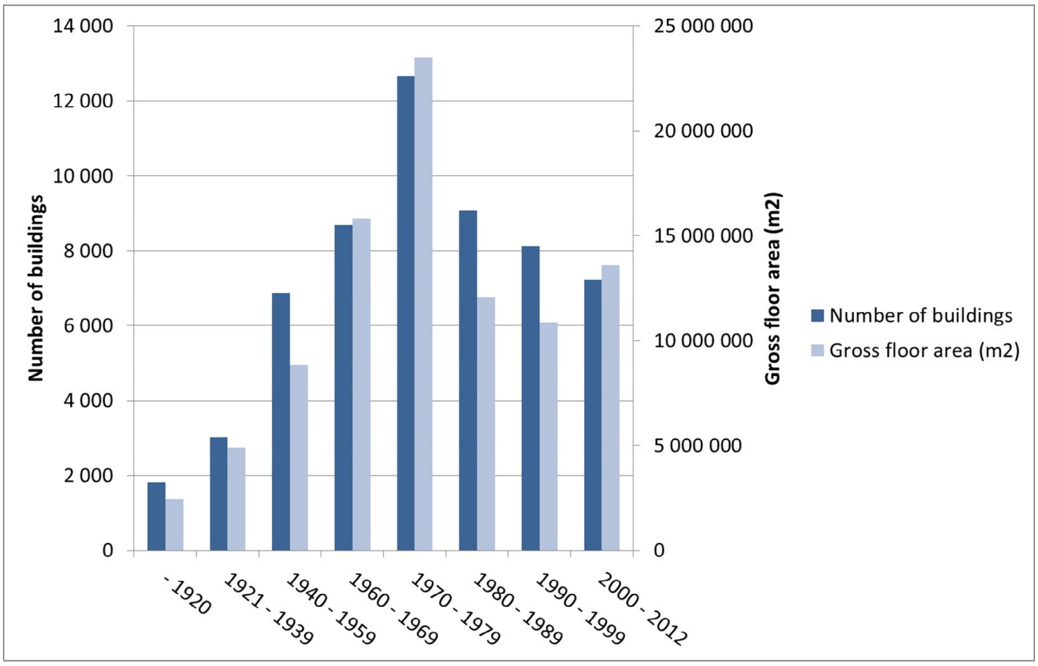


Figure 2. The Finnish apartment building stock as of 31.12.2012 (Statistics Finland, 2014).

In Finland based on the IMPRO-Building project (Nemry et al., 2008), nearly 50% of apartment buildings have concrete based walls. Brick based walls represents 33% of the constructions. The remaining constructions are wooden construction (17.6%). These wooden ones are mostly single-family houses. However, the last years have seen a growth on the multisorey wooden buildings. Several concrete wall configurations are described (Nemry et al., 2008; Häkkinen et al., 2012) concrete sandwich panels with low thickness insulation, breeze concrete walls, and reinforced concrete & breeze concrete walls. Typical U-values are presented in Table 2.

Table 2. Typical U-values for non-renovated apartment buildings in Finland and cold climate zones in general.

U-values in W/m^2K	For a Finnish apartment building from the 1970s (Nieminen, 2012)	For Finnish apartment buildings built in the 1970s (Häkkinen et al., 2012)	For buildings in cold climate zones built before 1975 (Lechtenböhmer & Schüring, 2011)	Maximum for buildings in cold climate zones built after 1975 (Lechtenböhmer & Schüring, 2011)
façade	0.3-0.40	0.475	0.50	0.25
roof	0.3-0.40	0.335	0.50	0.18
floor	N.A.	0.48	0.50	0.19
windows	2.10 - 2.40	2.44	3.00	1.60

N.A. = not available

4.2. The Russian apartment buildings

The housing stock of the Russian Federation amounted to 19,650 thousand buildings of the total floor space 3,177 mln. m^2 as of 2009 year end (IUE, 2011). The housing stock included 3,224 thousand apartment buildings of the total floor space 2,237 mln. m^2. Most part of Russia's housing stock, over 84%, is privately owned.

In the Russian Federation, most of the apartment buildings were constructed between 1960 and 1985 during the Soviet-era, and as a result the urban housing stock today consists mainly of a few standard building types (United Nations, 2004; Trumbull, 2013). Each building series represents a specific building design (Opitz et al., 1997; Raslanas et al., 2011). From an architectural perspective, residential areas with typical apartment buildings look monotonous, lack vitality, and are less aesthetically pleasing (Raslanas et al., 2011).

The housing stock in Russia has a rather high level of amenities. An average of 61.4% of housing is provided with all the amenities. In 2009, 89% of urban housing stock had access to water supply, 87% to sewerage, 92% to heat supply, and 80% to hot water. (IUE, 2011)

In these buildings, natural ventilation dominates. Almost no buildings have mechanical ventilation (Bobrovitskiy & Shilkin, 2010; Keikkala et al., 2007). District heating accounts for 70% of total heat supply in Russia (Masokin, 2007). It should be noted the Russian district heating systems differ technically from the ones in Finland. In Russia, the apartment buildings typically do not include building-specific heat exchangers or any other means to control the heating (Eliseev, 2011). So, just renovating building facades do not reduce the heating consumption of a building.

Major shares of the apartment buildings belong to the following two categories (United Nations, 2004):

- In buildings constructed between 1961 and 1975, the number of storeys varies but 9-storey buildings are the most common. The buildings are long and there are usually five to nine staircases in each. The external walls are different lightweight concrete structures without separate thermal insulation material. The housing norms of 1963 regulated their design and construction. Some of the buildings were based on their successful 5-storey predecessors, e.g. building 1-515.

- In suburb buildings built mainly after 1975, large elements and prefabricated modules were used. These buildings are 9-storey or higher, tower type blocks of flats or long, narrow buildings with four to seven staircases. The external walls are 35 cm thick expanded-clay lightweight concrete.

The composition of large panels varied tremendously, as well as their actual thermal properties. For example, the widely used 3-layer panel, including concrete, thermal insulation (either mineral wool or foam plastic), and concrete, had three typical internal configurations with shells, metal ties and ribs (Opitz et al., 1997). The typical U-values in Moscow buildings (see the “current status” in Table 5) are approximately 1.1 W/m^{2}K for wall constructions and 2.9 W/m^{2}K for fenestration (converted from transmission R-values by Matrosov et al., 1997). Opitz et al. (1997) point out that the design R-values differ minimally among older buildings built between 1954 and 1979, and they are essentially the same among buildings even with different wall structures (except for recently constructed buildings with 3-layes panel walls).

5. Energetic assessment of the Meefs system

For Helsinki, the energy load calculations were made during the initial stages of the Meefs project to allow the development planning. In this paper additional energy consumption analysis were made for easier comparison between Helsinki and Moscow, and for conclusions. For Moscow, the authors utilized the energy consumption results by Paiho et al. (2013) with complementary calculations. The energy consumptions of the buildings were calculated with WinEtana, which is a building energy analysis tool developed by VTT Technical Research Centre of Finland.

5.1. Energy analysis for a Finnish apartment building

A 2-phase approach was used for the energetic analyses of a Finnish apartment building located in Helsinki. Firstly, an energy load analysis was made to an apartment unit within an apartment building. Secondly, indicative heating energy consumptions were calculated for a typical apartment building.

5.1.1. Energy load analysis for an apartment unit in Helsinki

For Helsinki, a typical residential apartment unit was defined with dimensions 13.5 (width) x 7.0 (depth) x 2.70 (height) meters, with only one external façade (Capeluto & Ochoa, 2013). The four main orientations (North, South, East and West) were evaluated. The EnergyPlus software was used for modelling the basecase and the different façade solutions analyzed. The main features of the initially analyzed cases are described in Table 3. These initial cases were common within the European Meefs project though in the insulation and glazing cases the exact values varied from Southern to Northern climates.

Table 3. The different cases initially analyzed within the European context.

Abbreviation	Description
B = reference case	The basecase
V = ventilation	The hourly ventilation rate was increased from 1.5 h^{-1} to 4 h^{-1}. In addition, heat recovery was included.
S = shading	The initial basecase has unprotected windows, and for this technology an ideal “smart” shade covering the entire window area is used. It changes its transmittance to 20% during summer, and to 80% during winter.
I = insulation	Improving insulation of the façade from 0.7 W/m^2K to 0.17 W/m^2K.
G = glazing	The U-value for windows was reduced from 3.5 W/m^2K to 1.6 W/m^2K.
C = color	Changing the façade to a lighter hue from solar absorbance of 0.65 to 0.25.
A = all	Combination of all the measures assuming the technologies can be applied without interference from each other one the façade system.

The cooling loads were minimal or not existing in all the cases. In addition, cooling does not exist in typical Finnish apartment buildings. For the basecase, the annual heating loads per floor area varied between about 150-170 kWh/m^2,a. For the case A including all the analyzed features of the Meefs façade system, the annual heating loads per floor area varied between about 100-120 kWh/m^2,a depending on the orientation of the façade.

A combined use of measures achieved the lowest energy load (Capeluto & Ochoa, 2013). The most influential separate measures were using ventilation with heat recovery (around 20% reduction from initial basecase), improving glazing (10%-12% reduction from initial basecase) and improving insulation (10%-5% reduction from initial basecase). Ventilation with heat recovery has a large effect in total consumption due to savings in the pre-heating of outside air.

The U-values used for the basecase were higher than the typical ones for Finnish apartment buildings from the 1970s (see Table 2) so the results overestimate the energy load reduction potentials in the most typical apartment buildings but rather indicate maximum potentials in older buildings. But these estimations were only used as the first estimations of the energetic potentials of the Meefs system.

5.1.2. Heating consumptions of a Finnish apartment building

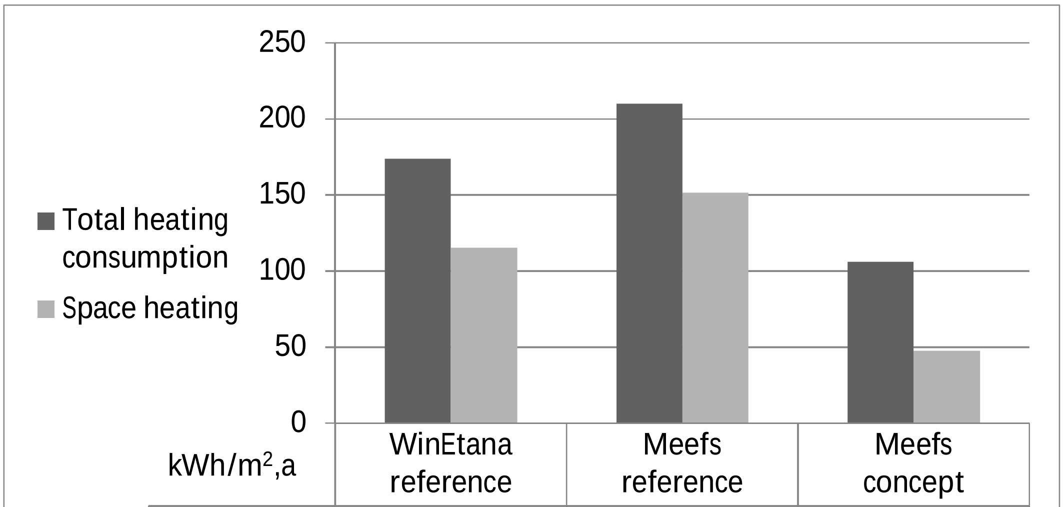
Since, heating loads and heating consumptions cannot be directly compared reference energy consumptions were calculated using the WinEtana program for a typical Finnish apartment building located in Helsinki and built in 1975. The WinEtana program contains a database of the most typical building systems and properties, including U-values, based on the building type and the year of construction. In addition, the program automatically suggests typical initial values for occupational and other internal loads, ventilation rates etc. Already with these initial values, often good estimates for annual heating and electricity consumptions can be obtained.

Building energy consumptions were calculated for three different cases varying the U-values of external walls and windows (Table 4). The “WinEtana reference” refers to the case using U-values suggested by WinEtana and the "Meefs reference" to the case using U-values from the Meefs basecase. In the "Meefs concept", the same U-values were used as in the energy load calculations (presented in the previous section) where the combination of all measures was included. For all the other input data needed by WinEtana, the suggested initial values were used except for the "Meefs concept" case where ventilation heat recovery was included with the efficiency of 60%. Since the Meefs system does not propose improvements to building domestic hot water or electrical systems at this stage such improvements were not incorporated in the calculations.

Table 4. The U-values (W/m^{2}K) used for different cases.

U-value (W/m^{2}K)	WinEtana reference	Meefs reference	Meefs concept
external wall	0.475	0.7	0.17
window	2.2	3.5	1.6

The results (Figure 3) indicate that the initial data for the Meefs basecase do not represent typical ones for the Finnish apartment buildings from the 1970s but some older apartment building types. In the "WinEtana reference" case, the total heating consumption is 17% and the space heating consumption 24% smaller than in the "Meefs reference" case. However, from a business oriented point of view the energy saving potential is one of the core issues of a product, and the "Meefs concept" reduces the total heating consumption by 39% and the space heating consumption by 57% compared to the "WinEtana reference", respectively.



kWh/m²,a	WinEtana reference	Meefs reference	Meefs concept
Total heating consumption	174	210	106
Space heating	115	151	48

Figure 3. The total heating consumptions (including water heating and losses) and the space heating consumptions for the different cases in the building level.

5.2. Energy analysis for an apartment building in Moscow

The energy saving potentials of holistic building renovation concepts rather than specific products were calculated for a typical Moscow apartment building. Only the main results are shown here since Paiho et al. (2013) performed a detailed analysis of the calculations. Since the Meefs system can also include combinations of technological solutions, it could – at least to a certain extent – be considered as a holistic concept.

Three holistic building energy renovation concepts were analysed and compared to the current status in a typical Russian apartment building built in 1965 (Table 5). The basic renovation refers to minimum mandatory repairs as well as easy-to-do retrofit measures, making use of inexpensive products, available on the market, with modest energy properties. The improved renovation improves the thermal insulation of buildings to a level comparable with or higher than current Moscow requirements for new buildings and introduces exhaust mechanical ventilation, which ensures sufficient air exchange rate in apartments. The advanced renovation suggests use of even more progressive solutions, which were considered realistic.

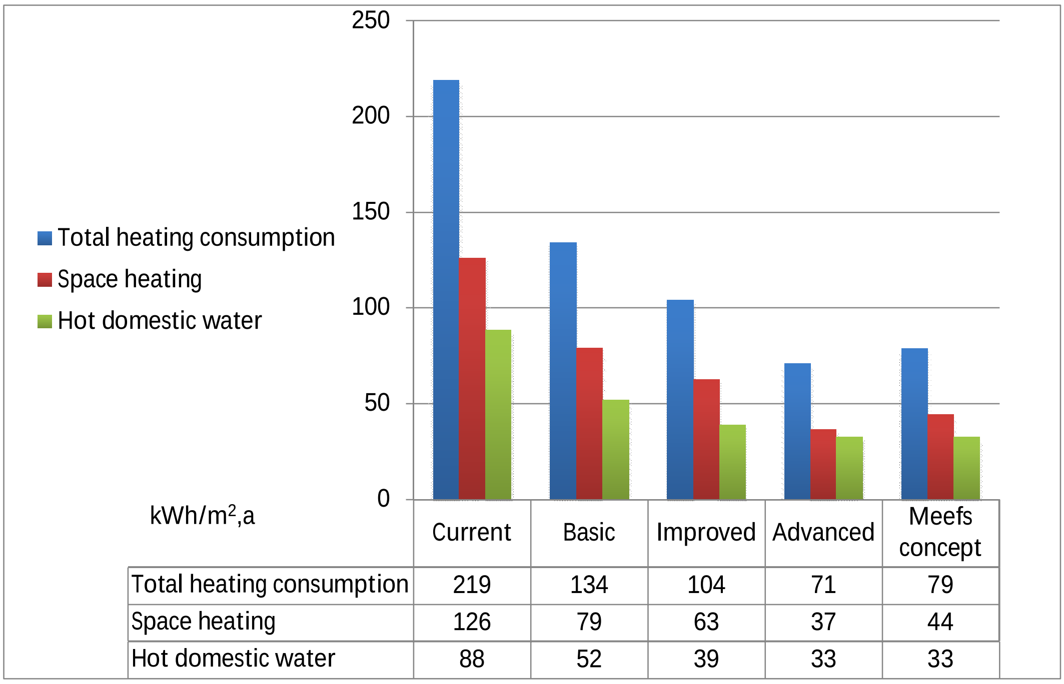
In addition to the three holistic energy renovation concepts, one new concept was introduced for the Meefs system. It was assumed to contain all the measures included in the Advanced concept but the U-values for external walls was 0.17 W/m^2K and for windows 1.6 W/m^2K instead of the values used in the Advanced concept. This case was named to “Meefs concept”.

Table 5. Holistic building renovation concepts. If not otherwise stated the improved and advanced concepts always include the solutions mentioned in the previous renovation.

Technology/ system	Current status	Basic renovation	Improved renovation	Advanced renovation
Structures: U-values (W/m^2K)				
• outer walls	1.1	0.5	0.32	0.15
• base floor	1.1	-	-	-
• roof	1.1	0.25	0.24	0.15
• windows and doors	2.9	1.85	1.5	1.0
Ventilation	Natural	Restoration of existing natural ventilation. Air inlet valves to ensure sufficient air exchange	Enhanced mechanical exhaust	Mechanical ventilation (supply and exhaust air) with annual heat recovery efficiency 60 %
Air tightness factor n50 (1/h)	6.5	4.0	2.0	< 2.0
Heating and hot water systems	Centralized control, no radiator temperature based control. Four-pipe system (centralized substations)	Replacement of radiators and pipes, pipe insulation, simple automated temperature regulators in buildings	Building heating substations and water heating (two-pipe system), thermostatic valves on radiators	
Electrical appliances and lighting		Energy efficient household appliances and lighting of public spaces	Energy efficient pumps and fans in new systems	Elevators – recovery breaking. Presence control of lighting in public spaces
Water supply systems (Consumption in l/day/occupant)	Old pipes and water appliances, building-level metering (272 / of which hot water 126)	Replacement of pipes, fixtures and appliances (160)	Installation of water saving fixtures and appliances. Remote meter reading (120)	Household-specific metering (100)

In Figure 4, there is shown the calculated energy consumptions of the typical (building type II-18) Russian apartment building for the current state and for the different renovation cases. Only the heating related consumptions are shown here since the Meefs system does not contain components reducing electricity consumption. The results show considerable energy saving potentials in heating. With the advanced renovation concept the total heating consumption would reduce 68% and with the Meefs concept 64% of the current value, respectively.

The space heating consumption would reduce 70% with the advanced concept and 65% with the Meefs concept, respectively.



	Current	Basic	Improved	Advanced	Meefs concept
Total heating consumption	219	134	104	71	79
Space heating	126	79	63	37	44
Hot domestic water	88	52	39	33	33

Figure 4. The building-level energy consumptions of different renovation cases compared to the current situation.

5.3. Aspects of other technical units of the Meefs system

In the Meefs system, different energy-efficient measures will be included to reduce the building energy consumption. In addition, generating energy from renewable sources by integrating these technologies into the retrofitted façade will be an additional option. No actual calculations related to adapting these technical units were done, in this paper, but in the following they are still briefly discussed.

5.3.1. Building Integrated Photovoltaic Technological Unit (BIVP TU)

BIVP TU produces electricity to be used either in the building or to be transferred to the grid. According to the photovoltaic potential estimation utility Photovoltaic Geographical Information System (PVGIS) (European Commission, 2012), the average yearly solar radiation on a horizontally inclined surface is 1120 kWh/m^2

for an optimal surface in Helsinki with an inclination angel of 41º and south orientation, and 1154 kWh/m^2 for an optimal surface in Moscow with an inclination angle of 39º and south-orientation. Paiho et al (2014) estimate that in Moscow for every kW-peak power installed a 1.060 kWh of electricity can be produced in a year when placing the CIS (copper–indium–selenium) technology based solar panels optimally. In the case analysis (Paiho et al., 2014), about 8% of the total electricity demand of a pilot residential district could be generated by building integrated solar panels (BIPV). Then, the panels would occupy half of the roof area in the district. For the different BIVP technologies there are not considerable differences in these electricity production values (European Commission, 2012).

For electricity generation, BIPV on vertical south façades yields are diminished by 30% (European Commission, 2012) compared to the optimal tilt, the annual generated value being 670 kWh/a (European Commission, 2012) for the Peak Power kW_p In Helsinki, while for east and west facades the performance ratio is approximately 50% (European Commission, 2012) lower than in the optimal tilt. This generation can be diminished by any element of building surrounding that cast shadows on it.

Façade area is larger than the roof area in a building. Thus, more BIVP units could be implemented to the building using the Meefs BIVP technical unit. However, their orientation would not be optimal for maximized electricity production. Still, some share of the electricity need could be provided by BIVP TUs also in the Northern climates.

5.3.2. The two technical units based on new technological solutions

Most of the technical units in the Meefs concept are based on existing proven technologies. In addition, two new technical units are being developed: Advanced Passive Solar Collector & Ventilation Unit Technical Unit (APSC&VU TU) and Advanced Solar Protection & Energy Absorption Technological Unit (ASP&EA TU. Both of them will utilize Phase Change Materials (PCM) for thermal energy absorption and accumulation. This is a substance with high heat of fusion which, by melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of thermal energy.

The APSC&VU TU has been designed as a dual layer system, of which, the external layer is semitransparent. A thermal storage wall, including PCM, is used as an internal layer for thermal storage – collaborating to both heating and cooling. Ventilation of the cavity is allowed by a series of lower and upper opening gaps, equipped with adjustable rollers. These rollers are operated according to external climate conditions (Figure 5).

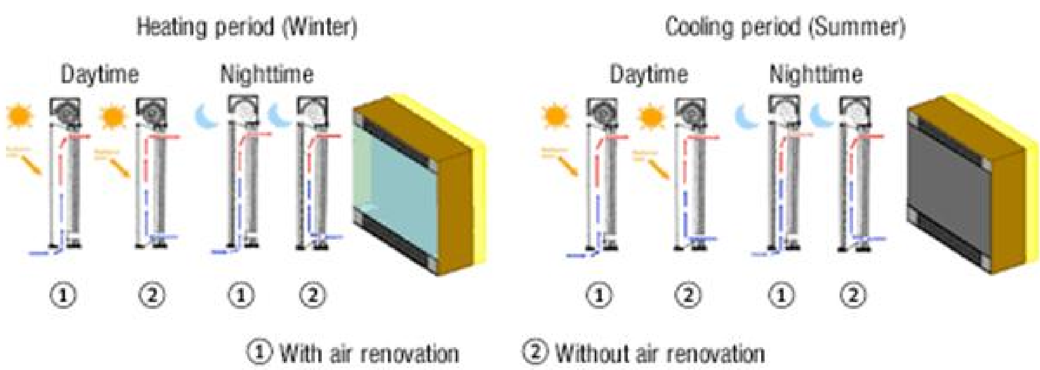


Figure 5. General operating strategies of the APSC&VU TUs (Source: http://www.meefs-retrofitting.eu/project/products-under-development/technological-units.html).

The main goal of the Advanced Solar Protection & Energy Absorption Technological Unit (ASP&EA TU) is to improve the annual energy performance of the buildings to be retrofitted, balancing heating and cooling requirements. Operating the ASP&EA TU will depend on the energy demands of the building (Figure 6). During the cold season when heat can be absorbed the face with warm selective coating and PCM will be on the exterior to store this heat and when the temperatures fall, the slats will rotate 180º to transfer the heat to the internal air gap and to protect the building with the thermal insulation face. During the hot season the slats will be inclined with the cool selective coating on the outside, so it will provide shade, reflect the solar radiation and cool the air entering in the interior by absorbing its heat with the PCM to reduce the temperature of the interior façade. During the night in the cooling period, the slats position will depend on the need and possibility of night ventilation.

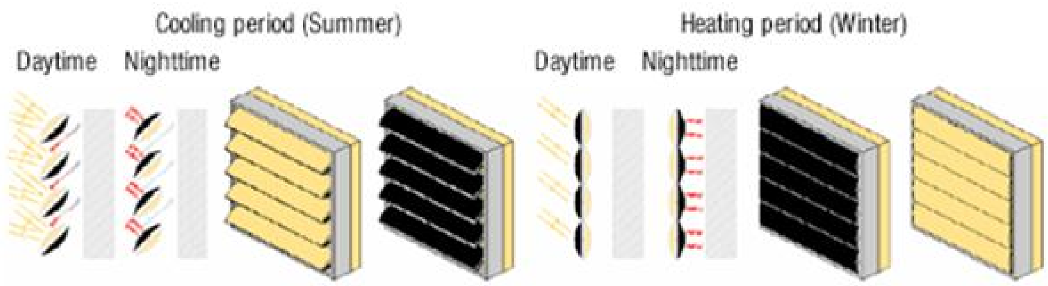


Figure 6. General operating strategies of the ASP&EA TUs (Source: http://www.meefs-retrofitting.eu/project/products-under-development/technological-units.html).

Both the new technical units are in principle thermal storages based on phase change materials. For such solutions, the vital issue is the intended purpose for which it is planned. This effects selection of the phase change material which may change phase for example at temperatures ranging between 20-24ºC. Both the units have quite complicated structures which set requirements for their implementation, operation, control and maintenance especially in cold climates. The units should be protected from rain and frost in order to avoid condensation of water inside the units and thus possibly leading to moisture problems. In case replacement air is taken through the units some air filtering solution should also be implemented guaranteeing cleaning of the supply air.

For solar thermal heat, one collector square meter produces annually 200–400 kWh for different types of systems and locations in Finland (Motiva, 2012), and 450 kWh in Germany (Bosselaar, 2011). Results from PVGIS (European Commission, 2012) shows that the potential in Moscow is closer to that of Berlin than Helsinki. The productions of solar thermal collector panels follow the same trend as BIVP discussed in the previous section. For the Moscow case district, 30% of the energy needed for heating domestic hot water could be produced by solar collectors covering 25% of the total roof area (Paiho et al., 2014).

6. DISCUSSION AND CONCLUSIONS

This study focused on the building typological and energetic issues of the multifunctional façade systems in two Northern locations, namely Helsinki and Moscow. There are also other important aspects, such as mechanical resistance and stability, safety in case of fire and in use, hygiene, health and local requirements, as well as legal issues which were not considered. The analysis, for the cold climates, of the structural design and applied system materials will be the focus of another study.

Even though building renovations may include only some measures improving energy-efficiency, the analyses of renovation packages are more practical if major capital repairs are required anyway, such as in Russia. In Finland, major renovations are often done in stages in owner-occupied apartment buildings but in social housing complete renovations are more common. Therefore, for easier comparison this last holistic approach was selected.

Directive 2010/31/EU (Official Journal of the European Union, 2010) states that minimum requirements for the energy performance of buildings and building elements should be set with a view to achieving the cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building. For Finland, these energy requirements are under development. In the national report on calculation of cost-optimal levels of minimum energy performance requirements, based on expert evaluation State of Finland highlights that the cost-optimal level in building renovation is a slightly more energy-efficient than the requirements defined in the Finnish building code (Finland, 2012). However, many calculation data in the report can be argued, such as the unrealistic lifespan (60 years) of all the building systems and the high discount rate of 6% while the typical interest rate for the Finnish households has been around or even less 2% for years (Bank of Finland, 2014). Paiho et al. (2015) analysed investment costs of different holistic energy-efficient renovation concepts of a Moscow residential district. At the building level, the investment costs of different renovation packages varied between €125/m^2 and € 200/m^2 depending on the extent of the selected renovation package. All packages covered improvements to external walls, windows and doors, upper ceiling, basement, ventilation, heating system, water and wastewater, electricity, gas, metering, and other improvements and costs, but the selected products and solutions varied from basic through improved to advanced ones. Repairing the external walls forms the biggest share of the costs in all the renovation packages, being around 35-40% of the total costs. Solutions reducing the investment costs of façade renovations, such as the objective of the Meefs system, would have a considerable impact to the total investment costs.

A general conclusion is that the Meefs solution, from the energetic point of view, could be feasibly in the Nordic climates in general and in both studied countries in particular. The majorities of the apartment building stocks in both countries have been built after the II World War and need renovations. Building renovation offers an important opportunity to upgrade buildings in order to meet the current and future energy and eco-efficiency requirements as well as other criteria supporting sustainable development. Prefabricated solutions, such as the Meefs system, provide many benefits, such as accelerated repairs, reduced errors on the construction site and less disturbances to residents. In addition, in the both countries there exist a big amount of typical buildings with typical properties of the period of construction. This makes industrialization of the system possible and cost-effective. Adapting prefabricated building facades to such typical buildings could be most beneficial to all involved stakeholders.

From an architectural perspective, (old) residential areas with typical apartment buildings look monotonous, lack vitality, and are less aesthetically pleasing (Raslanas et al., 2011). Through modernization the Meefs brings an aesthetics added value to the building. At the same time the similar building dimensions allow adds allow for standardize panels and measures and for cost-effective industrial production. This will allow retrofitting higher number of apartments and therefore the socio-economic impacts are higher.

In most Russian multi-family apartment buildings the wall elements themselves bear the building’s structural loads (Opitz et al., 1997). This must be taken into account when designing major facade renovations. In addition, tearing down the cladding, if needed, in Russian buildings can be more difficult than in Finnish sandwich elements because the interior and exterior claddings are casted in the edges of the elements. This may limit the utilization of some prefabricated façade elements. However the Meefs system works as a second skin façade and the original façade can be preserved.

The Meefs system can offer considerable energy savings in existing multi-family apartment buildings in both locations. In Finland, the solution could be implemented in individual buildings without additional mandatory improvements to other energy systems. However, it should be noticed that in Russia building energy renovations alone are seldom sufficient, since typically the district heating supply cannot be controlled. So, there energy renovations need to be planned more comprehensively taking also into account the whole energy infrastructure.

Integrating energy production from renewable energy sources to the Meefs panels is possible. In cold climates less solar energy is available than in the Southern countries. In addition, vertical surfaces are not optimal for solar radiation. However, energy generation in vertical surfaces can be increased with geometric designs (Hachem et al., 2014). But this aspect needs more research. Integrating solar collectors either to APSC&VU TU or to ASP&EA TU could also be an issue for future research.

In an assessment made for the St. Petersburg region, Kuznetsova et al. (2011) point out that just a single product is unlikely to achieve strong representation, but rather a complex package of technical and instrumental solutions with a clear demonstration of achievable results will have much better market acceptance. So, the Meefs system could be successfully adapted in the Russian market because it can be considered as a package of solutions when containing several technical features.

The Meefs system is still under development. Field testing is being done in Spain in Southern European climate. Many vital issues are still not developed for the Northern conditions. For example, the frame system itself causes thermal bridges that may affect the thermal performance. In addition, balconies and building ledges need to be solved case by case either respecting their existing state and integrating them physically with the MeeFS facade (e.g. built around) or replacing by the specific MeeFS equivalents. Also details of the anchorage system are not fully designed yet.

Since the climate in Finland is rather similar to that in Moscow and in the cold regions of Russia, many analyzed, tried and tested building and energy solutions applied in Finland could also be utilized in Russia. This paper also supports this development. Still field testing is required in both countries before actual implementations. In addition, Finnish experiences of cold climate buildings could be of use in updating Russian and East-European residential districts to become more energy-efficient. In a technical sense, there is clearly a huge market for companies to respond to the great renovation needs in Russia. However, there are issues other than technical ones that need to be clearly analyzed before successfully entering the market. Financial and business aspects could also be subjects of future research.

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An energetic analysis of a multifuntional facade system for energy efficient retrofitting of residential buildings in cold climates of Finland and Russia

Highlights

- Study on MEEFS multifunctional energy efficient façade system for retrofitting.
- System is suitable for retrofitting apartment buildings in Finland and Russia.
- The studied building stock is advantageous for the Meefs industrialization.
- Field testing are needed in Nordic climates, before actual implementations.