RENOVATION OF BUILDINGS USING STEEL TECHNOLOGIES
RFSR-CT-2007-0043

Energy performance of office and apartment buildings renovated with over-cladding solution based on steel

Authors: Jyri Nieminen, Riikka Holopainen

Confidentiality:

Author(s)
Jyri Nieminen, Riikka Holopainen

Title

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Abstract

ROBUST - Renovation of buildings using steel technologies project is a RFCS-funded project aiming at improved performance of buildings by utilisation of steel technologies. This report focuses on energy performance of concrete buildings of 1960 -. 1980 renovated using over-cladding technology. The main target was to assess the impact of facade renovation on the energy demand of a building

Energy performance of an apartment house built in early 1970's, and an office building of 1960's. was analysed. The case studies focused on the Finnish climate but the simulations were carried out as well in the climates of London, Berlin, and Moscow.

Improved thermal insulation of an office building results in decreased space heating demand but increased cooling demand. The heating demand may reduce by 50 - 60 % or even more, but at the same time, the cooling demand increases by 50 - 100 %. Exterior shading, efficient lighting control and low-energy lighting systems, and energy-efficient office equipment can reduce the cooling demand by more than 60% in cold climates. In warm climates passive and renewable energy based cooling systems need to be applied for low carbon cooling. In general, renovation design of buildings with high internal heat gains needs to be carried out as a whole building approach. Thermal insulation improvement is beneficial from the energy point of view in all climates, but it may increase the consumption of electrical energy for cooling.

Preface

ROBUST - Renovation of buildings using steel technologies project is a RFCS-funded project aiming at improved performance of buildings by utilisation of steel technologies. This report focuses on energy performance of concrete buildings of 1960 -. 1980.renovated using over-cladding technology.

The technology is analysed using two case studies: An apartment house built in early 1970's, and a office building of 1960's.The apartment house is a one kind of a type house. The building system is very common for the era, and it was used in roughly in 85 % of all the apartment buildings built between 1965 – 1980. The same wall system was also very typical in offices.

The case studies focus on the Finnish climate but the simulations were carried out as well in the climates of London, Berlin, and Moscow.

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1. Introduction

Buildings account for about 40 % of Europe's primary energy use, and 40 % of CO2 emissions. The total energy use in buildings was 5000 TWh (EU-15, primary energy 7000 TWh) in 2003. Residential sector is responsible of about 77 % of the energy use and related related CO_2 emissions. The emissions by country depend on energy production and industrial structure of a country, e.g., in Finland the building use related emissions are 30 % of the total.

Heating and cooling purposes account for 30 – 40 % of final energy use in buildings. The potential for saving energy by improved insulation level is high, in heating 40 – 60 % and in cooling 70 – 80% in the existing building stock.

The European Commission has recently proposed an Action Plan on Energy Efficiency with concrete measures to reach a target of reducing the EU's energy use on a business-as-usual scenario by 20% by 2020. This level can not be met without substantial investment in renovation of existing building stock, Figure 1.

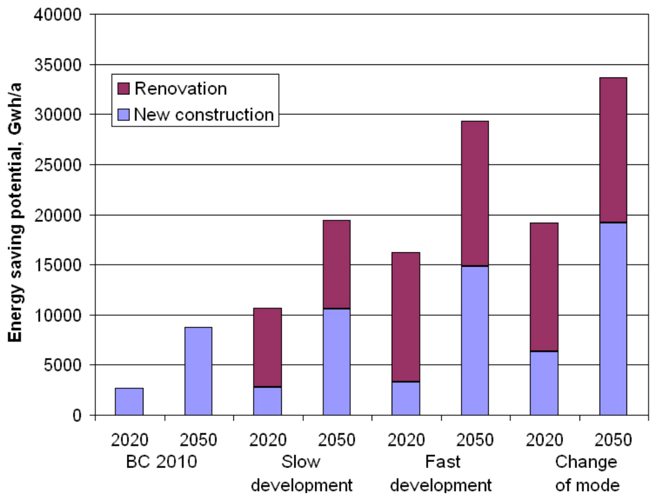

Figure 1. Development scenarios for heating energy demand of the Finnish building stock. The scenarios include the following four assumptions /1/.
(1)Present building code refers to heating energy demand reduction by 30% in 2010 in new construction.
(2) In slow development low-energy buildings are typical in new construction by 2030, and minor energy-efficiency improvements of existing buildings concern 3,5 % of the stock per year.
(3) In fast development low-energy buildings are typical by 2015 and passive houses by 2030, and major improvements in energy-efficiency of existing buildings
(4) Change in modes of operation refers to a situation where all new buildings are passive houses, and major improvements in energy-efficiency of existing
Renovation volume is 3,5 % of the stock a year, new construction 1 – 1,5 % a year, and demolishing rate 1 % a year. The analysis shows that major improvements in existing buildings are required if the aim is to reduce energy use by 20% until year 2020.

Renovation market is growing throughout the Europe, Figure 2. Improvement of energy-efficiency is economically more viable if connected to other improvements of buildings. Typical problems of a Finnish apartment house of 1970’s are given in Figure 3. Energy efficiency measures do not always reduce the energy demand. In old buildings indoor air quality is often poor, and the energy savings by implementation of various technologies may cover up the increased energy demand of ventilation. The profitableness of renovation depends also on the relationship between values and costs, and therefore, also improved durability, increased safety and healthiness, appearance and visual impacts of renovation need to be considered.

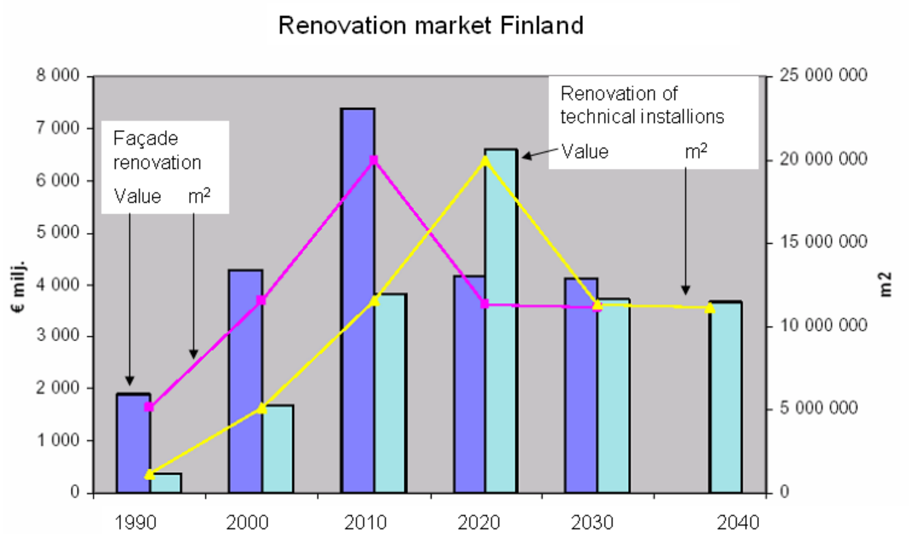

Figure 2. Estimated volume of renovation market in apartment buildings /2/.

Moisture problems, water tightness of concrete facade

Adaptability, level difference between stairwell

Weathered balconies

Adding exterior insulation: dismantling balconies and facade

Figure 3. Apartment house of the early 1980’s.

The aim of the simulations was to show the impacts of energy-efficiency improvements on heating and cooling demand of buildings in the climates of Helsinki, London, Berlin and Moscow.

2. Simulation application VTT House

The energy simulation were carried out using VTT House simulation application. VTT House is VTT's non-commercial building simulation application with integrated calculation of heat transfer and fluid flow processes, Figure 4. The calculation basics are:

- Free nodal approach with discrete definition of mass balance, momentum, and heat balance equations
- True modelling on thermal conduction, convection, and radiation
- SIMPLE Algorithm
- Sparse matrix solver (Preconditioned Conjugate Gradient Method)
- A graphical interface for building material, HVAC system, and other necessary input data definitions
- Graphical visualization of the simulation results

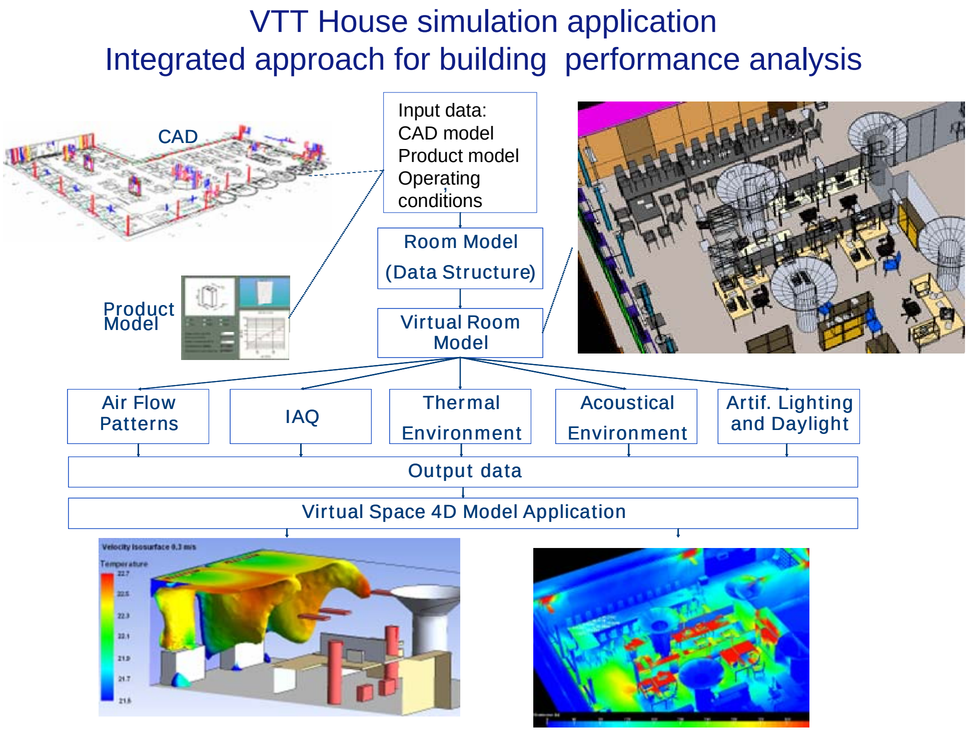

Figure 4. VTT House simulation processes.

3. Energy-efficiency case studies

3.1 Office building

3.1.1 Building system

The office building is a simplified version of an office built in 1970's. The floor plans were assumed to be identical for simplicity. The building is a four-floor building, with identical stories (Figure 5). The simulations are made in four locations: Helsinki (Finland), London (Great Britain), Moscow (Russia) and Berlin (Germany).

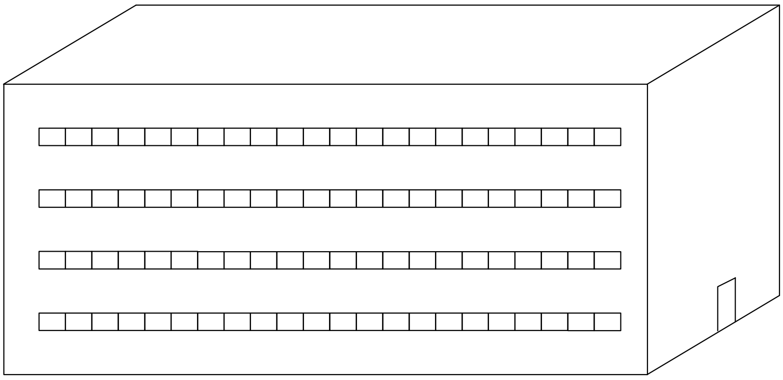

Figure 5. Office building used in calculations. The building dimensions are adopted from a test building for office simulations carried out in LVIS 2000 (HVAC 2000) energy research programme.

The building dimensions are in Table 1.The windows face south and north, altogether 8 continuous windows. The total window area is 517 m^2 (28.5 % of the total wall area). There are two alternatives for retrofitted windows. The air-tightness (n_{50}) of the building is 3.0 1/h (9.9 $m^3/h,m^2$), and after the renovation 1.0 1/h. Original and retrofitted office building structures are in *Table 2* and 3, and Figure 6.

Table 1. Dimensions of the building.

Inner dimensions	
Width	16 m (between the inner surfaces of outer walls)
Length	55 m (between the inner surfaces of outer walls)
Floor height	3.6 m
Inner height	3.2 m
Outer dimensions	
width	16.5 m (between the outer surfaces of outer walls)
length	55.5 m (between the outer surfaces of outer walls)
Areas	
treated floor area	880 m^2 (one floor), 3520 m^2 (all floors)
gross area	916 gross.m^2 (one floor), 3664 gross.m^2 (all floors)

Table 2. Original office house structures

	Structures (from outside)	Total thickness mm	U-value W/m²K
Wall	Concrete 60 mm, wood-wool 80 mm, concrete 160 mm	300	0.82
Roof	Concrete 60 mm, wood-wool 80 mm, concrete 180 mm	320	0.81
Base floor	Gravel 200 mm, concrete 100 mm, wood-wool 100 mm, concrete 60 mm, filler 20 mm	480	0.63
Floor slab	Filler 20 mm, cored slab 310 (190+120), filler 20 mm	350	2.1
Window	2 glass panes (glass thickness = 4 mm), air gap 60 mm	68	2.6

Table 3. Retrofitted structures

	Structures (from outside)	Total thickness mm	U-value, W/m²K
Exterior wall	Cement fibre board 4 mm Mineral wool 150/200/250 mm Wool/air (2/3 air) 50 mm, concrete 160 mm	364 (150) 414 (200) 464 (250)	0.249 0.203 0.171
Window 1	New windows		1.40
Window 2	Passive house windows, g-value 0.35		0.81

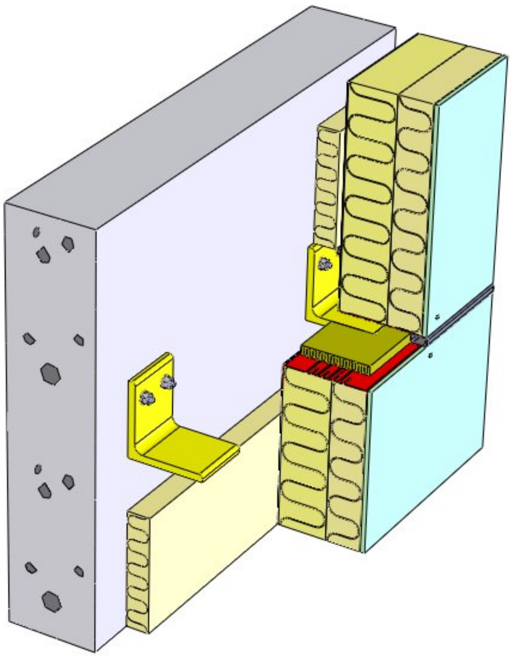

Figure 6. Exterior thermal insulation system in steel. The utilization of the system requires that the exterior slab of the concrete sandwich panel is removed, or that the exterior insulation system is attached to the load-bearing inside slab of the panel. On of the problems with old concrete panels is the poor durability of exterior slab.

3.1.2 Heating, cooling and ventilation

The heating set point is 21 ˚C and the cooling set point is 24 ˚ C. The cooling is on 06.00-20.00 week days when required. Heat distribution system is radiator heating based on district heat. Ventilation provides cooling. Windows have no additional shading.

The operating hours for ventilation are 06.00 - 20.00 on week days. Basic air change rate is 1.21 1/h. The annual heat recovery efficiency is 50 % in both original and renovated case. The heat recovery and space heating are off during June - August.

One person load (113 W) consists of sensible heat 75 W and latent heat 38 W. 70 % of the sensible heat load is considered to be heat transfer by radiation to the surrounding surfaces, and 30 % heat transfer by convection to the surrounding air. These values stand for a room temperature of 25 °C.

The thermal load of one computer or wide screen projector is considered to be 200 W. The office rooms have one computer per person, and the meeting rooms are equipped with wide screen projectors. Of the device heat load, 30 % is divided by radiation to the surrounding surfaces, and 70 % by convection to the surrounding air.

The lightning heat load is 15 W/m^2, and 60 % of the load transfers by radiation to the surrounding surfaces and 40 % by convection to the surrounding air.

Table 4. Internal loads, office building

Room	Person load	Device load	Lightning load
Model office room, A = m2	Work days 8-11.00 and 12-16.00 113 W (one person)	Work days 8-16.00 200 W	Work days 8-16.00 157.5 W
Block of 9 office rooms	Work days 8-11.00 and 12-16.00 1 017 W (9 persons)	Work days 8-16.00 1 800 W	Work days 8-16.00 1417.5 W
Open-plan office	Work days 8-11.00 and 12-16.00 3 277 W (29 persons)	Work days 8-16.00 5 800 W	Work days 8-16.00 4 425 W
Meeting room	Work days 9-11.00 and 13-16.00 565 W (5 persons)	Work days 9-11.00 and 13-16.00 200 W	Work days 9-11.00 and 13-16.00 315 W
Rest room			Work days 8-16.00 555 W

The building simulation follows a simplified approach: one zone per floor (no inner walls). The thermal mass of the inner walls was substituted by increasing the thickness of the floor slab so that the increased volume of the floor slabs represents the volume of the inner walls. The new thickness of the floor slab is 350 mm. The simplified inner loads are in Table 5 .

Table 5. Internal loads per one floor on work days

Time	Total load / one floor, W
0-7	0
7-8	12 529
8-9	20 010
9-10	21 880
10-11	23 750
11-12	20 010
12-13	21 880
13-14	23 750
14-15	25 620
15-16	23 750
16-17	14 399
17-18	12 529
18-00	0

3.1.3 Simulation results

Tables 6 and 7 show the simulation results. Annual space heating and cooling demand for each climate are given as total demand (MWh) and specific demand (kWh/gross-m^2).

Table 6. Annual heating demand in Helsinki, London, Berlin, and Moscow..

Structure		Annual heating demand, MWh (kWh / m^2 gross area)			
Location		Helsinki	London	Berlin	Moscow
Original structure		439 (120)	194 (53)	245 (67)	394 (108)
Retrofitted structures					
Insulation 150 mm	window U-value 1.4	227 (62)			
	window U-value 0.8	191 (52)	72 (19)	97 (27)	173 (47)
Insulation 200 mm	window U-value 1.4	221 (60)			
	window U-value 0.8	185 (50)			
Insulation 250 mm	window U-value 1.4	216 (59)			
	window U-value 0.8	181 (49)	67 (18)	91 (25)	163 (45)

Table 7. Annual cooling demand in Helsinki, London, berlin, and Moscow.

Structure		Annual cooling demand, MWh (kWh / m^2 gross area)			
Location		Helsinki	London	Berlin	Moscow
Original structure		22 (6)	40 (11)	52 (14)	36 (10)
Retrofitted structures					
Insulation 150 mm	window U-value 1.4	37 (10)			
	window U-value 0.8	43 (12)	69 (19)	75 (21)	54 (15)
Insulation 200 mm	window U-value 1.4	38 (10)			
	window U-value 0.8	44 (12)			
Insulation 250 mm	window U-value 1.4	39 (11)			
	window U-value 0.8	45 (12)	71 (20)	77 (21)	55 (15)

Table 9. Annual total heating and cooling demand in Helsinki, London, Bberlin, and Moscow.

Structure		Annual cooling demand, MWh (kWh / m^2 gross area)			
Location		Helsinki	London	Berlin	Moscow
Original structure		461 (126)	234 (64)	297 (81)	430 (128)
Retrofitted structures					
Insulation 150 mm	window U-value 1.4	264 (72)			
	window U-value 0.8	234 (64)	141 (38)	172 (48)	227 (62)
Insulation 200 mm	window U-value 1.4	259 (70)			
	window U-value 0.8	229 (62)			
Insulation 250 mm	window U-value 1.4	255 (70)			
	window U-value 0.8	226 (61)	138 (38)	168 (46)	218 (60)

3.1.4 Conclusions

Improved thermal insulation of an office building results into decreased space heating demand but increased cooling demand. The heating demand reduces by 50 - 60 %, and at the same time, the cooling demand increases by 50 - 100 %. No passive cooling measures were taken into consideration in the simulations. Figure 7 shows the relative effect of different passive technologies to control cooling demand. Exterior shading efficient lighting control, low-energy lighting systems and energy-efficient office equipment can reduce the cooling demand by more than 60% in cold climates. In warm climates the passive and renewable energy based cooling systems need to be applied for low carbon cooling.

In general, renovation design of buildings with high internal heat gains needs to be carried out as a whole building approach. Thermal insulation improvement is beneficial from the energy point of view in all climates, but it increases the consumption of electrical energy.

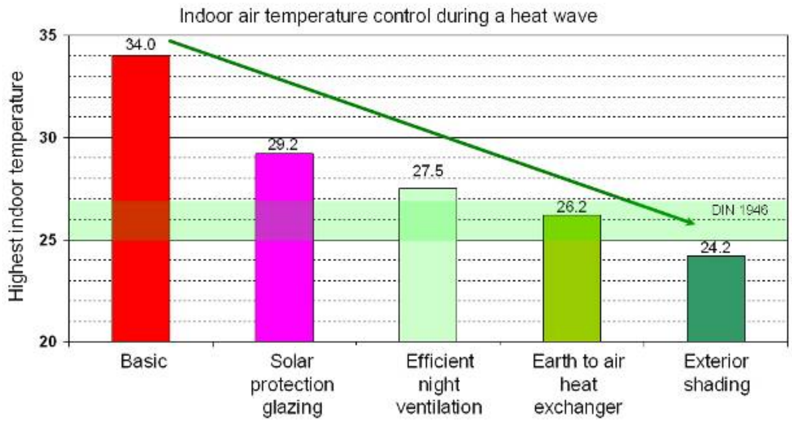

Figure 7. Passive cooling. Impact of passive measures on indoor temperature during a heat wave.

3.2 Apartment house

3.2.1 Building systems

The simulated apartment house is a four-storey building, with a basement and three identical apartment stores. The building type is very common solution for suburban areas built in the 1970's, Figures 3 and 9. The basic solution of buildings of this type is concrete-sandwich panel exterior wall, low-sloped roof with internal drainage, and concrete balconies attached to the inner slab of the panel. Typically, the insulation level in the walls varies between 80 and 120 mm of mineral wool insulation. The manufacturing technology varied as well, and concrete casting through the insulation or part of the insulation was common.

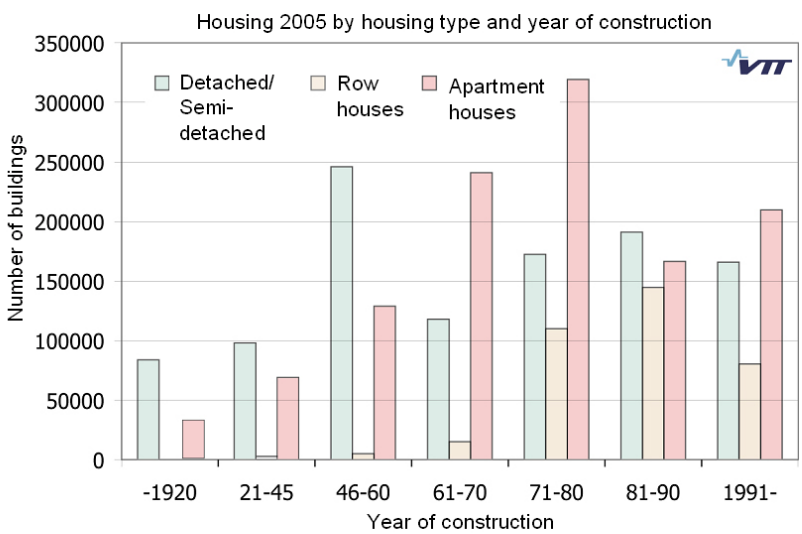

Figure 8. Finnish building stock by the year of construction. Roughly 85% of the apartment buildings 1960 – 1980 has concrete facades /3/.

Renovation of the facades requires typically dismantling of the outer slab of the panel if the durability of the concrete is low. Also, balcony lines need to be removed for additional insulation. Table 10 shows the dimensions of the analysed building.

The windows locate on the main facades only, and in the simulations they are assumed to face south and north. The windows areas are to south 132 m^2 and to north 73 m^2. The total window area is 205 m^2 (19.7 % of the total wall area).

The simulations are made in four locations: Helsinki (Finland), London (Great Britain), Moscow (Russia) and Berlin (Germany).

Table 10. Dimensions of the apartment building

Inner dimensions	
Width	10.5 m (between the inner surfaces of outer walls)
Length	52.5 m (between the inner surfaces of outer walls)
Floor height	2.7 m, basement 2.1 m
Inner height	2.4 m, basement 2.1 m
Outer dimensions	
width	11 m (between the outer surfaces of outer walls)
length	53 m (between the outer surfaces of outer walls)
Areas	
treat floor area	550 m2 (one floor), 2200 m2 (all floors)
gross area	583 gross.m2 (one floor), 2332 gross.m2 (all floors)

3.2.2 Heating, cooling, and ventilation

The heating set points are 21 ˚C for apartment floors and 19 ˚C for basement. There is no cooling. Typical heat distribution system is radiator heating based on district heat.

Mechanical exhaust ventilation is assumed to be on 24 hour/day with an air change rate of 0.5 1/h. In the original building there are no heat recovery from ventilation. After the renovation the annual heat recovery is assumed 75 %. The original air-tightness (n_{50}) of the building is 3.0 1/h. After the renovation the air tightness is about 1.0 1/h.

Original apartment house structures are in Table 11, and the retrofitted structures (exterior wall and windows) in Table 12.

Table 11. Original apartment house structures

	Structures (from outside)	Total thickness, mm	U-value, W/m^2K
Exterior wall	Concrete 60 mm Insulation 80 mm Concrete 120 mm	260	0.5
Interior wall	Concrete 200 mm	200	2.6
Roof	Insulation 150 mm, concrete 150 mm	300	0.3
Base floor	Insulation 80 mm, concrete 100 mm	180	0.4
Floor slab	Concrete slab 300 mm	300	2.7
Window	2 glass panes (glass thickness = 4 mm), air gap 60 mm	68	2.6

Table 12. Retrofitted structures

	Structures (from outside)	Total thickness, mm	U-value, W/m^2K
Exterior wall	Mineral wool 250 mm Concrete 60 mm Insulation 80 mm Concrete 120 mm	510	0.16
Roof	Mineral wool 300 mm Insulation 150 mm Concrete 150 mm	600	0.11
Base floor	Insulation 80 mm Concrete 100 mm Insulation 60 mm	240	0.22
Window	Passive house type windows, g-value 0.35 for the glass area		0.81

3.2.3 Thermal loads

Thermal loads (Table 13) for apartments are pre-calculated for every hour of the year. In the building there are three types of apartments: 4 rooms with kitchen, 3 rooms with kitchen and 1 room with kitchen. Every one of them have they own thermal load profile.

Table 13. Annual internal loads, aparment building

Apartment type	Internal load (MWh)
4 rooms + kitchen	3.4
3 rooms + kitchen	3.2
1 rooms + kitchen	1.9

The basement has no internal loads. The total annual internal load for the building is 50.7 MWh.

3.2.4 Simulation results, Helsinki

Tables 6 and 7 show the simulation results. Annual space heating and cooling demand for each climate are given as total demand (MWh) and specific demand (kWh/gross-m^2).

Table 14. Annual heating demand in Helsinki, London, Berlin, and Moscow

Structure	Annual heating demand, MWh (kWh / m^2 gross area)			
Location	Helsinki	London	Berlin	Moscow
Original structure, no heat recovery	212 (91)	107 (46)	126 (54)	
Retrofitted: Ventilation increased 50 %. Window transmissions decreased 40 % for June - September. Heat recovery efficiency is 75 %	39 (17)	8 (4)	15 (7)	

3.2.5 Conclusions

The suggested renovation procedure reduces the heating demand of the building down to a level typical for passive houses. The simulation of apartment houses did not take into account for cooling demand, which is suspected to increase due to improved thermal performance of the building envelope.

Shading or louvers should be included into the renovation concept. Night cooling and at least operable windows help for better thermal comfort in summer.

4. Discussion

Industrialized steel building technologies can help in saving energy in office and apartment buildings. Prefabrication of exterior insulation systems can also reduce the delivery cycle of a renovation process. Accurate measurement of the dimensions of the building is a presumption for utilising prefabrication. Laser scaling technologies are an efficient method to create a model of a building. The whole process of façade renovation requires improvements for cost-efficiency and reduced nuisance for the building users.

Old concrete buildings suffer fro water leakage problems, carbonisation of concrete and corrosion of reinforcement steel and even mechanical damages caused by freezing-thawing cycles. It is common that the exterior concrete layer of a sandwich structure need to be removed due to its decaying mechanical properties. As the exterior parts of the wall are dismantled, prefabricated structures become more attractive together with a possibility to improve the air-tightness of the building envelope.

The cost-efficiency of the proposed concept for additional insulation is not competitive to exterior insulation systems with rendering. However, if there is a need to dismantle the exterior slab, the wall system becomes competitive. Exterior insulation systems require an even surface for a good installation and thus the need to even out the exterior surface of the concrete layer can be omitted with prefabricated systems.

Office equipment and lighting are the major energy usages in an office. Heating demand is less that 50 % of the energy uses in a modern office building even in cold climates. Office building built in 1960's and 1970's have a poor thermal performance, and thus the heating energy demand is more dominating in the energy performance.

Old apartment buildings typically do not have mechanical cooling systems. Thus, the management of indoor air quality in terms of temperature by passive means is important in apartments as well. Typically, the renovation of the old concrete apartment houses does not include installation of cooling systems.

Indoor air quality in apartment buildings suffers from poor ventilation as well. Mechanical exhaust ventilation together with poor air tightness of window to wall and wall to floor connections cause draught. The fresh air vents can be closed and decrease the ventilation performance. As the a new ventilation system with efficient heat recovery is installed and adjusted to meet the requirements of a good indoor air quality, the heat recovery does not bring the expected energy efficiency improvement. The reduction of heating energy demand depends then on the level of measures used for the improvement of energy performance of building envelope and its components. Therefore, it is beneficial to look at the renovation as whole.

In general, renovation of existing building stock is an efficient way to achieve substantial energy savings in buildings compared to regulative changes of building codes for new buildings. Prefabricated exterior thermal insulation systems offer a possibility for steel industries to utilize the renovation markets. Industrialized multifunctional envelope systems for renovation help as well in routing of building services systems thus increasing the attractiveness of renovation with high amounts of facade insulation.