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The Economic Challenges of Deep Energy Renovation—Differences, Similarities, and Possible Solutions in Northern Europe: Estonia and Denmark

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ABSTRACT

The International Energy Agency's Energy in Buildings and Communities Programme Annex 61 focuses on developing and demonstrating financial and technical concepts for deep energy retrofits of public buildings. A first and important step to define the methodology is to examine the economic aspects of deep energy retrofits in each of the participating countries. Estonia, Germany, Canada, Austria, and Denmark have conducted a series of simulations in order to determine the economic conditions in the renovation of a pre-1980s building. The calculations are divided into three scenarios, corresponding to: (1) minor renovation (i.e., the minimum requirements of building codes or similar), (2) major renovation (i.e., a 50% reduction in site energy use), and (3) advanced level: reducing the site energy use to an advanced level which is to be defined on the national level. This can be the new building requirement renovation (i.e., reducing the site energy use to a level corresponding to that of a new building that fulfills the present requirements in national building regulations or specific standards like the passive house standard). The analysis shows how deep renovation solutions and economic conditions differ from country to country and emphasizes the individual economic challenges of deep energy renovation. The analysis will be used in developing and demonstrating new and alternative funding mechanisms for deep renovation projects. This paper describes results for northern Europe (particularly Estonia and Denmark).

INTRODUCTION

Denmark and Estonia are participating in IEA EBC Annex 61 "Development and demonstration of concepts for deep energy retrofit in government/public buildings." The purpose of the Annex is to improve the decision-making process to achieve deep energy retrofits of government/public buildings, starting with the determination of working bundles of technologies and corresponding business models using combined public and private funding.

Improving the energy efficiency of buildings represents a key target area in European countries, since 40% of the total energy consumption in the E.U. is related to the building sector (EU 2010). This implies, among other things, increasing the energy efficiency of existing buildings in order to reduce heat loss through building envelopes and implementing a greater share of renewable energy in buildings is necessary.

The scope of the Annex 61 project is to improve the decision-making process associated with achieving deep energy renovation of government/public buildings (office/administrative buildings, dormitories/barracks, educational buildings, etc.), starting with the determination of working bundles of technologies and corresponding related business models using combined public and private funding. This decision-making process must improve to overcome existing barriers in the execution of complex projects co-funded by government, public entities, energy service companies (ESCOs), and other market partners. Barriers include the exclusion of individual energy conservation measures (ECMs) with long payback times and the challenges of combining energy-related measures with non-energy-related measures (e.g., building sustainment, repurposing, and improvement in quality of life).

The objectives of Annex 61 are to

- Provide a framework and selected tools and guidelines to significantly reduce energy use (by more than 50%) and to improve indoor environment quality in government and public buildings and building communities undergoing renovation

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- Gather and, in some cases, research, develop, and demonstrate innovative and highly effective bundled packages of ECMs for selected building types and climatic conditions
- Develop and demonstrate innovative, highly resource-efficient business models for retrofitting/refurbishing buildings and community systems using appropriate combinations of public and private funding, such as energy savings performance contracts (ESPC) and other concepts to be developed together with the building owners
- Support decision makers in evaluating the efficiency, risks, financial attractiveness, and contractual and tendering options conforming to existing national legal frameworks
- Engage end users, mainly building owners and other market partners, in the proceedings and work of the Annex subtasks

A first and important step to define the methodology is to examine the economic aspects of deep energy retrofits in each of the participating countries. Estonia, Germany, Canada, Austria and Denmark have conducted a series of simulations in order to determine the economic conditions in the renovation of a pre-1980s building. The calculations are divided into three scenarios, corresponding to the following: (1) minor renovation (i.e., the minimum requirements of building codes or similar), (2) major renovation (i.e., a 50% reduction in site energy use), and (3) advanced level: reducing the site energy use to an advanced level which is to be defined on the national level. This can be the new building requirement renovation, (i.e., reducing the site energy use to a level corresponding to that of a new building that fulfills the present requirements in national building regulations or specific standards like the passive house standard). This paper describes the results obtained in northern Europe (particularly Denmark and Estonia).

METHODS

Studied Buildings

The Danish case study building (see Figure 1, left, and Table 1) is a generic school building with three stories totaling 3000 m^2 (32292 ft^2). Constructions and systems for the building have been chosen to correspond to the typical constructions and systems in a pre-1970s building (i.e., the exterior wall is a solid brick wall, the slab floor has 100 mm [0.3 ft] concrete and 200 mm [0.7 ft] clay aggregate, and the roof is based on wooden beams and has 100 mm [0.3 ft] insulation). Windows are traditional two-pane windows. The school building has natural ventilation, and the airtightness of the building corresponds to an air change rate. of 4.0 $l/s/m^2$ at 50 Pa pres-

Table 1. Characterization of Case-Study Buildings

Parameter	Denmark	Estonia
Number of floors	3	5
Net area	3000 m^2 (32,292 ft^2)	3824 m^2 (41,161 ft^2)
Heated area	3000 m^2 (32,292 ft^2)	3306 m^2 (35,586 ft^2)
Number of classrooms/apartments	18	80
Compactness: Building envelope, m^2/volume, m^3, m^{-1} (ft^{-1})	0.42	0.34
Usage of building	School	Dormitory

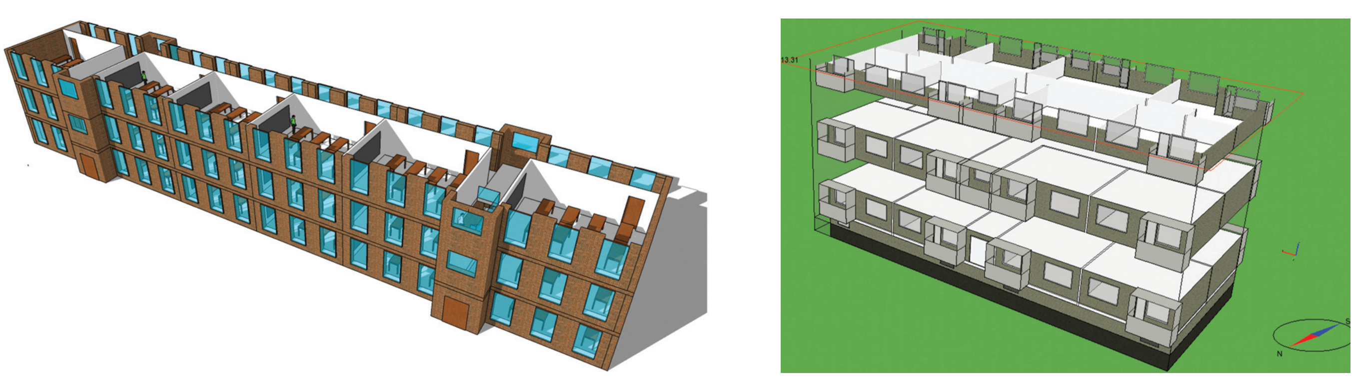

Figure 1 *Models of case-study building in Denmark (left) and in Estonia (right) based on real buildings.*

sure (5.9 gpm/ft^2 at 1.0 lb$_f$/ft^2). The building has a length of 86.5 m (283.8 ft) and a width of 11.5 m (37.7 ft). The building has three floors of 1000 m^2 (10,764 ft^2) each and the floor area is divided into 2100 m^2 (22,604 ft^2) classrooms and 900 m^2 (9688 ft^2) corridors. The window/floor area ratio is 25% in both classrooms and corridors (i.e., 70% of windows are in classrooms and facing south and 30% of windows are in corridors and facing north). The building is heated with natural gas through an old gas furnace with average efficiency and heating is supplied through radiators. The thermal transmittances of the building envelope are as follows: external walls—$U_{wall} \approx$ 0.57 W/(m^2·K) (0.10 Btu/h·ft^2·°F); roof—$U_{roof} \approx$ 0.40 W/(m^2·K) (0.07 Btu/h·ft^2·°F); windows—U_{window} ≈ 3.10 W/(m^2·K) (0.55 Btu/h·ft^2·°F). The linear thermal transmittances are as follows: foundation—0.30 W/(m·K) (0.17 Btu·ft/h·ft^2·°F); window/wall joint—0.10 W/(m·K) (0.06 Btu·ft/h·ft^2·°F).

The Estonian case study dormitory building (see Figure 1, right, and Table 1) is similar to many mass production apartment buildings built during 1970 to 1990. The five story building is composed of prefabricated concrete large panel elements (Series 111 through 121) in 1986. The building has a natural passive stack ventilation system and one-pipe radiator heating systems. Radiators are not equipped with thermostats. Room temperature for the whole building is regulated in heat substations depending on outdoor temperatures. The thermal transmittances of the building envelope are as follows: external walls—$U_{wall} \approx$ 1.1 W/(m^2·K) (0.19 Btu/h·ft^2·°F); roof-ceilings—U_{roof} ≈ 1.0 W/(m^2·K) (0.18 Btu/h·ft^2·°F); windows—U_{window} ≈ 1.6 W/(m^2·K) (0.28 Btu/h·ft^2·°F) (a two-pane window is tightened to the wall with tow (not an airtight connection), and windows were designed to be leaky to guarantee natural ventilation).

Indoor Climate and Energy Simulations

The energy performance of the building and related costs was calculated using the ASsociated COsTs (ASCOT) tool (Cenergia 2014). The calculation tool consists of a spreadsheet based on the energy calculation of the Danish energy compliance checker Be10 (Aggerholm and Grau 2014) coupled with a cost database for different energy saving measures. The Danish Design Reference Year (DRY) (Lund and Jensen 1995) is used for the calculations and it corresponds to approximately 2960 heating degree days based on t_i = 17°C (62.6°F). Energy performance of the Estonian reference building was simulated using the dynamic energy and indoor climate simulation program IDA Indoor Climate (EQUA 2009) and Energy 4.5 (IDA-ICE) with Estonian Test Reference Year for outdoor climate (annual heating degree days at t_i = 17°C: 4160°C·d (7028°F·d) (Kalamees and Kurnitski 2006) for Estonia.

The calculations in general were performed using standard usage and by unified calculation methodology (i.e., internal heat gains, DHW use, usage time, etc. based) on SBi-Direction 213 (Aggerholm and Grau 2014) and Estonian Government's Ordinances (RT I 2012b, 2012a), see Table 2.

The Energy Certification Class (ECC) for nondomestic buildings in Denmark uses a simple weighing system for energy sources. Electricity has a weighing factor of 2.5 and all other sources of energy have factors of 1.0. For new buildings, the weighing factors are different for 2015 and 2020 (i.e., in 2015 the factor for district heating will be reduced to 0.8 and in 2020 the factor for district heating will be reduced to 0.6 and the factor for electricity to 1.8. The Table 3 lists the present ratings in the Energy Certification Scheme. The ECC for apartment building in Estonia is defined according to primary energy (PE). PE takes into account the use of the primary energy (space heating, ventilation, domestic hot water, all electricity loads [including lighting and appliances (plug loads)]) and environmental impact according to the energy source. The following factors are used: wood, wood-based fuels, and other bio fuels: 0.75, district heating: 0.9, fossil fuel (gas, coal etc.): 1.0, electricity: 2.0.

Table 2. Standard Use of Buildings

Parameter	Denmark	Estonia
Usage time	45 hours per week, 8.00–17.00	24 h per day, 7 days per week
Internal heat gains from people	4.0 W/m^2 (1.3 Btu/h·ft^2)	3.0 W/m^2 (0.95 Btu/[h·ft^2]) and 80 W/person (273 Btu/h)
Internal heat gains from appliances (day night)	6.0 W/m^2/1.0 W/m^2 (1.9Btu/h·ft^2/0.3 Btu/h·ft^2)	3.0 W/m^2 (0.95 5 Btu/[h·ft^2]) usage rate is 0.6
Internal heat gains from lighting	14.0 W/m^2 (4.4 Btu/h·ft^2)	8.0 W/m^2 (2.54 Btu/[h·ft^2]) usage rate is 0.1
Ventilation	2.2 L/s/m^2 (3.2 gpm/ft^2) for classrooms and 0.3 L/s/m^2 (0.4 gpm/ft^2) for hallways	0.35 l/(s·m^2) (0.51 gpm/ft^2) for a nonrenovated case, 0.42 l/(s·m^2) (0.61 gpm/ft^2) for renovation packages
Infiltration	0.28 l/s/m^2 (0.4 gpm/ft^2): a low level of airtightness	4 m^3/(hm^2) at 50 Pa (1.6 gpm/ft^2 at 1.0 lb$_f$/ft^2)
Domestic hot water	0.03 m^3/m^2 per year, i.e. 90 m^3 per year (3178 ft^3/yr)	35–45 l/(pers × day) (1.2–1.6 ft^3) / 30 kWh/(m^{2}a) (9.51·103 Btu/m^2 yr)

Economic Calculations

Net present value (NPV) calculations were used to evaluate financial feasibility of different cases. The parameters used in the calculations are given in Table 4. Construction costs were taken from estimations of the construction companies.

The following formula was used for calculating NPV:

$$C_g = \frac{C_I + C_a \cdot f_{pv}(n)}{A_{\text{floor}}} \tag{1}$$

where C_g is the global cost; NPV is the net present value, €/m^2; C_I is the construction cost of the renovation variant, €; C_a is the annual energy cost during starting year, €; $f_{pv}(n)$ is the present value factor for the calculation period of n years; and A_{floor} is the heated net floor area, m^2.

The present value factor $f_{pv}(n)$ is calculated as follows:

$$f_{pv}(n) = \frac{1 - (1 + [R_R - e]/100)^{-n}}{(R_R - e)/100} \tag{2}$$

where R_R is the real interest rate, %; e is escalation of energy prices, %; and n is the length of the calculation period.

Energy Efficiency Measures

Denmark

Scenario 1: Baseline. The baseline (i.e., corresponding to the original building) has a total energy consumption of 210.4 kWh/m^2 (66,432 Btu/ft^2) per year for heating, 21.0 kWh/m^2 (6631 Btu/ft^2) for electricity (including lighting, pumps and fans), and 20.5 kWh/m^2 (6473 Btu/ft^2) for appliances (plug loads). Using the Danish weighing factors (1.0 for natural gas and 2.5 for electricity), this corresponds to a total primary energy use of 314.2 kWh/m^2 (99,206 Btu/ft^2) per year, which places the building as level F in the Energy Certification Scheme. The site energy use for the building corresponds to €108,079/yr ($122,129/yr).

Scenario 2: Minor renovation. The minor renovation of the school building corresponds to a situation where only cost effective measures are carried out (i.e., measures that fulfill Equation 5.

Table 3. Energy Certification Schemes, 1 kWh/(m^2·a) = 317 Btu/(ft^2·a)

Denmark		Estonia	
Level	**Maximum Consumption, kWh/(m^{2}a)**	**Level**	**Primary Energy Consumption, kWh/(m^{2}a)**
A2020	25.0 (Danish nearly zero energy buildings)	A	≤100 (Estonian nearly zero energy buildings)
A2015	41.0 + 1000/A (A is the gross floor area)		
A2010	71.3 + 1650/A (min. req. for new buildings)		
B	95.0 + 2200/A	B	≤120 (Estonian low energy buildings)
C	135.0 + 3200/A	C	≤150 (min. req. for new buildings)
D	175.0 + 4200/A	D	≤180 (min. req. for major renovation)
E	215.0 + 5200/A	E	≤220
F	265.0 + 6500/A	F	≤280
G	>265.0 + 6500/A	G	>281

Table 4. Parameters Used in Net Present Value Calculations (€1 ≈ $1.13 [Sept 2015])

Parameter	Denmark	Estonia
Energy price, district heating, €/MWh	107.33 ($413/MMBtu)	75.00 ($289/MMBtu)
Energy price, natural gas, €/MWh	116.00 ($447/MMBtu)	—
Energy price, electricity, €/MWh	280.00 ($1080/MMBtu)	140.00 ($540/MMBtu)
Discount rate, %	5.0	4.0
Inflation of energy, %	4.5	3.0
Inflation of maintenance, %	3.0	3.0
Expected economic lifetime, years	25.0	20.0
Present value factor, $f_{pv}(n)$	23.45	18.05

$$\frac{\text{Annual savings} \cdot \text{Lifetime}}{\text{Investment}} \geq 1.33 \tag{3}$$

The following measures fulfill Equation 3:

- Roof: add 300 mm (11.8 in.) insulation (e.g. mineral wool) to the roof construction
- Heating system: replace existing gas furnace with new condensing furnace

Replacing the gas furnace will reduce energy consumption significantly due to the increase in the furnace efficiency. However, if it is possible, changing from gas to district heating would be even more efficient since the installation is cheaper and saves more energy. District heating is not considered as a possibility in this scenario.

Scenario 3: Major renovation. This renovation scenario corresponds to an extension of the minor renovation scenario that aims at a reduction of the total site energy consumption of 50% compared to the situation before renovation (i.e., a total energy price below €54,040/yr ($61,065/yr). In order to reach this level, the following measures are added to Scenario 2:

- Windows: new two-layer energy glass
- Wall + 200 mm insulation
- Ventilation system: Balanced mechanical ventilation with high system efficiency (i.e., a mechanical ventilation system with same level of supply and exhaust air, a high heat recovery rate, and low electricity use for fans)
- Infiltration: Increased airtightness of the building (extra airtight corresponding to an infiltration rate of 0.09 L/s pr. m^2 [0.1 gpm/ft^2] or 1.0 L/s pr. m^2 [1.5 gpm/ft^2] at 50 Pa [1.0 lb_f/ft^2] pressure. The reference is 0.28 L/s pr. m^2 [0.4 gpm/ft^2] or 4.0 L/s pr. m^2 [5.9 gpm/ft^2] at 50 Pa [1.0 lb_f/ft^2] pressure)

Scenario 4: Renovation to represent the criteria of new building and low-energy building. This renovation scenario represents the level of renovation necessary in order to meet energy requirements for new buildings according to the Danish Building Regulations (i.e., corresponding to a primary energy use of less than 71.85 kWh/m^2 [6.32 Btu/(s·ft^2)]) per year for the particular school building. This level of energy efficiency can be achieved in several different ways, and, therefore, the scenario is split into several different solutions to illustrate the possibilities. The base case is described below:

- Heating system: heat pump
- Infiltration: increased airtightness of the building (extra airtight)
- Lighting: LED-lighting in classrooms with continuous automatic control

Table 5 sums up the scenarios investigated for the "new building criteria." For the scenario including the condensing gas furnace, it is necessary to include continuously controlled automatic LED-lighting in the corridors in order to reach a site energy use corresponding to "new building criteria."

Estonia

Energy simulations were made for different individual renovation measures (different thicknesses of additional external thermal insulation, improvement of windows, and ventilation systems). All renovation packages included the installation of an adequate ventilation system in order not to compromise indoor climate. Different heat sources than district heating (gas boilers, heat pumps, etc.) were not analyzed in this study. Public buildings in urban areas are mostly heated with district heating in Estonia. Results from individual measures were summarized in order to create renovation packages to correspond to different ECC.

Table 5. Scenarios Investigated as "New Building Criteria"

Energy Saving Measures	Scenario	4	4a	4b
Roof + 300 mm (1.0 ft) insulation		X	X	X
Two-layer energy glass		X	X	X
Wall + 200 mm (0.7 ft) insulation		X	X	X
Balanced mechanical ventilation with heat recovery		X	X	X
Airtightness (Extra airtight)		X	X	X
Continuous automatic LED lighting in classrooms		X	X	X
Continuous automatic LED lighting in corridors			X	
Condensing gas furnace			X	
Heat pump		X		
District heating				X

RESULTS AND DISCUSSION

Denmark

Individual renovation measures. Figure 2 and Table 6 show the calculated energy savings of individual energy saving measurements.

From Figure 2 it is clear that individual measures including roof insulation, changing the heating system, and windows with two-layer energy glass have positive net present values. In Figure 2, balanced mechanical ventilation with heat recovery and airtightness of the building has been combined since the heat recovery will not obtain the full potential unless the ventilation air goes through the exchanger. The energy saving potential for this measure is quite significant, however, the NPV is still negative due to the relatively large investment needed. New lighting systems, exterior wall insulation, and windows with three-layer energy glass are all quite expensive measures resulting in negative NPVs.

Figure 3 shows the energy savings cost in €/kWh for individual measures as a function of the total energy savings in kWh/m^2 per year. Figure 3 shows that a new condensing gas furnace or the installation of district heating is the most inexpensive ways to achieve large reductions in energy consumption.

Packages for Energy Renovation

Energy renovation packages as described earlier were calculated. Table 7 shows the calculated energy use including appliances (plug loads) and resulting site energy cost. Table 8 shows the economy of individual renovation packages.

The investment necessary to complete the minor renovation is €86,711. From there if you invest a further €839,314, it is possible to reach 50% energy savings with an NPV of 0.

The minor renovation lifts the energy label of the building from a "F" to a "E" with an investment of approximately €86,000. The site energy cost is reduced by approximately €5600, resulting in a simple payback time of 5.2 years.

The major renovation lifts the energy label of the building to a "C" rating with an investment of approximately €1,315,000. The site energy cost is reduced by approximately €55,000 resulting in a simple payback time of 23.9 years.

The "new building criteria" (NBC) scenarios all lift the energy label of the building to an "A2010" rating. If a gas furnace is used instead of a heat pump (scenario 4a), it is necessary to also add more energy efficient lighting in the corridors in order to achieve the "A2010" rating. If district heating is used, the building easily fulfills the requirement for "A2010" rating. An investment of more than €1,500,000 is necessary to reach the "A2010" rating and results in simple payback times of 22 to 25 years.

Table 9 shows a summary of the calculation results (i.e., the reduction in primary energy demand for each of the investigated scenarios along with the corresponding reduction in the heating demand). The latter reflects the ratio of reductions in transmission heat losses to reductions in the remaining parts of the energy consumption of the buildings.

Estonia

Single energy renovation measures. The change of the NPV and energy performance was selected to assess the cost effectiveness of individual renovation measures. The influence of individual energy renovation measures on the delivered energy is shown in Figure 4.

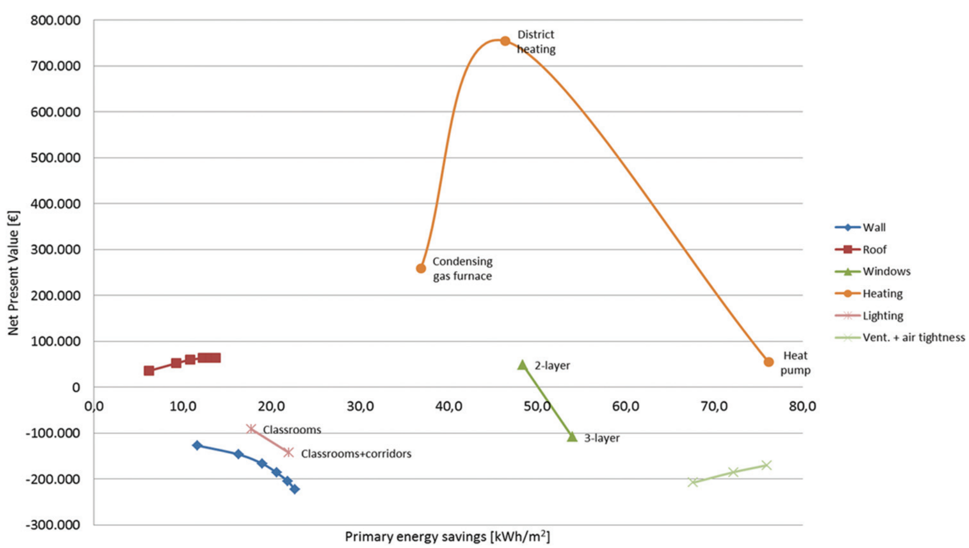

Figure 2 *Net present value in € for individual energy saving measures as a function of the total primary energy savings in kWh/m^2 (1 kWh/m^2 = 317 Btu/ft²; € ≈ \$1.13 [Sept 2015]).*

Table 6. Annual Energy Savings for Individual Energy Saving Measures in kWh/m^2 (1 kWh/m^2 = 317 Btu/ft^2)

		Energy Use			Energy Savings		
		Heating	Electricity	Primary	Heating	Electricity	Primary
Baseline		210.4	41.5	314.2	—	—	—
Wall	+ 50 mm (0.16 ft)	199.7	41.1	302.5	10.7	0.4	11.7
	+ 100 mm (0.33 ft)	195.3	41.0	297.8	15.1	0.5	16.4
	+ 150 mm (0.49 ft)	192.9	40.9	295.2	17.5	0.6	19.0
	+ 200 mm (0.66 ft)	191.3	40.9	293.6	19.1	0.6	20.6
	+ 250 mm (0.82 ft)	190.3	40.8	292.3	20.1	0.7	21.9
	+ 300 mm (0.98 ft)	189.5	40.8	291.5	20.9	0.7	22.7
Roof	+ 50 mm (0.16 ft)	204.7	41.3	308.0	5.7	0.2	6.2
	+ 100 mm (0.33 ft)	201.9	41.2	304.9	8.5	0.3	9.3
	+ 150 mm (0.49 ft)	200.3	41.2	303.3	10.1	0.3	10.9
	+ 200 mm (0.66 ft)	199.1	41.1	301.9	11.3	0.4	12.3
	+ 250 mm (0.82 ft)	198.3	41.1	301.1	12.1	0.4	13.1
	+ 300 mm (0.98 ft)	197.7	41.1	300.5	12.7	0.4	13.7
Windows	Two-layer energy glass	160.0	42.3	265.8	50.4	–0.8	48.4
	Three-layer energy glass	152.4	43.1	260.2	58.0	–1.6	54.0
Airtightness	BR08 standard	188.3	20.4	239.3	22.1	0.6	23.6
	Extra airtight	184.0	20.3	234.8	26.4	0.7	28.2
	Passive house	180.5	20.2	231.0	29.9	0.8	31.9
Ventilation	Mechanical ventilation with HR	166.6	41.4	270.1	43.8	0.1	44.1
Heating	Condensing furnace	173.5	41.5	277.3	36.9	0.0	36.9
	District heating	164.0	41.5	267.8	46.4	0.0	46.4
	Heat pump	0.0	95.2	238.0	210.4	–53.7	76.2
Lighting	LED classrooms	210.4	34.4	296.4	0.0	7.1	17.8
	LED classrooms + corridor	210.4	32.7	292.2	0.0	8.8	22.0

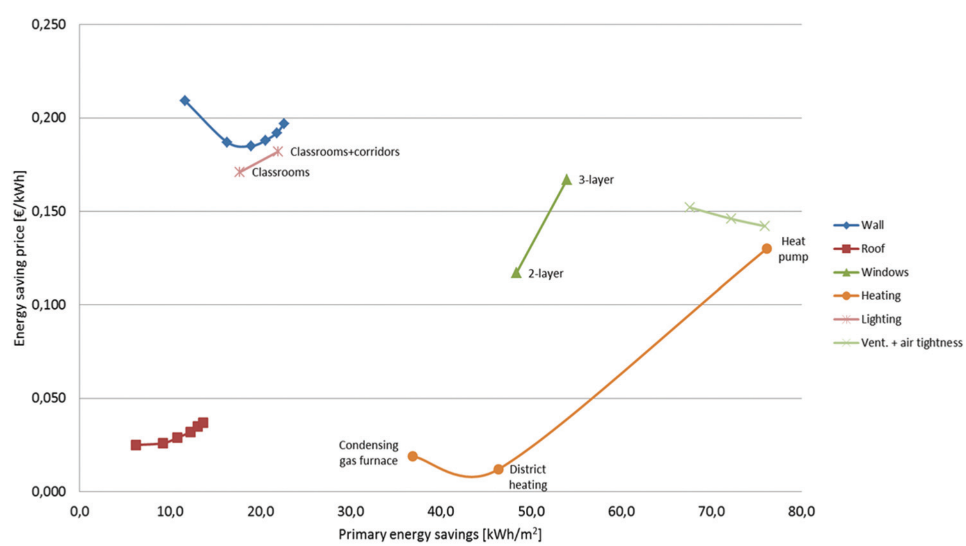

Figure 3 *Energy savings cost €/kWh for individual energy saving measures as a function of the total primary energy savings in kWh/m^2 (1 kWh/m^2 = 317 Btu/ft^2; € ≈ \$1.13, [Sept 2015]).*

Table 7. Energy Use and Economy for Renovation Packages

Scenario	Heating		Electricity		Site Energy Cost	
	kWh/m²	Btu/ft²	kWh/m²	Btu/ft²	€/year	$/year
Baseline	210.4	66432	41.5	13103	108,079	122,129
2. Minor renovation	163.1	51497	41.1	12977	91,283	103,150
3. Major renovation	70.2	22165	41.0	12945	53,058	59,956
4. NBC. Heat pump	0.0	0	46.2	14587	38,808	43,853
4a. NBC. Condensing gas	53.5	16892	27.0	8525	41,298	46,667
4b. NBC. District heating	43.7	13798	29.5	9314	38,851	43,902

Table 8. Economy for Renovation Packages (€ ≈ $1.13 [Sept 2015])

Scenario	Investment, €	NPV of Expenses, €	NPV of Energy Savings Cost, €	NPV, €	Allowable Increase in Budget for NPV = 0, €
2. Minor renovation	86,711	0	394,899	308,188	394,899
3. Major renovation	1,314.596	100,254	1,026,278	–21,504	1,293,092
4. NBC. Heat pump	1,697,207	100,254	1,508,206	–289,255	1,407,952
4a. NBC. Gas furnace	1,650,013	100,254	1,450,232	–300,035	1,349,978
4b. NBC. District heating	1,548,381	100,254	1,589,207	–59,427	1,488,954

Table 9. Energy Use for Individual Scenarios Compared to Base Case in %

Country	Bldg. Type	Climate	Site Energy				Source Energy				Heat Load			
			BL	BC	DER	Dream	BL	BC	DER	Dream	BL	BC	DER	Dream
DK	School	5A	100	81	44	18	100	84	55	37	100	78	33	15

The vertical axis in Figure 4 shows the change of cost and the horizontal axis shows the change of energy performance (both per heated area). The current state is €0/m²–0 kWh/(m²·a) position. Moving on the vertical axis down means that less money is used during a given time period and up means that more money will be used, compared to doing nothing. Moving on the horizontal axis to the left means that the energy use is smaller than now and vice versa for moving to the right.

Individual energy renovation measures in Figure 4 are presented as follows:

- Additional thermal insulation of building envelope (external wall, roof, basement ceiling [floor of the first story])
- Thermal transmittance of new windows (U-0.6 means weighed average [frame, pane, and edge of pane package]; thermal transmittance 0.6 W/m²·K of window);
- Three different ventilation systems:
    - 80%: apartment-based air-handling unit with heat recovery efficiency of 80%
    - HP: exhaust ventilation with heat pump (for domestic hot water and heating)
    - EXH: exhaust ventilation without heat recovery.

Insulating the exterior of the external wall showed the highest effect on energy and money saving. Insulation layer thicknesses over 200 mm (7.9 in.) have the largest impact on the reduction of the global cost. Replacement of windows reduced the delivered energy in all cases because of the high thermal transmittance of existing windows. The price of the

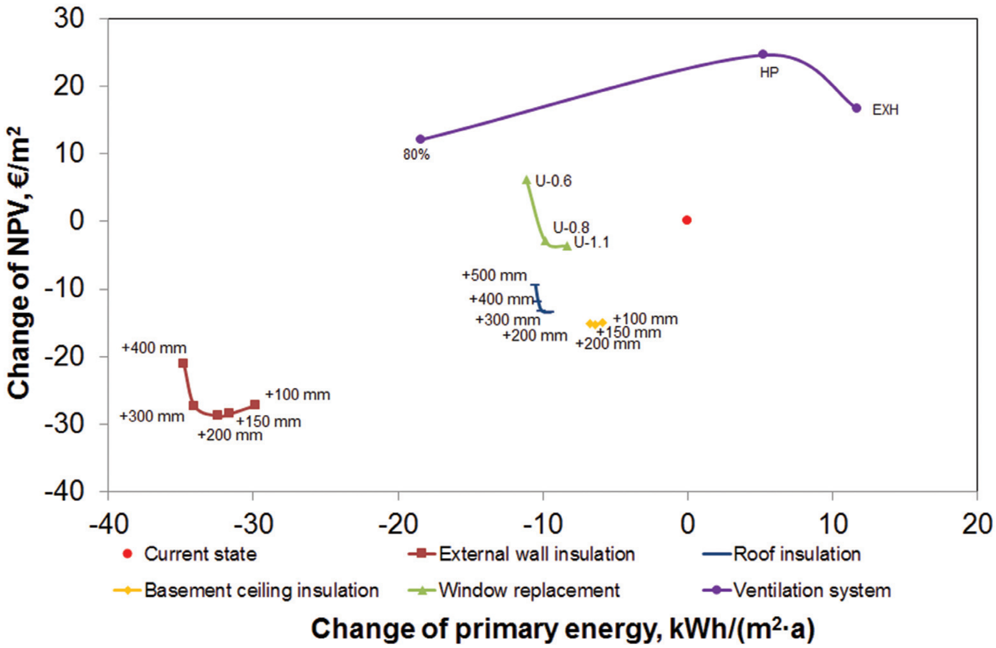

Figure 4 *The change of energy performance and NPV on different individual renovation measures (1 kWh/m² = 317 Btu/ft²; € ≈ $1.13 [Sept 2015]).*

most efficient window is, at the moment, a little expensive to be the most cost effective. The best ventilation system from an energy efficiency point of view is an apartment based on the air-handling unit with heat recovery (efficiency of ~80%). The improvement of current natural ventilation is needed anyway to improve the indoor air quality.

Packages for Energy Renovation

Energy renovation packages were made with different individual renovation measures (shown in Figure 5: different thicknesses of additional external thermal insulation, improvement of windows, ventilation system). In order to show the effect of the extent of the energy renovation measures, the renovation packages are composed with different number of individual measures (2× means two measures, 3× means three measures, etc.). Results are shown in Figure 5 (primary energy) and Figure 6 (delivered energy).

The economical optimum of energy renovation measures is around the PE 110 kWh/(m^2·a) (34,731 Btu/ft^2), which corresponds to the requirements for low-energy apartment buildings. The performance level of a low-energy building is achievable without significant increase of the current state of NPV.

Investments

Investments for reaching different energy efficiency levels are shown in Figure 7, left. Investment need for major renovation energy efficiency requirement is approximately €100 to €120/net m^2 ($1220 to $1464/ft^2), for new building level ≈ €130 to €150/net m^2 ($1587 to $1831/ft^2), and for low energy building level ≈ €160/net m^2 ($1953/ft^2). Investment needs to decrease delivered energy usage are shown in Figure 7, right. The graph is relatively linear and a 10 kWh (34,100Btu) decrease in delivered energy usage requires additional investment, approximately €8/net m^2 ($98/ft^2).

CONCLUSION

Estonia and Denmark have conducted a series of simulations in order to determine the economic conditions in the renovation of a pre-1980s building. The calculations covered three scenarios corresponding to: (1) minor renovation (i.e., the minimum requirements of building codes or similar), (2) major renovation (i.e., a 50% reduction in site energy use), and (3) advanced level (reducing the site energy use to an advanced level defined nationally).

The calculations performed for the Danish case study have shown that the extra investment necessary to move from the minor renovation to at least 50% energy savings with a net present value of 0 is €839,314 ($948,425), corresponding to €280/m^2 ($3417/ft^2). The minor renovation can be achieved with an investment of approximately €86,000 ($97,180) and reduces the site energy cost by approximately €5600 ($6328), resulting in a simple payback time of 5.2 years. The major renovation can be achieved with an investment of approximately €1,315,000 ($1,485,950) and reduces the site energy cost by approximately €55,000 ($62,150), resulting in a simple payback time of 23.9 years. And finally, an investment of more than €1,500,000 ($1,695,000) is necessary to reach the "A2010" rating and results in simple payback times of 22 to 25 years.

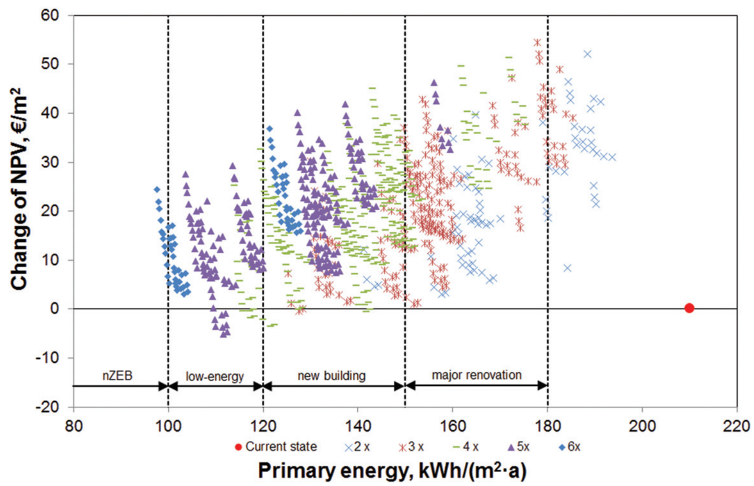

Figure 5 *The change of NPV and primary energy relative to the current state of building (1 kWh/m^2 = 317 Btu/ft²; € ≈ $1.13 [Sept 2015]).*

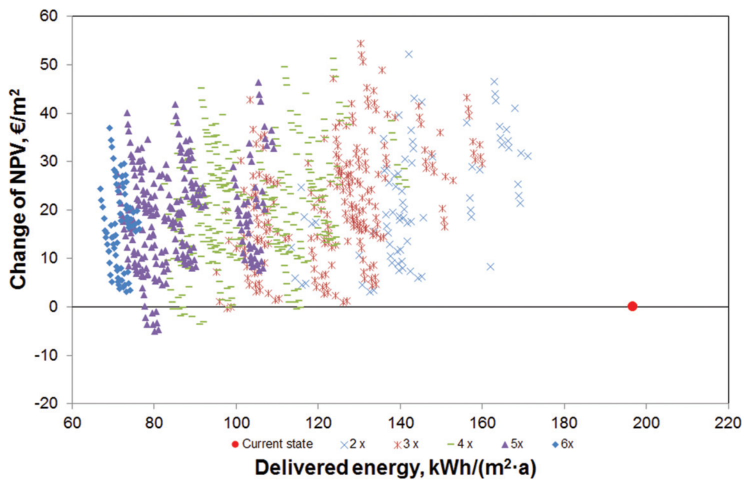

Figure 6 *The change of NPV and delivered energy relative to the current state of building (1 kWh/m^2 = 317 Btu/ft²; € ≈ $1.13 [Sept 2015]).*

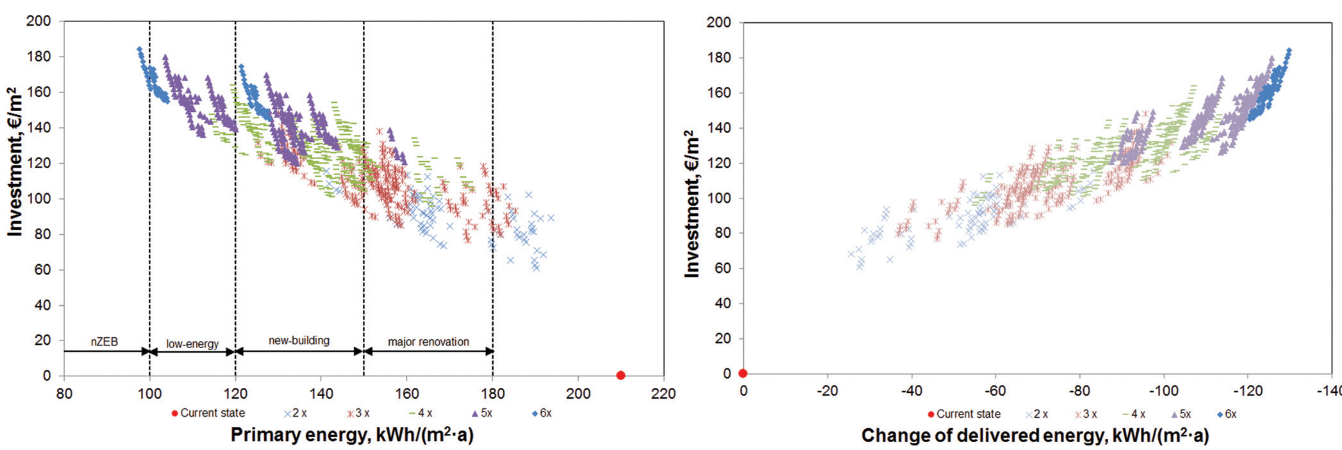

Figure 7 *Investments need for different energy efficiency requirements (left) and investment need to decrease delivered energy use (1 kWh/m^2 = 317 Btu/ft²; € ≈ $1.13 [Sept 2015]).*

The calculations performed for the Estonian case study showed that investment need for major renovation energy-efficiency requirement is approximately €120/net m^2 (\$1464/ft^2), for new building level ≈ €150/net m^2 (\$1831/ft^2), and for low energy building level ≈ €170/net m^2 (\$2075/ft^2). These prices are minimal and include only energy renovation measures. The cost-optimal level in 20 years' time for apartment building renovation was low energy building energy performance level, the investment cost of which was between €170 and €200/m^2 (\$2075 and \$2441/ft^2). Heating energy need is reduced more than 80% and delivered energy (heating energy and electricity) need is reduced more than 50%.

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