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NZEB and market-based renovation case study of an existing office building

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Abstract. The goal of decarbonizing the building stock in the EU requires a multi-fold increase of the current renovation rates. In Estonia, the non-residential building sector has had little or no public support to improve the energy efficiency. Therefore, it is essential to study the energy efficient and cost-optimal measures for non-residential building renovation to give guidance to real estate companies and other stakeholders about the renovation alternatives. Furthermore, crucial is to provide input to the government to develop the renovation grant and incentives for renovation. In this study, energy renovation measures and savings to improve the energy performance to NZEB level were identified in a large (16 990 m^2 heated area) office building. For that purpose, energy use was measured, simulation model developed and calibrated, feasible and more comprehensive energy improvements and costs analysed. The improvement of lighting, AHU, heating, installation of a 69 kW PV system, and window replacement was needed to achieve the goal with a primary energy use of 163 kWh/m^2. However, some of the applied measures had long payback times of 40-70 years and are not realistic to be implemented without renovation incentives.

1 Introduction

European Union (EU) has a goal to develop a sustainable, competitive, secure, and decarbonised energy system in EU Member States by 2050. The purpose and guidelines are brought out in the energy performance (EP) of building directive (EPBD). [1]–[3] Further steps are to develop measures that reduce the final energy use of buildings to reduce greenhouse gas emissions. Non-residential buildings account for 25% (m^2) of the total stock in Europe and office buildings are the second biggest category (23%). However, the specific energy use of non-residential buildings (covering all end-uses) is at least 40% greater than the equivalent value for the residential sector. [4], [5]

Energy use of a building is evaluated with the energy performance certificate (EPC) that indicates the EP of a building calculated by a methodology adopted in accordance with Directive 2010/31/EU [3]. In Estonia it is defined as primary energy (PE) and the limits from [6] are in **Table 1**. Regarding the standard ISO 52000-1 [7], to calculate the PE use and EPC of an existing buildings, the measured energy use can be used. However, the electricity for other uses than energy performance of buildings (non-EPB) (e.g., small power plug loads, commercial activities, elevators, industrial kitchen) should be excluded from calculation. Nevertheless, in Estonian regulation [6], [8] the appliances are included to the energy calculation. Therefore, as shown in [4] and [11], today major electricity uses in the office are not necessarily considered by long-term renovation strategies.

Estonian long-term renovation strategy states that today the annual PE use is 225-270 kWh/m^2 (delivered heating 130 kWh/m^2 and electricity 70 kWh/m^2) in office buildings constructed before 2000. However, to achieve the major renovation NZEB level (class C in **Table 1**), the PE for an office building should be 136-160 kWh/m^2 (delivered heating 70 kWh/m^2, electricity 45 kWh/m^2). Unfortunately, today building stock has several barriers that prevent to achieve the NZEB level renovation. One main barrier is the long, 20-30 year payback time of NZEB renovation, as real estate companies prefer the payback time around 10 years. [9]

Table 1. Primary energy limits of Energy Performance Certificate level in Estonia (EPBD scope without appliances)

Class	Office, kWh/m^2	Office EPBD scope, kWh/m^2
A[1]	100	62
B	130	92
C[2]	160	122
D	210	172
E	260	222

[1]NZEB for a new building
[2]NZEB for major renovation

This study is a continuation and clarification of the article [9], that has contributed to Estonian long-term renovation strategy [11]. The idea is to give an overview of the measured energy consumption and analyse the energy renovation measures to improve the energy performance of NZEB major renovation in office buildings.

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2 Methods and materials

2.1 Reference building measured energy use

The reference building (**Figure 1**) is actively used, well maintained, and with good ventilation system 5 storey office building with heated area 16 990 m^2 built in 2008. The construction has a deep foundation and non-loadbearing exterior walls (EW) (wood frame with mineral wool thickness 0,15-0,18 m), external floor (EF) towards ambient air (concrete panel with wood frames and insulation thickness 0,25 m), EF towards the ground (concrete floor with insulation in perimeter), roof (load-bearing profile plate and mineral wool plates or concrete panel with 0,18 m mineral wool and 0,05 m EPS 65F). Building has an uncommon shape and WWR about 50%. We consider that the reference building has 3 elevators (one for each building section). On the first floor, the trade areas and canteen (respectively, 10% and 3% of the total area) are located, and the other floors are for offices (about 83% of the total area) and health care (5% of the total area). Heat supply comes from the local natural gas substation and electricity from the power grid.

Figure 1. Reference office building built in 2008 (AU Energiateenus)

We collected the delivered energy of the reference building from the energy invoices measured by the main energy meters (look in **Figure 2**). Measured total delivered heating energy was 104 kWh/m^2 and electricity 126 kWh/m^2 (non-EPB included). Specific services were not measured, but assumed by calculations and other studies. Domestic cold water use was measured and the domestic hot water (DHW) percentage of this was assumed to be 40%. Using this data, the DHW use was calculated by Equation 1:

$$Q_{DHW} = m \times C_p \times \rho \times \frac{\Delta T}{3600} \quad (1)$$

Where

E: energy, kWh
m: the mass of water, l
Cp: specific heat of water, kJ/kg °C
ΔT: temperature difference, °C
ρ - density of water in 50 °C

DHW use was separated from heating energy use and the last one was weather normalized with degree day method. **Table 2** shows the monthly weather normalized heating energy, domestic hot water (DHW) heating, and electricity energy use in the reference building in the years 2012-2014.

Table 2. Actual measured weather normalized energy use in the reference building

	Space and ventilation heat, kWh/m^2			DHW, kWh/m^2			Electricity, kWh/m^2		
Year / Month	2012	2013	2014	2012	2013	2014	2012	2013	2014
Jan	16.6	15.6	14.7	0.60	0.56	0.51	12.9	9.92	9.36
Feb	13.7	13.3	15.2	0.52	0.48	0.47	11.0	8.77	8.75
Mar	11.3	11.6	12.1	0.57	0.46	0.89	11.5	8.61	9.33
Apr	7.94	7.93	8.01	0.53	0.50	0.53	10.9	8.75	9.75
May	5.02	3.77	4.28	0.59	0.59	0.56	11.5	9.77	11.2
Jun	2.11	2.78	2.04	0.54	0.50	0.67	11.6	10.1	11.0
Jul	2.78	1.68	3.01	0.43	0.59	0.58	10.8	10.8	13.7
Aug	2.03	2.00	2.27	0.47	0.42	0.58	10.6	12.1	12.5
Sep	4.61	4.96	4.92	0.57	0.50	0.57	9.8	11.2	11.4
Oct	6.92	8.23	7.42	0.49	0.55	0.76	11.1	10.8	11.1
Nov	10.9	12.1	11.0	0.55	0.50	0.59	9.7	10.0	9.9
Dec	12.2	16.0	14.8	0.42	0.52	0.61	9.0	9.6	10.0

The specific electricity for non-EPB use (**Figure 2**) has been estimated by further calculations. Cooling electricity and plug load electricity for the server room has been calculated by the installed power of fan coils in server room. This building has 18 electrical service or server rooms that are cooled by fan coils with different cooling power: 1 kW to 4 kW. The sum of fan coil cooling power is about 61 kW and it was assumed that the servers will work every day all over the year (8760h). Annual cooling power is about 31 kWh/m^2. The SEER of chiller has been taken 3.5 and therefore, the electricity use is 9 kWh/m^2. Outdoor lighting is fluorescent lights with bulb power 58 W. As there are about 25 lights, the annual electricity energy for outdoor lighting was 6.2 MWh (0.36 kWh/m^2). The electricity of the 3 lifts was about 13 kWh/m^2, estimated by the study [12].

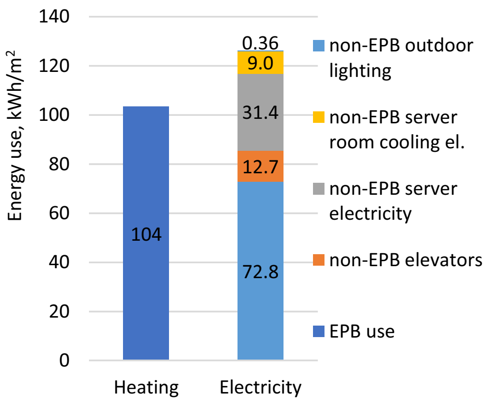


Figure 2. Energy use in the reference building

2.2 Energy simulation model

For further analyses, there was built an energy simulation model (further as the base model) of the reference building (**Figure 3**) in the energy and indoor climate simulation program IDA Indoor Climate and Energy 4.8 (IDA-ICE) by using project documentation and energy audit information. The test reference year of Estonia was used [13].

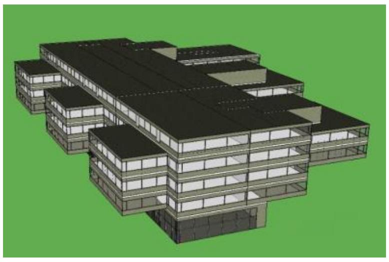


Figure 3. IDA-ICE model of the reference building

Table 3 represents the input data of the base model.

In the calculation of heating energy use, the generation and distribution were considered with heat source efficiency factor and efficiency factor of the distribution and output of radiator (
Table 3). For cooling calculation, there was taken into account also the heat loss coefficient and Eq. 2 was used from [8].

$$Q_j = (1 + \beta_{je})Q_{je}(1 + \beta_{rs})Q_{rs} \quad (2)$$

where

Q_{je} - annual net energy of AHU cooling elements kWh;
Q_{rs} - annual net energy of zone units kWh;
β_{je} – the energy loss associated with AHU cooling elements
β_{rs} - the energy loss of cooling energy distribution to zone

Base model imitates the real performance of the reference building and has occupancy, appliances, lighting, and AHU schedules according to real use (in Appendix 1, **Figure 9-Figure 14**).

Finally, the delivered energy has been correlated with primary energy factors as for natural gas 1.0 and for electricity 2.0 to calculate the PE.

Table 3. Input data of the base model and for energy use calculations

Occupants. m^2 per occupant	17
Equipment. W/m^2 (average, office/trade)	12/1
Lightning. W/m^2 (average, office/trade)	10/12
Temperature setpoint for heating. °C	21
Temperature setpoint for cooling. °C	24
Air flow rate. l/(s m^2) (average)	1.7
Heating system (radiators) efficiency. -	0.97
Heat source (gas) efficiency. -	0.95
AHU fans SFP kW/(m^3/s)	1.1-1.9
SEER of chiller. -	3.5
Ventilation heat exchanger efficiency, -	0.7/0.4
Annual DHW consumption. l/m^2	103
Average U-value of model, W/(m^{2}K)	0.38
SFP - specific fan power.	

2.3 Calibration method of energy simulation model

Energy simulation model has been calibrated with the corresponding and normalized energy use of the reference building (**Table 2**), both data for year 2014.

The calibration was done and the modelling uncertainty was controlled by the coefficient of variation of root mean square error (CV(RMSE)) Eq. 3, (regarding to ASHRAE Guideline [14]) which indicates the uncertainty inherent in the model and the computer model shall have a CV(RMSE) of 15% relative to the monthly calibration data. Results are in **Table 4**.

$$CVRMSE = 100 \times \left[\sum (y_i - \hat{y}_i)^2/(n-p)\right]^{1/2}/\bar{y} \quad (3)$$

The energy performance simulation in standard condition was done to calculate the energy performance certificate (EPC) and clarify whether the measures achieve the level of NZEB major renovation. The base model according to standard conditions uses the schedule in Appendix 1, **Figure 9**, every zone for occupancy, appliances and lighting (except in the trade area, where the lighting and appliances schedule is 0.55 at 7-21:00). The AHU works in full capacity from 6:00 to 19:00 and outside these hours is set to work 7.5% of the total capacity.

2.4 Improvement of energy performance

Several energy saving measures have already been implemented in this building. However, the improvement of automatics, rebuilding of the cooling system, improvement of free cooling of ventilation and cooling system did not achieve the NZEB level of this building regarding to energy audit. Furthermore, there has been constructed the combined heat and power (CHP) station and the photovoltaic (PV) panel system. Arithmetical calculation shows that these savings will achieve the C-level of this building, but needs further detailed investigation.

Table 4. Calibrated data and uncertainty of energy simulation model (measured and simulated results are for year 2014)

Measured, kWh/m^2		Simulated, kWh/m^2		RMSE		NMBE	
Heat.	Electr.	Heat.	Electr.	Heat.	Electr.	Heat.	Electr.
15.2	4.82	15.5	6.06	0.09	1.54	-0.30	-1.24
15.7	4.65	15.1	5.33	0.37	0.47	0.61	-0.68
13.0	4.80	11.9	5.77	1.10	0.95	1.05	-0.97
8.54	5.36	8.11	5.91	0.18	0.30	0.43	-0.55
4.84	6.63	5.80	6.61	0.92	0.00	-0.96	0.02
2.71	6.57	3.45	6.55	0.55	0.00	-0.74	0.01
3.59	9.12	1.41	8.32	4.76	0.64	2.18	0.80
2.85	7.97	2.50	7.04	0.12	0.87	0.35	0.93
5.48	6.98	3.74	6.05	3.05	0.88	1.75	0.94
8.17	6.59	7.79	6.09	0.15	0.24	0.39	0.49
11.6	5.48	12.8	5.48	1.41	0.00	-1.19	0.00
15.4	5.43	15.2	6.06	0.05	0.39	0.21	-0.62
			CV>	**12%**	**12%**	**3.8%**	**-0.9%**

This study was considering different measures to increase the energy use and achieve the C-level of the reference building. Several measures were selected by the suggestion of energy audits, the knowledge of the authors, and measures earlier studied in [9] were improved.

The measures were added to the base model individually (method described in **Figure 4**) and the saving of every measure has been calculated with the energy simulation software IDA-ICE 4.8.

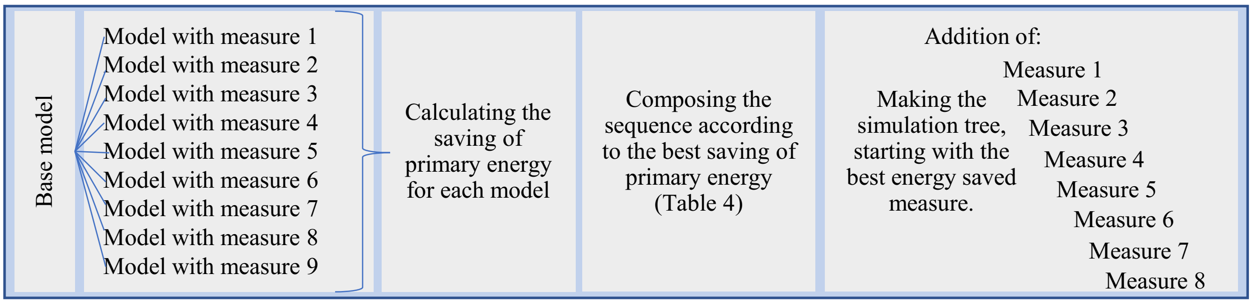


Figure 4. Methodology to compose the energy saving packages

Furthermore, the sequence of measures regarding the best saving of primary energy was composed and the models with measure packages were composed by adding each measure one by one to the model, so each package had one measure more than previous.

The costal savings and investment of each measure was estimated by calculations with data from project documentation and energy audits, and the experience of the authors of this study. The energy price has been taken from energy invoices in the years 2017-2018 as 0.031 €/kWh and 0.072 €/kWh, respectively, natural gas and electricity.

3 Results and discussion

Specific energy use for heating and electricity of the base model has brought out in **Figure 5**. The calculation of real use resulted the energy use of 113 kWh/m² and 75 kWh/m², respectively, for heating and electricity. This achieves the PE of 263 kWh/m². The calculation of standard use gives the heating energy 89 kWh/m² and electricity energy 56 kWh/m² that resulted PE 201 kWh/m² (D-level).

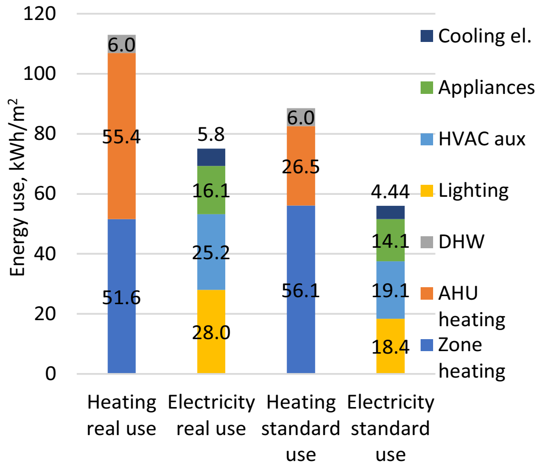
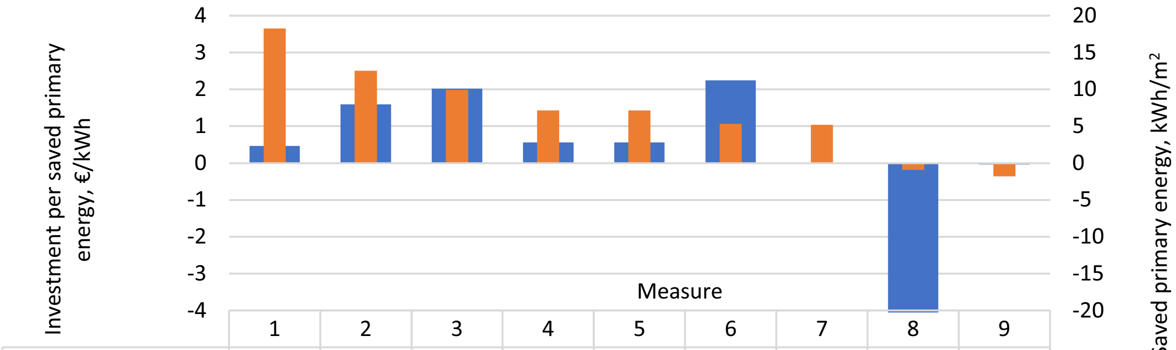


Figure 5. Heating and electricity use of the base model

Table 5. Individual measures implemented in the base model (the sequence is according to the highest saving in primary energy)

No	Measure description	Parameters: Base model	Parameters: After	Delivered energy savings kWh/m²: Electr.	Delivered energy savings kWh/m²: Heat.	Annual costal savings, €/m²: Electr.	Annual costal savings, €/m²: Heat.	Invest-ment, €/m²	Saved PE, kWh/m²	€ per saved PE, €/kWh	Pay-back time, y
1	Improving the lighting	In trade area 12 W/m², office 10 W/m²	In trade area 12 W/m², in office 6 W/m²	11.4	-4.45	0.82	-0.14	8.52	18.3	0.47	12.5
2	Improvement of AHU fans SFP	SFP = 1.098-1.93 kW/(m³/s)	SFP = 1-1.7 kW/(m³/s)	6.25	0.01	0.45	0.00	20.0	12.5	1.60	44.4
3	Improvement of AHU heat exchanger	Efficiency: rotated hex. 70%; coil hex. 40%	Efficiency: rotated hex. 80%; coil hex. 60%	0.08	9.74	0.01	0.30	20.0	9.91	2.02	65.0
4	Adding the cooling effect to AHU heat exchanger	Heat exchanger is not working between 14 May and 31 August	Heat exchanger is working all the time	0.11	6.92	0.01	0.21	4.0	7.13	0.56	18.0
5	Change of canteens AHU ventilation control	CAV	VAV with CO_2 control and setpoints min 700, max 800	1.50	4.15	0.11	0.13	4.0	7.16	0.56	16.9
6	Changing the windows from 2-layer to 3-layer windows with better sun protection	Pilkington Suncool 66/33 (6C(66)-15Ar-4): g0.36, T0.33, T_{vis}0.66, U1.1	Pilkington Suncool 40/22 (6C(40)-15Ar-4-15Ar-S(3)4): g0.2, T0.17, T_{vis}0.36, U0.6	0.75	3.84	0.05	0.12	12.0	5.34	2.24	69.3
7	Night setback of indoor temperature	constant 21°C	6-20:00 set to 21°C; Other time set to 19°C	0.20	4.78	0.01	0.15	0.06	5.18	0.01	0.39
8	Sun protection film improving the windows shading	Shading parameters: g0.36, T0.33	Shading parameters: g0.20, T0.13	0.73	-2.41	0.05	-0.07	6.33	-0.94	-6.70	NA
9	Improvement of free cooling function [1]	Tamb <11°C Tsupply = 18°C; Tamb >11°C Tsupply = 16°C	Tamb <15°C Tsupply = 18°C; Tamb >15°C Tsupply = 16°C	-0.33	-1.14	-0.02	-0.04	0.06	-1.80	-0.04	NA
10	PV panels installation	No PV system	Installation of 230 panels with system power 69 kW	3.28	0	0.24	0.00	5.62	6.6	0.86	23.8

[1] Setpoint of supply air temperature (T_{supply}) was adjusted by ambient temperature (T_{amb})



	1	2	3	4	5	6	7	8	9
€ per saved PE kWh	0.47	1.60	2.02	0.56	0.56	2.24	0.01	-6.70	-0.04
Saved PE, kWh/m2	18.3	12.5	9.91	7.13	7.16	5.34	5.18	-0.94	-1.80

Figure 6. The investment and saved primary energy of individual measures

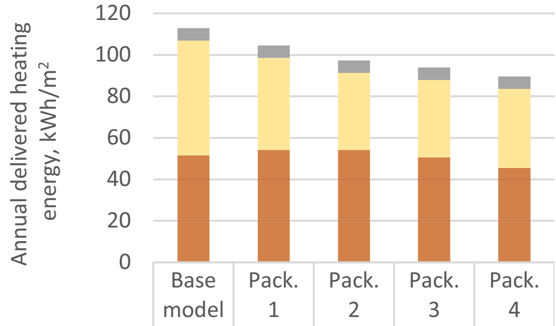
Furthermore, several renovation measures in **Table 5** were implemented in the base model and the energy savings were identified. The highest saving in primary energy was achieved by replacing the fluorescent lighting with LED – 18.6 kWh/m^2 annually. That was also the cheapest measure with 0.47 €/kWh saved primary energy and the shortest 12.5-year payback time. Measures 2 and 3 have bigger investment, because the improvement of AHU fans or heat exchanger separately still needs a replacement of the entire air handling unit that costs about 20 €/m^2. The payback time will be 26 years, if the measures are made together (AHU replaced with unit with better fans SFP and heat exchanger temperature efficiency). From **Figure 6** we can see that measures like sun protection film and improvement of free cooling function were less worth measures and in further analyses they are not involved. The installation of the PV-panel system was an additional measure to achieve NZEB level.

The energy simulations were done with the base model and models with the four following packages (pack.) with similar payback time:

- Package 1 – measures 1-4: pay-back time 32 years
- Package 2 – measures 1-5: pay-back time 30 years
- Package 3 – measures 1-6: pay-back time 34 years
- Package 4 – measures 1-7: pay-back time 32 years

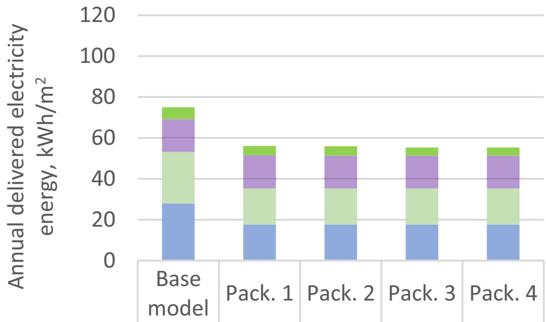
PV-panel (measure no 10) was later added to all packages. Previously mentioned, the base model had standard use PE 200 kWh/m^2 and EPC label D. Package 1 improved the electricity and heating energy considerably (**Figure 7-Figure 8**) - respectively, 19 kWh/m^2 and 8.4 kWh/m^2. However, the standard use PE is 173 kWh/m^2 that stays in EPC D-level. Further packages did not improve the electricity performance, but reduced the heating energy use considerably. Adding measure 5, the canteen AHU control with CO_2 sensors (package 2) reduced the heating energy for 7.2 kWh/m^2 and resulted the standard use PE 165 kWh/m^2, that is close to NZEB level. With package 3, after replacing the windows, the heating energy reduces for 3.5 kWh/m^2 and resulted in NZEB level with standard PE use 160 kWh/m^2. Using the night setback of indoor temperature in addition to previous measures (package 4) saved the heating energy for 4.3 kWh/m^2 and gave good PE use even without PV-panels - 163 kWh/m^2. Nevertheless, to achieve NZEB major renovation, the installation of PV panel system is essential.

The payback time of individual measures is high and will be over 40 years for half of measures. However, if measures are made as packages, the payback time is smaller, but still in between 30-34 years. Furthermore, replacing the window change measure with the night setback measure will reduce the investment of package 3, but the pay-back time will be still about 28 years.



	Base model	Pack. 1	Pack. 2	Pack. 3	Pack. 4
DHW	6.0	6.0	6.0	6.0	6.0
AHU heating	55.4	44.5	37.2	37.2	38.1
Zone heating	51.6	54.1	54.1	50.6	45.5

Figure 7. Annual delivered real heating energy for the base model and models with different renovation packages



	Base model	Pack. 1	Pack. 2	Pack. 3	Pack. 4
Cooling el.	5.8	4.5	4.5	3.9	3.9
Equipment	16.1	16.1	16.1	16.1	16.1
HVAC aux	25.2	17.7	17.7	17.7	17.7
Lighting	28.0	17.7	17.7	17.7	17.7

Figure 8. Annual delivered real electricity energy for the base model and models with different renovation packages

4 Conclusion

Analyse of energy efficiency and cost-optimal measures for non-residential building renovation is essential to achieve the goal and decrease greenhouse gas emissions. Therefore, this study focused on energy performance and renovation measures, citing one larger office building as an example. The measured energy consumption, the calibration method of energy simulation with energy consumption of the existing office building, and identification of energy renovation measures were the tools to discover the improvement of the energy performance to NZEB level of major renovation.

The cheapest measure, changing the lighting improved the electricity energy performance significantly and therefore, saved the primary energy for 18.6 kWh/m^2. In general, the majority of measures were with good primary energy saving (5-18 kWh/m^2), but at the same time with long payback time for real estate companies – over 16 years, and even will reach over 60 years. Using the measures together in renovation packages reduced the payback time to 30 years, that is still not suitable for real estate companies.

Authors found that replacing fluorescent lighting to LED, upgrading the AHU with a better performance unit, and improving the automatics, using night setback for heating and replacing windows will result the primary energy use close to the NZEB as 163 kWh/m^2. However, to reach this goal, the 69 kW photovoltaic panel system is needed.

The replacing of the windows in an office building is a big investment measure and will be under serious consideration, is it needed or not. Calculations show that replacing the window change measure with the night setback measure will result the PE use 161 kWh/m^2, that is almost NZEB level, but it needs further investigation with some more case studies.

The limitation of this study is the calibration method, as the measured data has been weather normalized, but the simulation were done with test reference year. Further studies need to be done to investigate the impact of this difference and to develop the calibration methodology.

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References

[1] THE EUROPEAN PARLIAMENT AND THE COUNCIL, “DIRECTIVE (EU) 2018/844,” 2018. doi: 10.1007/3-540-47891-4_10.

[2] The European Comission, “Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency,” no. November 2010, pp. 1–56, 2012.

[3] European Union, “Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings,” 2010.

[4] BPIE, *Europe ’ s buildings under the microscope, Buildings Performance Institute Europe*. 2011.

[5] M. Hinnells, “Technologies to achieve demand reduction and microgeneration in buildings,” *Energy Policy*, vol. 36, no. 12, pp. 4427–4433, 2008, doi: 10.1016/j.enpol.2008.09.029.

[6] Estonian Government’s Ordinance, “Minimum requirements for energy audit - (Energiaauditi miinimumnõuded),” 2016. https://www.riigiteataja.ee/akt/123122016003?leiaKehtiv (accessed Dec. 15, 2020).

[7] ISO, “EN ISO 52000-1:2017,” 2017.

[8] Estonian Government’s Ordinance, “Methodology for calculating the energy performance of buildings,” *Riigi Teataja*, 2019. https://www.riigiteataja.ee/en/eli/520102014002/consolide (accessed Aug. 20, 2020).

[9] H. Kuivjõgi, A. Uutar, K. Kuusk, M. Thalfeldt, and J. Kurnitski, “Market based renovation solutions in non-residential buildings – why commercial buildings are not renovated to NZEB,” 2021.

[10] SINTEF, “LECO - Energibruk i fem kontorbygg i Norge (LECO - Energy use in five office buildings in Norway),” Oslo, 2009.

[11] Ministry of Economics, “Long-Term Strategy for Building Renovation (Estonia),” 2020. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/2014_article4_en_latvia.pdf.

[12] P. Bannister, C. Bloomfield, and H. Chen, “Empirical prediction of office building lift energy consumption,” *Proc. Build. Simul. 2011 12th Conf. Int. Build. Perform. Simul. Assoc.*, pp. 2635–2642, 2011.

[13] T. Kalamees and J. Kurnitski, “Estonian test reference year for energy calculations,” no. January, pp. 40–58, 2006.

[14] ANSI/ASHRAE, “ASHRAE Guideline 14-2002 Measurement of Energy and Demand Savings,” *Ashrae*, vol. 8400, p. 170, 2002.

https://doi.org/10.1051/e3sconf/202124605002

Appendix 1

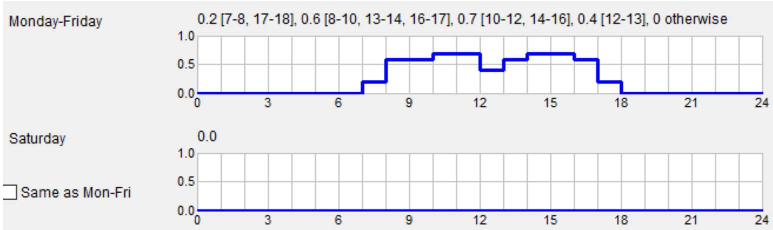

Figure 9. Schedule for occupants, equipment and lighting

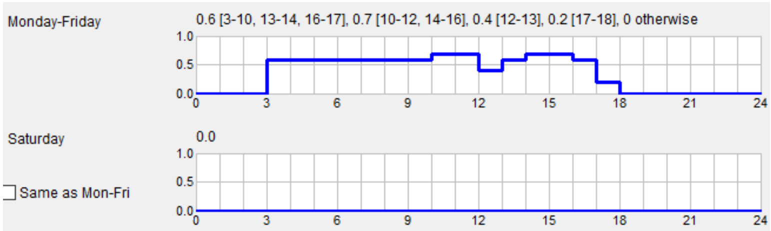

Figure 10. Schedule for C-building occupants, equipment and offices

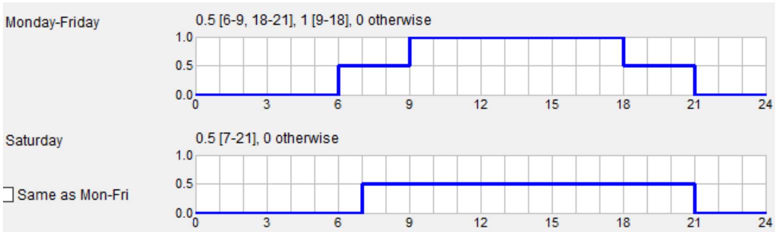

Figure 11. Schedule for AHU1

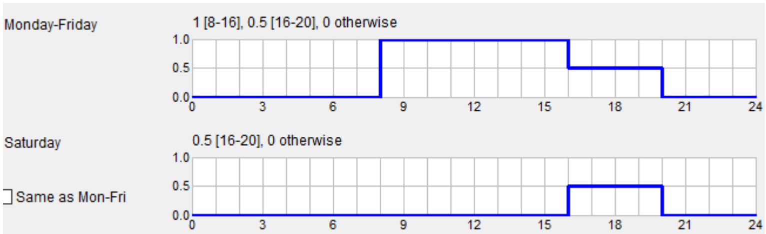

Figure 12. Schedule for AHU2 (canteen)

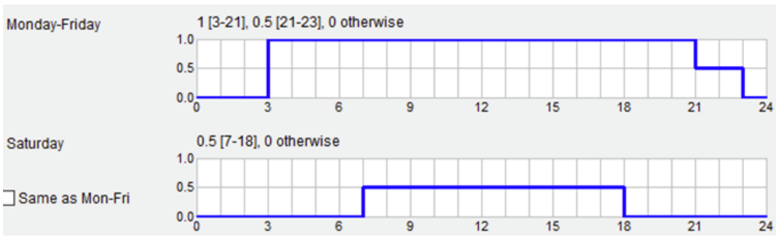

Figure 13. Schedule for AHU3 (C-building)

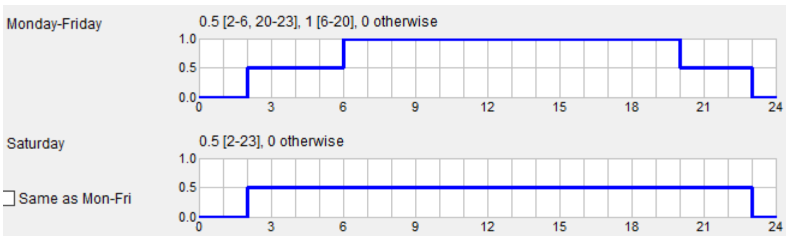

Figure 14. Schedule for AHU4