Effects of different techno-economic regimes on viability of deep energy renovation of an existing Swedish multi-family building

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We investigate the cost-effectiveness of energy efficiency measures for a typical multi-story building from the Swedish Million Housing program

- Concrete building built in 1972
- Located in Ronneby, South of Sweden
- Three-story above ground and a basement
- 27 apartments
- 2000m^2 total heated living area
- 5400 m^3 ventilated volume
- District heated

The building, owned by Ronnebyhus, is good conditions, located in popular housing area, with a remaining lifetime of at least 50 years

Building constructed after the Swedish Building Code of 1967 – Thermal characteristics

Building elements	Components	U-value (W/m^2K)
Windows	_	2.9
Doors	_	3.0
Attic floor (initial state)	160mm concrete + 120mm rock wool	0.285
Attic floor (current state)	160mm concrete + 350mm rock wool	0.082
Slab of the first floor	190mm concrete + 70mm wood-fibre wool panel	0.823
East / West façade: Brick façade	120mm brick + 20mm air gap + 30mm polystyrene + 70mm rock wool + 13mm gypsum plaster	0.337
South/North façade: Brick façade	120mm brick + 20mm air gap + 100mm rock wool + 150mm concrete + 13mm gypsum panel	0.331
Wooden cladding (east/west)	10mm wooden cladding + 20mm polystyrene + 100mm rock wool + 13mm gypsum panel	0.301
Basement walls: East/West	15mm cement plaster + 50mm Leca cement bond + 150mm concrete	1.44
Basement walls: North/South	15mm cement plaster + 50mm Leca cement bond + 250mm concrete	1.33
Slab on ground	230mm concrete	0.26

Cost-effectiveness criteria

Net present value (NPV) of energy savings ≥ investment cost

Single measures

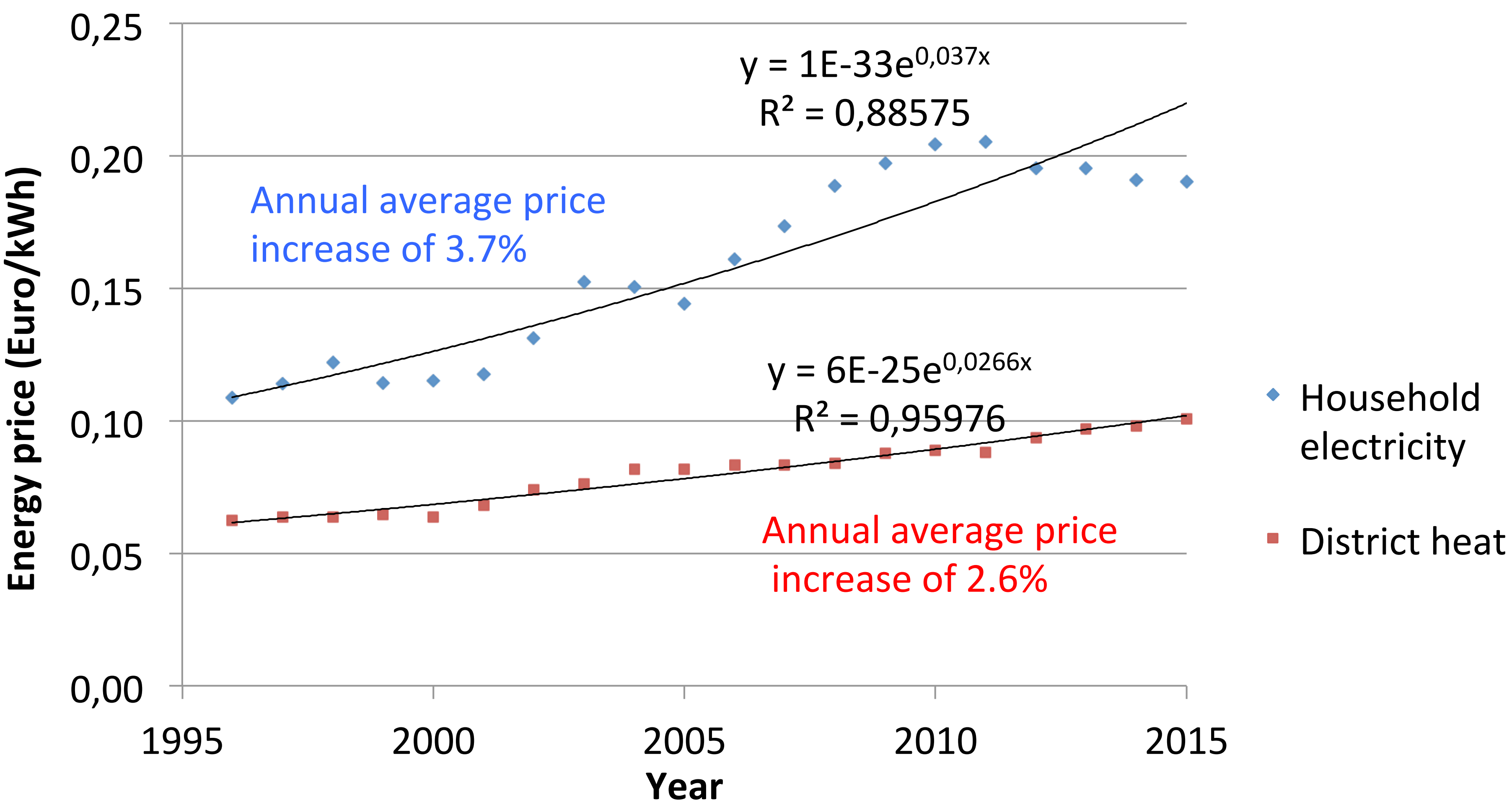
Total savings and investment	and	**Marginal** savings and investment

Package of measures applied in order of cost efficiency

Key parameters in cost-analysis of energy renovation measures

- Electricity and heat price development
- Discount rate
- Investment cost considering maintenance need
- Service life of measures
- Final energy savings of measures

Energy prices for Swedish households in 2016 price level



Source: Swedish Energy Agency, Energiläget i siffror 2017 (In English: Energy in Sweden—Facts and Figures 2017).

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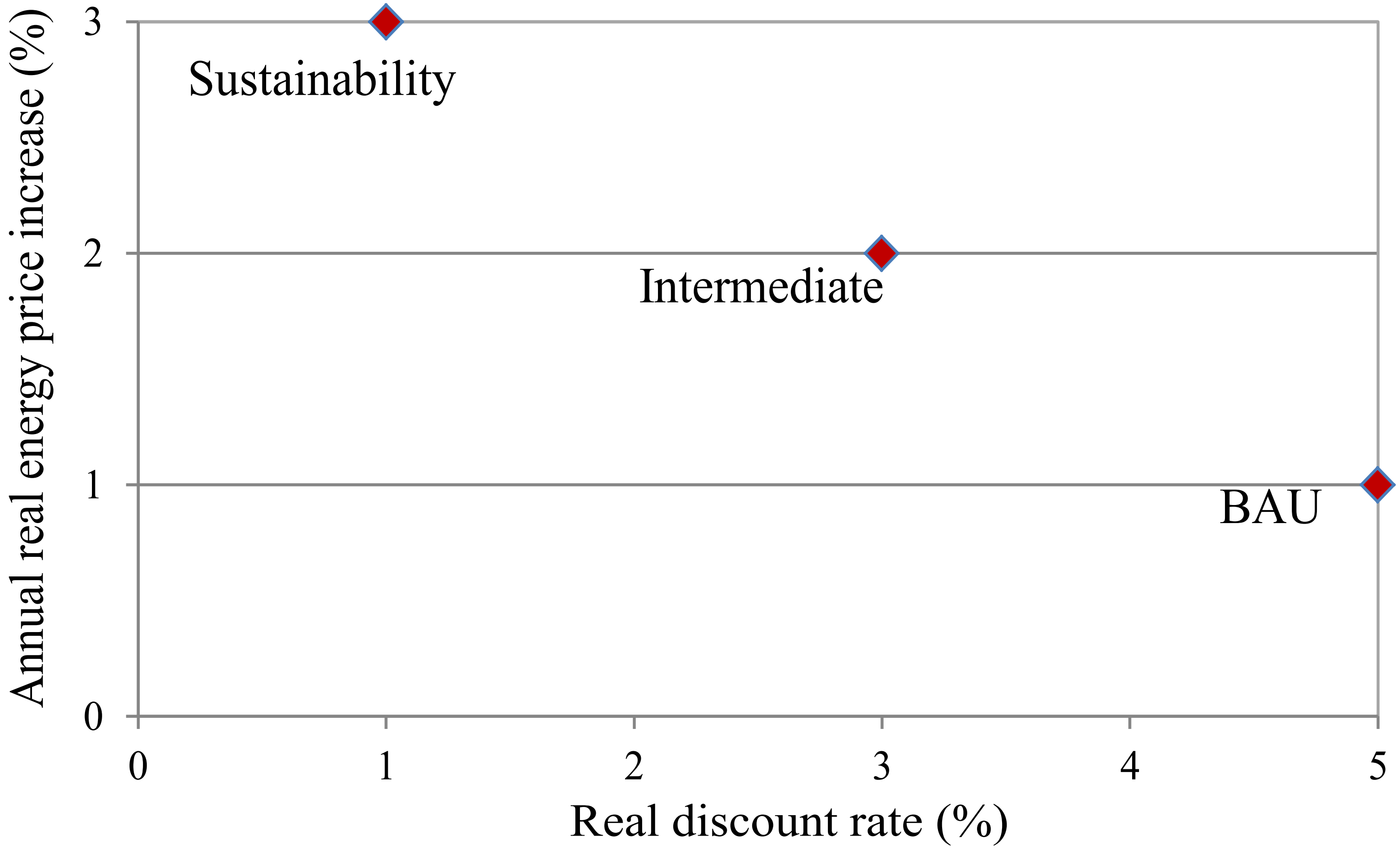
Economic scenarios in real terms



Economic value of energy and water savings based on 2015 tariffs for Ronneby municipality except for energy part of electricity that is based on 2015 Swedish average price

District heat	Price
Fixed charge (€/year)	2990.1
Energy price (€/kWh)	0.08
Capacity cost (€/kW)	0
Flow / pumping cost (€/m³)	0

Electricity	Price
Energy	
Fixed fee (€/ year)	894.5
Variable fees (€/ kWh)	0.095
Network	
Fixed fee (€/ year)	0
Variable fees (€/ kWh)	0.025

Cold water	Price
Cost (€/m³)	2.87

Energy renovation measures analysed and assumed lifetime

Energy renovation measure	Range	Lifetime
Extra insulation to:		
Attic	50 to 500 mm mineral wool insulation	50 years
Basement walls	50 to 350 mm styrofoam insulation panels	50 years
Exterior walls	45 to 510 mm mineral wool insulation	50 years
New improved windows	1.5 to 0.7 W/m^2 K U-value	50 years
New improved taps	Faucets based on best available technologies	200 months
Efficient appliances and lighting	Best available technologies	200 months
Ventilation heat recovery system	Based on Central or semi-centralized air handing units(AHUs)	50 years for ducts/ 25 years for AHU

Building's condition and need of maintenance

- Building's structure and existing façades are in good physical condition
- Exterior walls have insulation with thicknesses of 95 to 120 mm
- Existing windows generally require some repairs and maintenance - have not been replaced since the building was constructed
- Reinforced concrete basement walls have no insulation
- Air supply problems for the existing ventilation system - slots are created in the exterior walls around the radiators to augment supply of fresh air
- Attic insulation was increased from 120 mm to 350mm in a renovation in 2010 but still space for more insulation

Calculations of investment cost for renovations

Swedish building renovation works tariff for 2015/2016

Calculations of final energy savings

Hour-by-hour energy balance modeling with VIP+ for the whole building before and after applying energy efficiency measures

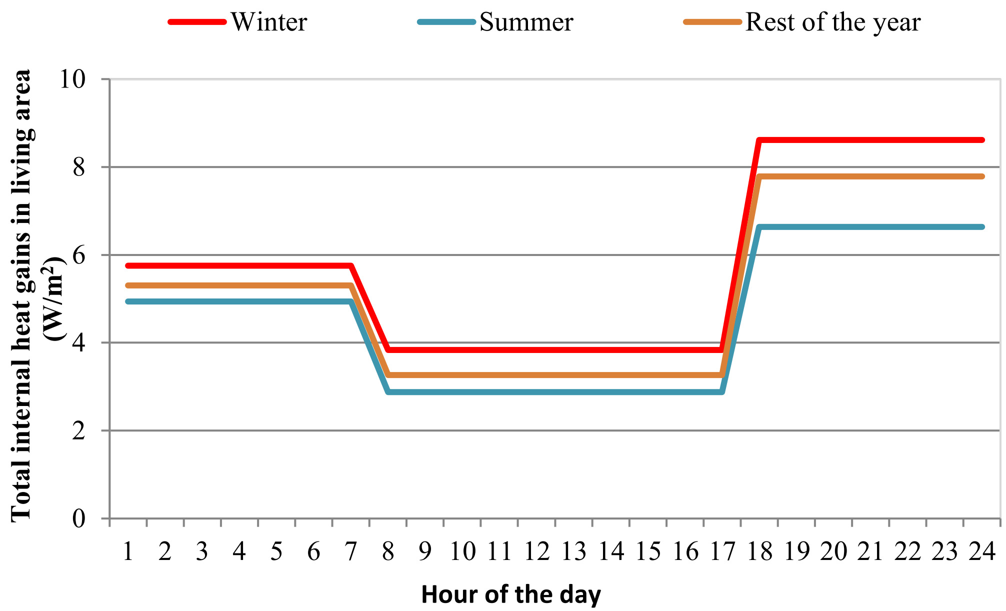
Key data and assumptions

Parameter	Data / description	Remark
Weather data	Ronneby (2013)	Meteonorm
Indoor temperature in apartments*	22 ºC	Based on measurements. Reduced to 21ºC when new improved windows are applied
Ventilation rate	0.1 and 0.35 l /s m^2	
Ventilation system	Mechanical exhaust	
Airtightness at 50 Pa	0.8 l /m^2s	Assumed based on construction data

*Based on measurements

Ref: Dodoo, A., Tettey U.Y.A. and L. Gustavsson, (2017). On input parameters, methods and assumptions for energy balance and retrofit analyses for residential buildings. Energy and Buildings. 137. 76-89.

Heat gain assumptions

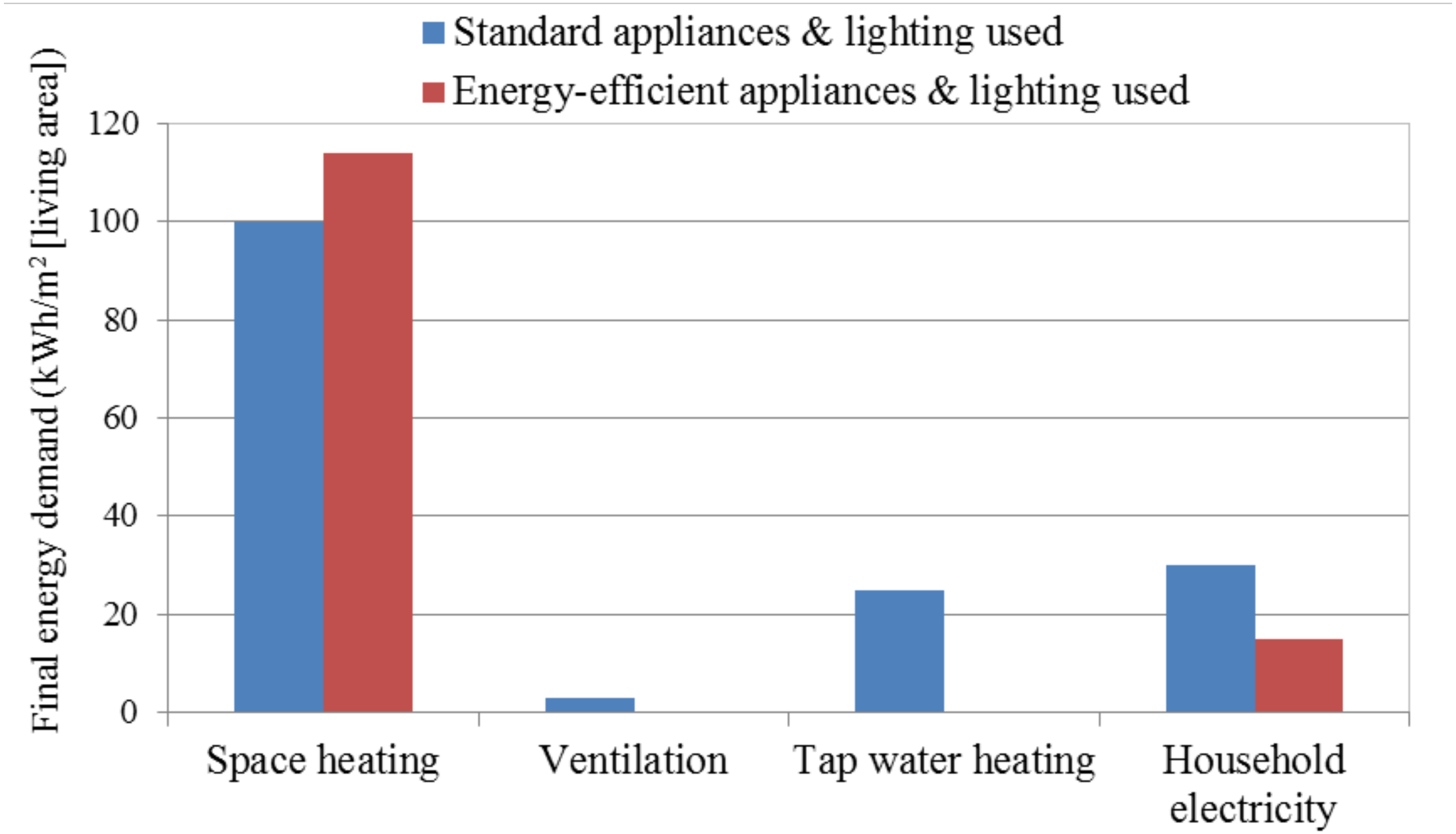


Total heat gain (from persons, electric appliances & lighting and hot water circulation) profile for an average day in different seasons

Parameter	Data / description	Remark
Persons	80 W/ person	Recommendation by SVEBY. Variable profile modelled
Electric appliances & lighting	Variable profile modelled	Calculated with bottom-up model Variable profile modelled
Sun	Based on weather file	Calculated hourly by VIP+
Hot water circulation	Variable profile modelled	Calculated with bottom-up model

Ref: Dodoo, A., Tettey U.Y.A. and L. Gustavsson, (2017). Influence of simulation assumptions and input parameters on energy balance calculations of residential buildings. Energy, 120, 1:718–730

Annual energy balance of existing building



Implications of different appliances and lighting – final energy savings and investment costs

Efficient appliances and lighting	Household electricity use (MWh/ year)	Electricity savings (MWh / year)	Increased space heat use (MWh / year)	Total investment cost (k€)
Reference	59.8	-	-	-
Non-tenants owned:				
Clothes dryer	58.3	1.5	0.8	3.3
Dishwasher	58.6	1.2	0.2	4.4
Freezer	54.8	5.0	2.5	3.9
Lights (Facility)	59.1	0.7	0.04	0.2
Oven/cooker	58.2	1.6	0.6	9.4
Refrigerator	57.9	1.9	0.9	3.9
Washing machine	58.5	1.3	0.2	3.8
All above	46.6	13.2	5.2	28.9
Non-tenants and tenants owned	29.6	30.2	22.7	

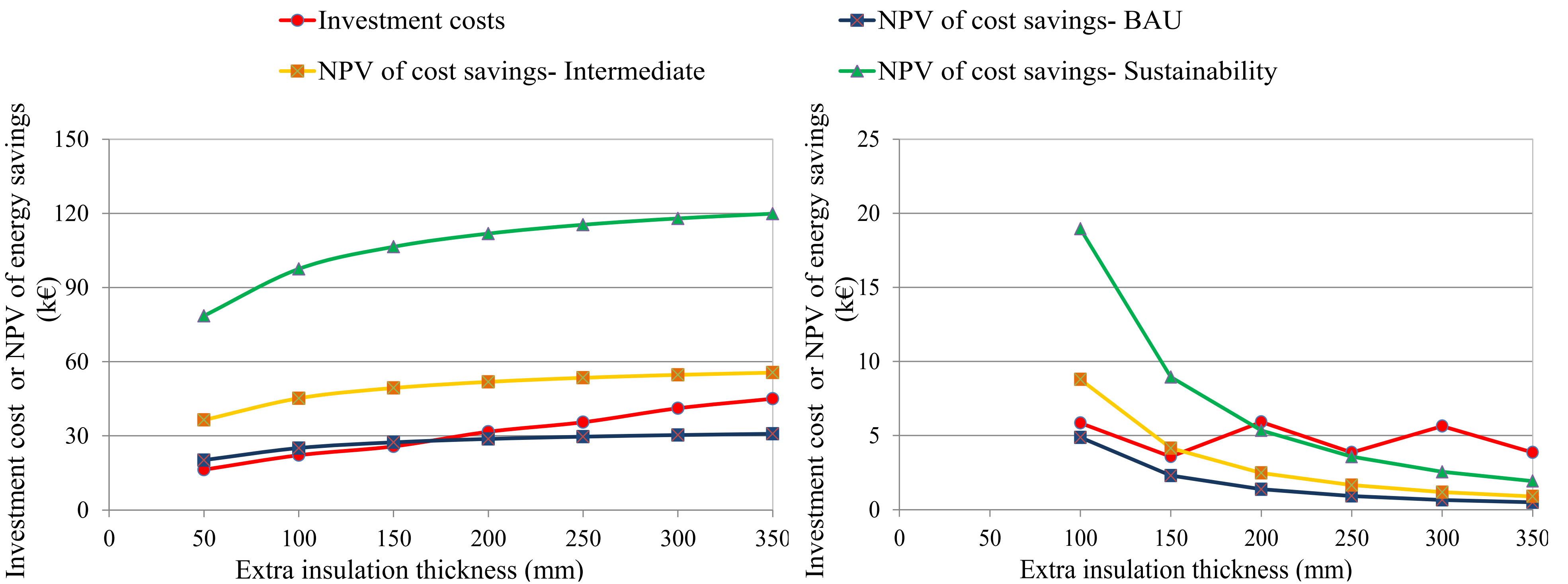
Cost-effectiveness of appliances and lighting

Description	NPV of total net energy cost savings (k€)			NPV of total net energy cost savings (k€) / total investment cost (k€)		
	BAU	Inter.	Sust.	BAU	Inter.	Sust.
Clothes dryer	1.9	2.4	3.1	0.6	0.7	0.9
Dishwasher	2	2.5	3.3	0.5	0.6	0.7
Freezer	7.7	9.8	12.7	2	2.5	3.3
Lights (Facility)	1.1	1.4	1.8	5.5	6.9	9.0
Oven/cooker	2.3	2.9	3.8	0.2	0.3	0.4
Refrigerator	0.8	1.1	1.4	0.2	0.3	0.4
Washing machine	2.0	2.6	3.3	0.5	0.7	0.9
All major appliances	19	24.1	31.2	0.7	0.8	1.1

Implications of different thickness of basement wall insulation- final energy savings and investment costs

Styrofoam insulation to basement wall	Improved U-value (W/ m²K)	Space heating (kWh/m²/yr)	Final heat savings (MWh/ yr)	Total investment cost (k€)	Marginal investment cost (k€)
Reference	(1.33 / 1.44)	114.1	-	-	-
50 mm	0.45 / 0.46	108.1	12.0	16.3	-
100 mm	0.27 / 0.28	106.7	14.9	22.2	5.8
150 mm	0.19 / 0.20	106.0	16.2	25.7	3.6
200 mm	0.151 / 0.152	105.6	17.0	31.7	5.9
250 mm	0.123 / 0.124	105.3	17.6	35.5	3.9
300 mm	0.10 / 0.11	105.1	18.0	41.2	5.6
350 mm	0.091	105.0	18.3	45.0	3.9

Total and marginal optimisations for basement wall insulation



Total optimisations

Marginal optimisations

Implications of different ventilation heat recovery systems – final energy savings and investment costs

Ventilation system with heat recovery	Space heating (MWh /yr)	Final heat savings (MWh/yr)	Hourly peak heat load (kW)	Increased electricity (MWh/yr)	Total investment cost (k€)
Reference	228.2	-	95	-	-
Centralised	186.4	41.8	79	2.2	129.1[a]/132.7[b]/138.5[c]
Semi-centralised	185.0	43.2	79	1.4	146.4[a]/152.3[b]/162.1[c]

[a] BAU scenario; [b] intermediate scenario; [c] sustainability scenario

Cost-effectiveness of ventilation heat recovery systems

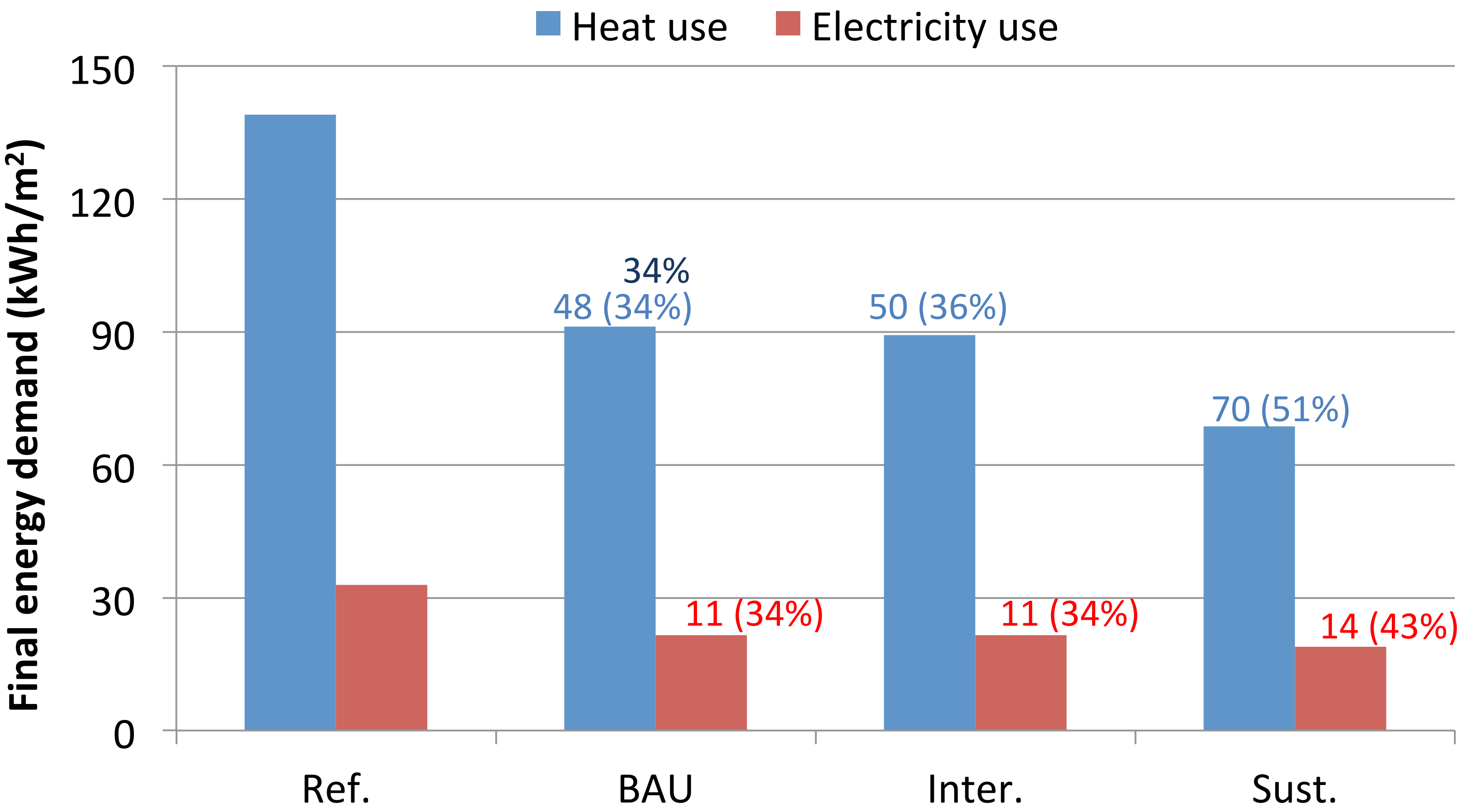
Ventilation system with heat recovery	NPV of total net energy cost savings (k€)			NPV of total net energy cost savings (k€) / total investment cost (k€)		
	BAU	Inter.	Sust.	BAU	Inter.	Sust.
Centralised AHU	63.8	115.1	248.3	0.5	0.9	1.8
Semi-centralised AHU	68.8	124.0	267.5	0.5	0.8	1.7

Cost-effective packages for different remaining lifetimes of the building

Scenario	BAU	Intermediate	Sustainability
40 years lifespan (for building envelope measures)	Efficient taps Efficient lighting and freezer 50mm Basement insulation	Efficient taps Efficient lighting and freezer 100mm Basement insulation 1.2 W/K m^2 New windows	Efficient taps Efficient appliances & lighting 150mm Basement insulation 1.2 W/K m^2 New windows 400mm Attic insulation
50 years lifespan (for building envelope measures)	Efficient taps Efficient lighting and freezer 50mm Basement insulation 1.5 W/K m^2 New windows	Efficient taps Efficient lighting and freezer 150mm Basement insulation 1.2 W/K m^2 New windows	Efficient taps Efficient appliances & lighting (all) 150mm Basement insulation 1.1 W/K m^2 New windows 500mm Attic insulation VHR system
60 years lifespan (for building envelope measures)	Efficient taps Efficient lighting and freezer 50mm Basement insulation 1.2 W/K m^2 New windows	Efficient taps Efficient lighting and freezer 150mm Basement insulation 1.2 W/K m^2 New windows VHR system (only centralised)	Efficient taps Efficient appliances & lighting 250mm Basement insulation 0.8 W/K m^2 New windows 500mm Attic insulation VHR system

Annual total final energy use for different scenarios based on a remaining building lifetime of 50 years

(space and tap water heating & household and ventilation electricity)



% reductions of heat or electricity use relative to references

Summary of savings of cost-effective of packages

Scenario	Heat savings (MWh/yr)	Electricity savings (MWh/yr)	Total investment cost (k€)	NPV of savings [energy & water] (k€)	Total cost savings (k€)
BAU	95.5 (34%)	22.7 (34%)	128.3	306.3	178
Intermediate	99.4 (36%)	22.7 (34%)	137.7	484.3	347
Sustainability	140.7 (51%)	28.0 (43%)	335.7	1106.5	771

Conclusion

- Economic analysis should be based on both a total and a marginal analysis
- Some energy efficiency measures lifetime is as long as the remaining lifetime of the building
- Cost-effectiveness of the measures is sensitive to assumed real discount rates and real energy price increases
- Cost-optimal heat savings varies between 34 -51 %
- Cost-optimal electricity savings is between 34 % and 43%
- Cost savings is between 178 and 771 k€
- The sustainability scenario give most energy and cost savings

Thank you!