Primary energy benefits of cost-effective energy renovation of a district heated building under different energy supply systems

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We analysed implications of energy savings in a district heated building

- Integrating economic optimization with energy balance and energy system analysis
- Evaluating primary energy changes due to different energy efficiency measures, considering:
  - different location for the building
  - three different district heating systems with varied scale and technical setup as well as tariffs
  - hourly variation of final energy savings based on real climate data for 2013
  - hourly operation of district heat production units based on:
    - o real operation for 2013
    - o renewable-based DHS

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Analysed district heated building

- 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 is good conditions, located in popular housing area, with a remaining lifetime of at least 50 years

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Building thermal characteristics currently

Building elements	Components	U-value (W/m^{2}K)
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

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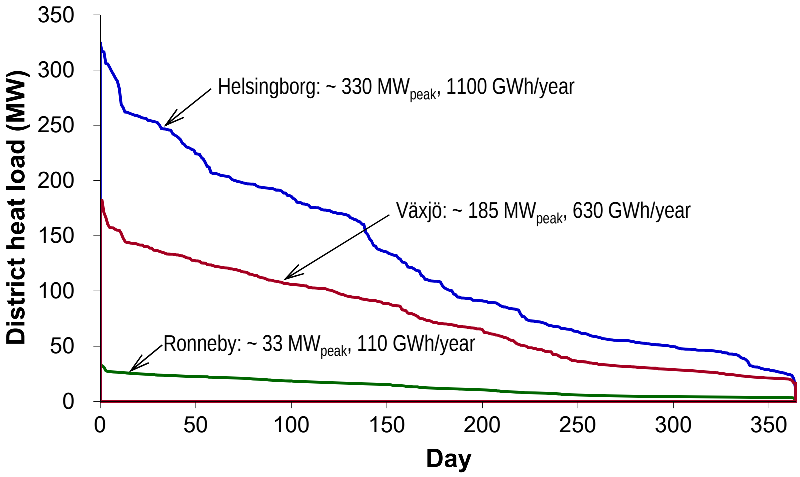
District heating systems



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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	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 m²	Building code (BBR 2012)
Ventilation system	Mechanical exhaust	
Airtightness at 50 Pa	0.8 l /m²s	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.
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

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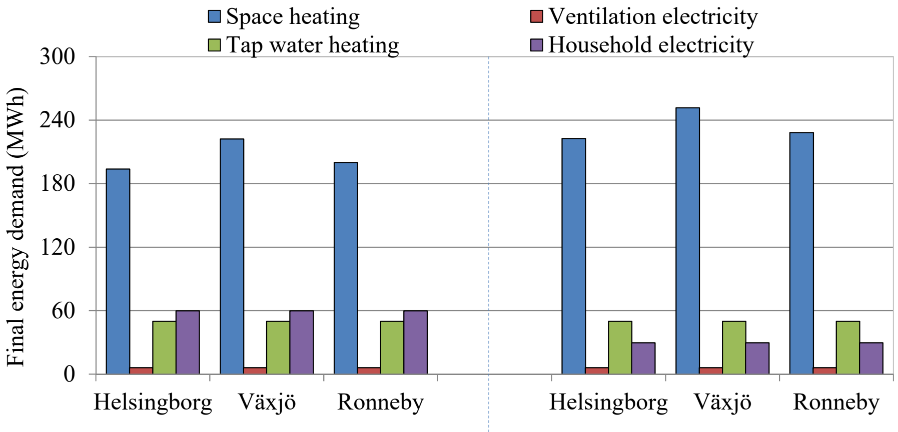
Annual final energy balance of building in different locations



Without measures to reduce household electricity use and hot water circulation losses

With measures to reduce household electricity use & hot water circulation losses

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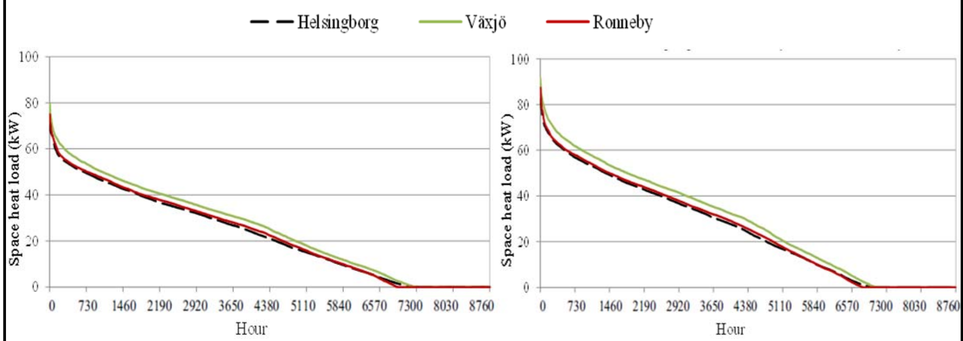
Annual profiles of hourly final space heat demands in different locations



Without measures to reduce household electricity use and hot water circulation losses

With measures to reduce household electricity use & hot water circulation losses

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Energy renovation measures analysed

Energy renovation measure	Range
Extra insulation to:	
Attic	50 to 500 mm mineral wool insulation
Basement walls	50 to 350 mm styrofoam insulation panels
Exterior walls	45 to 510 mm mineral wool insulation
New improved windows	1.5 to 0.7 W/m^2 K U-value
New improved taps	Faucets based on best available technologies
Efficient appliances and lighting	Best available technologies
Ventilation heat recovery system	Central and semi-centralized units

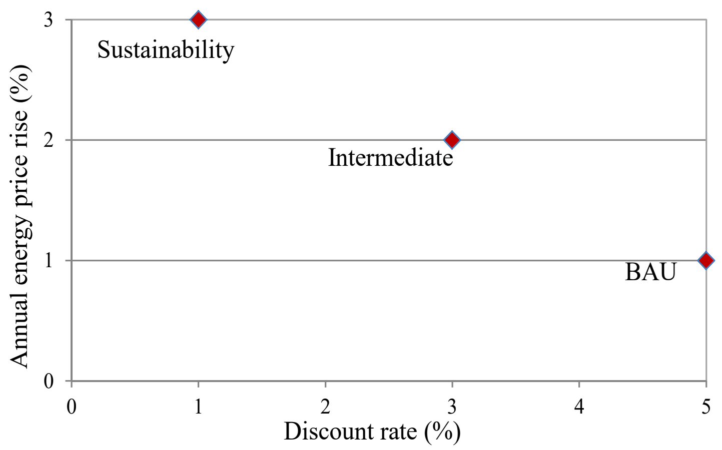
Total- and marginal-based optimisation of energy efficiency renovation measures and packages

Net present economic value of (NPV) of energy savings are compared to estimated investment cost

Two step analysis of measures:

1. Single measures
2. Package of measures applied in order of cost efficiency

Economic scenarios in real terms



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Cost-effectiveness criteria

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

Totals of savings and investment

and

Marginals of savings and investment

(for incremental measures)

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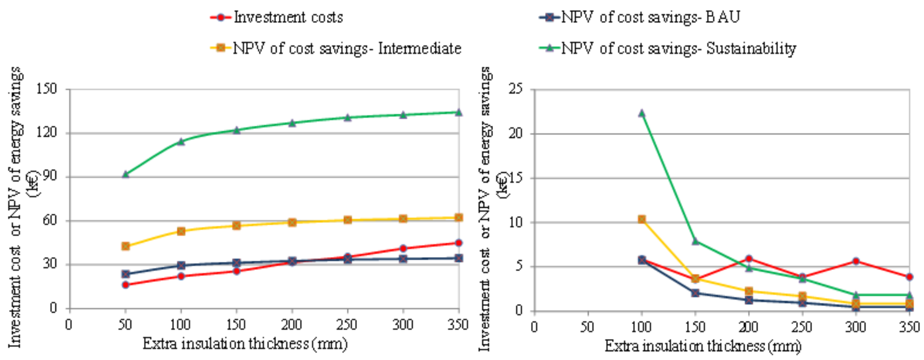
Total and marginal optimisations for basement wall insulation in Helsingborg



Total optimisations

Marginal optimisations

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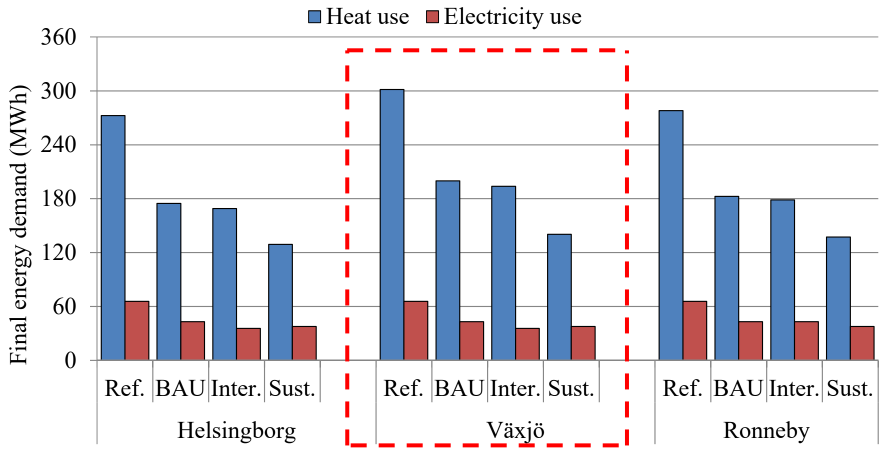
Cost-effective packages considering all measures

Scenario	BAU	Intermediate	Sustainability
Helsingborg	Efficient taps Efficient lighting & freezer 100 mm basement insul. 1.2 W/ m² K windows	Efficient taps Efficient appliances 150 mm basement insul. 1.2 W/ m² K windows 400 mm attic insulation	Efficient taps Efficient appliances 150 mm basement insul. 1.1 W/ m² K windows 400 mm attic insulation VHR system (centralised)
Växjö	Efficient taps Efficient lighting & freezer 50 mm basement insul. 1.2 W/ m² K windows	Efficient taps Efficient appliances 250 mm basement insul. 1.2 W/ m² K windows	Efficient taps Efficient appliances 250 mm basement insul. 0.9 W/ m² K windows 400 mm attic insulation VHR system (centralised)
Ronneby	Efficient taps Efficient lighting & freezer 50 mm basement insul. 1.2 W/ m² K windows	Efficient taps Efficient lighting & freezer 150 mm basement insul. 1.2 W/ m² K windows	Efficient taps Efficient appliances 150 mm basement insul. 1.1 W/ m² K windows 500 mm attic insulation VHR system (centralised)

Annual final energy use for different scenarios and contexts
(space and tap water heating and household & ventilation electricity)



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Summary of savings of cost-effective of packages

Context/ location	Scenario	Heat savings (MWh/yr)	Electricity savings (MWh/yr)	Total investment cost (k€)	NPV of savings [energy & water] (k€)	NPV/ invest. costs
Helsingborg	BAU	97.7 (36%)	22.7 (34%)	134.2	278.8	2.1
	Intermediate	103.4 (38%)	30.2 (46%)	180.8	474.1	2.6
	Sustainability	143.3 (53%)	28 (43%)	331.7	1118.3	3.4
Växjö	BAU	101.7 (34%)	22.7 (34%)	128.3	313.5	2.4
	Intermediate	107.8 (36%)	30.2 (46%)	172.3	473.7	2.7
	Sustainability	161.1 (53%)	28 (43%)	384.0	1129.6	2.9
Ronneby	BAU	95.5 (34%)	22.7 (34%)	128.3	306.3	2.4
	Intermediate	99.4 (36%)	22.7 (34%)	137.7	484.3	3.5
	Sustainability	140.7 (51%)	28 (43%)	335.7	1106.5	3.3

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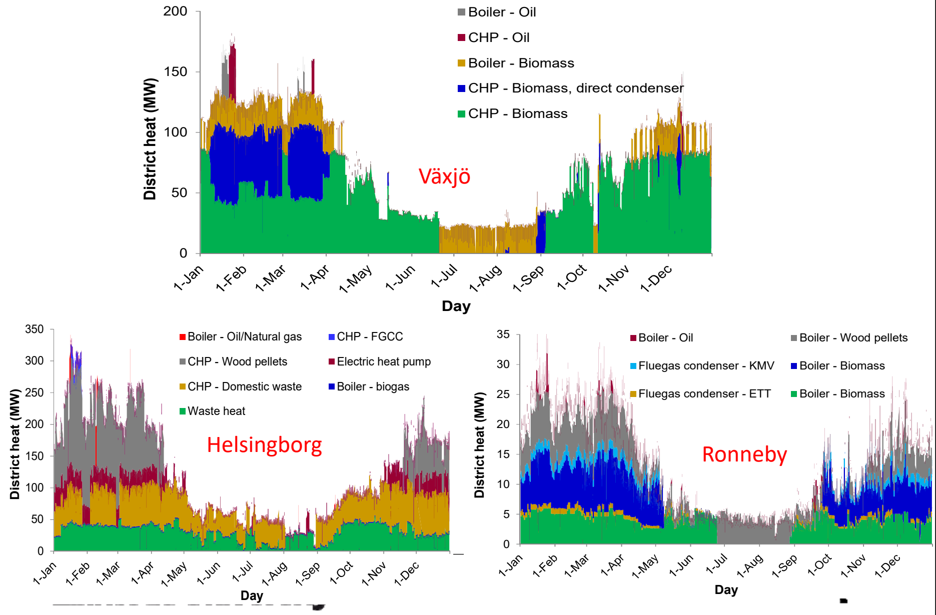
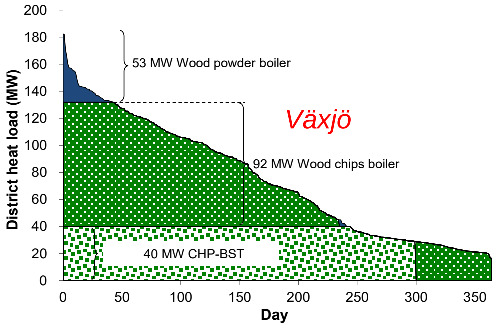
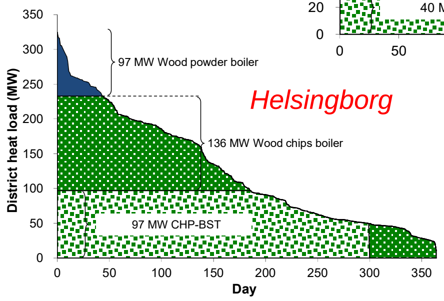
Primary energy savings analysis

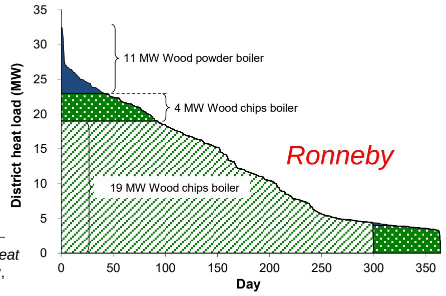
Analysed district heat production systems



Renewable-based district heat production

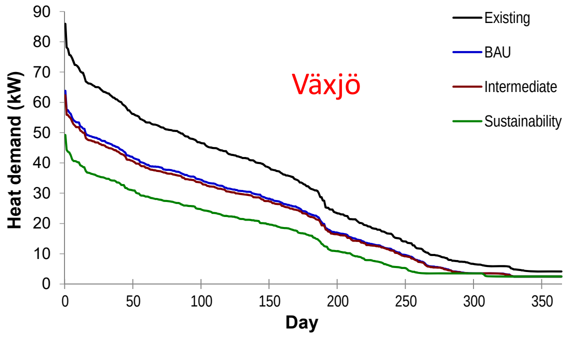


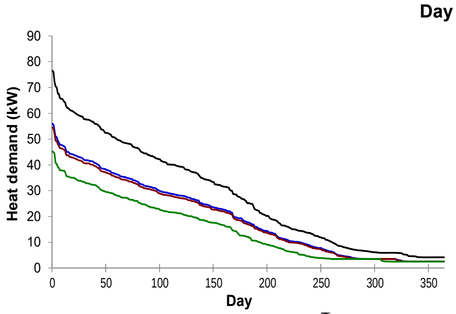


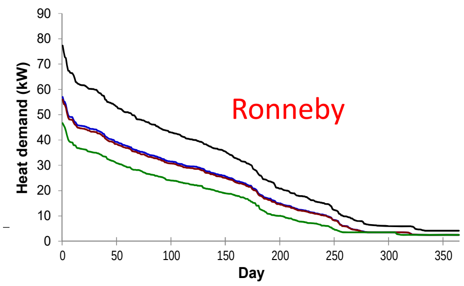


Ref: Truong, N.L., A. Dodoo, and L. Gustavsson, *Renewable-based heat supply of multi-apartment buildings with varied heat demands.* Energy, 2015. **93**(1): p. 1053–1062.

Final heat use of different techno-economic scenarios

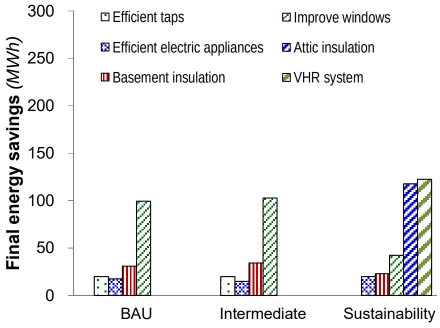


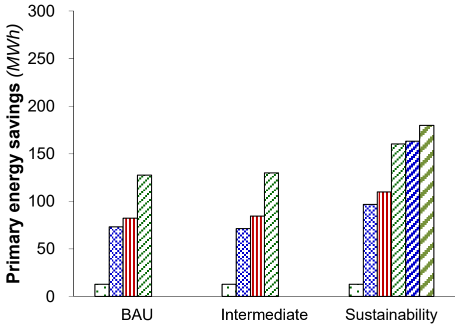




Final and primary energy savings - existing energy systems

Växjö:





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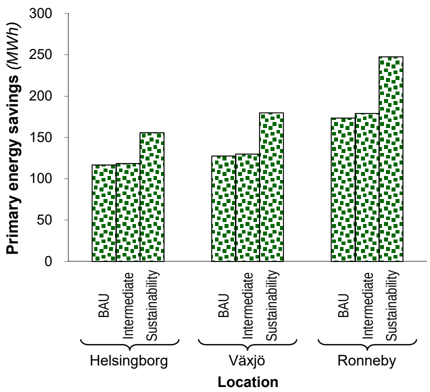
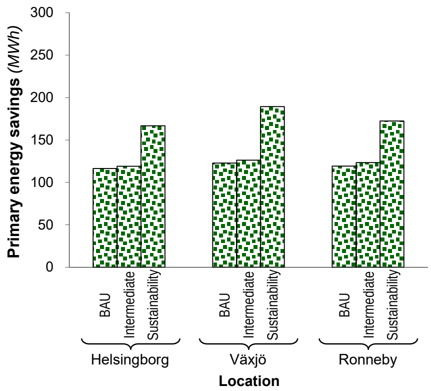
Primary energy savings



Existing energy supply systems



Renewable-based energy supply systems

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Conclusions I

- Large cost-effective final energy savings are achieved for the building with the analyzed measures
  - Annual final heat savings of 97.7-161.7 MWh (34-51%)
  - Annual end-use electricity savings of 22.7- 30.2 MWh (34-46%)
  - Biggest energy savings is achieved with sustainability scenario
- Primary energy savings of the measures vary, depending on:
  - Characteristics of energy supply systems
  - Type of energy efficiency measure

Conclusions II

- Annual total primary energy savings vary from 116.4 – 247.6 MWh, depending on supply systems
- Primary energy savings are lower with cost-optimally designed renewable-based energy supply compared to the existing supply system
- Evaluation of energy efficiency measures in district-heated buildings requires a systems perspective

Thank you!

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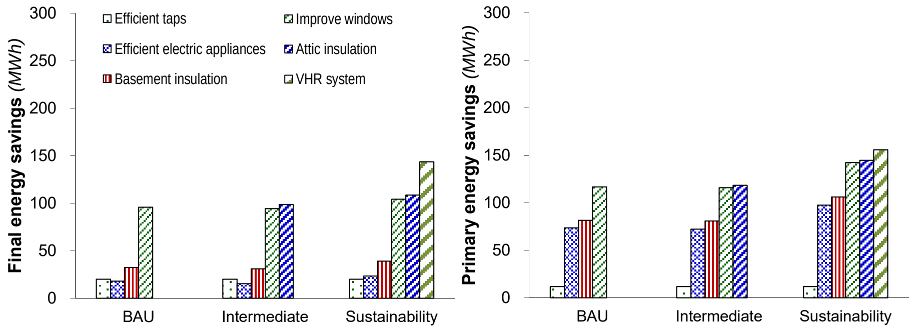
Final and Primary energy savings – Existing energy systems

Helsingborg:



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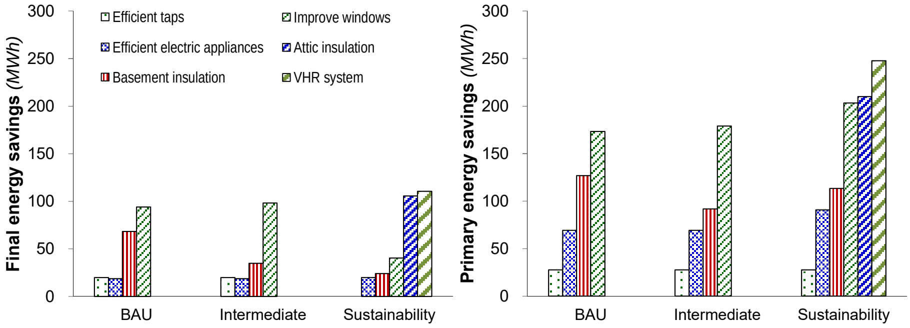
Final and Primary energy savings – Existing energy systems

Ronneby:



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