Techno-Economic assessment of Potential for Energy savings (TEPE)

Potential and policies for energy efficiency in Swedish buildings built before 1945

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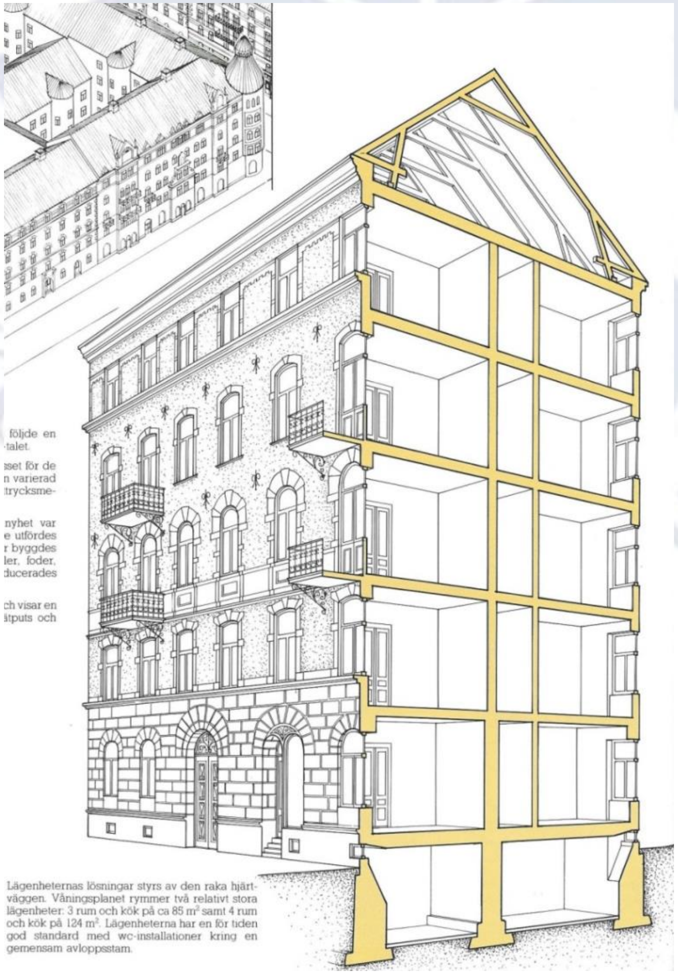
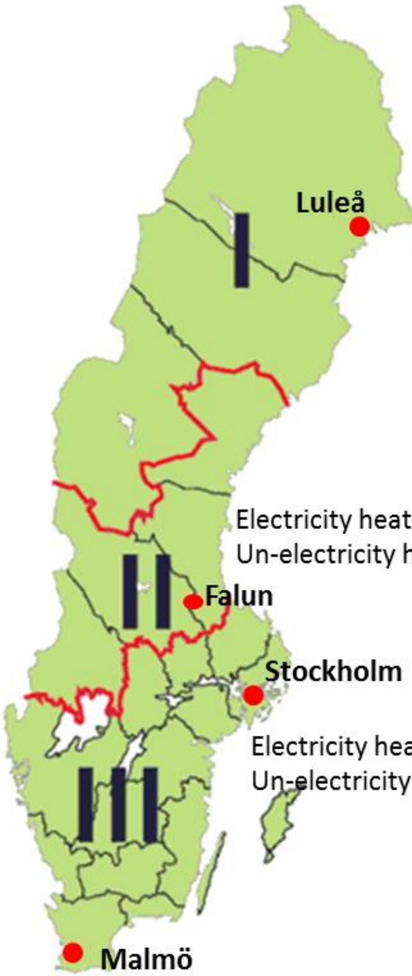
Background

- About a third of the buildings in Sweden are from before 1945 with an estimated annual energy use of 60 TWh.
- In Europe there are approximately 55 million buildings built before 1945 with an estimated annual energy use of 1400 TWh.
- Each saved percent in buildings built before 1945 corresponds in Sweden to an estimated 0.6 TWh and in Europe to 14 TWh.
- Swedish energy goal of the building sector's energy use: The building's energy use should be reduced by 20% by 2020 and by 50% by 2050 in relation to energy use in 1995.



Building's specific energy use by different heating sources in different climate zones in Sweden



Objectives

- To develop a tool for Techno-Economic assessment of Potential for Energy savings (TEPE)
- To develop methods to manage heritage values in this decision-making context
- To make statistically sound assessment of the cost effective energy-saving potential of the historic building stock
- To investigate the barriers and drivers for implementing energy efficiency measures in historic buildings
- To provide input for policies and guidelines in order to harmonize the societal objectives on energy conservation and building conservation.

The OPERA - MILP model
A short description

- A computer program for optimal refurbishment of buildings
- Present values! LCC
- Minimization
- Calculus and trail-and-error
- Starts with an old building (In the form of a computer text file)
- Ends with a new building (Also a text file)

OPERA – MILP (Optimal Energy Retrofits Advisory - Mixed Integer Linear Program)

Present value calculations

- For a single event we calculate the present value as:

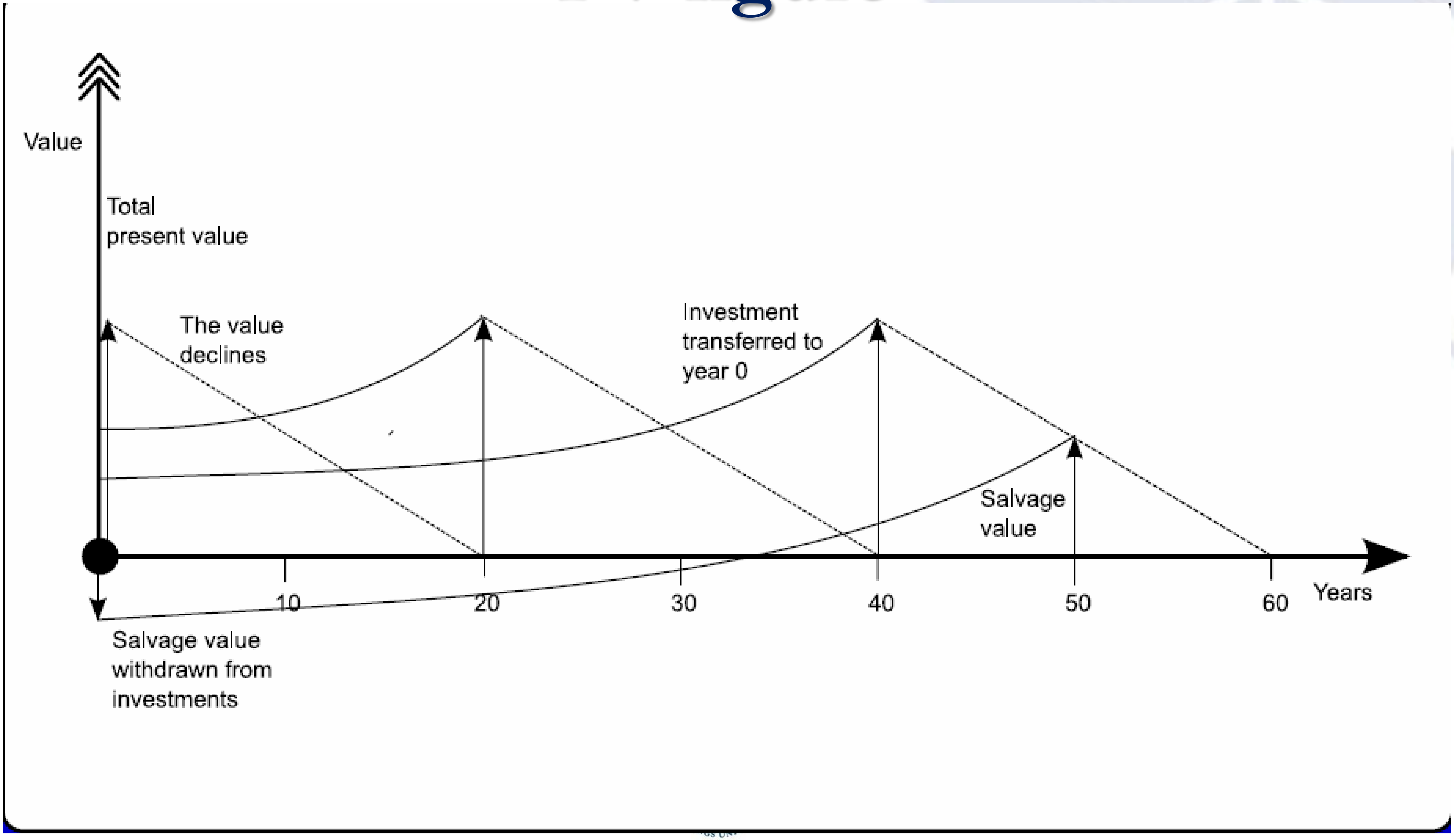
$$PV_s = C_s \times (1 + r)^{-n}$$

- For annually emerging costs we use:

$$PV_a = C_a \times \frac{1 - (1 + r)^{-m}}{r}$$

where C_s, C_a are the costs, r is the interest rate, n and m are the time span in years.

PV figure

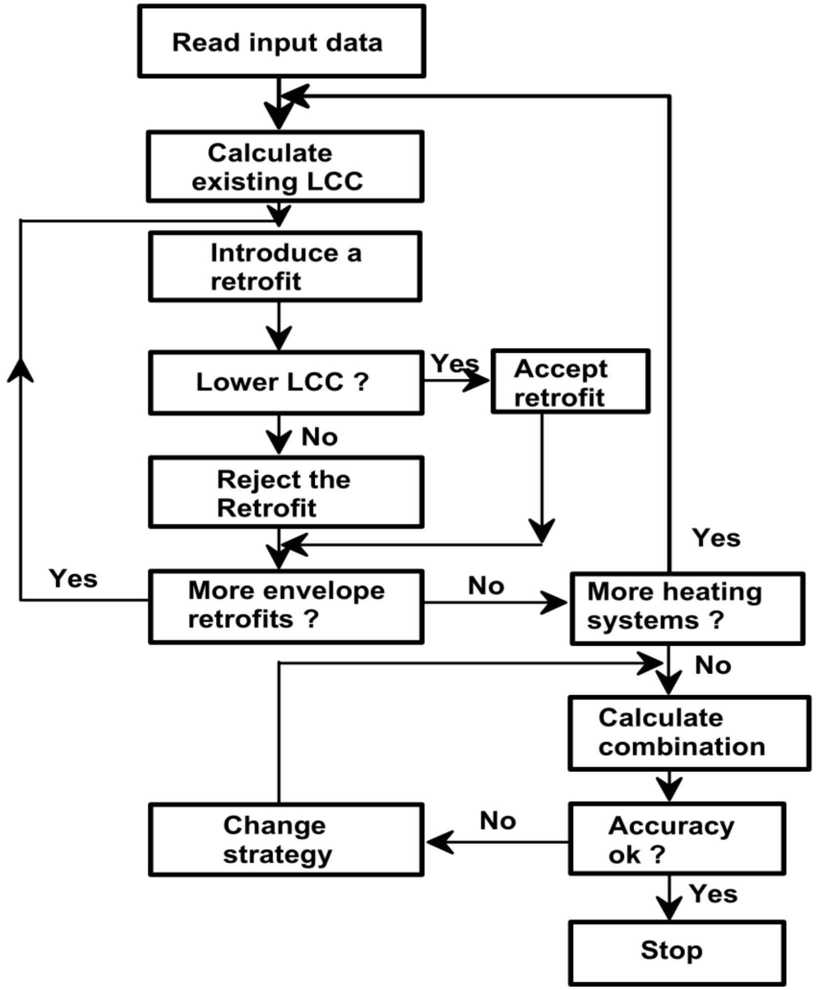


Value
Total
present value
The value
declines
Investment
transferred to
year 0
Salvage
value
10
20
30
40
50
60
Years
Salvage value
withdrawn from
investments

Life-Cycle Cost, LCC

- The LCC is the sum of all costs calculated as present values. It is therefore possible to compare different solutions.
- Each building has its own LCC.
- The best solution is found when the LCC assumes its lowest possible cost.

Principal scheme



Optimization

LCC-calculations and optimisation can be easy at first sight:

- Find a function describing the cost
- Finding the minimum point for that function

But:

- Is the function continuous?
- One function enough?
- One function influenced by another?
- Optimization method(s)?

Optimization

The climate conditions is described as follows:

- November – March (three values: day time, night time and weekend)
- April – October (one value)

MILP consists of:

- Constraints, ordinary variables and binary variables

$$(\frac{1}{e_{DH}} \times P_{DH} \times Price_{DH} + \frac{1}{e_{HP}} \times P_{HP} \times Price_{HP} + \frac{1}{e_{WB}} \times P_{WB} \times Price_{WB}) \times (1 + r)^{n} \times t$$

Optimization code:

- ZOOM (possible to use LAMPS and CPLEX)
- SORAD code for solar radiation

Program is written in C which generate the MPS file

Inevitable retrofits

All buildings must be retrofitted. If you have a new building it takes a long time before you have to do anything. An old building must perhaps be taken care of immediately. Hence, we show the cost for wall measures by using the following expression:

$$C_{wall} = C_1 + C_2 + t \times C_3$$

C_1 is the cost for ”the facade” or things you must do even if you do not add insulation, t is the insulation thickness. Scaffolding, demolition, new facade, painting and so forth are examples of C_1.

Inevitable retrofits

We have inevitable costs also for windows, boilers and many other things in the building. The ”Existing LCC” includes costs for changing one old item to a new item with the same *”energy standard”*. A poor double-paned window is changed to a new good one of the same type.

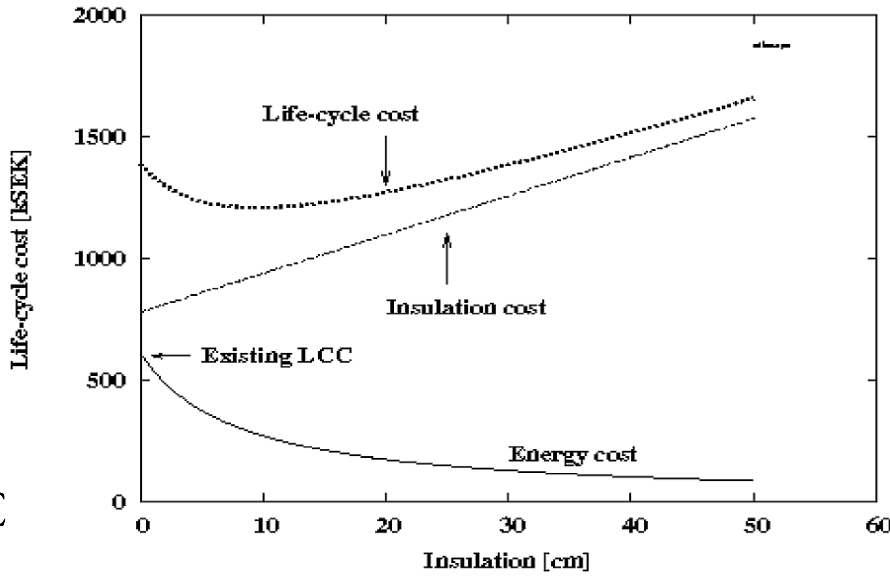
Inevitable retrofits

Consider oil-fired boilers with chimneys, ground-water coupled heat pumps with water wells or solar heating devices with all pipes. A water well will have alonger life than the compressor in a heat pump. This must be considered.

Optimal insulation level

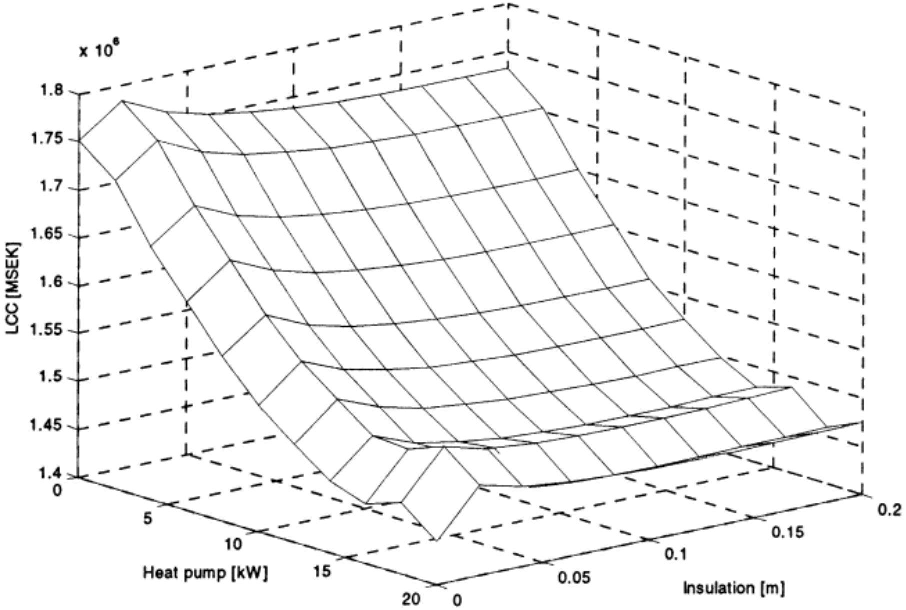
It is possible to describe the LCC in a continuous function in many cases. For an existing building attic floor, with extra insulation, the optimal thickness ***t*** can be derived as:

$$t = -\left(\frac{k}{U_{exi}}\right) + \left(k\frac{F}{C_3}\right)^{0.5}$$



The lowest LCC is found when the upper curve has its minimum or the existing LCC is lower. If you have a new house the existing cost will be low. No measures will be profitable.

Heat pump and insulation



$$LCC = 878958 +$$

$$5731P + \frac{5824.5}{0.04+0.8t} + \frac{14.08+281.7P^2t-16335Pt-919.4P+161210t+9354.8}{0.09163+1.5792t}$$

Trail and error

Sometimes it is difficult to find continuous functions. This is the case for e.g.:

- Different window constructions
- Different boilers or heating systems
- Time-of-use tariffs
- Different ventilation systems
- Exhaust air heat pumps
- Weather-stripping

The energy cost

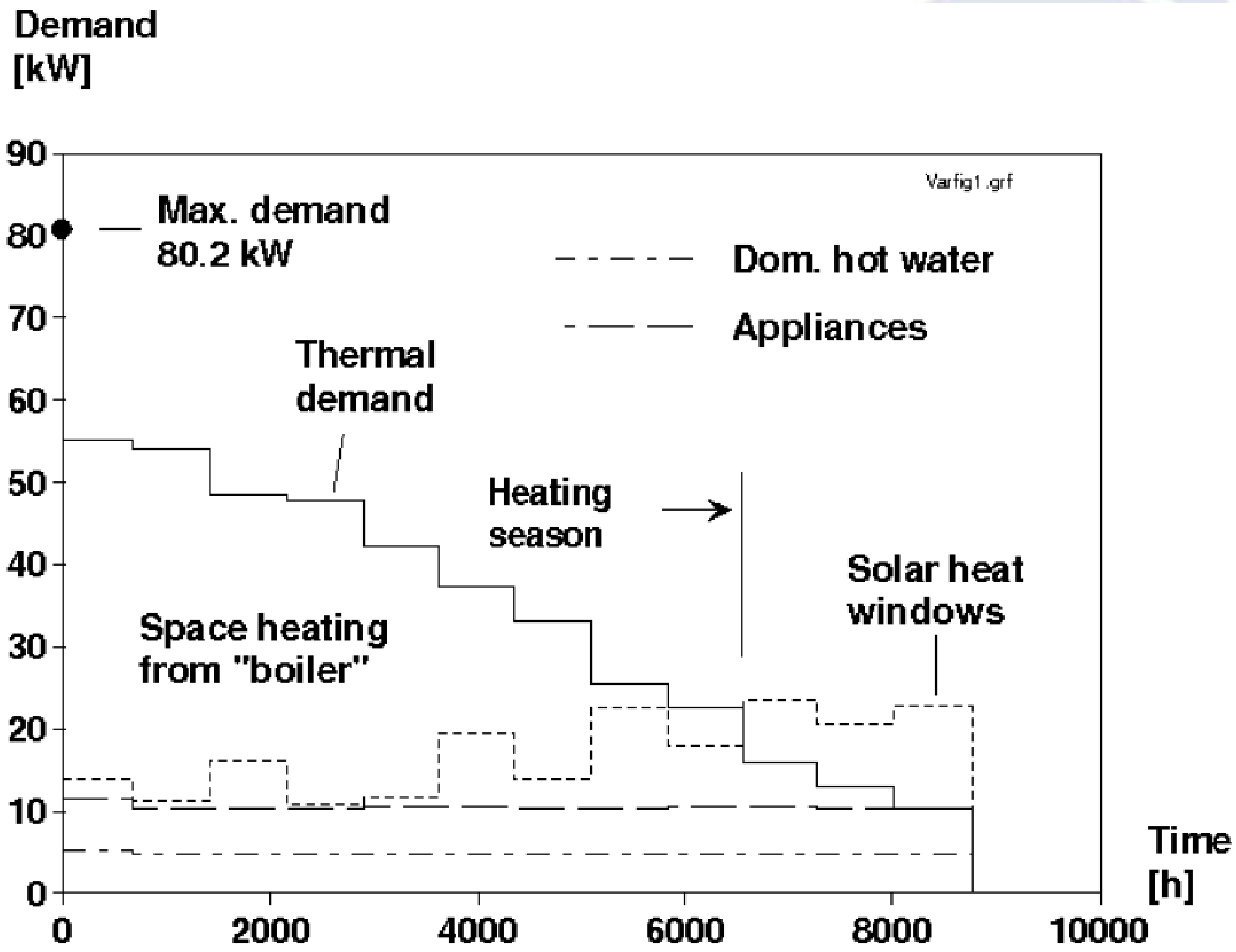
Sometimes it is difficult to find the proper energy cost

- The cost is based on a tariff
- The total cost is valid for a complete building, not only a part of the building.
- Some of the costs are only applied during the winter
- The heating season might change
- Saving heat in the summer is normally ”useless”
- The tariff is not continuous

The energy use

MONTH NO	DEG.- HOURS	ENERGY- TRANS	HOT- WATER	FREE ENERGY	SOLAR HEAT	UTILIZ FREE	FROM BOILER
1	15996.	32893.	3501.	4167.	1201.	5368.	31027.
2	14713.	30254.	3502.	4167.	2609.	6776.	26980.
3	14582.	29987.	3503.	4167.	6078.	10245.	23245.
4	10800.	22209.	3504.	4167.	8998.	13165.	12548.
5	7440.	15299.	3505.	4167.	12717.	15299.	3505.
6	4320.	8883.	3506.	4167.	13200.	8883.	3506.
7	2827.	5814.	3507.	4167.	12933.	5814.	3507.
8	3199.	6579.	3508.	4167.	10900.	6579.	3508.
9	5400.	11104.	3509.	4167.	7712.	11104.	3509.
10	9002.	18512.	3510.	4167.	4109.	8276.	13746.
11	11592.	23837.	3511.	4167.	1561.	5728.	21620.
12	14136.	29069.	3512.	4167.	778.	4945.	27635.
TOTAL	114008.	234440.	42078.	50004.	82796.	102183.	174335.

The duration diagram



OPERA can treat the following measures

- Attic floor insulation
- Ground floor insulation
- External wall insulation from outside
- External wall insulation from inside
- Window change
- Weather stripping
- Heating systems
  - Wood boiler – WB;
  - Ground water heat pump – GHP;
  - District Heating –DH
  - Exhaust air heat pump – EAHP

Flow chart of the methodology TEPE

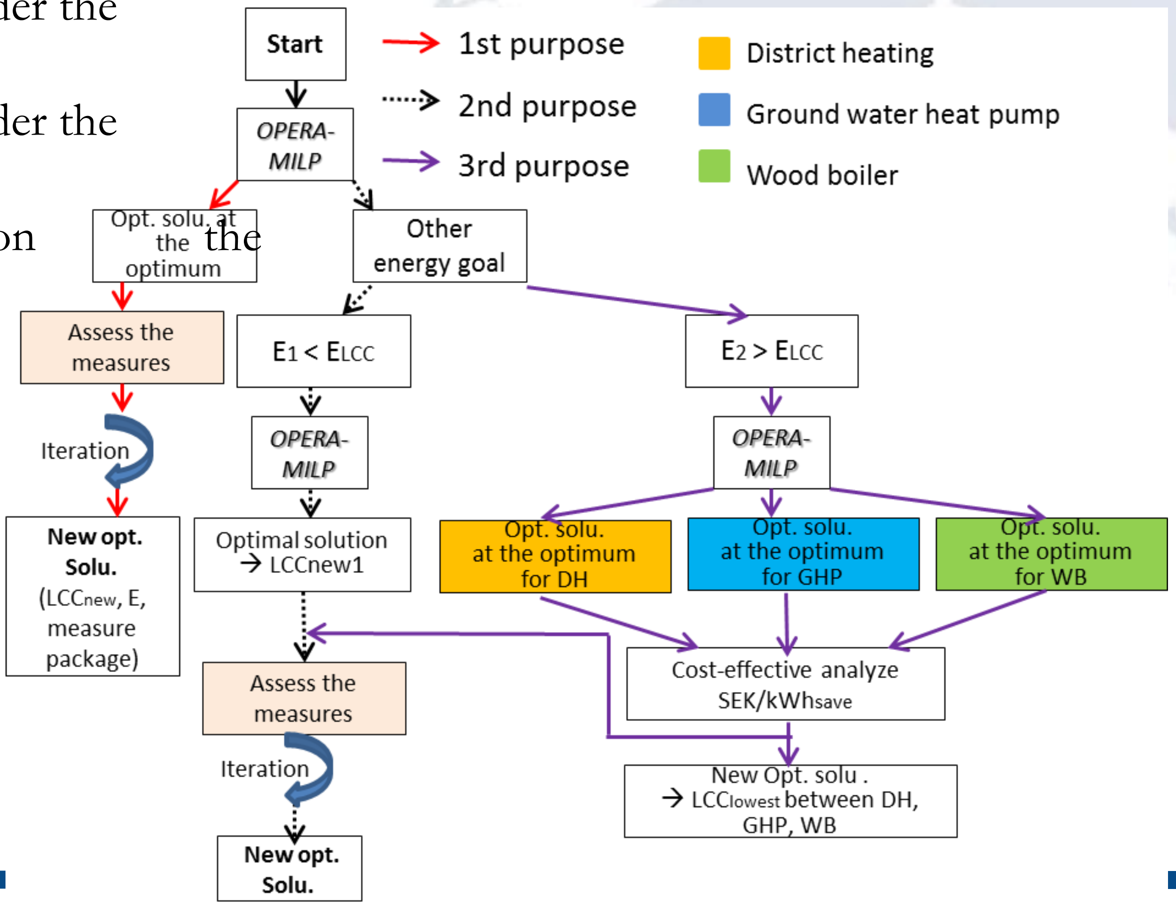
The TEPE methodology can be used for four purposes:

A) to access the lowest LCC (corresponding energy use is E_{LCC});

B) to find the optimal solution under the condition $E_B < E_{LCC}$; and

C) to find the optimal solution under the condition $E_C > E_{LCC}$

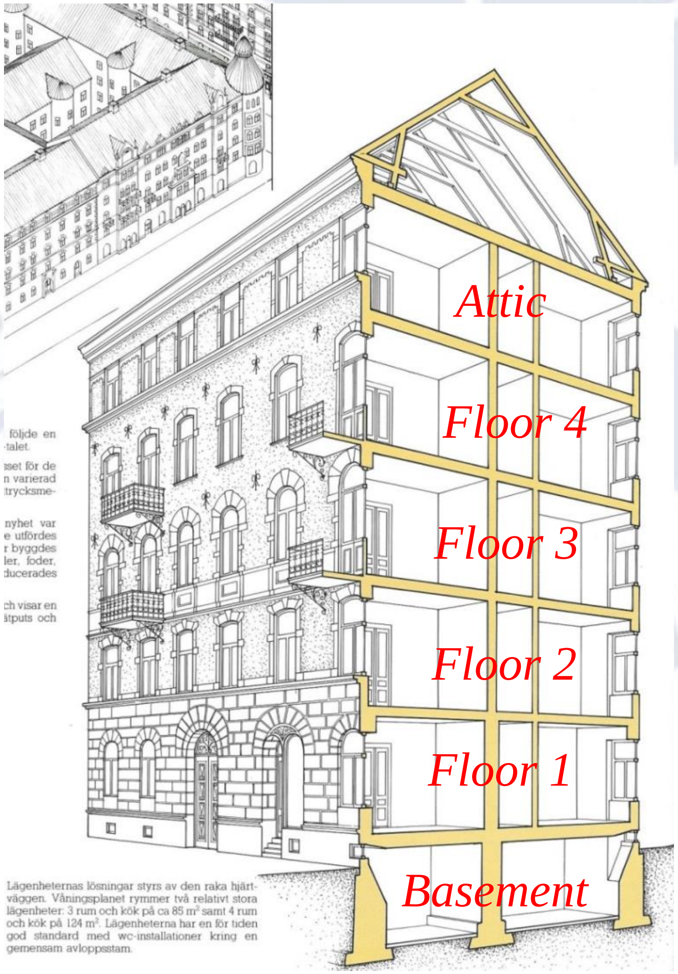
D) to assess the impact of ECMs on building's heritage value



Case study: A Swedish historic multi-family building built in 1890 with heterogenic constructions

Input data:

T_{indoor}, $T_{outdoor}$, U_{window}, U_{wall}, U_{attic}, U_{floor}, A_{window}, A_{wall}, A_{floor}, Air leakage rate, Ventilation airflow, Internal heat gains (people, Appliances, Solar heat gain etc), Hot water use.



Length 20 m, Width 10 m,
Basement height 2.2 m,
Floor height 3 m,
Attic height 1.2 m

Input data

λ- & U-values of the insulation materials / new windows and the new Air Change Rate (ACH_{new})

Construction part	Insulation material	Properties
Attic floor	Cellulose /glass fibre	0.038 ($W/m^2 \cdot {}^oC$)
Underground	EPS	0.038 ($W/m^2 \cdot {}^oC$)
External wall outside/inside	Minerall wool	0.038 ($W/m^2 \cdot {}^oC$)
Weather-stripping	Window stripping	ACH_{new}=0.5 (1/h)
Window	2+1 window	U=1.5 ($W/m^2 \cdot {}^oC$)
	3 pane + LE	U=1.1 ($W/m^2 \cdot {}^oC$)
	3 pane + LE + gas	U=0.8 ($W/m^2 \cdot {}^oC$)

Input data

Constants of the cost functions of EEMs

	C_1 (SEK/m^2)	C_2 (SEK/m^2)	C_3 (SEK/m^2, m)	C_4 (SEK/m^2)
Attic floor	0	41	556	
Underground	0	582.1	841.9	
External wall inside	276.9	365.4	1 432.2	
External wall outside	217.9	1055.5	6587.5	
Double-glazed				7 156
2+1 glazed				9 726
3 glazed with LE glass				10 316
3 glazed+ LE + Gas				11 880

Input data of the remained and new life times of different construction parts of different floors.

Input data

Life time of different heating system units, efficiency/COP and the installation costs

	Life time of the unit (yr)	Life time of the pipe network (yr)	Efficiency/COP of the unit	C_5 (SEK)
Wood boiler (WB)	15	50	η=0.75	2693.4
Ground water heat pump	10	50	COP=2.5	10713.6
District heating	25	50	η=0.95	5909.2

Energy prices

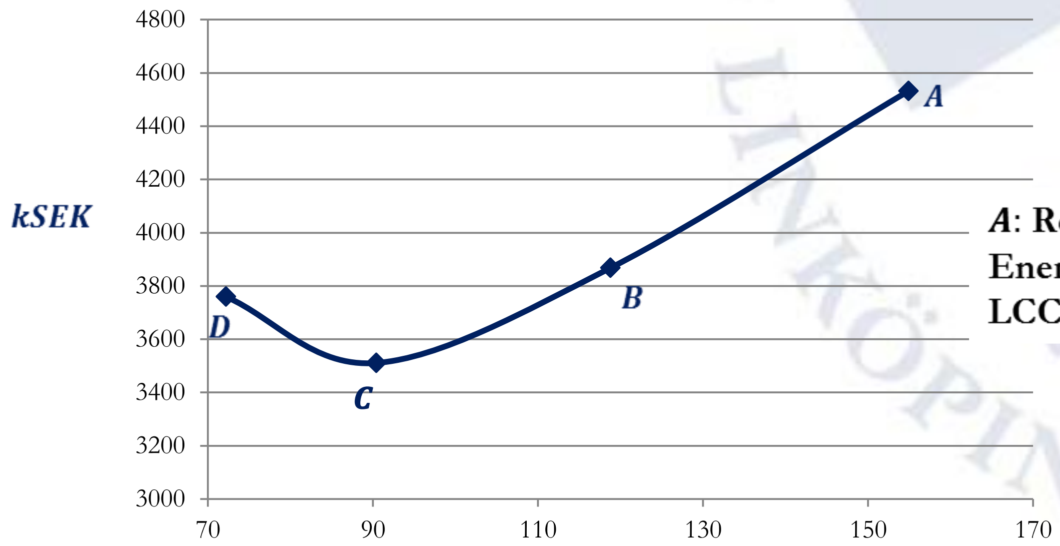
Electricity price: fixed fee 0.95 SEK/kWh and a flexible grid fee 0.52 SEK/kWh

District heating price: fixed price 0.68 SEK/kWh and a subscription fee 6000 SEK/year

Biomass price: 0.53 SEK/kWh

Discount rate: 3%

Energy demand and LCC for different scenarios



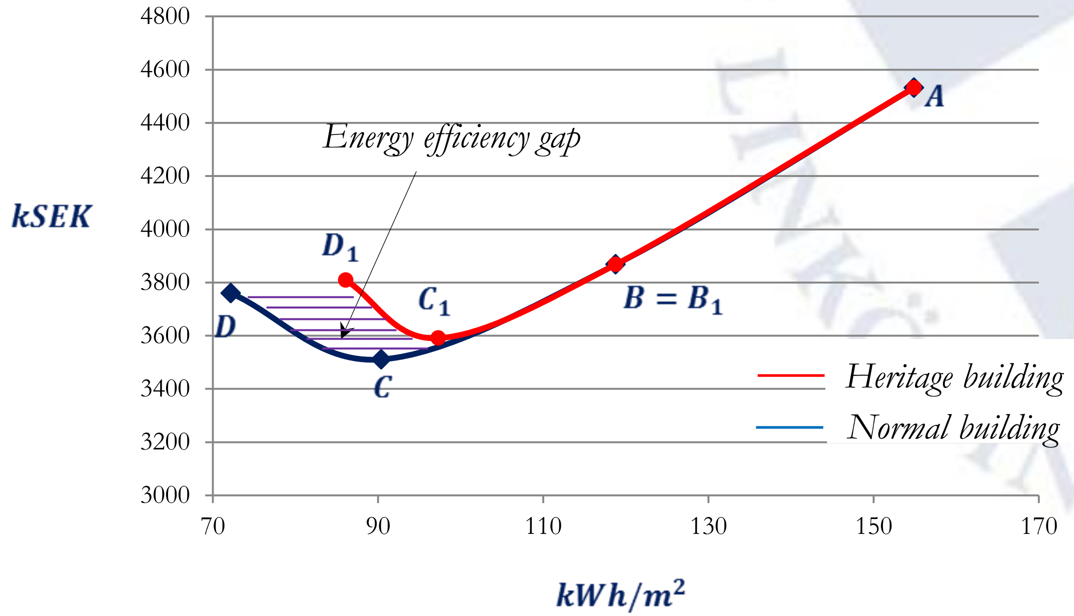
A: Reference case
Energy demand = 155 kWh/m^2
LCC = 4532 $kSEK$

D: 50% energy use reduction
Energy demand = 72 kWh/m^2
LCC = 3758 $kSEK$
Measures:

- Wood boiler: 27.9 kW
- Weather stripping: F1-F4.
- Attic floor insulation 30 cm
- Base Floor insulation: 42 cm
- External wall insulation inside: 12 cm (basement); 20 cm (F1-F3); 2 cm (F4)
- Change all the windows to 3 glazed+LE: F1-F3

8 cm (F1-F4). ι (basement) & 2 cm (F1-F3).

Energy demand and LCC for different scenarios



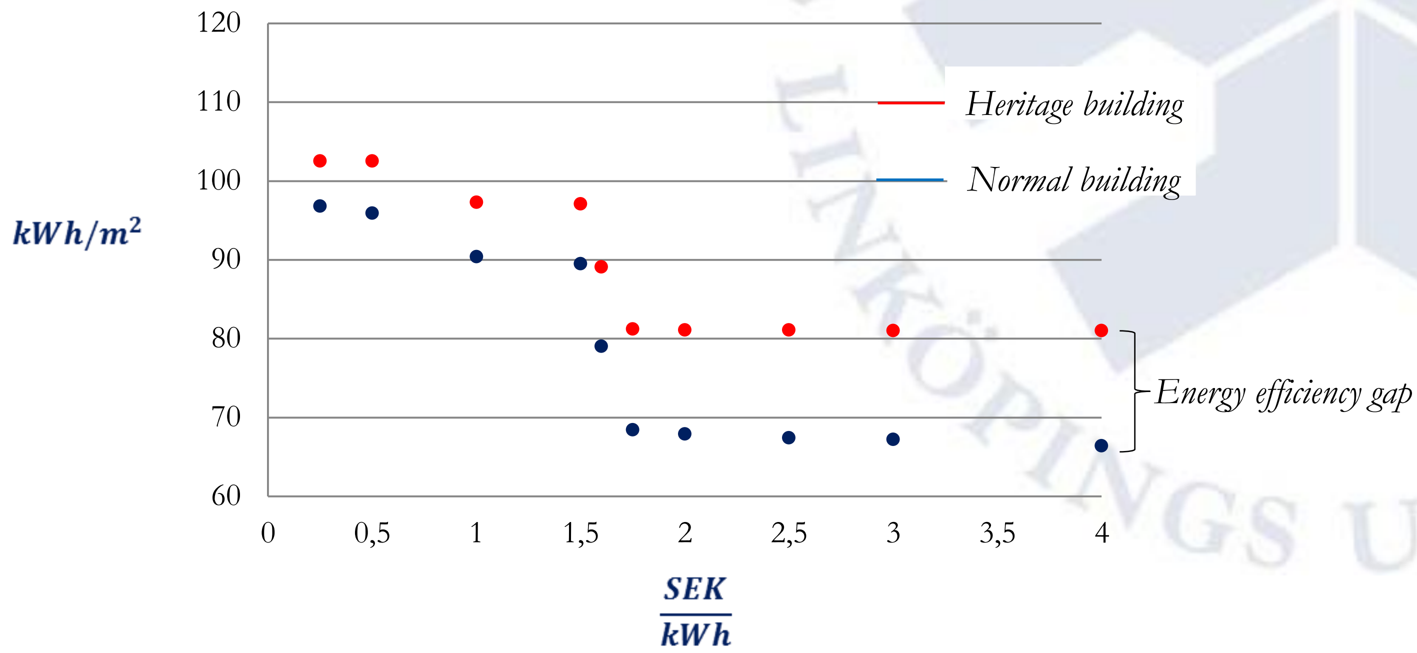
C: The optimal case
Energy demand = 90 kWh/m^2
LCC = 3511 $kSEK$
Measures:

- Heat pump: 13.2 kW
- Weather stripping: F1-F4.
- Attic floor insulation 30 cm.
- External wall insulation inside: 12 cm (basement); 18 cm (F1-F4).

C_1: The optimal case for the heritage building
Energy demand = 97 kWh/m^2
LCC = 3591 $kSEK$
Measures:

- Heat pump: 14.2 kW
- Weather stripping: F1-F4
- Attic floor insulation 30 cm.
- External wall insulation inside: 12 cm (basement); 6 cm (F1-F4).

Energy demand vs electricity price



Thanks!