Method for use of economical optimization in design of nearly zero energy buildings

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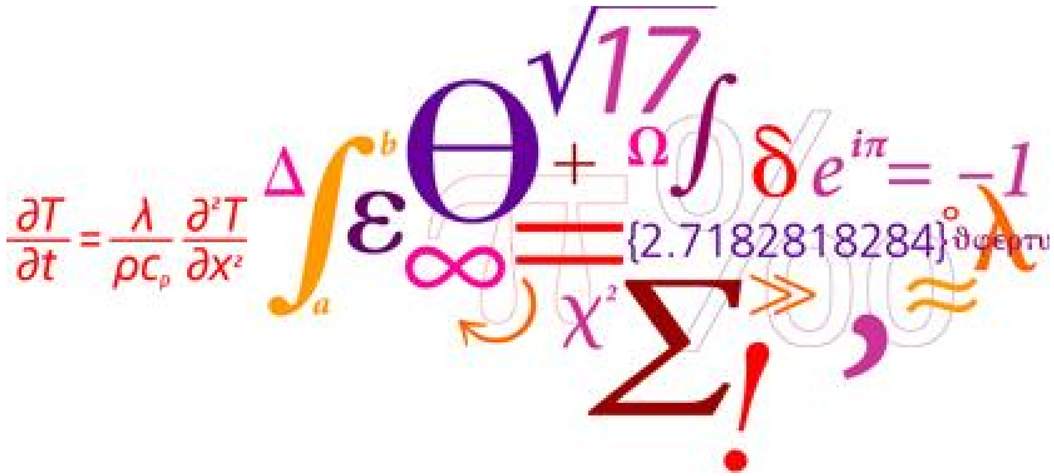

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Objective

By use of:

- Information on construction cost
- A simple model of the energy use

} Cost of Conserved Energy

for each main building envelope part and building service system

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It is possible to find the economical optimal mix of solutions for the whole building with the constraint that the total energy performance of the building is fulfilling the requirements

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A simple and transparent method for economic optimization which is suitable for the early stages of building design

Outline

- Background
- Cost of Conserved Energy
- Economic optimization
- Building elements with continuous energy properties
- Building elements with discrete energy properties
- Building optimization
- Case example
- Analysing the method
- Conclusions

Background

According to a recent European study, residential and commercial buildings are responsible for about 40 % of the total energy consumption and CO_2 emissions in Europe

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Therefore ambitious targets for energy consumption of new buildings are being implemented, and by the year 2020 nearly zero energy buildings will become a requirement in the European Union

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As a result, energy performance has become an important issue in the design of new buildings

Cost of Conserved Energy

The suggested definition of Cost of Conserved Energy

$$CCE = \frac{t \cdot a(n_r, d) \cdot I_{measure} + \Delta M_{year}}{p_1 \cdot \Delta E_{year} - p_2 \cdot E_{operation,year}} \qquad t = \frac{n_r}{n_u} \qquad a(n_r, d) = \frac{d}{1-(1+d)^{-n_r}}$$

where

CCE is the Cost of Conserved Energy (€/kWh)
n_r is the reference period (years)
n_u is the useful life time of the building element (years)
$a(n_r,d)$ is the capital recovery rate (-)
d is the real interest rate (shares of unit)
$I_{measure}$ is the investment cost of an energy-conserving building element (€)
ΔM_{year} is the increase in annual maintenance cost (€)
p_1 is the primary energy factor for the conserved energy of the building element
ΔE_{year} is the annual energy conserved by the building element (kWh)
p_2 is the primary energy factor for the consumed energy of the building element
$E_{operation,year}$ is the annual energy consumption by the building element (kWh)

Economic optimization

- Objective function: The total cost of the energy conserving building elements.
- Constraint: The sum of the energy use of the building elements equal to the energy performance requirement.
- Solution:

$$\frac{dP_1}{dE_1} = \frac{dP_2}{dE_2} = \ldots = \frac{dP_n}{dE_n}$$

where the differential quotient dP/dE is analogous to the definition of Cost of Conserved Energy.

The solution with the lowest cost that fulfills the energy constraint can thus be found where the marginal Cost of Conserved Energy is identical.

Sources: (Friedman, 2007) and (Crown et al, 1993)

Continuous energy properties

The construction parts, walls, roof and floor, are building elements with continuous energy properties

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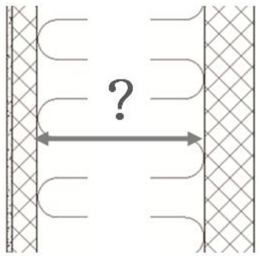
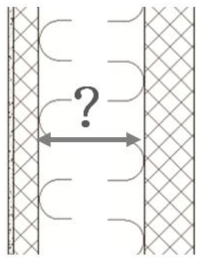
The optimization of such a building element is a question of optimizing quantity, e.g. the amount of insulation material in a construction





Discrete energy properties

The windows and the ventilation system are building elements with discrete energy properties

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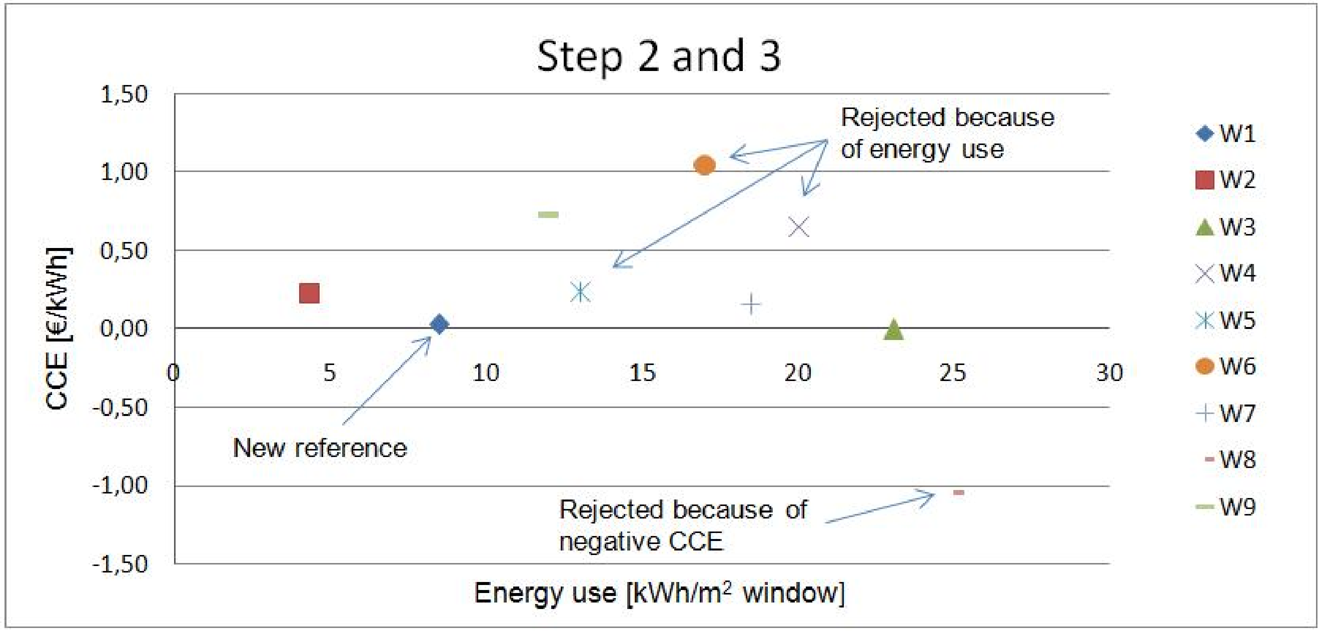
The optimization of such a building element is about evaluating the quality of the measure, e.g. the window type or a ventilation unit

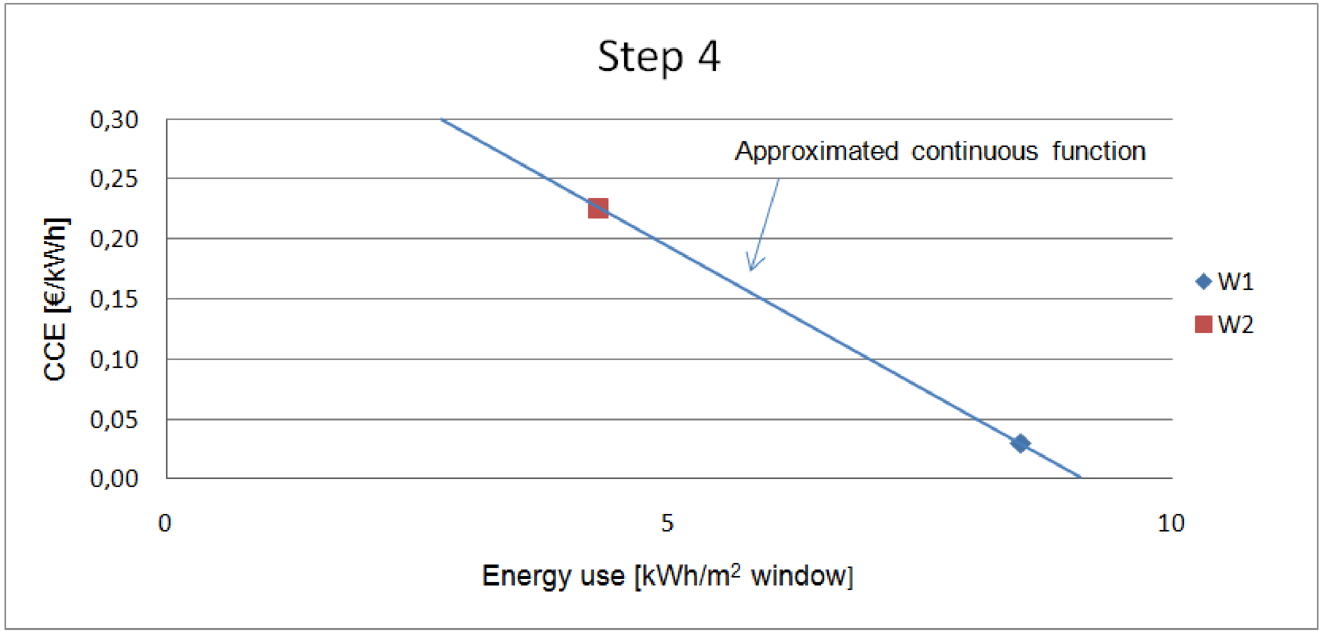
Discrete energy properties

The building elements with discrete energy properties can be approximated with a continuous function in four steps:

Step 1: The annual energy use for the building element is calculated and listed with their respective cost. The component with the lowest cost is chosen as reference.



Discrete energy properties



The discrete dataset approximated with a continuous function can be used for treating the components with discrete energy properties as components with continuous energy properties.

Building optimization

1. In order to find the optimal solution for the building as a whole, continuous functions for building elements are generated.

2. The quantity of each building element is stated, in form of the area of the constructions and windows, the ventilation rate etc.

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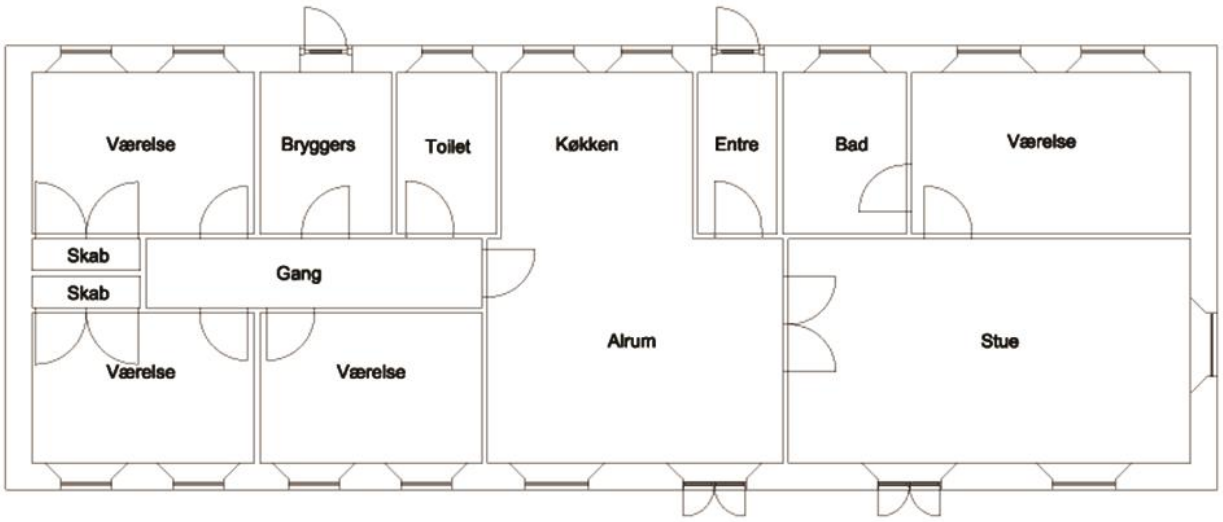
3. The optimal distribution of the energy-conserving building elements for the building design are found where the marginal Cost of Conserved Energy is identical.

4. This task can be facilitated by using the standard numerical solver in Microsoft Excel.

Case example

Typical Danish single-family house:



Input: Heated floor area, windows area and the average mechanical ventilation rate.

The building will be optimized to fulfill an energy performance of 35.2 kWh/m^2 year (the Danish requirement for 2015).

Case example

Economically optimal solution for case example:

Building element	Energy use kWh/m^2 year	CCE €/kWh	Measure
Wall	7.1	0.09	400 mm insulation
Roof	6.5	0.11	550 mm insulation
Floor	6.0	0.11	300 mm insulation
Windows	0.2	0.11	Between W1 and W2
Ventilation	8.6	0.28	Between V1 and V2

The method overestimates the energy use with around 5 % compared to the energy use calculated with the program used to document the energy performance requirement in Denmark.

Analysing the method

The biggest weakness to the method is the limitation in available energy-conserving building elements

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Problems with reaching the energy performance requirement with building elements which have the same Cost of Conserved Energy

The method can be used to identify potentials for further product development:

- Sandwich panels of high performance concrete
- Insulation with a lower thermal conductivity in order to avoid the constraint on insulation thickness in i.e. the walls
- Ventilation units with lower SFP
- Windows with a larger net energy gain

Conclusions

1. The presented method can in a simple and transparent way integrate economic optimization into the design decisions made in the early stages of design.

2. An economic optimum can be found where the marginal Cost of Conserved Energy is identical for all energy-conserving building elements.

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   The method can identify the economically optimized combination of various energy-conserving building elements needed to fulfill the energy performance requirement.

3. The method can be used to identify the potentials for further product development.