Statens Byggeforskningsinstitut
AALBORG UNIVERSITET

3rd International Symposium on
Energy Challenges & Mechanics
- towards a big picture
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Heat Loss Measurements in Buildings Utilizing a U-value Meter

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Session 07
ENERGY AND ENVIRONMENT

- Energy consume in buildings in Denmark accounts for approximately 40% of the entire national energy consumption.
- For this reason, a reduction of heat losses from building envelopes are of great importance in order to reach the Bologna CO_2 emission reduction targets.

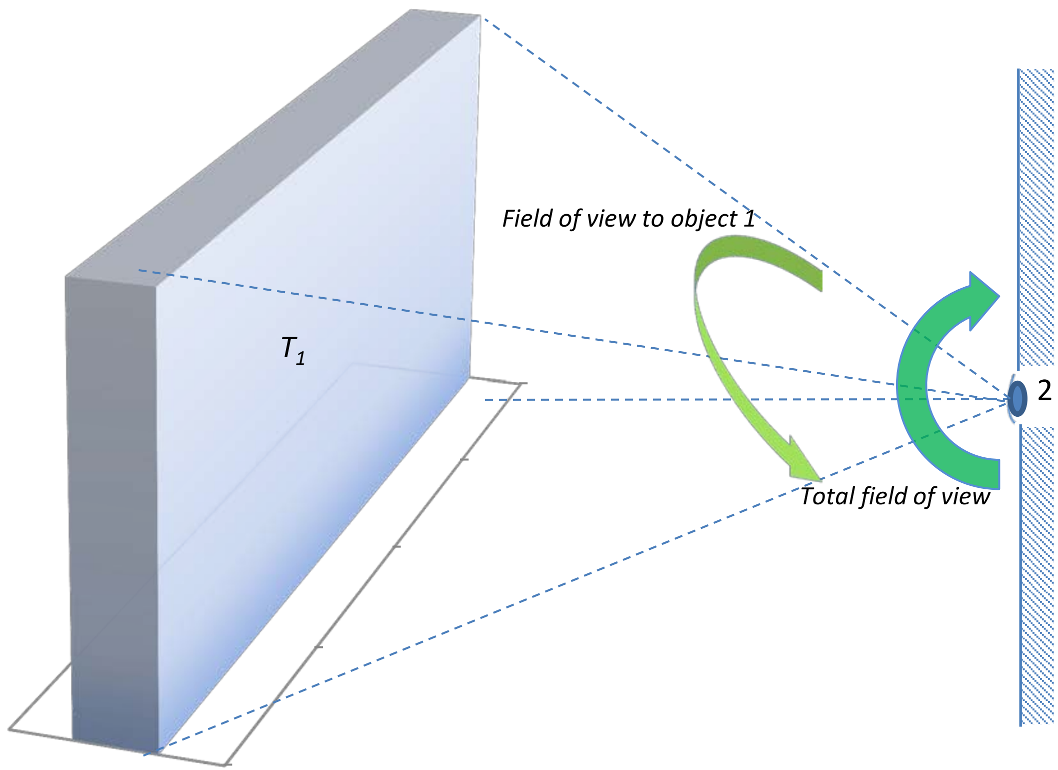
- Upgrading of the energy performance of buildings is a topic of huge global interest these years.
- Not only heating in the temperate and arctic regions are important, but also air conditioning in the tropical countries contribute to an enormous energy consumption and corresponding CO_2 emission.

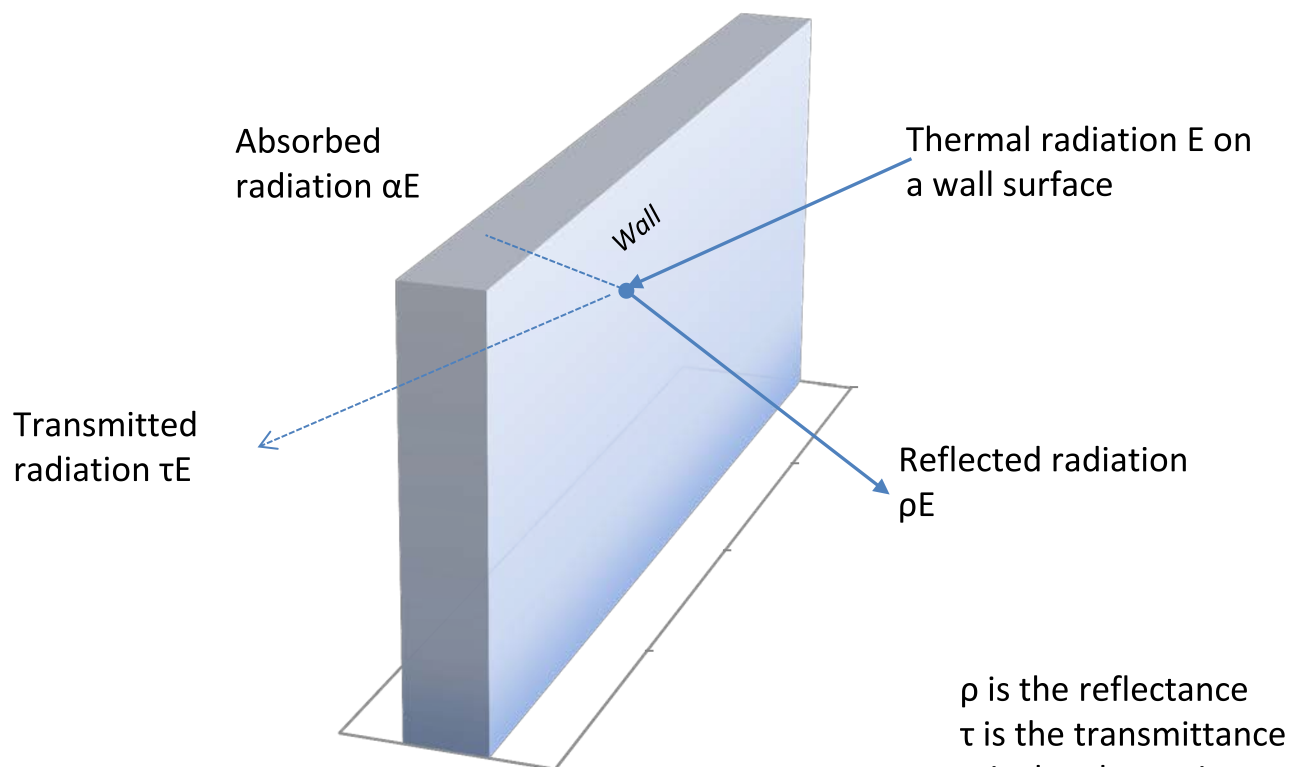
- In order to establish the best basis for upgrading the energy performance, it is important to measure the heat losses at different locations on a building facade, in order to optimize the energy performance.
- The author has invented a U-value meter, enabling measurements of heat transfer coefficients.

- The meter has been used in several projects to upgrade the energy performance of buildings in temperate regions.
- For instance, the U-value meter was utilized in a EUDP (Energy Technological Development and Demonstration Program) focusing on renovation of houses from the 1960s and 1970s.

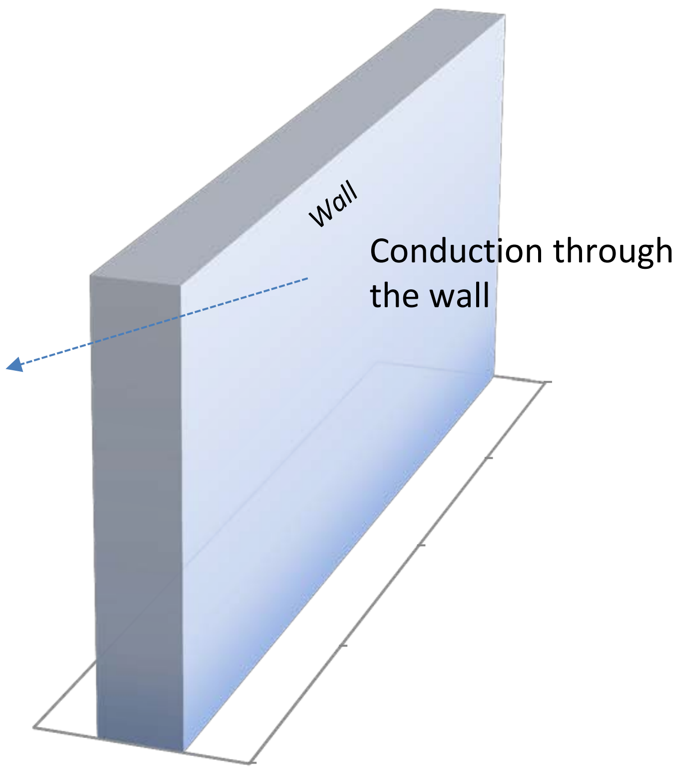
- This study has focus on the consumption of energy for heating and cooling of buildings. There is a huge energy-saving potential in this area for reducing both the global climate problems as well as economy challenges.

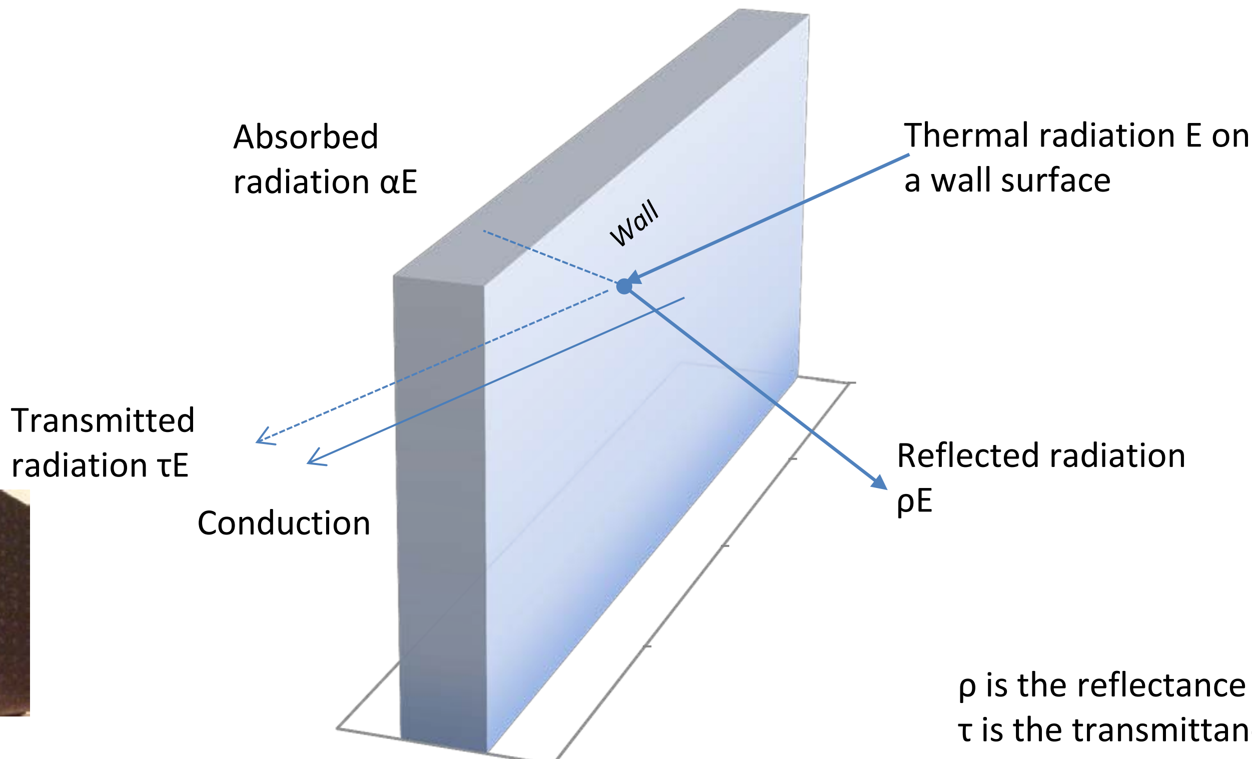
- In fact, global energy efficiency can be obtained in two ordinary ways. One way is to improve the energy production and supply side, and the other way is, in general, to reduce the consumption of energy in society.
- The U-value meter is intended for the latter purpose.


T_1
Field of view to object 1
2
Total field of view



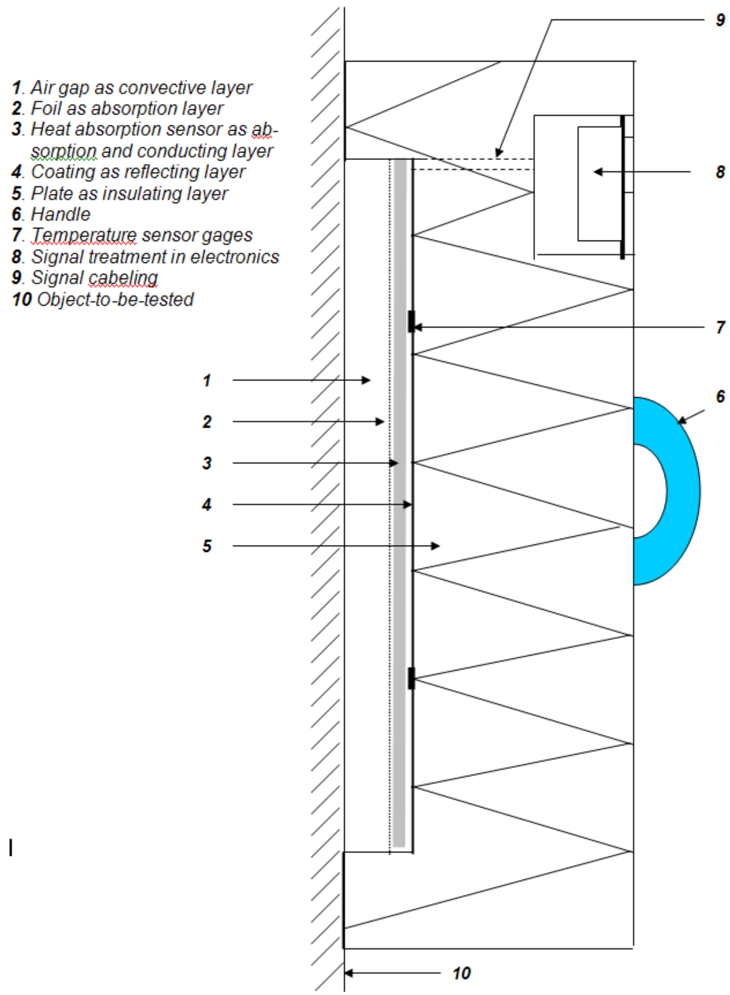
ρ is the reflectance
τ is the transmittance
α is the absorption


Wall
Conduction through the wall



ρ is the reflectance
τ is the transmittance
α is the absorption

U-value meter in principle



U-value meter in use and it`s storage

Theory

One of the main objectives of the U-value meters` processor is to solve Fourier's heat transfer equation for a steady-state situation. This equation, in differential form, can be expressed as:

$$\Phi = k \cdot dT/dx \quad (1)$$

where dT/dx is the temperature gradient through a homogenous material, in the direction of heat transfer. The equation is representing the heat loss in Joules per second for each square meter of the test piece. (1) is a special 1D form of Fourier`s law, which only applies to the steady-state.

The energy (heat) leave the cold side of the test object and hits the U-value meters` heat absorption sensor in two ways:

I. By convective heat transmission:

$$\Phi_c = h \cdot (T_{air} - T_{cu}) \qquad (2)$$

II. By thermal radiation, where the approximate equation for the radiative heat flux (*i.e.*, radiative heat transfer per unit area) between the surfaces bounding the air gap is:

$$\Phi_r = \frac{\sigma \cdot (T_{test\,piece}{}^4 - T_{cu}{}^4)}{\frac{1}{\varepsilon_{test\,piece}} + \frac{1}{\varepsilon_{cu}} - 1} \qquad (3)$$

The heat transmission coefficient, or U-value, is obtained this way: The summarised energy in the heat absorption sensor will rise the temperature in the sensor to a level corresponding to the new level of internal energy, governed by the product:

$$m_{cu} \cdot c_{cu} \cdot \Delta T_{cu} \quad (4)$$

Therefore the rise in level of internal energy should equal the amount of energy transmitted to the heat absorption sensor which can be expressed like this:

$$\Sigma(\Phi_c + \Phi_r)_i \Delta t_i \quad (5)$$

The heat transmission coefficient through a multilayer slab with thermal resistances at the inner and outer surfaces is defined by:

$$1/U = \Sigma dX_i/k_i + R_{in} + R_{out} \quad (6)$$

We also need to take the area of the heat absorption sensor plate into consideration. The equation:

$$\Sigma(\Phi_c + \Phi_r)_i \Delta t_i \cdot A = m_{cu} \cdot c_{cu} \cdot \Delta T_{cu} \tag{7}$$

T_{in} and T_{out} are the absolute indoor and outdoor temperatures, respectively

$$\Phi = (\Phi_c + \Phi_r)\cdot A = U\cdot A\cdot(T_{in} - T_{out}) \quad (8)$$

From (8) we are able to get the U-value expression as:

$$U = (\Phi_c + \Phi_r)\cdot A/(T_{in} - T_{out})\cdot A \quad (9)$$

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By multiplying numerator and denominator with the measuring time Δt (= 20s) and utilize the relations given by (7) noting that $\Delta t = \Sigma \Delta t_i$, we get:

$$U = m_{cu} \cdot c_{cu} \cdot \Delta T_{cu} / (T_{in} - T_{out}) \cdot A \cdot \Delta t \qquad 10$$

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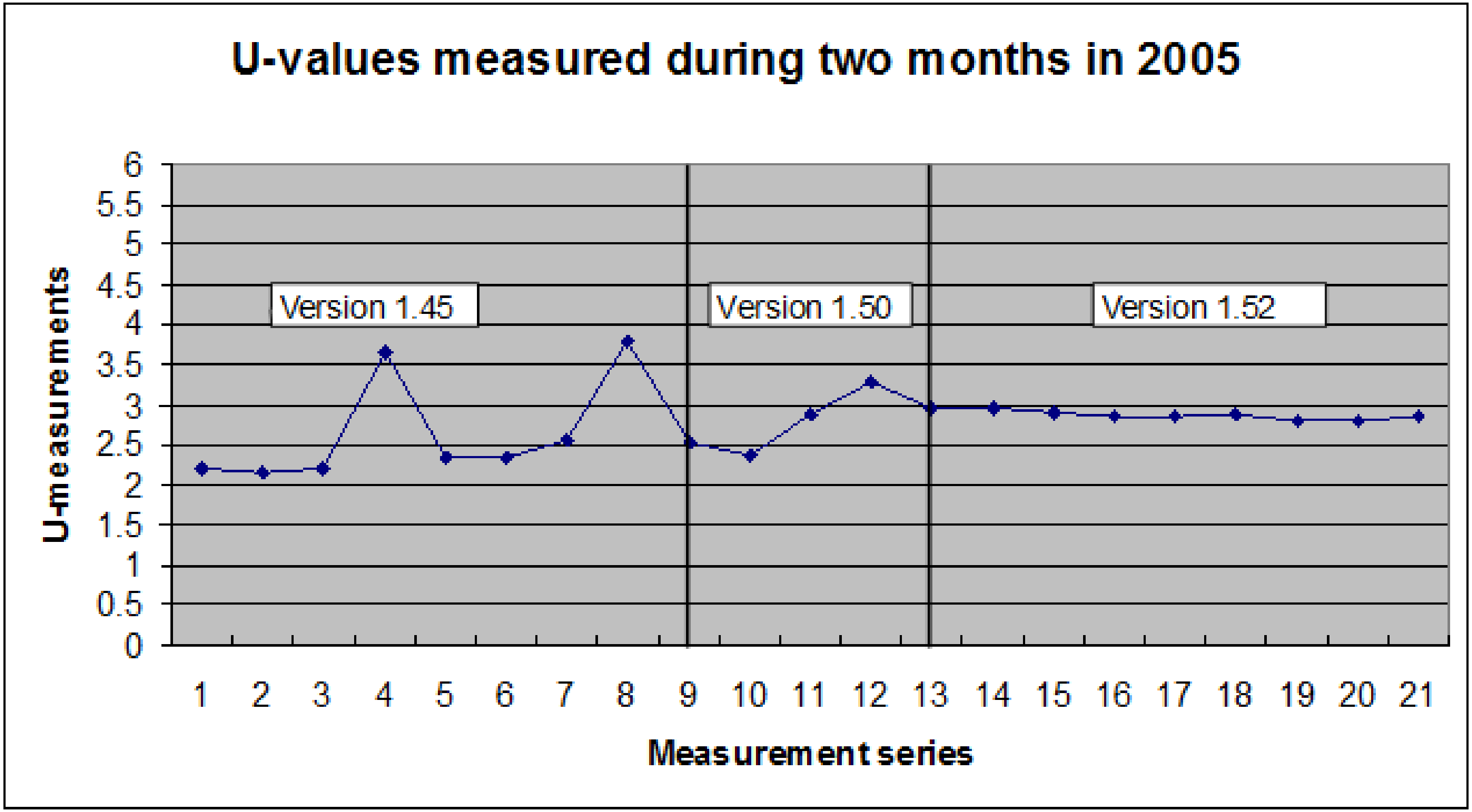
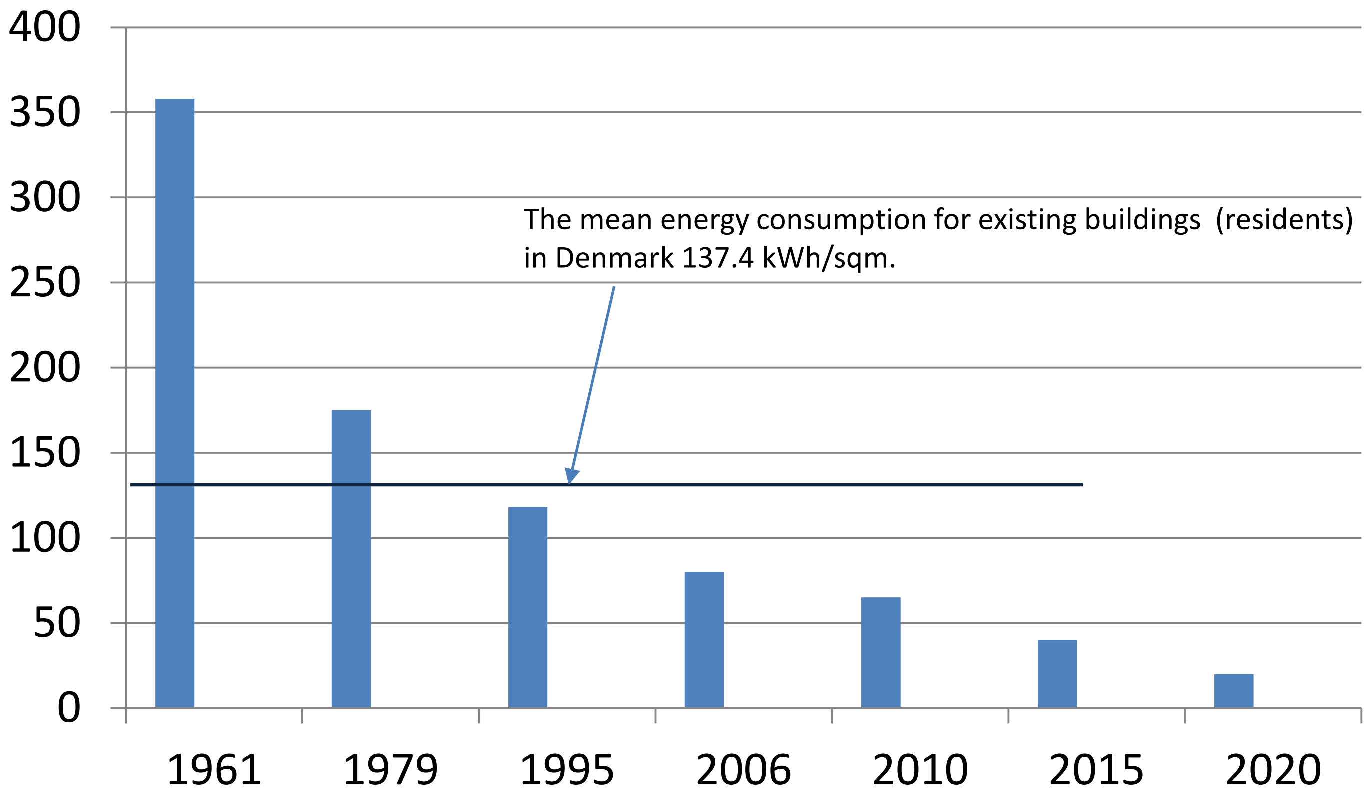


U-value requirements

Building Regulations	1961	1966	1972	1977	1982	1985	1995	2008	2010
Outer wall light	0.60	0.60	0.60	0.30	0.30	0,30	0.40	0.40	0.30
Outer wall heavy	1.00	1.00	1.00	0.40	0.40	0.40	0.40	0.40	0.30
Windows	3.60	3.60	3.60	2.90	2.90	2.90	2.30	2.00	1.80
Ground slab	0.45	0.45	0.45	0.30	0.30	0.30	0.30	0.30	0.20
Facade doors	-		3.60	2.00	2.00	2.00	2.30	2.00	1.80
Inner walls*	2.00	2.00	2.00	0.50	0.50	0.50	0.50	0.50	0.40
Roof	0.45	0.45	0.45	0.20	0.20	0.20	0.25	0.25	0.20
Crawl space slab	0.45	0.60	0.60	0.30	0.30	0.30	0.30	0.30	0.20
Plinth	-	-	-	-	-	-	0.40	0.40	0.40

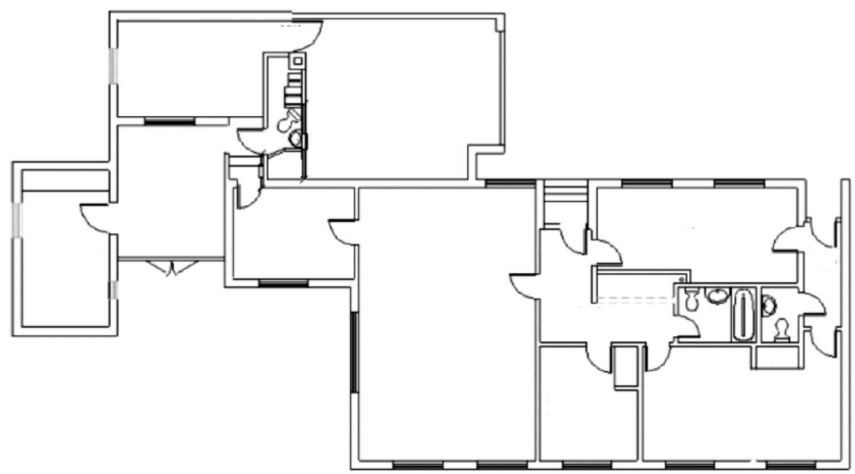
* Inner walls against not heated or low heated rooms

Energy requirements



Source: Energistyrelsen

- One of the test houses involved in the Energy Technological Development and Demonstration Program (EUDP) project.



Thermography


11.0 °C
8.0
4.0

Table 1. Measurements of U-values for a typical Danish residential house from the 1960s.

Id	Object	T_{in} (°C)	Remark	U-value (W/m^{2}K)
1	Parapet	21.9	2 thin wooden boards with air/insulation between. 3 cm thick in total	1.44
2	Outer wall	23.0	Measured at 70 cm height	0.80
3	Outer wall	22.4	Measured at 1.5 m height	0.84
4	Outer wall	23.3	Measured at 1.5 m height	0.88
5	Pane	23.3	Measured at the middle of the pane	1.24
6	Outer wall	23.3	Measured at 1.5 m height	0.87
7	Outer wall	23.5	Measured at 1.5 m height	0.81
8	Outer wall	23.5	Measured at 1.5 m height	0.85
9	Exterior door	22.0	Door made of 4 cm thick wood (possibly teak)	1.72
10	Pane	22.3	Measured at the middle of the pane	1.30
11	Outer wall	22.3	Measured at 1.5 m height	0.89
12	Beam	22.3	Window lintel (lightweight concrete)	1.12
13	Edge of wall	22.3	No significant peripheral effects were measured	0.91
14	Exterior door	22.0	Door made of 4 cm thick wood (possibly teak)	1.78
15	Wall	22.4	Wall between the garage and living room	0.32
16	Outer wall	20.5	Outer wall of utility room/laundry room (facade)	0.26
17	Outer wall	20.5	Outer wall of utility room/laundry room (gable)	0.29
18	Outer wall	20.5	Outer wall of utility room/laundry room (gable)	0.29
19	Socket	21.9	Measured at the center of the base	1.03
20	Outer wall	22.7	Built-in cupboard stood up against this wall. Measured at 40 cm height	0.36
21	Pane	22.7	Measured at the middle of the pane	1.16
22	Outer wall	22.7	Measured at wall section below the window	0.32
23	Outer wall	22.7	Measured at 40 cm above socket level	0.20
24	Outer wall	22.7	Measured 80 cm above bottom of wall	0.23

Savings

Based on the measured U-values in Table 1, thermography and measurements of surface areas for the different types of structures and building elements (outer walls, exterior doors, windows etc.), it is possible to calculate potential reduction (saving) in energy (Q) for heating with the renovation in 2005 as reference-level.

$$Q = \Sigma\Phi_i \cdot t = \Sigma U_i \cdot A_i \cdot (T_{in} - T_{out}) \cdot t$$

The equation is used for both the measured U-values and the required U-values and the difference ΔQ is an expression for savings in energy (Joule).

Conclusion

- It is indeed the houses build before approx. 1985 that represents a saving potential of about 80 %
- Therfore our focus should be on energy renovation of buildings from before 1985.
- The use of a U-value meter gives the actual U-values (not the intended or calculated).
- By use of the U-value meter it is possible to find the potential savings on heat loss through the facades, already during the planning process.