Article

Energy reduction in buildings in temperate and tropic regions utilizing a heat loss measuring device

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There exist two ordinary ways to obtain global energy efficiency. One way is to make improvement on the energy production and supply side, and the other way is, in general, to reduce the consume of energy in the society. This paper has focus on the latter and especially the consume of energy for heating and cooling our houses. There is a huge energy saving potential on this area reducing both the World climate problems and economy challenges as well.

Heating of buildings in Denmark counts for approximately 40% of the entire national energy consumption. Of 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. Energy renovation of buildings is a topic of huge focus around the world these years. Not only heating in the temperate and arctic regions are of importance, but also ACMV in the “warm countries” contribute to an enormous energy consumption and corresponding CO_2 emission.

In order to establish the best basis for energy renovation, it is important to have measures of the heat losses at different places on a building facade, for optimizing the energy renovation. This paper presents a method for measuring the heat loss by utilizing a U-value meter [2]. The U-value meter measure the heat transfer in the unit W/Km^2 and has been used in several energy renovation projects in temperate regions. The U-value meter was also utilized in a EUDP-project focusing on renovation of houses from the 1960`ties and 1970`ties. The U-value meter is now planned to be utilized in the tropics for measuring the thermal performance of facades with the aim to reduce the costs to AC. In this context we introduce the initiation of a project between NUS (National University of Singapore), AAU (Aalborg University, Denmark) and HT-Meter, the latter as the U-value meter developer company.

Keywords: energy reduction from buildings, heat loss measuring; energy renovation; heat loss measuring device; temperate and tropic regions, CO_2-emission, World climate, world economy.

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1. Introduction

1.1. Introduction to Energy Renovation

Around the world, building owners are able to decrease heating costs remarkably with a rational energy renovation of their buildings. This is proven by measurements of different houses, built in different decades of the past century. A few examples are described for houses from the Nineteen-sixties and the Nineteen-seventies in this paper.

Heating accounts for some 40% of the total Danish energy consumption which, therefore, represents vast potential savings. The U-value meter is an ideal instrument by which to establish the locations of greatest heat loss on a facade, arming owners with the knowledge of where best to concentrate efforts to insulate and optimize savings. In this way overall costs of energy renovation can be reduced considerably, and an optimal relation between investment and savings achieved.

The mean ambient temperature in Denmark has increased by about 1.2 ºC during a period of approximate 130 years [4]. The period encompasses a part of the industrial revolution which began during the second half of the 18th century. Energy renovation of as many houses as possible worldwide would benefit the environment by slowing and decreasing the consequent global heating.

A EUDP-project with the aim of designing standardized solutions for energy renovation of facades is currently running. In the project the U-value meter is utilized to measure representative U-values for a number of different residential houses built in a period from nineteen-sixties to the nineteen-seventies representing over 90 percent of private houses in Denmark. The measurements will be compared to the U-value requirements for the respective construction periods. From this approach we are able to calculate the potential heat savings compared to the present U-value requirements, as per the Building Regulations. Furthermore, we compare heat consumption before and after energy renovations where the developed standard solutions for the renovation of facades are used. The involved parties are, among others, HT-Meter ApS., Saint-Gobain Isover A/S together with DTU. The project aims to minimize the emission of CO_2 caused by unnecessarily large energy consumption for heating [2].

1.2. Introduction to U-value Meter

Measurements of U-values have traditional been made in laboratories with the assistance of heat flux measurements and heat conductivity apparatus [3]. Such measurement methods are complicated and laborious because the target wall or window elements must be transported to the laboratory and mounted into the test arrangement designed for the experiment. Then controlled amounts of energy, resulting in rises in temperature, must be supplied to the test arrangement in order to initiate the essential heat transfer in the test piece.

Fourier's law $\Phi = k\Delta T/\Delta x$ (a special 1D form of Fourier's law) representing heat conduction, only applies to the steady-state. Laboratory measurements of U-values can take several hours or even days before a steady-state measurement can be obtained.

The time required to reach a steady state situation depends primarily on the thermal inertia of the test piece, *i.e.*, material based properties such as heat capacity, density, thermal conductivity and material thickness. After that measurements of the heat flux are typically carried out for a relatively long period of time. This is done by means of measurements in test arrangements which are large in volume, typically several cubic meters. The heat flux is measured by holding a constant temperature level on the heat receiving side, *i.e.*, the cold side of the test piece. The basis of finding heat conductivities practically is by means of laboratory based measurements on conditioned test specimens brought to steady state by means of a plate apparatus with a protective ring or with a heat flux meter per DS/EN 12664 or DS/EN 12667. The results from the measurements refer to a mean temperature of 10 ºC. Common to the aforementioned measuring methods is the problem of a transition insulation factor at the bounding surfaces on the two sides of a test piece. The surface temperatures of the test piece are not identical to the air temperatures very near to its surfaces. This problem is addressed in different ways by state of the art technology and with reasonable accuracy [3].

With the newly developed U-value meter, such process can be omitted and U-values can be measured directly on site. See figure 1 for a picture of the U-value meter.

Figure 1. U-value measurement on outer wall. The figure also shows an insulated acclimation suitcase, in which the meter is placed in between the individual measurements.

This apparatus is based on a principle where the heat is ‘trapped’ by a heat absorption sensor (copper plate) when it leaves the outdoor surface of the test piece. A copper plate is used, as the absorption sensor due to its high thermal diffusivity and high conductivity.

The temperature of the heat absorption sensor is measured continuously over a short period of time, and from the relative increase of energy the U-value can be calculated. The system is separated from the surrounding environment with a highly insulating material, of low thermal diffusivity and low conductivity.

Heat transfer occurs by thermal radiation, conduction and convection and the apparatus is designed to ensure that these constituent energy components are collected by the sensor plate. In fact, in the case of windows, radiation alone can account for as much as 70 percent of its total heat loss. However, this value can be reduced drastically with a low emissivity coating: windows with and without these coatings can be handled by the U-value meter.

Heat conduction is the molecular oscillation transport whereas radiation is electromagnetic energy transport. In the U-value meter it is chosen to transform the heat conduction (conduction in a solid) to convection in a fluid (an air gap in front of the copper plate is included to do this). That is to say the transfer process to the heat absorption sensor is changed from conduction to convection through the air gap. It is important to ensure that the temperature of the heat absorption sensor is identical with the outdoor temperature just before a heat transmission coefficient (i.e. U-value) measurement is initiated [3].

The heat absorption sensor is coated with a material of high heat absorption capacity to secure a quick and effective heat transfer from test piece to heat absorption sensor. Heat transfer occurs by convection as well as thermal radiation *via* the described air gap. Following this procedure, there is no ongoing heat transfer from the surface of the test piece to the heat absorption sensor by direct contact.

By the new 'air gap' technique, developed with this U-value meter, the problems of transition insulation factor and surface temperature are eliminated, creating more accurate results. At the same time, geometrical inaccuracies at the surface of the test piece are eliminated by the air gap. These would, by direct contact, cause irregular heat conduction between the two surfaces, *i.e.*, between the test piece and the copper plate.

The coating is placed on the side of the heat absorption sensor facing the test piece. On the opposite side of the heat absorption sensor, apart from the test piece, is placed a reflecting layer, to ensure energy transmitted to the heat absorption sensor is trapped and kept inside during the test.

Behind the reflecting foil is a heat insulating layer, of relatively thick dimensions, and low thermal conductivity and diffusivity as basic thermal properties [3].

With this invention a very good accuracy is achieved for measuring of transmission coefficients (U-values). The accuracy of the results is between +/–5 percent from the 'correct' result according to information from different producers of building components, tested *via* laboratory.

Another advantage of the invention is that the U-values are measured on site and in real time, giving current information of transmission coefficients for a particular building as opposed to the 'new building element' U-value. This is important of several reasons: first of all in a building element, an outer wall for instance, the moisture content changes during the years in which the element has been a part of the building. Moisture levels will influence the U-value, depending on the relative humidity and the type of material in focus. Furthermore the insulation in an outer wall can 'fall down' a bit during the years resulting in poorly distributed insulation. For windows the glazing can puncture and the insulating effect is reduced significant [2,3].

1.3. Main Processor

One of the main objectives of the processor in the U-value device is to solve Fourier's heat transfer equation for a steady-state situation [3]. 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. The apparatus is intended mainly for existing buildings where a steady-state heat flow is already obtained. The heat loss expressed by the above differential equation is integrated by the processor during a fixed measuring period of 20 seconds. The energy is transmitted to and captured by the heat absorption sensor through a ‘five layer thermal system’. The total transport of energy from the surface of the test object to the surface of the heat absorption sensor takes place by two separate processes (convective heat transmission and thermal radiation)

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:

$$m_{cu} \cdot c_{cu} \cdot \Delta T_{cu} \tag{2}$$

where m_{cu} is the mass and c_{cu} is the specific heat capacity of the heat absorption sensor. ΔT_{cu} is the temperature rise in the heat absorption sensor during the measuring period [2,3].

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:

$$\Sigma(\Phi_c + \Phi_r)_i \Delta t_i \tag{3}$$

where Φ_c is the convective heat flux and Φ_r the radiative heat flux. Δt_i is 1 s intervals over which the sensor energy integration is performed. The energy is integrated over the measurement period, *i.e.*, 20 s. The heat transmission coefficient through a multilayer slab with thermal resistances at the inner and outer surfaces is defined by:

$$1/U = \Sigma dX_i/k_i + R_{in} + R_{out} \tag{4}$$

where R_{in} and R_{out} are the interface resistances from the air layer at the inner and outer surfaces respectively. dX_i is the thickness in meter of layer number ‘i’ in a composite construction, and k_i is that layer’s corresponding heat conduction coefficient in [W/m·K]. We also need to take the area of the heat absorption sensor plate into consideration. The equation:

$$\Sigma(\Phi_c + \Phi_r)_i \Delta t_i \cdot A = m_{cu} \cdot c_{cu} \cdot \Delta T_{cu} \tag{5}$$

where A is the area (m^2) of the heat absorption sensor plate is the main equation, and it is solved taking the following relation from [2,3] into account:

$$\Phi = (\Phi_c + \Phi_r) \cdot A = U \cdot A \cdot (T_{in} - T_{out}) \tag{6}$$

T_{in} and T_{out} are the absolute indoor and outdoor temperatures, respectively. From (6) we are able to get the U-value expression as:

$$U = (\Phi_c + \Phi_r) \cdot A/(T_{in} - T_{out}) \cdot A \tag{7}$$

By multiplying numerator and denominator with the measuring time Δt (= 20s) and utilize the relations given by (5) noting that $\Delta t = \Sigma \Delta t_i$, we get:

$$U = m_{cu} \cdot c_{cu} \cdot \Delta T_{cu}/(T_{in} - T_{out}) \cdot A \cdot \Delta t \tag{8}$$

Therefore, before a measurement is started, we need to know the temperatures on both sides of the test object *i.e.*, T_{in} and T_{out} respectively. The apparatus is able to measure T_{out} automatically.

It is beyond the scope of this presentation in detail to present the form of the related data processing algorithm in the main processor, including output validation. But, the data processing aims to solve the above described thermo-physics. For further information see [2].

2. EUDP-project

In Denmark there is a great energy saving potential in houses built in the nineteen-sixties and seventies. Special scrutiny is given to these houses since they account for a large part of the total residential dwellings. In principle it is possible to energy renovate all types of housing up to modern requirements. It just depends on a sufficient increase of insulation in facades and ceiling, replacing traditional double-glazed panes with energy saving panes of low U-value (<1.1 W/m^{2}K), mounting draught-exclusion strips around doors and windows, optimizing heating systems, changing to energy saving light sources and, crucially, on willingness to pay up-front costs for hidden benefits.

During a EUPD-project [6] with participants from Technical University of Denmark, Saint-Gobain, Weber, Isolink, HT-Meter and others, measurements are made on typical residential houses from the nineteen-sixties and seventies. As an example table 1 presents measurement results (U-values) for a 145 sqm. house build in 1964, located at Christianshøjvej, Kirke Værløse, Denmark. The house was partly rebuilt and added in 2005. Outer walls are made of solid aircrete blocks. Some of the outer walls were insulated (inside) during the rebuilt in 2005. Heating of the house is done via a new condensing natural gas boiler. The U-measurements were made the 6th April 2011 between 9:30 and 12.10 AM by the U-value Meter (software version 1.60) together with a RayTek laser/infrared temperature measuring device. Weather conditions were calm, with wind speed < 5 m/s, no rain and with outdoor temperatures ranging from 8.0 ºC at 9:30 AM and increasing to 10.0 ºC at 12:10. The U-vale measurements were accompanied with thermography, and a few examples of these are shown on the figures 3 to 5. A plan drawing of the house is shown on figure 2.

Figure 2. One of the test houses involved in the EUDP-project.

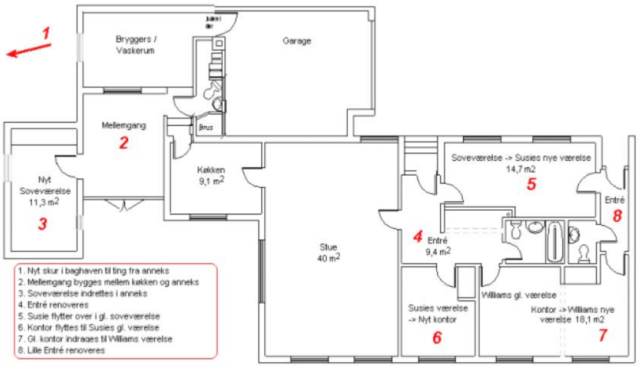

Figure 3. Poorly insulated window/door section along a corridor that connect the main house with an annexe. The U-value is measured to U-value=1.44 (Id 1,the wood parapet). The outer wall next to the wind/door section was measured to U-value=0.80 (Id 2). See table 1 for measured U-values.

Figur 4. Gable (west) with window to the bedroom. This room`s outer wall was previously insulated from inside. However a thermal bridge interruption was omitted along the floor concrete slab and therfore the socket is enlighted at the thermography to the right. The U-value was measured to 1.03 (Id 19) compared to the insulated outerwall U-value=0.32 (Id 22), see table 1.

Figur 5. The transition between the wall and the floor is okay. There were not registered leaks in this door. The door dark shades indicate cold surfaces and a relatively large heat loss through the door. That corresponds to a high U-value, which is confirmed by Table 1, where the door is measured to U-value = 1.72 (Id 9) compared to the outer wall`s U-value = 0.89 (Id 11).

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

Id	Object	T_{in} (°C)	Remark	U-value (W/m^2K)
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 (possible 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 (light weight concrete)	1.12
13	Edge of wall	22.3	There was not measured any significant peripheral effects	0.91
14	Exterior door	22.0	Door made of 4 cm thick wood (possible teak)	1.78
15	Wall	22.4	Wall between the garage and living room	0.32
16	Outer wall	20.5	Outer wall of the utility room/laundry room (facade)	0.26
17	Outer wall	20.5	Outer wall of the utility room/laundry room (gable)	0.29
18	Outer wall	20.5	Outer wall of the 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 (2th brick)	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

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 the potential savings in energy (Q) for heating. If an energy renovation fulfilling the current requirements to U-values stated in the Building regulations is implemented, we can write:

$$Q = \Sigma\Phi_i \cdot t = \Sigma U_i \cdot A_i \cdot (T_{in} - T_{out}) \cdot t \quad (9)$$

U_i and A_i are U-values and areas, respectively, for the building parts (windows, exterior doors, outer walls). t represents the time (could be set to a year) if we use an average indoor temperature and the year mean temperature. The Q-equation (9) is calculated for measured U_i as well as for required U_i-values, and the difference (ΔQ) represents the saving of energy.

The budget for energy renovation of this house was about DKK 470,000 (USD 94,000). The energy consumption (heat and electricity) was as much as DKK 39,000 (USD 7,800) per year (including heat for a pool). Natural gas for heating in year 2009/2010 was 1,906 m^3 (heating of house excl. pool) corresponding to 145 kWh/m^2. A small part of the house (a corridor and a bedroom) was heated by electricity with consumption in 2010 of 1,354 kWh. Indoor temperature (year average) is 22 ºC. The saving potential on heating (gas consumption alone) was DKK 10,800 (USD 2,160) per year corresponding to approximately 60% saving of the heat expenses for the main house, disregarding the swimming pool. This saving potential corresponds to the below listed energy renovation:

- Outer walls including sockets are insulated with 195 mm mineral wool which is plastered.
- One exterior door replaced with a modern entrance door with low U-value. The other exterior door is removed and the opening closed and insulated as the rest of the façade.
- Insulating of the house entrance with 100 mm insulation
- Gables and foot of roof is insulated with good connection to the ceiling insulation
- Digging up soil around the concrete foundation and in top establishment of new foundation blocks made of light weight concrete and insulated with phenolic foam (PF).
- The existing windows (with energy panes) are moved out to align with the façade.
- Installation of mechanical ventilation (balanced) aggregate with heat recovery
- Airtight of the ceiling and between ceiling and outer walls.
- Insulating of bedroom (previously insulated from inside to a certain level)

A number of other measurements are made on different buildings during the last seven years, partly in parallel with the development of the apparatus and integrated OS-software. Other examples on measurements are presented in [2]. In the same reference you will find a discussion of the limitations and uncertainties of the U-value meter.

3. Planned measurements in tropic regions

A research cooperation about thermal performance of facades in tropics is initiated with SERIS (Solar Energy Research Institute) at NUS in Singapore. After a number of phone meetings about proposals, agreements (including scope of work), non-disclosure agreement etc. we have the first meeting in Singapore during a PVAP Conference organized by SERIS. We made the first U-value measures of a façade and held an introduction course on how to use the U-value meter and so forth. A strategy for the coming measurements of the thermal performance of facades was outlined. A number of houses in Singapore is the focus for measurements. The measured U-values will be the basis for proposals of thermal improvements of different types of facades, panes etc. The outcome of the project will be published by end of the cooperation for interested journals and/or at conferences.

4. Conclusions

Energy efficiency, energy reduction and energy renovation is elaborated. A new heat loss measuring device, called a U-value meter, has been developed. The device was invented in 2001 and the first application to the Danish Patent Office took place in March 2002. A Danish patent has been granted in 2009 (Patent number 176757). An international patent application has been filed in March 2003. The device can be utilized as a stand-alone apparatus, or in combination with thermograph-equipment. The latter should be in order to get a picture of the distribution of hot and cold locations of a buildings facade. But, since a thermography only gives a picture of the surface temperatures, and not the heat loss distribution, there arises a need for a heat loss measuring device. The device measures heat losses through the facades in the SI-unit [W/m^{2}K]. By means of the measuring device, it is possible to achieve a more cost-effective building renovation. It is possible to check whether heat transmission coefficients (U-values) meet the requirements as stated in the Building Regulations. The corresponding potential in reduction of energy consumption can be calculated. A huge energy saving potential for residential houses is demonstrated during a EUDP-project in a temperate region (Denmark). The initiation of a project in tropic climate in cooperation with NUS is introduced.

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