Calorimetric measurement of indoor sunshields

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Abstract:

Because of the sun irradiation the incorrect dimensioning of a house can lead to excessive internal temperatures. Cooling is a common solution, but this consumes a large amount of energy. Preventing the entry of solar radiation into the building is a better solution. The main question is, which thermal effect (g- and U- value) curtains and blinds have on the internal room temperature and cooling energy, due to less sun irradiation.

There are two identical rooms; one is used as a reference room without any installed sunshades, and the other is used for measurements (blind installed). Both test rooms where kept at the same reference temperature. With measuring all the energy flows into and out of both rooms, due to energy balance comparisons between the two rooms after a few measurement days, the values sought-after can be calculated.

During the U-value calibration an error was found, the flow meters for the cooling water flow, measured 10% wrong. Therefore with this system, no representative curtain measurement so far was possible. With another laboratory for an extra uncoated glazing a U-value of 5.88 W/m²K was measured. For a curtain which was mounted in a frame with the embrasure a few centimeter in front of a window 7.4 W/m²K was measured. It was figured out, that the way how it is mounted is important for this value.

Keywords: Energiemessung, Sonnenschutz, Vorhang, calorimetric measurement, sun shield

1 Motivation

Because of the sun irradiation the incorrect dimensioning of a house can lead to excessive internal temperatures, especially when the external temperature is high. Because of this, this system has been designed and built to measure indoor sunshields such as curtains and blinds in conditions as realistic as possible. With a system for outdoor shields it is not possible to measure the behavior in realistic conditions, it would be possible to measure the g- and U-value, it wouldn't be possible to consider that the shields heat up and change the “natural” air circulation and this change the behavior of the room.

[1] Jungautor

Normally cooling is a common solution to reducing room temperature to a moderate level, but this consumes a large amount of energy. Preventing the entry of solar radiation into the building in the first place is a better solution; while the initial investment is higher, energy consumption is greatly reduced, to the point where it is close to not having a sunshield at all. Other benefits include:

- Lower running costs
- Reduced dependence on electric power
- Less use of Freon

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Definition

- **U-value** [W/m²K] gives the heat flow rate in Watts [W] in the steady state divided by the temperature difference [K] between the ambiance's on each side of the system or component and the area [m²] of the considered material.
- **g-value** [-] is the heat flow rate [W] transmitted through the component to the internal environment under steady state conditions, caused by solar radiation incident on the outside surface, divided by the intensity of incident solar radiation [W] on the plane of the component. [2],[7]

2 The Laboratories

2.1 State of the art (PASSYS)

The European commission started the PASSYS project (Passive Solar Systems and Component Testing) in 1985 with the aim of testing passive solar components and developing calculation methods. The PASLINK Network (formed in 1986) emerged from PASSYS, with the fundamental aim of developing and improving methods for obtaining the thermal and solar properties of building/sunshade components. The PASSYS standardized test cells are used for measurements under realistic conditions with a controllable test environment, but it was determined that the measurements should also be obtainable under different and especially dynamic outdoor conditions.

As a result, a special room was developed (Figure 1). Various building facades were utilized, and the thermal properties determined by outdoor tests at different locations across Europe. While the evaluation of the solar gain factor (g-value) of passive solar components was the main purpose, but it was also possible to measure the U-value and thermal capacity. The test cells provided a well controlled environment in a realistic room size without occupancy effects. At the beginning of PASSYS the test methodology were based on steady state evaluations, but as the project progressed it became clear, that dynamic testing and analysis methods were required for high quality performance in real climates. [2],[8]

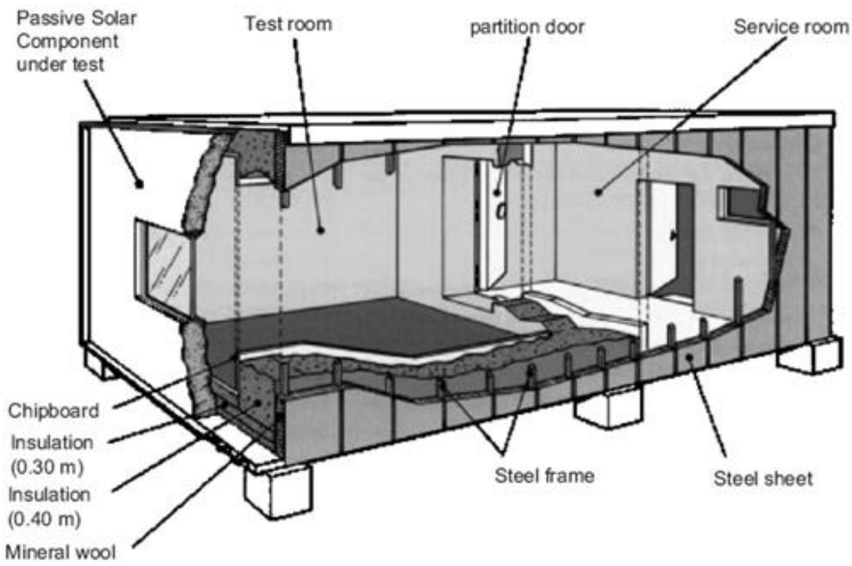

Figure 1: Room construction of PASSYS system [2]

The main features of this test room design are:

- controllable climate within the room
- realistic room size
- the room is located in a real outdoor climate
- two rooms (not at each place)
- not occupied
- well-insulated, exchangeable south wall

Each PASSYS test cell has a test room of 13.8m² ground area and 38m³ air volume, with an adjoining room to the north. The measuring and air-conditioning equipment are contained in this service room (see Figure 2).

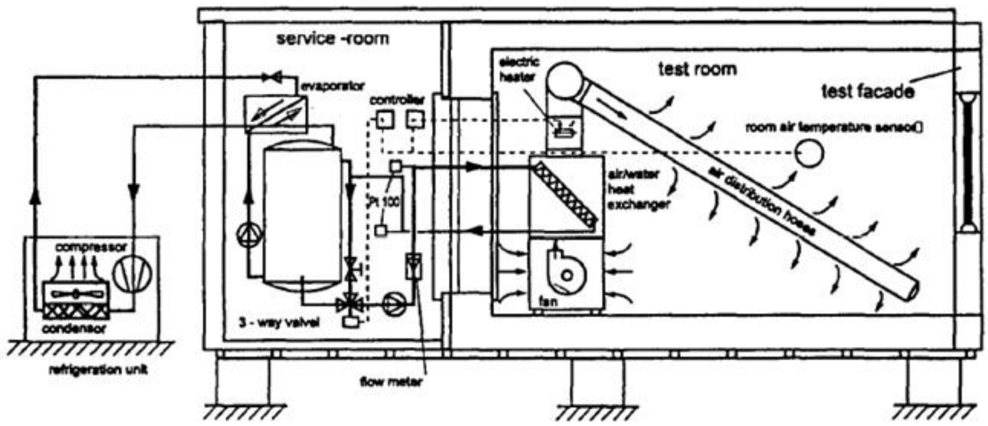

Figure 2: Details of room construction [6]

2.2 The lund tekniska högskola (LTH)- system

The basic measurement and controlling principle of the LTH system is the same as for the PASSYS system. One difference is, that there are two test rooms which did not exist at each PASSYS location. Both of them are surrounded by a bigger laboratory building. This can be imagined as well insulated portakabins within a building. In Figure 3 the two right window fronts belong to the sunshield measurement rooms. This has the advantage, that the outdoor conditions (like wind) only have an effect on the south facing wall. With the control system the room temperature of both test rooms and the surrounding laboratory is kept at the same temperature. This minimizes the heat losses through the walls, except the glass window front, which is oriented to the south. The advantage of having two rooms is that not each minor temperature effect has to be modeled. If there is a modeling error, it is the same for both rooms and using the energy difference as representative value the error zeros out.

Figure 3: South facade of the LTH- system [4]

The specifications for the calorimetric rooms were:

- Air temperature range: 16 °C - 27 °C
- Precision of temperature control: ±1 °C
- Heating power: 0.6kW
- Cooling power: 2.7kW

3 Measurement method

While many passive solar system concepts are quite simple, the involved thermal processes are very complex and the experimental determination of these properties is not straight forward. The performance depends on numerous diverse factors, such as relative area, the building's thermal mass, orientation and position of the component, to mention a few examples. The isolation of these factors and the understanding of how the component interacts with its surrounding is the primary task of experiments.

Because of the simultaneous operation of a mixture of heat transfer mechanisms, such as thermal radiation and free convection, it is not possible to measure the heat loss factor (U·A) or the solar gain (g·A) directly. Based on the measurement of the net heat flow through the building component, these quantities can be determined indirectly. The test cells are well equipped to measure this quantity.

After a long integration time of a few days/weeks the measured values are obtained to solve the steady state heat balance equ.(1). A physical illustration of this equation is shown in Figure 4.

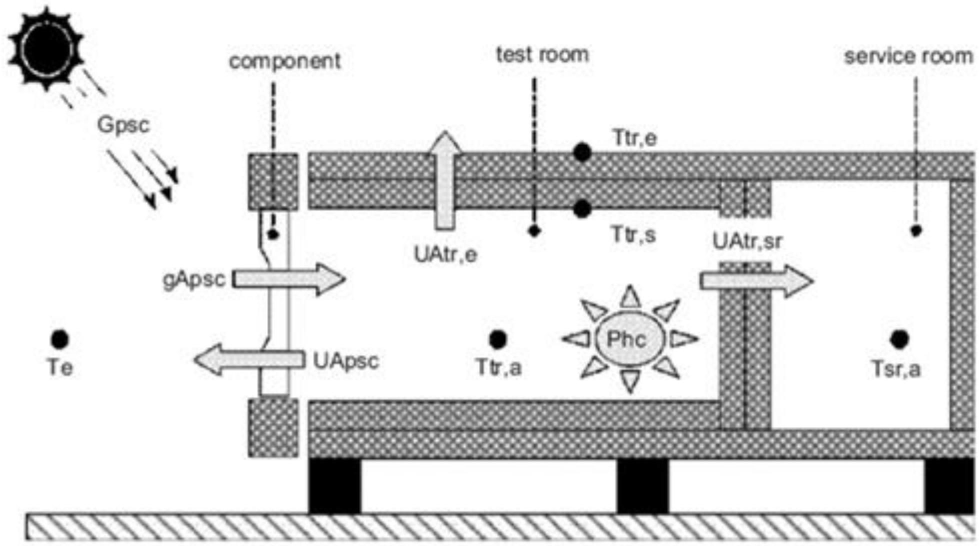

Figure 4: Schematic temperature behavior of PASSYS test cell [2]

$$-(UA)_{psc} \cdot \left(T_{tr,a} - T_e\right) + (gA)_{psc} \cdot G_{psc} =$$
$$(UA)_{tr,e} \cdot \left(T_{tr,s} - T_{tr,e}\right) + (UA)_{tr,sr} \cdot (T_{tr} - T_{sr}) - Q_{he} + Q_{co} \quad (1)$$

The first term on the left side of equ.(1) represent the losses through the measuring object, while the second shows the irradiation energy going through. On the right side, the first term represents the losses from the test room to the outside, while the second the losses from the test room to the service room characterize. The last two parts are the heating and cooling energies. It is possible to assume a constant room temperature because it is controlled via cooling and heating, then both sides must be equal.

All the different temperatures (e.g.: $T_{tr,s}$, $T_{tr,e}$, the heating (P_{he}) and cooling- energy (P_{co})) are measured. If $(UA)_{tr,e}$ and $(UA)_{tr,sr}$, are obtained via calibration and it is assumed that two or more measurements with different conditions are available, equ.(1) yields the values for $(UA)_{obj}$ and $(gA)_{obj}$. In steady state measurements, the temperatures of the test room and service room are kept at the same level $(T_{tr}-T_{sr})\approx 0$ and this part of equ.(1) becomes negligible. At the LTH- system the test- rooms are surrounded by the laboratory building, with the controlling system, both temperatures are kept at the same level too. Therefore

$(T_{tr,s}-T_{tr,e})\approx 0$ and this part becomes insignificant too. For more accuracy both of the terms are still considered in the further modeling process. The advantage of this operation is that it is straightforward. The disadvantage is that there needs to be time between each measurement in order, to avoid the influence of transient effects, therefore a sufficiently long period is necessary. It has to be considered that the test cells have a time constant to the order of two days due to the high insulation level, but other heavy and heavily insulated components may also have as high inertia. Another obvious disadvantage is, that this method only yields the steady state characteristics. [2],[3],[5]

The fact, that because of the test room design (laboratory surrounding) there is no difference between heat losses to the test room or to the surrounding. The first two terms of equ.(1) can be modeled as one part and reordered a little, which is shown in equ.(2). Where A_{glass} is the glass area and A_{total} is the frame and glass area, Q_{losses} is the combination of the two terms at equ.(1).

$$Q_{tot} = g \cdot G \cdot A_{glass} - U \cdot \Delta T \cdot A_{total} - Q_{co} + Q_{he} - Q_{losses} \qquad (2)$$

Equation (2) was modeled twice, once for the reference room and once for the measurement room. With the Newton- Raphson method (Figure 5) the g-value for the test room was calculated in such way. That the energy difference after a few days of measurement between both rooms became a minimum $(Q_{tot,\ reference}-Q_{tot,\ measurement})$<<.

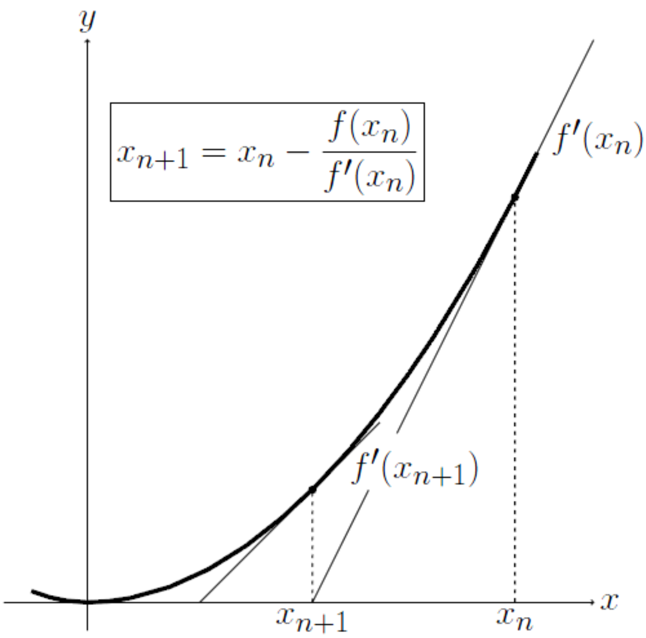

Figure 5: Schematic description of Newton- Raphson approximations

4 Results

Figure 6 shows the calibration process for the g-value calculation. The vertical sun irradiation for three days is displayed with the red line. The blue line represents the energy balance of the reference room (room 109). In the other room (108) half of the windows where covered with aluminum foil, which is equal with a g-value reduction of the original window size. The brown line shows the uncorrected energy balance of room 108, there is a gab during noon. After the g-value calculation (green line) the energy balance for both rooms is similar (blue and green line) and the difference over all three days is only 0.62Wh. Compared with a energy gab before the g-value calculation of 2.3kWh.

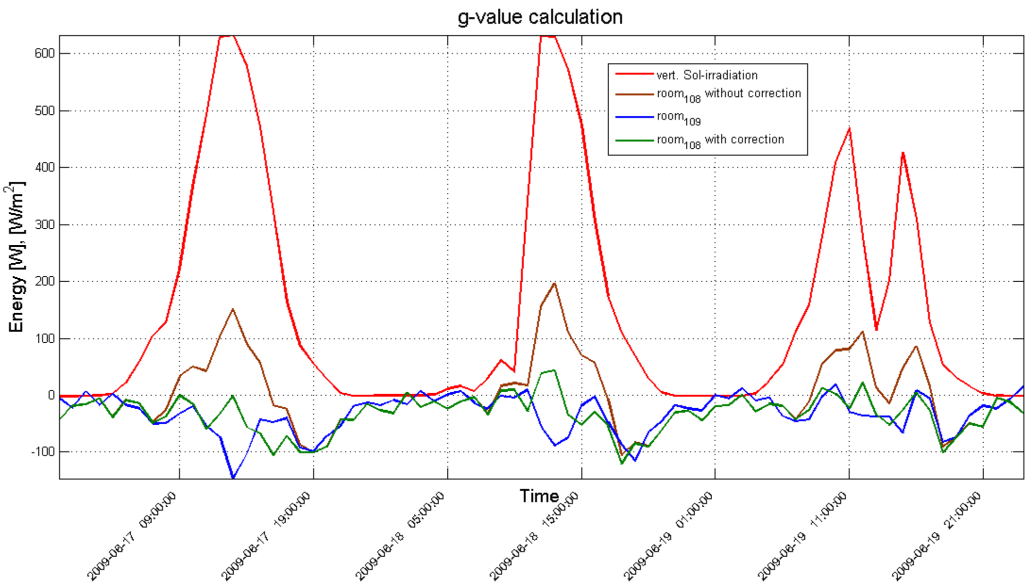

Figure 6: g-value calculation

The next calibration process was the U-value calibration. During this process an error was found, the flow meters for the cooling water flow, measured 10% wrong. Because of this with this system, so far no representative curtain measurement was possible. The error is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The blue line represents the heating energy and the green line the cooling energy which is afflicted with the 10% systematic error. The red line displays via software corrected cooling energy, for which still an error is left. This rest error made it impossible to get reliable values out of the measurement and a changing of the flow meters is necessary, which apparently couldn't be done so far.

But with another laboratory for an extra uncoated glazing a U-value of 5.88 W/m²K was measured. For a curtain which was mounted in a frame with the embrasure a few centimeter in front of a window 7.4 W/m²K was measured. It was figured out, that the way how it is mounted is important for this value. For instance if the frame was removed and better air circulation was possible the U-value was significant higher.

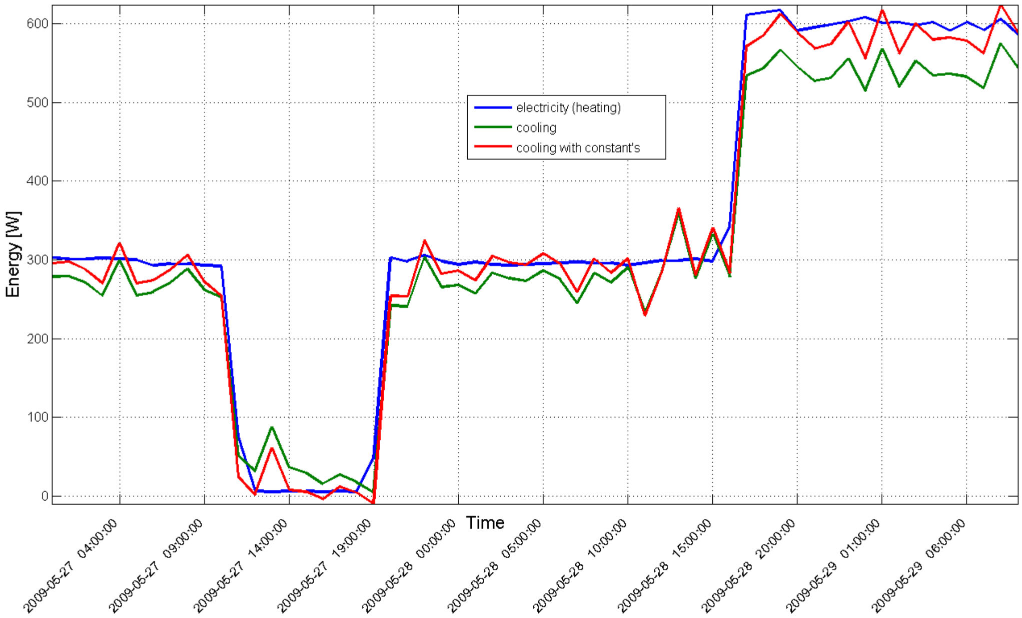

Figure 7: Measurement error of cooling measurement

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