A SIMPLE METHOD TO CALCULATE THE HEAT GAINS OF SOLAR WALL HEATING WITH TRANSPARENT INSULATION

M. Ochs and A. Haller
Ernst Schweizer AG, 8908 Hedingen, Switzerland, Tel. +41 1 763 63 64 and +41 1 763 63 80, Fax +41 1 763 63 18, markus.ochs@schweizer-metallbau.ch and andreas.haller@schweizer-metallbau.ch

H. H. Simmler
Swiss Federal Laboratories for Materials Testing and Research (EMPA), Ueberlandstr. 129, 8600 Dübendorf, Switzerland, Tel. +41 1 823 42 76, Fax +41 1 821 62 44, hans.simmler@empa.ch

Abstract - This paper describes a method to calculate in a simple way the heat gains of solar wall heating with transparent insulation (SWH-TI). A time independent g-value of the SWH-TI system is determined which allows to calculate the heat gains of SWH-TI in a static way, formally like these of a window (as defined e. g. in SN EN 832 or in the Swiss Standard SIA 380/1). Some constructive parameters are discussed in order to ease their quantification for architects and planning engineers. The heat gains calculated with the static method are compared to the results of a dynamic calculation with HELIOS. The method is illustrated with some examples for different SWH-TI systems.

1 INTRODUCTION

Solar wall heating with transparent insulation (SWH-TI) becomes more and more a common design option for new low energy buildings and solar building renovation. In several European countries, the building codes require a fairly sophisticated calculation of the heat energy demand for new buildings. With the advent of public funding and subsidies for energy efficient renovation, compliance with standards and codes is also required for building rehabilitation. Therefore, simple and easy to follow procedures are required on how to calculate energy gains of SWH-TI systems within the standard heat energy demand calculation methods.

In Platzer (1999) a method is proposed to handle SWH-TI systems in a static way. The energy relevant characteristics, i. e. the g-value and the thermal resistances, are not simple product characteristics and need to be calculated from the properties of the layers used for the SWH-TI design.

The present paper is based on the article of Platzer (1999). In order to determine a time independent g-value of the TI element, a slightly different way is investigated. The potential errors of the method are evaluated. In order to ease the use of the method for architects and planning engineers, some constructive parameters are discussd (temperature dependence of the thermal resistances of air gaps and of the TI material) and values for the absorptance of coloured walls are summerized. The heat gains calculated with the static method are compared to the results of a dynamic calculation with HELIOS. The method is illustrated with some simple examples for different SWH-TI systems.

2 MODEL FOR THE CALCULATION OF HEAT GAINS OF SWH-TI

There are mainly two types of TI elements:

- TI elements without integrated absorber. Solar absorption takes place at the surface of the massive wall which is usually painted with a dark colour.
- TI elements with integrated absorber at the backside of the element.

The following components are distinguished:

- The insulating element in front of the massive wall: The element may be more or less transparent, with or without integrated absorber. To simplify matters it is in any case termed TI element. It is labelled with the index "B".
- The air gap between the TI element and the massive wall. (Dependent on the design, this air gap can also not take place.)
- TI system: TI element including project specific characteristics, e. g. the air gap between TI element and massive wall. The boundary between TI system and massive wall is the outer surface of the wall, that is, the air gap is generally included in the TI system. (This is useful in the case of a ventilated TI.) Its index is "TI".
- (Massive) wall, supporting structure. Index "W".
- Solar wall heating with TI: This is the entire construction with TI system and massive wall. Index "swh".

Figure 1 shows the two types of TI elements, its components, the thermal resistances, and all the different g-values introduced in the following.

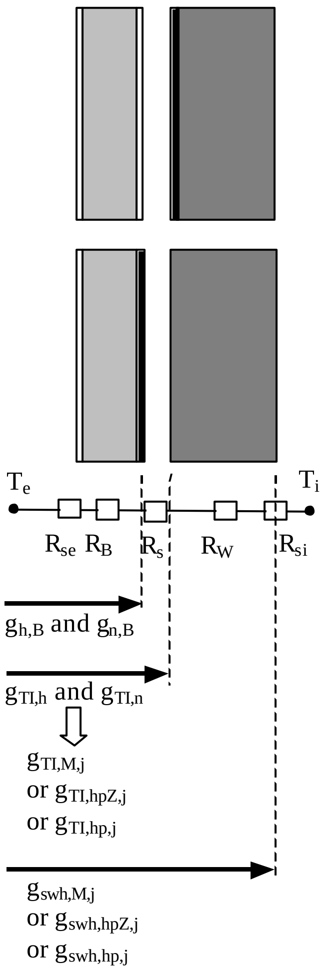

Figure 1: Sketch of the two types of TI elements, the thermal resistances, and the different g-values.

2.1 Summary of the article of Platzer (1999)

In this section the main results of the article of Platzer (1999) are summarized. Starting with the total energy transmittance values of the TI element for hemispherical and normal incidence of solar radiation, $g_{h,B}$ and $g_{n,B}$ (which are have to be known), the corresponding g-values $g_{TI,h}$ and $g_{TI,n}$ of the TI system are calculated. For that purpose, the above mentioned two TI types (with/without integrated absorber) have to be distinguished. In case of an integrated absorber, it should be differentiated between a solar absorptance α_s larger or smaller than 90 %. If it is smaller than 90 %, at least the solar radiation transmittance $\tau_{h,B}$ and $\tau_{n,B}$ of the TI element should be known. (The reflectance $\rho_{h,B}$ of the TI element at the inner surface can often be approximated by 0.)

- TI element without integrated absorber (k = h, n):

$$\alpha_s > 0.9: \quad g_{TI,k} = g_{k,B} \cdot \alpha_s \tag{1}$$

$$\alpha_s < 0.9: \quad g_{TI,k} = \frac{\tau_{k,B} \cdot \alpha_s}{1 - \rho_{h,B} \cdot (1 - \alpha_s)} + (g_{k,B} - \tau_{k,B}) \cdot [1 + \tau_{k,B} \cdot (1 - \alpha_s)] \tag{2}$$

Note: Equation (2) is the precise one and results in higher g-values. Equation (1) is an approximation of equation (2). Thus, it is recommended to use equation (2) also for $\alpha_s > 0.9$.

- TI element with integrated absorber (k = h, n):

$$g_{TI,k} = \frac{g_{k,B}}{1 + \dfrac{R_s}{R_{se} + R_B}} \tag{3}$$

Note: In this case the solar absorption is taken into account in the g-values $g_{h,B}$ and $g_{n,B}$ of the TI element.

The total energy transmittance was measured in dependence of the incidence angle of the light for 7 products of TI systems. With these measurements it was possible to calculate from the g-values $g_{TI,h}$ and $g_{TI,n}$ of the TI system a total transmittance $g_{TI,M,j}$ of the TI system of the form:

$$g_{TI,M,j} = g_{TI,h} - a_{M,j} \cdot g_{TI,n} \tag{4}$$

It could be shown that the coefficients $a_{M,j}$ are in a good approximation independent of the climate location (tested with 12 stations in Germany) and of the TI product. They depend on the time (month M) and the orientation j. Monthly averaged values $a_{M,j}$ were calculated (Table 1).

	S	SW/SE	W/E	NW/NE	N
Oct.	-0.054	-0.025	0.024	0.014	0.000
Nov.	-0.093	-0.034	0.049	0.004	0.000
Dec.	-0.105	-0.026	0.052	0.000	0.000
Jan.	-0.105	-0.034	0.054	0.002	0.000
Feb.	-0.067	-0.027	0.033	0.008	0.000
March	-0.023	-0.010	0.016	0.016	0.000
April	0.042	0.002	-0.012	0.030	0.011
May	0.073	0.022	-0.005	0.018	0.021
June	0.089	0.037	-0.002	0.013	0.031
July	0.094	0.036	-0.012	0.013	0.042
Aug.	0.062	0.013	-0.007	0.024	0.012
Sept.	0.005	-0.015	-0.001	0.033	0.000

Table 1: Coefficients $a_{M,j}$ dependent on the month M and the orientation j (Platzer (1999)).

The negative values in the winter for S and SW/SE orientation means that the influence of the normal transmittance $g_{TI,n}$ is increased. This is given by the fact that the sun shines more in the normal direction onto the TI in winter, thus the influence of the transmittance $g_{TI,n}$ at normal incidence becomes greater and the more

negative the coefficient $a_{M,j}$ has to be. Mostly $|a_{M,j}| < 0.1$, thus the hemispherical part $g_{TI,h}$ could be used as a rough approximation for $g_{TI,M,j}$. But this would lead to an underestimation of the solar heat gains in the important winter months.
The total energy transmittance $g_{swh,M,j}$ (also called efficiency) of the SWH-TI system is now given by:

$$g_{swh,M,j} = g_{TI,M,j} \cdot \frac{R_{se} + R_B + R_s}{R_{se} + R_B + R_s + R_W + R_{si}} \qquad (5)$$

The monthly heat gain of SWH-TI is:

$$Q_{swh,M,j} = A_{swh,j}\, F_F\, F_S\, F_C\, I_{s,M,j}\, g_{swh,M,j} \qquad (6)$$

This looks similar to the formula for calculating heat gains of windows. However, here the g-values $g_{swh,M,j}$ depend on time (month).

As Platzer (1999) pointed out, in the standards (e. g. SN EN 832) the heat gains of SWH-TI are decreased by the same utilization factor η as the direct solar gains. The storage effect of the massive wall is not taken into account which leads to a considerable underestimation of the heat gains of SWH-TI systems.

For an entire heating period (Index "hp") the following approximation is given:

$$g_{TI,hpZ,j} = g_{TI,h} \cdot Z_j \qquad (7)$$

with the orientation dependent factor Z_j (Table 2).

Orientation j:	S	SW/SE	W/E	NW/NE	N
Z_j:	1.04	1.02	0.98	0.99	1.00

Table 2: Orientation dependent factors Z_j (Platzer (1999)).

In this approximation the effective g-value $g_{TI,hpZ,j}$ does not depend anymore on the time and on the normal energy transmittance $g_{TI,n}$.

2.2 Calculation of constant g-values during the heating period

The aim of this section is to find in the following equation (analogous to equation (4))

$$g_{TI,hp,j} = g_{TI,h} - a_{hp,j} \cdot g_{TI,n} \qquad (8)$$

coefficients $a_{hp,j}$ which are constant over the heating period (i. e. independent of the length of the heating period for "usual" lengths). By using equation (8), the influence of the normal part $g_{TI,n}$ is still explicitly taken into account. With this time independent g-value $g_{TI,hp,j}$ also the g-value of the SWH-TI system

$$g_{swh,hp,j} = g_{TI,hp,j} \cdot \frac{R_{se} + R_B + R_s}{R_{se} + R_B + R_s + R_W + R_{si}} \qquad (9)$$

is time independent. Now, the heat gains can be calculated like the heat gains of a window (according to SN EN 832 or SIA 380/1):

$$Q_{swh,hp,j} = A_{swh,j}\, F_F\, F_S\, F_C\, I_{s,M,j}\, g_{swh,hp,j} \qquad (10)$$

In order to determine the time independent coefficients $a_{hp,j}$, a simple approximation is to average the coefficients $a_{M,j}$ over different lengths of the heating period. This was done for the south orientation and the heating periods December to February, November to March, October to March, and October to April. These four averages are shown in Figure 2 with the white columns. The column at the very right is the average of this four averages. The shorter the heating period, the larger is the increase of $g_{TI,M,j}$ caused by the normal part $g_{TI,n}$ (see discussion of Table 1).
A more precise approximation is to compare the sums over the heating period of equations (6) and (10) by putting equations (4) and (5) into equation (6) and equations (8) and (9) into equation (10). This leads to

$$a_{hp,j} = \frac{\sum_M a_{M,j} \cdot I_{s,M,j}}{\sum_M I_{s,M,j}} \qquad (11)$$

The formula was evaluated for the above mentioned heating periods and 4 climate stations in Switzerland (Meteonorm (1999)): Zurich-SMA (midland, 596 m altitude, yearly averaged outside temperature $T_{e,av,y}$ = 9.0 °C, global horizontal irradiation per year $I_{s,h,y}$ = 3906 MJ/m^2), Basel-Binningen (northwest of Jura, 317 m alt., $T_{e,av,y}$ = 10.0 °C, $I_{s,h,y}$ = 3938 MJ/m^2), Davos (alpine, 1590 m alt., $T_{e,av,y}$ = 3.3 °C, $I_{s,h,y}$ = 4967 MJ/m^2), and Lugano (south of the alps, 276 m alt., $T_{e,av,y}$ = 12.0 °C, $I_{s,h,y}$ = 4064 MJ/m^2). The results for south orientation is shown in Figure 2. Again, the columns termed "Average" are the averages for every station over the 4 heating periods. The differences between the 4 stations as well as between the stations and the averaged $a_{M,j}$ are small. For the different heating periods the coefficient $a_{hp,S}$ varies between -0.09 for a short heating period and -0.05 for a long heating period. The average of $a_{hp,S}$ over the 4 heating periods is about -0.07. Considering that $g_{n,B}$ is typically around 20 % higher than $g_{h,B}$, this leads to an error of less than 3 %. The results for the coefficients $a_{hp,j}$ averaged over the 4 heating periods for the 4 climate stations and all orientations are given in Table 3. With a g-value $g_{n,B}$ being e. g. 20 % higher than $g_{h,B}$, $g_{TI,hp,S}$ (equation (8)) is 8 % higher than $g_{h,B}$, while $g_{TI,hpZ,S}$ (equation (7)) is 4 % higher than $g_{h,B}$. An example for these differences is also shown in Figure 3.

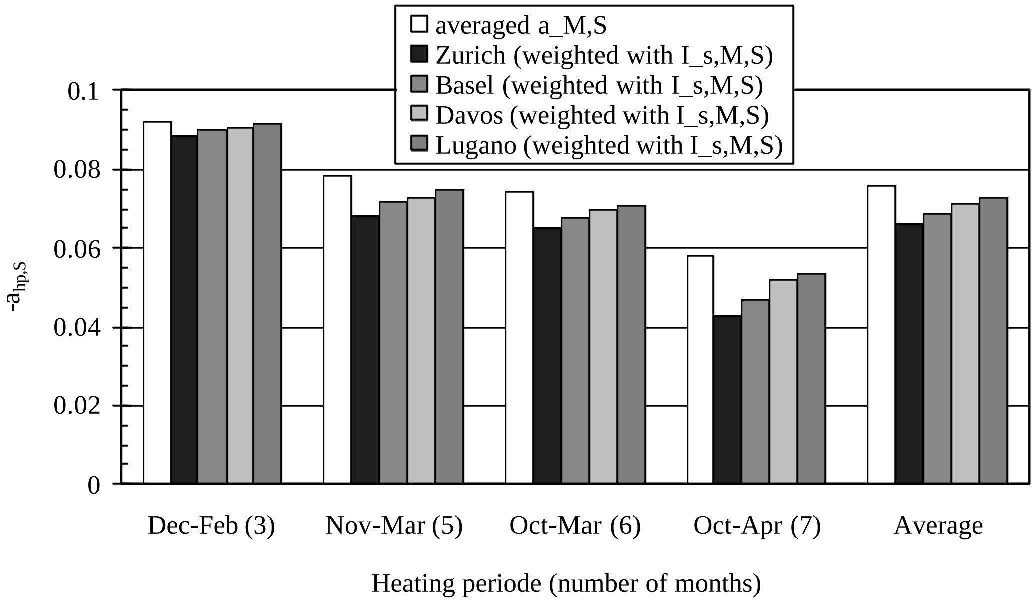

Figure 2: Coefficient $-a_{hp,S}$ for south orientation and different lengths of heating periods and different climate stations.

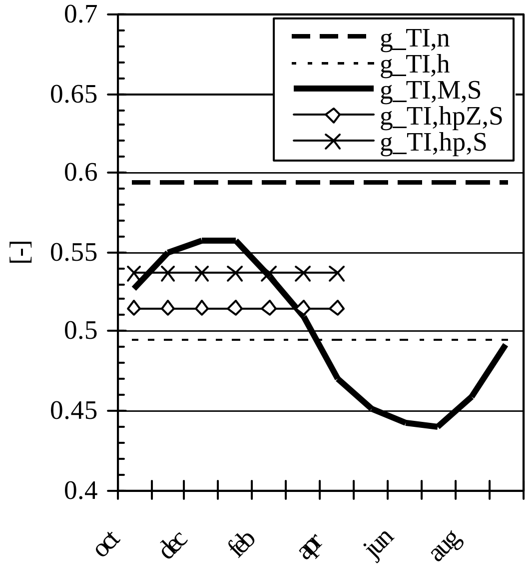

Figure 3: g-values for a south orientated TI element without integrated absorber with characteristic values $g_{h,B}$ = 0.55, $g_{n,B}$ = 0.66, and α_s = 0.9. $g_{TI,M,S}$ is the time dependent value, $g_{TI,hp,S}$ is the suggested average over the heating period.

To summarize, the suggested way to calculate a constant g-value for the TI system over the heating period by equation (8), takes the g-value $g_{n,B}$ explicitly into account. For the south orientation it results usually in values $g_{TI,hp,j}$ slightly higher than $g_{TI,hpZ,j}$ (equation (7)). For the other orientations the two g-values are about the same. The differences can be higher for TI elements with especially high differences between $g_{n,B}$ and $g_{h,B}$.

	S	SW/SE	W/E	NW/NE	N
Zurich-SMA	-0.066	-0.023	0.033	0.010	0.001
Basel-Binn.	-0.069	-0.024	0.033	0.009	0.001
Davos	-0.071	-0.024	0.034	0.009	0.001
Lugano	-0.073	-0.025	0.035	0.009	0.000
Average $a_{hp,j}$	-0.07	-0.02	0.03	0.01	0.00

Table 3: Averaged coefficients $a_{hp,j}$ in dependence of the orientiation j.

3 CONSTRUCTIVE PARAMETERS

The aim of this section is to give approximative values for some parameters of the construction.

3.1 Temperature dependence of the thermal resistance of air gaps and TI materials

The thermal resistance R_s of an air gap between TI element and massive wall (presupposing that the depth of the gap is much smaller than the width) can be calculated according to EN ISO 6946 (for small temperature differences between the surfaces) or EN 673 (for any temperature differences). In Figure 4 the thermal resistance R_s for horizontal heat flow is calculated for several air temperatures T_s in the gap and several temperature differences dT between the gap surfaces (both surfaces with a high emissivity of ε = 0.9). It is seen that the air temperature T_s has a strong influence on the resistance, but that the influence of the temperature differences dT can be neglected, i. e. it is sufficient to calculate R_s according to EN ISO 6946.

The temperature dependence of the thermal resistance R_B of the TI element is determined mainly by the temperature dependence of the thermal conductivity λ_{TIM} of the TI material. For middle temperatures T_{TIM} of the TI material between about 0 °C and 50 °C the change in λ_{TIM} can be approximated roughly by (Wellinger et al. (1990)):

$$\frac{\Delta\lambda_{TIM}}{\Delta T_{TIM}} \approx \frac{0.001\ W/(m \cdot K)}{K} \qquad (12)$$

The middle temperature T_{TIM} of the TI material is the average of the temperature at the outer, colder material surface and the inner, warmer surface. For the important wintertime the outer surface temperature is assumed to be around 0 °C. The inner temperature is estimated to be at most 80 °C (assuming a non-selective absorber). Thus, T_{TIM} is about 40 °C. For a TI material with e. g. λ_{TIM} = 0.1 W/(m·K) measured at T_{TIM} = 20 °C, this will lead to λ_{TIM} = 0.12 W/(m·K) at T_{TIM} = 40 °C, resulting in an increase of 20 % in λ_{TIM}. This leads also to a decrease of about 20 % in the thermal resistance R_B of the TI element.

Both effects together, the temperature dependence of R_s and R_B, are now quantified with an example. It is assumed: middle air gap temperature T_s = 20 °C, R_B of the TI element is 1 m^2·K/W, R_s of the air gap is 0.15 m^2·K/W, and R_W of the massive wall is 0.3 m^2·K/W (R_{se} = 0.04 m^2·K/W and R_{si} = 0.13 m^2·K/W). At T_s = 80 °C: R_s = 0.1 m^2·K/W, the middle temperature of the TI material T_{TIM} = 40 °C, thus R_B = 0.8 m^2·K/W. In case of a TI element with integrated absorber the relevant ratio of the thermal resistances at T_s = 20 °C is: $(R_{se} + R_B)/(R_{se} + R_B + R_s + R_W + R_{si})$ = 1.04/1.62 = 0.64, at T_s = 80 °C: 0.84/1.37 = 0.61. In case of a TI element without integrated absorber the ratio of the thermal resistances at T_s = 20 °C is: $(R_{se} + R_B + R_s)/(R_{se} + R_B + R_s + R_W + R_{si})$ = 1.19/1.62 = 0.73, at T_s = 80 °C: 0.94/1.37 = 0.69. In both cases the difference is about 5 %.

This is an estimation for a worst case scenario. It is valid only during short times, because the air gap temperature is this high only during short times around noon. Most of the captured heat is stored in the massive wall and released at a later time. Then the air gap temperature is again lower, so that the ratio of the thermal resistances has relaxed.

It can be concluded that for the thermal resistance R_B of the TI element the value measured at room temperature can be used, and that for the thermal resistance R_s of the air gap the standard values at room temperature from EN ISO 6946 can be taken. As an example, the standard thermal resistances R_s from EN ISO 6946 for T_s = 10 °C, ε = 0.9 (corresponding to a non-selective absorber) and horizontal heat flow in dependence of the depth d_s of the air gap is given in Table 4. The values are valid for gaps with depths that are smaller than a tenth of the width and smaller than 300 mm. Gaps with a depth d_s between 20 and 300 mm have a constant resistance.

d_s [mm]:	0	5	7	10	15	20	300
R_s [m^2·K/W]	0	0.11	0.13	0.15	0.17	0.18	0.18

Table 4: Thermal resistance R_s of air gaps with depths d_s for horizontal heat flow, T_s = 10 °C and ε = 0.9 (non-selective absorber) (EN ISO 6946).

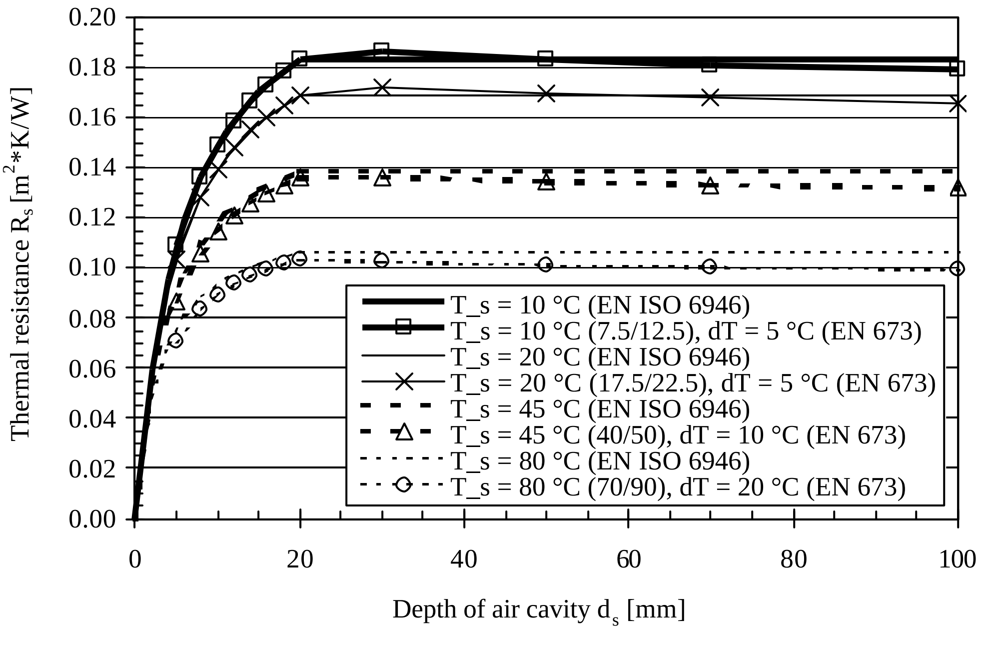

Figure 4: Thermal resistance R_s of air gaps for horizontal heat flow calculated for different air gap temperatures T_s and temperature difference dT between the gap surfaces according to EN ISO 6946 and EN 673 (surfaces with ε = 0.9).

3.2 Absorptance of coloured wall surfaces

Some values for the solar absorptance α_s are put together in Table 5 and Table 6. The absorptance of plasters with rough surfaces may be higher due to multiple scattering.

Colour:	ochre	dark beige, blue	red, brown	dark brown	very dark colours
α_s:	0.6	0.7	0.75	0.83	0.9

Table 5: Solar absorptance α_s for different colours (Sagelsdorff and Frank (1990)).

Colour:	green	blue	black
α_s:	0.47	0.62	0.91

Table 6: Measured solar absorptance α_s for plasters with different colours (Beck et al. (1998)).

4 HEAT GAINS CALCULATED WITH THE SIMPLIFIED METHOD COMPARED WITH A DYNAMIC CALCULATION

In order to get an estimate of the accuracy of the simplified method, the g-values of two simple SWH-TI systems were compared with results obtained by the dynamic building energy simulation tool HELIOS (Frank et al. (1992)). The program performs an hourly energy balance in a single zone based on a response factor method. The net solar heat gain was determined as the difference of the total energy input in a control volume at 20 °C with and without solar absorption in the exposed SWH-TI system, normalized with the total incident solar energy during the calculation period.

The properties of the TI materials are taken into account in the following way: For the direct solar energy transmittance, measured angular dependent values g(θ) are used. For the other components of the global solar radiation a constant value g_h is assumed. The temperature dependence of the thermal conductivity is modelled by a second order polynome. In the dynamic calculations, a 120-mm PMMA capillary material with an external 4-mm float glass cover was used. For simplicity, no air gap was assumed. The solar absorptance of the wall was set to α_s = 0.95. In the simplified calculation, the resulting values are: $g_{TI,n}$ = 0.759, $g_{TI,h}$ = 0.498, $R_{se}+R_B+R_s = R_e$ = 0.984 m²K/W.

The climatic data of the Swiss town Interlaken were applied in a period from October until April (average outdoor temperature T_e=2.4°C, total incident solar energy $I_{s,south}$ = 1923 MJ/m², $I_{s,south\text{-}west}$ = 1586 MJ/m²). The results are shown in Table 7.

Description		System 1	System 2
Wall type		24 cm Brick wall (fired clay)	20 cm Light weight concrete
R_{total}	m²K/W	1.693	1.309
R_e/R_{total}	-	0.581	0.752
$g_{TI,hp,south}$	-	0.551	0.551
$g_{swh,hp,south}$	-	0.320	0.414
$g_{dynamic,south}$	-	0.316	0.381
$g_{TI,hp,south\text{-}west}$	-	0.513	0.513
$g_{swh,hp,south\text{-}west}$	-	0.298	0.386
$g_{dynamic,south\text{-}west}$	-	0.309	0.372

Table 7: Comparison of the simplified model and the dynamic calculation.

In general, a good agreement between the simplified method and the dynamic calculation can be observed. A substantial difference occurs for the south oriented concrete wall with a low thermal resistance. At present, it cannot be decided if this is a systematic effect for systems with high gains. The relation between solar gain and boundary conditions, orientation, TI properties and thermal capacity-transmittance properties of the wall will be further investigated.

5 SUMMARIZED STEP BY STEP PROCDURE FOR CALCULATING THE HEAT GAINS OF SWH-TI

In the following, all the characteristic values of the TI element and all the geometric dimensions of wall and air gap should be delivered by the producer of the TI element and the architect/planning engineer respectively. The suggested step by step procedure is as follows:

(1) The basic characteristic values of the TI element must be known: $g_{h,B}$, $g_{n,B}$, R_B.
(2) If it is a TI element without integrated absorber the solar absorptance α_s of the wall surface can be taken from Table 5 and Table 6.
(3) If it is a TI element without integrated absorber and if the solar absorptance α_s of the wall surface is smaller than about 90 %, the solar radiation transmittance $\tau_{h,B}$ and $\tau_{n,B}$ and the reflectance $\rho_{h,B}$ of the TI element should also be known. ($\rho_{h,B}$ can often be approximated by 0.)
(4) If there is an air gap between TI element and massive wall, its thermal resistance R_s can be calculated according to EN ISO 6946. In case of a non-selective absorber, R_s can be taken from Table 4.
(5) The thermal resistance R_W of the massive wall is the sum of the resistances of the layers of the wall (EN ISO 6946).
(6) The outer and inner resistance are R_{se} = 0.04 m²·K/W and R_{si} = 0.13 m²·K/W (EN ISO 6946).

(7) The g-values $g_{TI,h}$ and $g_{TI,n}$ of the TI system are calculated with equations (1), (2) or (3).
(8) The coefficient $a_{hp,j}$ can be taken from Table 3.
(9) The g-value $g_{TI,hp,j}$ of the TI system, the g-value $g_{swh,hp,j}$ and the solar heat gain $Q_{swh,hp,j}$ of the SWH-TI are calculated with equations (8), (9), and (10) respectively.

6 ILLUSTRATIVE EXAMPLES

6.1 TI element without integrated absorber

The following system is supposed: The characteristic values of the TI element are: $g_{h,B}$ = 0.63, $g_{n,B}$ = 0.75, R_B = 0.93 m^2·K/W. There is an air gap of 7 mm between TI element and wall. This leads to a thermal resistance R_s = 0.13 m^2·K/W. The wall is coated with a black plaster with a solar absorptance α_s = 0.9. The system is south oriented, thus $a_{hp,S}$ = -0.07. The massive wall consists of 24 cm sand-lime brick with λ = 1.0 W/(m·K) and 2 cm of a plaster layer with λ = 0.7 W/(m·K). This leads to a thermal resistance of the wall of R_W = 0.27 m^2·K/W.

$$g_{TI,h} = g_{h,B} \cdot \alpha_s = 0.63 \cdot 0.9 = 0.567$$

$$g_{TI,n} = g_{n,B} \cdot \alpha_s = 0.75 \cdot 0.9 = 0.675$$

$$g_{TI,hp,S} = g_{TI,h} - a_{hp,S} \cdot g_{TI,n} = 0.567 - (-0.07) \cdot 0.675 = 0.614$$

$$\frac{R_{se} + R_B + R_s}{R_{se} + R_B + R_s + R_W + R_{si}} = \frac{0.04 + 0.93 + 0.13}{0.04 + 0.93 + 0.13 + 0.27 + 0.13} = \frac{1.1}{1.5} = 0.733$$

$$g_{swh,hp,S} = g_{TI,hp,S} \cdot \frac{R_{se} + R_B + R_s}{R_{se} + R_B + R_s + R_W + R_{si}} = 0.614 \cdot 0.733 = 0.45$$

6.2 TI element with integrated absorber

The characteristic values of the TI element are: $g_{h,B}$ = 0.43, $g_{n,B}$ = 0.62, R_B = 1.06 m^2·K/W. The other values are the same as in the example above.

$$g_{TI,h} = \frac{g_{h,B}}{1 + \frac{R_s}{R_{se} + R_B}} = \frac{0.43}{1 + \frac{0.13}{0.04 + 1.06}} = 0.385$$

$$g_{TI,n} = \frac{g_{n,B}}{1 + \frac{R_s}{R_{se} + R_B}} = \frac{0.62}{1 + \frac{0.13}{0.04 + 1.06}} = 0.554$$

$$g_{TI,hp,S} = g_{TI,h} - a_{hp,S} \cdot g_{TI,n} = 0.385 - (-0.07) \cdot 0.554 = 0.424$$

$$\frac{R_{se} + R_B + R_s}{R_{se} + R_B + R_s + R_W + R_{si}} = \frac{0.04 + 1.06 + 0.13}{0.04 + 1.06 + 0.13 + 0.27 + 0.13} = \frac{1.23}{1.63} = 0.755$$

$$g_{swh,hp,S} = g_{TI,hp,S} \cdot \frac{R_{se} + R_B + R_s}{R_{se} + R_B + R_s + R_W + R_{si}} = 0.424 \cdot 0.755 = 0.32$$

7 CONCLUSIONS

A method is presented to calculate in a simple static way the heat gains of solar wall heating with transparent insulation (SWH-TI). A time independent g-value of the SWH-TI system is determined. The comparison of heat gains calculated with the suggested static method and with the dynamic model (HELIOS) gave a good agreement. The calculation method is applicable within the framework of static calculations of energy use for heating in residential buildings, as defined e. g. in SN EN 832 or in the Swiss Standard SIA 380/1.

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NOMENCLATURE

a	-	coefficient for calculating the g-value of the TI system (eq. (4) and (8))
A_{swh}	m^2	total area of the solar wall heating
g	-	total energy transmittance
F_C	-	reduction factor due to shading devices
F_F	-	reduction factor due to the frame area
F_S	-	reduction factor due to natural shading
I_s	J/m^2	solar irradiation
Q_s	J	solar heat gain
R	m^2·K/W	thermal resistance

Greek symbols

α_s	-	absorptance of solar radiation
ρ	-	reflectance of solar radiation
τ	-	transmittance of solar radiation

Subscripts

B	TI element
h	hemispherical irradiation
hp	heating period (defined by eq. (8))
hpZ	heating period (defined by the factor Z, eq. (7))
j	orientation
M	month
n	normal irradiation

s solar
s space (air gap)
se external surface
si internal surface
swh solar wall heating with TI (TI system plus wall)
TI TI system (TI element plus air gap)
W wall

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