vA Consult

- REPORT -
Proposals for revision of EN 15316-4-3 version 2007

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Foreword

This report was commissioned by the Solar Certification Fund (=SCF) under the acronym EPBD-12.

The report will be offered to the TC228 workgroup 4 for further processing.

1 Introduction

The CEN EN 15316-4-3 standard, “Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4-3: Space heating generation systems, thermal solar systems.”, was published in 2007. The CEN EN 15316 was primarily created to support of the EPBD directive. Part 4-3 covers solar thermal system performance.

Currently several European countries have implemented this method in their EPBD regulatory frame works. The most heard comment is the absence of a correction factor for the heat storage losses.

The Eco design Lot 2 (water heaters and heat storage systems) references an implementation of the CEN EN 15316-4-3, method B in the so called ‘SOLCAL’ method. This implementation of the method differs on some aspects, amongst which the addition of a correction for the heat losses of the heat storage tank.

The report proposes revisions in the CEN EN 15316-4-3 to add a correction for the heat storage losses and to comply with the Eco design implementation of the method. The revisions are formulated and the argumentation for each revision is described.

2 Scope

The scope of the report is limited to method B of the CEN EN 15316-4-3 and the currently known issues for revisions from the experience with the EPBD and Eco design.

3 References

3.1 Normative references

EN-15316-4-3	Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-3: Space heating generation systems, thermal solar systems	2007

3.2 Other references

[1] Solar heating design by the f-chart method, W.A. Beckman, S.A. Klein, J.A. Duffie Wiley & Sons, 1977

[2] John A. Duffie and William A. Beckman: Solar Engineering of Thermal Processes. Wiley-Interscience ed., 1991

[3] John A. Duffie and William A. Beckman: Solar Engineering of Thermal Processes. John Wiley & Sons, 3rd ed., 2006

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[4] Draft working document, Testing Calculation Water Heater-AfterISC, June 2012

4 Revisions in the text

Editorial note:

The revisions in the current text of the standard are marked by a blue background colour. Text on a white background is in accordance with the original text.

4.1 Revised text on paragraph 6.3.3.1 – Basic principles –

Replace sentence:

> "For determination of the parameters X, Y and f_{st} , the collector area is multiplied by the coefficient P_H in order to …."

with:

> "For determination of the parameters X, Y, $Q_{st,ls,cor,m}$ and f_{st} , the collector area is multiplied by the coefficient P_H in order to ….

4.2 Revised text on paragraph 6.3.3.2 - General calculation of solar output -

The non-solar heat contribution of the back-up heater is calculated, month by month, by:

Rev. 1.0

$$Q_{bu,m} = Q_{sol;us;m} - Q_{sol,out,m} + U_{st} \cdot V_{sol} / V_{nom} \cdot (\theta_1 - \theta_{a,avg}) \cdot t_m \text{ [kWh]} \qquad (10b)$$

where

U_{st}	the overall heat loss coefficient of the heat storage tank; Values from test EN 12977-3 or calculated according to B.6.	[W/K]
V_{sol}	volume of the solar part of the heat storage tank;	[l]
V_{nom}	total volume of the heat storage tank;	[l]
θ_1	domestic hot water applications: 60 for space heating applications: the distribution temperature;	[°C]
$\theta_{a,avg}$	is the average ambient air temperature: – if the solar storage tank is installed in the heated space: $\theta_{a,avg} = 20$; – if the solar storage tank is installed in an un-heated space: $\theta_{a,avg} = \theta_{e,avg} + (20 - \theta_{e,avg}) / 2$; – if the solar storage tank is installed outside: $\theta_{a,avg} = \theta_{e,avg}$ (see B.4).	[°C]
t_m	is the length of the month;	[h]

The output of the thermal solar system is calculated, month by month, by:

Rev. 1.1

$$Q^1_{sol,out,m} = F_c \cdot (a \cdot Y + b \cdot X + c \cdot Y^2 + d \cdot X^2 + e \cdot Y^3 + f \cdot X^3) \cdot Q_{sol;us;m} \text{ [kWh]}$$

$$Q_{sol,out,m} = Q^1_{sol,out,m} - Q_{st,ls,cor,m} \text{ [kWh]} \qquad (11)$$

where

$Q_{sol,us,m}$	is the monthly heat use applied to the thermal solar system. The heat use to be applied for calculation of solar output is determined according to definitions above;	[kWh]
a, b, c, d, e	are the correlation factors depending on storage tank type. The values, calculated in the f-chart method ([1]), are defined in B.1;	[-]
f	is the new correlation factor specific to direct solar floor ([3]).	[-]

	Value is defined in B.1;	
X and Y	are dimensionless factors;	[-]
F_c	A correction factor to compensate for the decrease in calculated output caused by the addition of $Q_{st,ls,cor,m}$ and tuning issues. Default: F_c =1.08	
$Q_{st,ls,cor,m}$	is a correction for the heat losses of the heat storage tank. Value is determined by (11b)	[kWh]

The minimum value of $Q_{sol,out,m}$ is limited to 0 and the maximum value of $Q_{sol,out,m}$ is limited to $Q_{sol;us;m}$.

Rev. 1.2

Determination of $Q_{st,ls,cor,m}$:

$$Q_{st,ls,cor,m} = U_{st} \bullet V_{sol} / V_{nom} \bullet (\theta_2 + (\theta_1 - \theta_2) \bullet Q^1_{sol,out,m} / Q_{sol,us,m} - \theta_{a,avg}) \bullet Q^1_{sol,out,m} / Q_{sol,us,m} \bullet t_m \quad [kWh] \qquad (11b)$$

where

θ_2	for domestic hot water applications:	the cold water temperature;	[°C]
	for space heating applications:	20;	

Determination of X:

The value X is calculated according to Equation (12). It depends on the collector loop heat loss coefficient and the temperature difference, but also on the storage tank volume that is taken into account by the storage tank capacity correction coefficient:

$$X = A \bullet U_{loop} \bullet \eta_{loop} \bullet \Delta T \bullet f_{st} \bullet t_m / (Q_{sol,us,m} \bullet 1\,000) \quad [-] \qquad (12)$$

where

A	is the collector aperture area according to EN 12975-2;	[m²]
U_{loop}	is the heat loss coefficient of the collector loop (collector and pipes); See Equation (13).	[W/(m²·K)]
η_{loop}	is the efficiency factor of the collector loop taking into account [-] loop influence of heat exchanger; The value is defined in B.2.	[-]
ΔT	is the reference temperature difference; See Equation (14).	[K]
f_{st}	is the storage tank capacity correction factor; The values are given in B.3.	[-]
$Q_{sol,us,m}$	is the monthly heat use applied to the thermal solar system according to definitions above.	[kWh]

Rev. 1.3

The minimum value of X is limited to 0 and the maximum value of X is limited to 18.

The heat loss coefficient of the collector loop, collectors and pipes, is determined by the collector characteristics and the insulation of the pipes. The heat loss coefficient is calculated by:

$$U_{loop} = a_1 + a_2 \bullet 40 + U_{loop,p} / A \quad [W/(m^2 \cdot K)] \qquad (13)$$

where

a_1	is the heat loss coefficient of solar collector related to the aperture area. This parameter is obtained according to EN 12975-2; Default values are given in B.2.	[W/(m^{2}K)]
a_2	is the temperature dependence of the heat loss coefficient related to the aperture area. This parameter is obtained according to EN 12975-2; Default values are given in B.2.	[W/(m^{2}K^2)]
$U_{loop,p}$	is the overall heat loss coefficient of all pipes in the collector loop, including pipes between collectors and array pipes between collector array and solar storage tank: – if the pipe and insulation for the collector loop are known, then $U_{loop,p}$ can be calculated using the formulas for insulated pipes (see [1]); – if the collector loop characteristics are not known, then $U_{loop,p}$ is to be determined according to B.2;	[W/m^{2}K]

The reference temperature difference is calculated by:

$$\Delta T = \theta_{ref} - \theta_{e,avg} \quad [K] \qquad (14)$$

where

θ_{ref}	is the reference temperature depending on application and storage tank type; Values are defined in B.4;	[^{o}C]
$\theta_{e,avg}$	is the average outside air temperature over the considered period. Values are given in B.4.	[^{o}C]

<u>Determination of Y:</u>

The value Y is calculated according to Equation (15). It depends on the collector data (zero-loss collector efficiency) and the solar irradiance on the collector plane:

$$Y = A \cdot IAM \cdot \eta_o \cdot \eta_{loop} \cdot I_m \cdot t_m / (Q_{sol,us,m} \cdot 1\,000) \quad [-] \qquad (15)$$

where

A	is the collector aperture area according to EN 12975-2;	[m²]
IAM	is the incidence angle modifier of the collector = K_{50} (τα) from the collector test standard EN 12975-2; Default values are given in B.5.	[-]
η_o	is the zero-loss collector efficiency factor from the collector test standard EN 12975-2 and related to the aperture area; Default values are given in B.2.	[-]
η_{loop}	is the efficiency factor of the collector loop taking into account the influence of heat exchanger; The value is defined in B.2.	[-]
I_m	is the average solar irradiance on the collector plane during the considered period;	[W/m]

	The values are defined in B.5.	
t_m	is the length of the month;	[h]
$Q_{sol,us,m}$	is the monthly heat use applied to the thermal solar system according to definitions above.	[kWh]

The minimum value of Y is limited to 0 and the maximum value of Y is limited to 3.

Rev. 1.4

4.3 Revised text on paragraph 6.3.4 - Auxiliary energy consumption of thermal system auxiliaries -

Rev. 1.5

The auxiliary energy consumption in the thermal solar system is calculated by:

$$W_{sol,aux,m} = \sum W_{sol,aux,dev,m} \quad [kWh] \qquad (16)$$

where

$\sum W_{sol,aux,dev,m}$	is the sum of the auxiliary energy consumption of all applied electrically powered devices needed to make the solar thermal system operational (e.g. pumps, controls, frost protection devices).	[kWh]

The auxiliary energy consumption of an electrically powered device in the solar thermal system is calculated by:

$$W_{sol,aux,dev,m} = P_{aux,dev} \cdot t_{aux,dev,m} / 1\,000 \quad [kWh]$$

where

$P_{aux,dev}$	is the total nominal input power of the device as stated on the label on the device. In case of a none continuous constant power consumption: – Start-up effects under 5 minutes are disregarded. – Pumps that are continuously controlled, or controlled in at least three steps, are rated as 50% of the rated electrical power of the solar pump. If the nominal power is not known, default values are given in B.2;	[W]
$t_{aux,dev,m}$	is the monthly operation time of the device.	[h]

The annual operation time of the collector pump according to EN 12976 is 2 000 h. This operation time can be used for solar hot water or solar combi system applications.

The monthly operation time of the collector pump is determined by distribution of the annual operation time corresponding to the monthly distribution of the solar irradiance from B.5 (e.g. if January irradiation is 5 % of annual irradiation, then January operation time of the pump is 5 % of the annual operation time of the pump).

The annual operation time of a continuously operated collector pump control is 8 760 h.

4.4 Added text to paragraph 6.3.7.3 –Reduction of thermal losses from back-up heat generator(s) –

Add the following text to the end of the paragraph:

Gas and oil fired water heaters may show a decrease of the efficiency when adding a solar hot water system. The decrease in efficiency is caused by higher heat losses, that are calculated according to:

Rev. 1.6

$$Q_{bu,ls,m} = Q_{bu,m} / (1.1 \cdot \eta_{bu} - 0.1) \quad [kWh] \qquad (19.b)$$

where

$Q_{bu,m}$	is the non-solar heat contribution of the back-up heater;	[kWh]
η_{bu}	is the water heating energy efficiency of the backup heater.	[-]

4.5 Revision on annex B.3 – Storage tank capacity correction coefficient F_{st}

In the case of a water storage tank, the storage tank correction coefficient F_{st} is given by:

$$F_{st} = (V_{ref} / V_{sol})^{0.25}$$

where

V_{ref} is the reference volume equal to 75 litres per m^2 of collector;

V_{sol} is the solar storage tank volume.

4.6 Revised text on annex B.6 – Thermal losses of the solar storage tank –

Rev. 1.7

The overall heat loss coefficient of the storage tank can be calculated from the energy label class [4], according to:

$$U_{st} = (c_1 + c_2 \cdot V_{nom}^{\wedge 0.4}) / 45 \quad [W/K] \qquad (B.9)$$

where

c_1 & c_2 according to:

Energy efficiency class	c_1	c_2	Remarks
A+	5.50	3.16	
A	8.50	4.25	e.g. evacuated insulation
B	12.00	5.93	Excellent, conventional
C	16.66	8.33	Typical
D	21.00	10.33	
E	26.00	13.66	
F	31.00	16.66	

U_{st}	the overall heat loss coefficient of the heat storage tank; Values from test EN 12977-3 or calculated according to B.6.	[W/K]
V_{nom}	total volume of the heat storage tank;	[l]

5 Notes on revisions

5.1 Rev. 1.0

Formula (10b), $Q_{bu,sol}$, is added for conformity with the Ecodesign method [4] 'SOLCAL'.

5.2 Rev. 1.1 & 1.2

The current version of the CEN-EN 15316-4-3, method B, paragraph 6.3.3.1 assumes a heat storage tank without heat losses. This is not a realistic assumption. The energy output of a solar thermal system decreases with increasing heat losses of the tank. The heat storage tank losses should be taken into account.

The Ecodesign energy labelling uses the method B of the CEN-EN 15316-4-3, in the so-called 'SOLCAL' method, with the addition of a correction for the heat storage losses, according to:

$$Q_{st,ls,cor,m} = U_{st} \cdot V_{sol} / V_{nom} \cdot (\theta_2 + (\theta_1 - \theta_2) \cdot f_{solar} - \theta_{a,avg}) \cdot t_m \text{ [kWh]} \quad \text{Formula A}$$

where

f_{solar}	is the part of the annual heat demand supplied by the solar system, calculated with the not for heat losses corrected solar output;		
U_{st}	the overall heat loss coefficient of the heat storage tank;		[W/K]
	Values from test EN 12976-3 or calculated according to B.6.		
V_{sol}	volume of the solar part of the heat storage tank;		[l]
V_{nom}	total volume of the heat storage tank;		[l]
θ_1	domestic hot water applications:	60	[°C]
	Space heating applications:	Distribution temperature	
θ_2	for domestic hot water applications:	the cold water temperature;	[°C]
	for space heating applications:	20;	
$\theta_{a,avg}$	is the average ambient air temperature: – if the solar storage tank is installed in the heated space: $\theta_{a,avg} = 20$; – if the solar storage tank is installed in an un-heated space: $\theta_{a,avg} = \theta_{e,avg} + (20 - \theta_{e,avg}) / 2$; – if the solar storage tank is installed outside: $\theta_{a,avg} = \theta_{e,avg}$ (see B.4).		[°C]
t_m	is the length of the month;		[h]

Formula A is verified by simulation model calculations according to annex A. It is noted that the heat storage losses can account for up to 25% of the solar energy output, depending on a complex interaction of system design and application conditions.

Figure 1 shows the results expressed in the relative error of the heat storage losses estimated with formula A (= Qsto;ls;est) as a function of the calculated heat losses (=Qsto;ls;calc) for all variants of the calculations.

Figure 2 shows the results expressed in the relative error in the solar output ([Qsto;ls;est – Qsto;ls;calc] / Qsol;out) as a function of the calculated solar output.

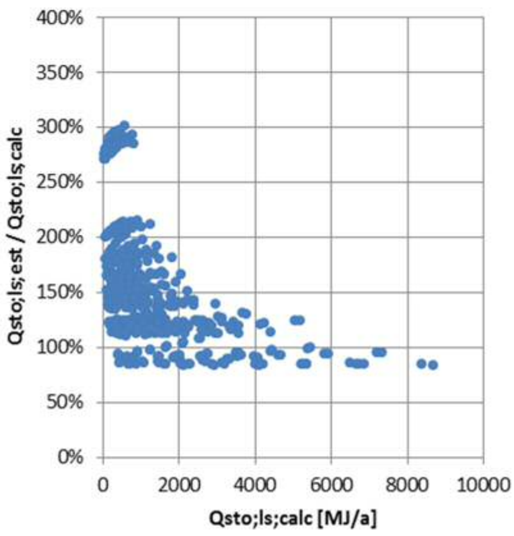

Figure 1 - The error in the prediction of the heat storage losses according to formula A.

$Q_{sto;ls;calc}$: heat losses, $Q_{sto;ls;est}$: estimated heat losses.

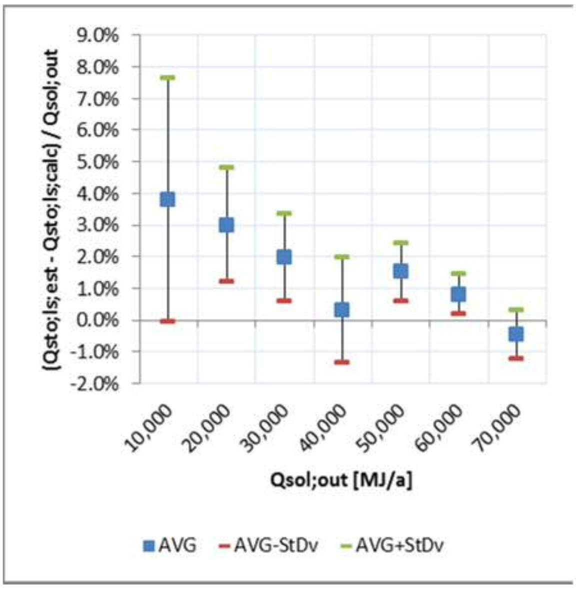

Figure 2 - The relative error in the calculated solar output according to formula A.

AVG: average, StDv: standard deviation

$Q_{sto;ls;calc}$: heat losses, $Q_{sto;ls;est}$: estimated heat losses, $Q_{sol;out}$: solar energy output.

The heat storage losses are estimated with an accuracy between -75% and +300% of the calculated value. The effect of this error on the calculation of the solar energy output is between -1% and +8%. It is noted that the error of the estimation is decreasing with higher values of the solar energy output.

The maximum of the Y-axis scale figure 1 is limited to 400%. At very low Qsto values (< 100 MJ/a) significantly higher errors (up to 2500%) were observed, but for visibility reasons not displayed.

With an error margin between -1% and +8% (between 0% and +4% on average) on the solar energy output the formula A shows a limited accurate, but practically useful estimation of the effect of the heat storage losses. The formula A systematically overestimates the effect of the heat losses.

► Alternative correction formula

As an alternative, the following formula is evaluated.

$$Q_{st,ls,cor,m} = U_{st} \cdot V_{sol} / V_{nom} \cdot (\theta_2 + (\theta_1 - \theta_2) \cdot f_{solar} - \theta_{a,avg}) \cdot f_{solar} \cdot t_m \text{ [kWh]} \qquad \text{Formula B}$$

The results are shown in

figure 3 and figure 4.

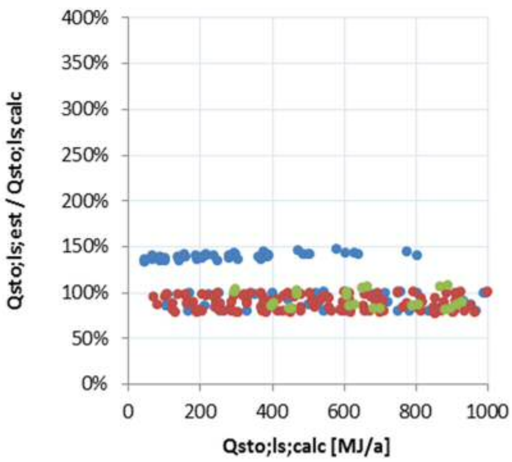

Figure 3 - The error in the prediction of the heat storage losses according to formula B.

$Q_{sto;ls;calc}$: heat losses, $Q_{sto;ls;est}$: estimated heat losses.

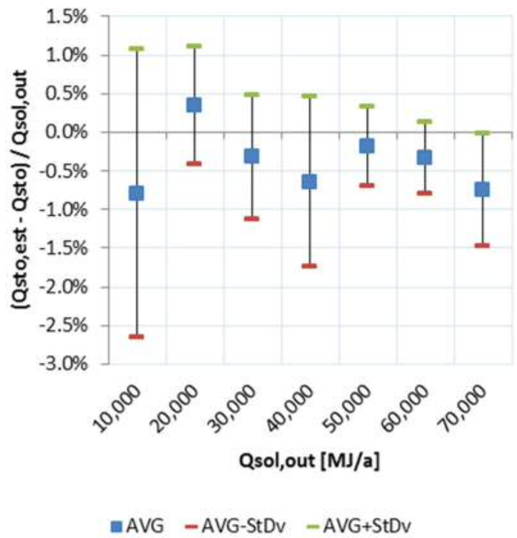

Figure 4 - The relative error in the calculated solar output according to formula B.

AVG: average, StDv: standard deviation

$Q_{sto;ls;calc}$: heat losses, $Q_{sto;ls;est}$: estimated heat losses, $Q_{sol;out}$: solar energy output.

The heat storage losses are estimated with an accuracy between -75% and +150% of the calculated value. The effect of this error to the calculation of the solar energy output is between -2.5% and +1%. It is noted that the error of the estimation is decreasing with higher values of the solar energy output.

The maximum of the Y-axis scale in

figure 3 is limited to 400%. At very low Qsto values (< 100 MJ/a) significantly higher errors (up to 1000%) were observed, but for visibility reasons not displayed.

With an error margin between -2.5% and +1%. (between -1% and +0.5% on average) on the solar energy output the formula B shows a significantly more accurate estimation of the effect of the heat storage losses. The formula B does not show a systematic deviation and is practically useful.

All in all the formula B gives a good approximation of the effect of the heat losses of the solar heat storage tank. If possible, this formula should replace the current formula in Ecodesign and will improve the method of CEN-EN 15316-4-3, method B.

► The effect of the formula on the calculated solar output

The effect of formula A & B on the solar energy output, calculated according to EN 15316-4-3, B is evaluated for two climates and two ratios of Vsto / Acol (storage volume [l] / Collector area [m^2]). The results are shown in figure 5 and figure 6.

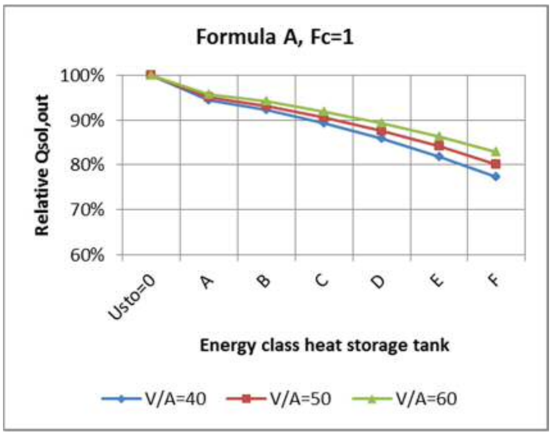

Figure 5 - Relative effect of formula A on the solar output for an average European climate zone (Wurzburg).

V/A = V_{nom} / A in l/m^2

100% = the solar output according to the current version of the EN15316-4-3, B.

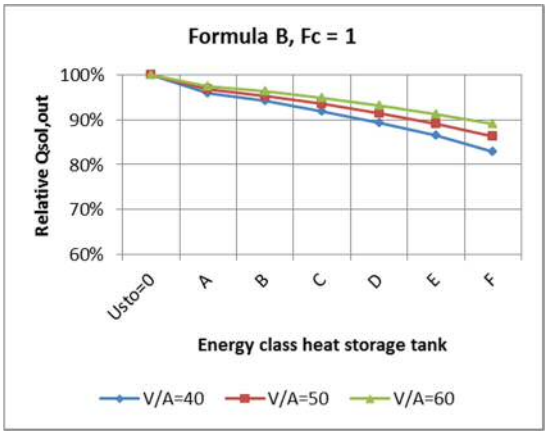

Figure 6 - Relative effect of formula B on the solar output for an average European climate zone (Wurzburg).

V/A = V_{nom} / A in l/m^2

100% = the solar output according to the current version of the EN15316-4-3, B.

Both formulas A & B decrease the solar output in relation to the heat loss coefficient of the heat storage tank. The effect of formula B is smaller than formula A. Formula B gives a better estimation and is the better of the two options.

As a result of adding a correction for the heat losses the solar output calculated with the method EN15316-4-3, B will generally decrease up to 30% (formula A) and 25% (formula B). The average label class of a heat storage tank in a solar thermal system is ‘C’. In most cases the decrease of solar output is then limited to 10% (formula A) and 8% (formula B).

It is noted that there are no indications that the calculated output level of the current version of EN 15316-4-3, B is too high. As a result, it is justifiable that the systematic deviation is corrected in the method. For that reason formula (B.5) is revised.

► Overall compensation of decreased (calculated) solar energy output

In order to compensate for the systematic decrease of the solar output, introduced by adding a correction for the heat storage losses, a correction factor is introduced (=F_c). This factor can also be used to tune the results of the calculations to specific use.

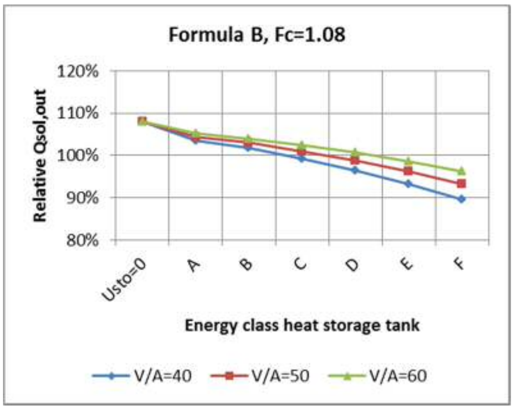

Figure 7 - Relative effect of formula B with Fc=1.08 on the solar output for an average European climate zone (Wurzburg).

V/A = V_{nom} / A in l/m^2

100% = the solar output according to the current version of the EN15316-4-3, B.

For a heat loss label class of 'C' (currently average) the same output is calculated as with the current version of EN 15316-4-3, B. A such this revision compensates effectively for the decrease of the solar output due to the addition of a correction for the storage heat losses according to formula B.
For a very well insulated tank ('A+') the calculated solar output is 8% higher. However, it should be noted that for such a label class very innovative insulation measures are needed, that currently is not available on a commercial scale.

5.3 Rev. 1.3 & 1.4

The values of X and Y are limited according to [1]. To prevent unrealistic results for exceptional situations, this limits are added to the method. This is in accordance with [3].

5.4 Rev. 1.5

The method is expanded in conformity with [4].

5.5 Rev. 1.6

The method is added in conformity with [4].

5.6 Rev. 1.7

The method is revised in conformity with [4].

Annex A - Main Parameters used in simulations -

A.1 Climate data:

Climates:	1	2	3	4	5	6	7	
	De Bilt (NL)	Eskdalemuir (UK)	Evora (PT)	Stockholm (SE)	Ukkel (BE)	Valencia (ES)	Wurzburg (DE)	
Q_{sun} =	3 758	3 263	5 424	4 103	3 557	5 729	4 207	$MJ/m^2/a$
T_{amb} =	9.5	7.1	15.8	6.7	10.1	16.9	9.4	^oC
T_{cold} =	10	5	15	5	10	15	10	^oC
Latitude =	52.11	55.27	38.57	59.33	50.80	39.47	49.79	^{o}
Longitude =	5.18	-3.25	7.91	18.06	4.33	-0.38	9.95	^{o}

A.2 Collector:

A_{col} =	V_{sto} / VA, where VA = 25, 40 or 55	
η_o =	0.8	-
a_1 =	3.5	$W/(m^2.K)$
a_2 =	0	$W/(m^2.K^2)$
Collector orientation:		
Azimuth:	South	
Tilt:	Latitude of the geographical location	

A.3 Heat storage:

V_{store}	150, 500 or 1000	litre
U_{sto}:	Class: A+, A, B, C, D, E or F according to Ecodesign heat storages	

A.4 Heat load:

T_{demand}	60	^oC
Water demand	V_{sto}	l/day
Load profile:	07:00h 20% of daily heat load 08:00h 20% of daily heat load 13:00h 20% of daily heat load 18:00h 20% of daily heat load 19:00h 20% of daily heat load	

A.5 Simulation model

Software:	Zboil version 4.8 (NL)	
Time step:	1 hour	