Danish Energy Management A/S

A part of Danish Management Group

Algorithms for Compliance Method - Alternative 1 in Energy Efficiency Building Code for Mauritius

UNDP - 00058178/
Removal of Barriers to Energy Efficiency and Energy Conservation in Buildings – PS/MAR2010/002

Preparation of Building Control Bill, Building Regulation and Code for Energy Efficiency and Compliance Mechanisms.

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August 2011

ALGORITHMS FOR CALCULATION OF ENERGY CONSUMPTION AND OTTV
(Compliance Method Alternative 1 of the EEBC)

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PART 1: Overall thermal transfer value (OTTV) and solar factor (S)

1 About the overall thermal transfer value (OTTV)

The OTTV is a measure of the energy consumption of a building due to its envelope. The OTTV concept originates from the first energy conservation standard of the" American Society of Heating, Refrigerating and Air-Conditioning Engineers" (ASHRAE Standard 90-75)

The OTTV is basically a measure of average rate of heat transfer from the outdoor environment into a building, through the building envelope (walls and roof). The higher the OTTV value, the greater the heat gains in the building. The principle behind the OTTV is to reduce heat gains and therefore reduce the cooling load of the air-conditioning systems.

The prescriptive requirements for the OTTV are inspired by the requirements in Thailand, Malaysia and Singapore. As the climatic zone 2 is in a cooler climate it seems natural that the requirements are slightly lower. The prescriptive requirements for the OTTV from the Energy Efficiency Code section 8.1.2 are:

	Climatic zone 1 W/m²	**Climatic zone 2 W/m²**
Wall	45	40
Roof	45	40

2 OTTV for walls and fenestration

For walls the equation for the OTTV is defined as follows:

$$OTTV_w = \frac{Q_{wc} + Q_{gc} + Q_{sol}}{A_i} = \frac{\left(A_w \cdot U_w \cdot TD_{eqw}\right) + \left(A_f \cdot U_f \cdot DT\right) + \left(A_f \cdot SC_{win} \cdot SSF \cdot SF\right)}{A_i} \qquad (2.1)$$

Where

$OTTV_w$ is the overall thermal transfer value of the external wall (W/m^2)

Q_{wc} is the heat conduction through opaque walls (W)

Q_{gc} is the heat conduction through window glass (W)

Q_{sol} is the solar radiation through window glass (W)

A_w is the area of opaque wall (m^2)

U_w is the U-value of opaque wall (W/m^2 ^{o}C)

TD_{eqw} is the equivalent temperature difference for walls (^{o}C) – Annex C

A_f is the area of fenestration (m^2)

U_f is the U-value of fenestration (W/m^2 ^{o}C)

DT is the temperature difference between interior and exterior (^{o}C)

SC_{win} is the shading coefficient of window glass – Annex A

SSF is the solar shading factor of external shading devices (-) – Annex D

SF is the solar factor of fenestration (W/m^2) – Annex E

A_i is the gross area of the walls (m^2)

2.1 Definition of areas

In equation 2.1, three areas are included. The area of opaque wall (A_w), the area of fenestration (A_f) and the gross area (A_i).

For opaque element areas (A_w) with different orientation, weight or resistance, should be calculated as partial areas. Thus, the respective equivalent temperature difference and U-value can be multiplied.

For fenestration, the different orientation, resistance, solar shading coefficient and external shading should determine how to section the areas. The fenestration areas should include the entire window or door element, including frame.

The gross area is the total area of wall and fenestration, without regarding other factors.

$$A_i = \sum A_w + \sum A_f \qquad (2.2)$$

2.2 Definition of U-values

The U-value is also called the "overall heat transfer coefficient", and describes the thermal transmittance of an element. It is a measure of how much heat can go through one square meter of the element when the air temperatures on either side differ by one degree. U-values are expressed in units of Watts per square meter per degree of temperature difference (W/m2K). The U-value of an element is based on the combination of the resistance (denoted as the R-value) of the materials that make up that element.

$$U = \frac{1}{R} \qquad (2.3)$$

Where

U is the U-value ($W/m^{2o}C$)

R is the thermal resistance ($m^{2o}C/W$)

The resistance can be calculated based on the thermal conductivity of the material and its thickness.

$$R = \frac{d}{\lambda} = \sum_{i=1}^{n} \frac{d}{\lambda_i \cdot F_i} \qquad (2.4)$$

Where

R is the thermal resistance ($m^{2o}C/W$)

λ is the conductivity ($W/m^{o}C$)

d is the thickness (m)

F is the fraction of a partial material

For inhomogeneous layers the resistance should be calculated as a weighted average.

$$R = \frac{d}{\sum_{i=1}^{n} \lambda_i \cdot F_i}$$

The lower the U value, the greater the resistance to heat and therefore has a better insulating value.

For fenestration, the U-value can be obtained from the manufacture. It is the U-value of the window, which should be used. A data list of commonly used glass types is presented in annex A.

2.3 Definition of temperature differences

Energy simulation studies have indicated that thermal mass affects the heat conduction through walls. The equivalent temperature difference (TD_{eq}) should take into account the wall mass, density and orientation.

Heavyweight construction gives a better performance than lightweight constructions because it resists the passage of heat. The equivalent temperature difference can be obtained from annex C.

The temperature difference between interior and exterior (DT) is based on the design temperatures. The exterior design temperature is based on the average of maximum daily temperatures. Due to different climatic conditions the exterior design temperature depends on the climatic zone. Whereas the interior design temperature is based on comfort.

$$DT = T_e - T_i \qquad (2.5)$$

Where

DT is the temperature difference between interior and exterior (^{o}C)

T_e is the exterior design temperature (^{o}C)

T_i is the interior design temperature (^{o}C)

2.3.1 Design temperatures

According to the thermal comfort equation by P.O. Fanger, the operative temperature with activity level of 1,2 Met and clothing level at 0,5 clo is approximately 24^{o}C.

	T_i ^{o}C	T_e ^{o}C
Climatic zone 1 (Coastal Area)	24	30
Climatic zone 2 (High Lands)	24	27,7

2.4 Solar shading factor (SSF)

Shading of openings is important in reducing solar heat gain to the building. In the OTTV two distinguished external shadings is considered, horizontal and vertical shading. In some cases a combination can be used as well. Where shading is provided, the SSF value should be obtained from annex D, depending on the opening orientation and the type/depth of shading.

For horizontal or overhang projections the relation between depth/type of projection and height of window can be obtained from the figure below.

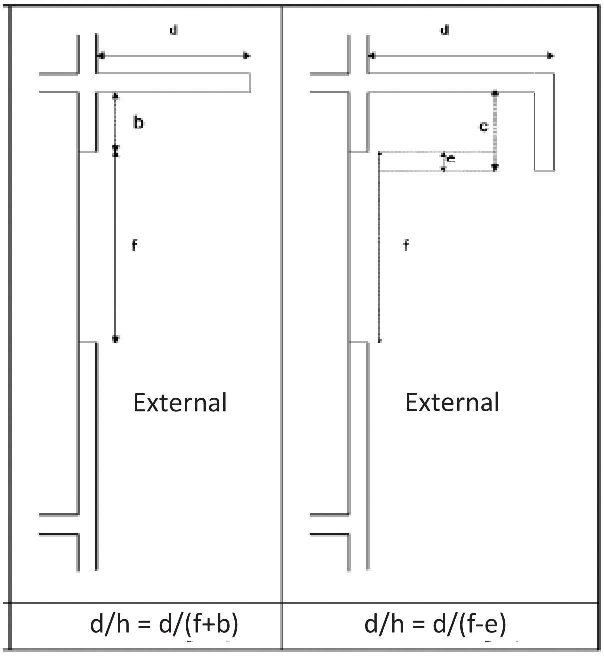


Figure 1: Principle for calculating the d/h relation depending on type of projection.

For windows and doors with a vertical side protection, this should be taken into account. The values depend on the d/h relation in Figure 1 and whether it is the right, left or both sides which is protected. The values should be obtained from annex D. It is assumed that the depth of the overhang is equal to the depth of the side protection.

2.5 Shading coefficient of window glass (SC_{win})

The shading coefficient (SC_{win}) measures how well a window blocks heat from sunlight. The SC_{win} is the fraction of the heat from the sun that enters through a window. SC_{win} is expressed as a number between 0 and 1. The lower a window's SC_{win}, the less solar heat it transmits. The figure below illustrates the principle.

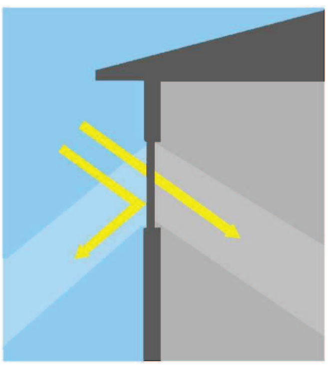


Figure 2: Illustration of the shading coefficient, the value expresses the fraction which enters the building.

The SC_{win}-value can be obtained from the manufacture. If the value cannot be obtained from the manufacture, annex A contains a list of commonly used glass types and data.

2.6 Solar factor (SF)

The solar factor is an expression of the effect of sun on one square meter. The solar radiation is the diffuse contribution from the sun. For vertical surfaces at various orientations and that for horizontal surfaces should be obtained from annex E. For any sloping or angled wall or roof the surface can be resolved into a vertical or a horizontal component. The short example below shows how.

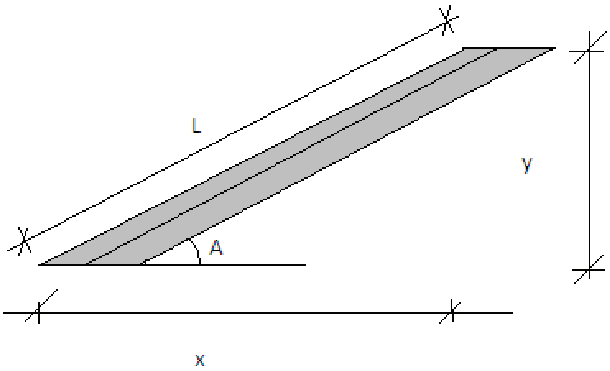


Figure 3: Illustration of a sloped surface.

$$SC = SC_x \cdot \frac{x}{(x+y)} + SC_y \frac{y}{(x+y)}$$
$$x = \cos(A) \cdot L \qquad (2.6)$$
$$y = \sin(A) \cdot L$$

3 OTTV for roofs

The roof equation for the OTTV is slightly different from the wall and fenestration equation. The Energy Efficiency Code states that skylights are prohibited, which exclude the fenestration part Q_{gc} and the heat gain from radiation Q_{sol}.

$$OTTV_r = \frac{Q_{rc} + Q_{gc} + Q_{sol}}{A_i} = \frac{(A_r \cdot U_r \cdot TD_{eqr}) + (A_s \cdot U_s \cdot DT) + (A_s \cdot SC_{win} \cdot SSF \cdot SF)}{A_i} \qquad (3.1)$$

Where

$OTTV_r$	is the overall thermal transfer value of the external wall (W/m^2)
Q_{rc}	is the heat conduction through opaque roof (W)
Q_{gc}	is the heat conduction through skylight glass (W)
Q_{sol}	is the solar radiation through skylight glass (W)
A_r	is the area of opaque wall (m^2)
U_r	is the U-value of opaque wall (W/m^2 ^{o}C)
TD_{eqr}	is the equivalent temperature difference (^{o}C) – Annex C
A_s	is the area of skylight fenestration (m^2)
U_f	is the U-value of fenestration (W/m^2 ^{o}C)
DT	is the temperature difference between interior and exterior (^{o}C)
SC_{win}	is the shading coefficient of skylight glass – Annex A
SSF	is the solar shading factor of external shading devices (-) – Annex D
SF	is the solar factor of fenestration (W/m^2) – Annex E
A_i	is the gross area of the roof (m^2)

3.1 Definition of area

The roof area (A_r) taken into account is the horizontal area, ignoring if any sloped roof. The figure below illustrates the principle.

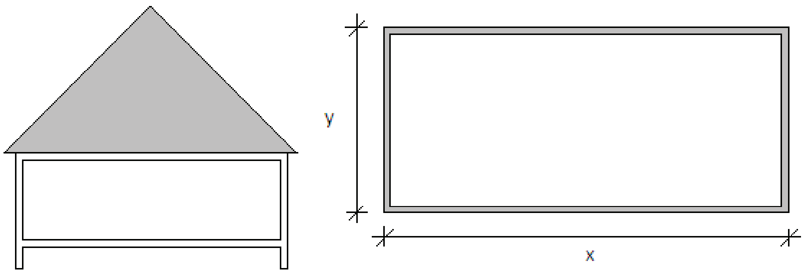


Figure 4: Principle measuring the roof area.

$$A_r = x \cdot y$$

The areas should be split regarding difference in U-value or equivalent temperature difference (TD_{eqr}).

The Gross area (A_i) is all partial areas summarized.

3.2 Calculating the U-value

The U-value is calculated as for a wall the only difference is the direction of the heat flow. For a wall the direction will in most cases be horizontal, whereas for roofs the direction will be downward. That makes a small difference in the surface film coefficient, which can be obtained from annex G.

For at pitched roof, the cavity between the ceiling and the roof construction is in most cases ventilated. In that case the resistance of the roof construction should be neglected and the specific resistance for "pitched ventilated roof spaces" in annex G should be used.

3.3 Equivalent temperature difference (TD_{eqr})

As for walls the equivalent temperature difference for roofs should take into account, roof mass and density and should be obtained from annex C.

4 About the solar factor (s)

The solar factor is used as a requirement for wall, window and roof. It takes the resistance of the element, its protection from direct solar gains and its solar absorbance into account. The solar factor is split into three equations; fenestration, roof and wall. Thus, there are different requirements in the energy efficiency code.

The prescriptive requirements for the solar factor, S:

Element	< S
Wall	0,09
Roof	0,03
Opening adjacent to a air-conditioned space	0,25
Opening adjacent to a un-conditioned space	0,65

5 Solar factor for wall and roof

The solar factor equation for wall and roof is different due to the direction of the heat flow. For walls the direction of the heat flow is in most cases horizontal. For roof the direction is normally downward.

The solar factor for walls is defined as follows:

$$S = \frac{0{,}074 \cdot SSF \cdot \alpha}{R + 0{,}20} \qquad (5.1)$$

Where

S is the solar factor (-)

SSF is the solar shading factor of external shading devices (-) – Annex D

R is the thermal resistance of the element (m^2°C/W)

α is the absorption coefficient (-) – Annex I

The constant factor 0,074 and 0,20 are the interior surface film coefficient and the interior and exterior surface film coefficient summarized, respectively. In this case the heat flow direction is horizontal.

For walls with difference in SSF, α or R a combined value which should meet the limiting solar factor in the energy efficiency code can be calculated as a weighted average.

$$S = \frac{\sum_{i=1}^{n} S_i \cdot A_i}{\sum_{i=1}^{n} A_i} = \frac{S_1 \cdot A_1 + S_2 \cdot A_2 + ... + S_n \cdot A_n}{A_1 + A_2 + ... + A_n} \qquad (5.2)$$

The solar factor for roofs is defined as follows:

$$S = \frac{0{,}074 \cdot SSF \cdot \alpha}{R + 0{,}21} \qquad (5.3)$$

Where

S is the solar factor (-)

SSF is the solar shading factor of external shading devices (-) – Annex D

R is the thermal resistance of the element (m^2°C/W)

α is the absorption coefficient (-) – Annex I

The constant factor 0,074 and 0,23 are the interior surface film coefficient and the interior and exterior surface film coefficient summarized, respectively. In this case heat flow direction is downward. For roof with difference in SSF, α or R a combined value, which should meet the limiting solar factor in the energy efficiency code can be calculated as a weighted average in equation 5.2.

5.1 Solar shading factor (SSF)

SSF is the same as for the OTTV, see 2.4. In annex D the factor can be obtained, depending on type/depth of projection and height of the current wall.

For a horizontal surface (i.e. roof), the SSF depends on whether the roof is ventilated and shaded. The value can be obtained in annex D.

5.2 Thermal resistance (R)

The thermal resistance of the element is calculated using equation 3.4. In this case the interior and exterior surface film coefficient is not included.

5.3 The absorption coefficient (α)

Energy simulation studies have shown that the external surface and color of walls and roofs, and therefore their absorptivity, have a significant effect on heat gain. This should be included in the heat gain calculation. The absorptivity for wall and roof can be obtained from annex I.

6 Solar factor for fenestration

The solar factor for fenestration is defined as follows:

$$S = So \cdot SSF \qquad (6.1)$$

Where

So is the solar factor without horizontal shading and

SSF is the solar shading factor of external shading devices (-) – Annex D

In the energy efficiency code it is stated that each orientation should meet the limiting solar factor. Thus, it’s convenient to split the calculation in parts regarding orientations. If each orientation should consists of various opening elements, a combined value can be calculated as follows:

$$S = \frac{A_1 \cdot So_1 \cdot SSF_1 + A_2 \cdot So_2 \cdot SSF_2 + ... + A_n \cdot So_n \cdot SSF_n}{A_1 + A_2 + ... + A_n} \qquad (6.2)$$

6.1 Solar shading factor (SSF)

SSF is the same as for the OTTV, see 2.4. In annex D the factor can be obtained, depending on type/depth of projection and height of the current window.

6.2 Solar factor without horizontal shading (So)

So is an expression of the type of opening and its function. In annex H So should be obtained from the six tables, depending on the closing method, shading characteristics around the fenestration and the functions due to natural ventilation for thermal comfort.

If a door is opaque it should be considered whether to take it into account as a wall with a different resistance or an opaque movable opening. Both ways is accepted, but one element can only be calculated in one of the equations.

7 References

Arrêté du 17 avril 2009 définissant les caractéristiques thermiques minimales des bâtiments d'habitation neufs dans les DOM (Journal officiel de la république française), April 2009

ASHRAE Handbook, (2005) Fundamentals

Building Energy Codes Resource Center (2009) Article#93

Code of Practice For Overall Thermal Transfer Value In Buildings, (1995) Building Authority Hong Kong

Code on Envelope Thermal Performance For Buildings, Singapore

Danish Standard 418:2002

Perene Réunion, Performances Energétiques des bâtiments á La Réunion (2009)

South African National Standard 204-3:2008

Annexes

Annex A:

Glass Type (Product)	Visible Transmittance (% Daylight)	U-factor ($W/m^2 \, ^oC$)	Solar Heat Gain Coefficient (SHGC)
Single Pane glass (standard clear)	89	6,19	0,81
Single White Laminated w/Heat Rejecting Coating (*Southwall California Series*®)	73	6,02	0,46
Double Pane Insulated Glass (standard clear)	79	2,73	0,70
Double Bronze Reflective Glass (*LOF Eclipse*®)	21	2,73	0,35
Triple Pane Insulated Glass (standard clear)	74	2,04	0,67
Pyrolitic Low-e Double Glass (*LOF Clear Low-e*®)	75	1,87	0,71
Soft-coat Low-e Double Glass w/Argon gas fill (*PPG Sungate*® *100 Clear*)	73	1,48	0,57
High Efficiency Low-e (*Solarscreen 2000 VEI-2M*™)	70	1,65	0,37
Suspended Coated Film (*Heat Mirror*™ *66 Clear*)	55	1,42	0,35
Suspended Coated Film w/ Argon gas fill (*Azurlite*® *Heat Mirror SC75*)	53	1,08	0,27
Double Suspended Coated Films w/ Krypton (*Heat Mirror*™ *77 Superglass*)	55	0,57	0,34

From "Passive solar design guidelines, 2010"

Annex B: Resistance of air spaces unventilated

	Direction of heat flow		
Thickness	up	horizontal	down
mm	$m^{2o}C/W$	$m^2\,^oC$ /W	$m^2\,^oC$ /W
0	0	0	0
5	0,11	0,11	0,11
7	0,13	0,13	0,13
10	0,15	0,15	0,15
15	0,16	0,17	0,17
25	0,16	0,18	0,19
50	0,16	0,18	0,21
100	0,16	0,18	0,22
300	0,16	0,18	0,23

From Danish Standard 418:2002

Annex C: Equivalent Temperature difference (TD_{eqw} and TD_{eqr})

Wall (TD_{eqw})

Orientation Mauritius	Weight of wall construction		
	< 100 kg/m²	100-300 kg/m²	> 300 kg/m²
S	3,45	3,05	2,02
SE	5,16	4,44	2,62
E	6,86	5,84	3,22
NE	6,02	5,07	2,65
N	5,16	4,30	2,09
NW	5,99	5,02	2,53
W	5,95	5,06	2,80
SW	4,70	4,06	2,41

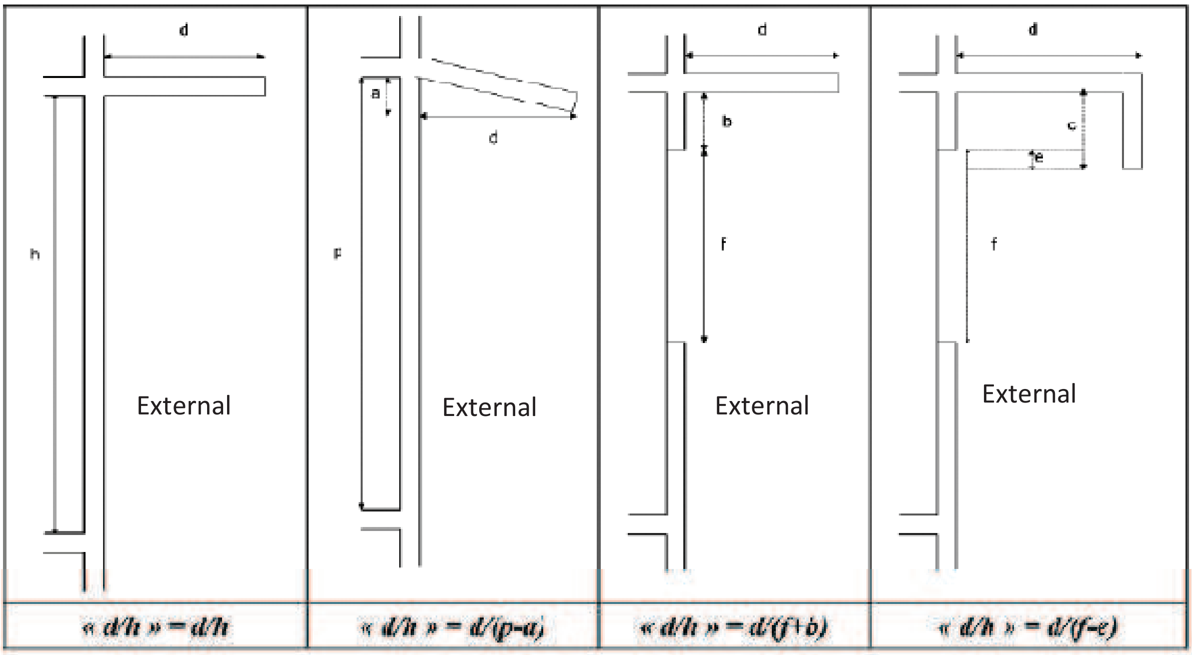
From Building Authority Hong Kong, 1995

Roof (TD_{eqr})

	Weight of roof construction		
	< 100 kg/m²	100-300 kg/m²	> 300 kg/m²
TD_{eqr}	17,26	15,11	9,61

From Building Authority Hong Kong, 1995

Annex D: Solar shading factor (SSF)



From RTAA-DOM, 2009

Opaque elements

Orientation	No Shading	Ventilated vertical shading	Wall with horizontal shading			
			d/h ≥ 0,25	d/h ≥ 0,50	d/h ≥ 0,75	d/h = 1
East	1	0,3	0,63	0,5	0,42	0,37
South	1	0,3	0,32	0,22	0,18	0,14
North	1	0,3	0,32	0,22	0,18	0,12
West	1	0,3	0,66	0,52	0,44	0,39

From Perene, 2009

Only overhang

Orientation	No Shading	d/h ≥ 0,25	d/h ≥ 0,50	d/h ≥ 0,75	d/h = 1
East	1	0,62	0,48	0,4	0,34
South	1	0,53	0,53	0,53	0,53
North	1	0,74	0,58	0,58	0,53
West	1	0,66	0,52	0,44	0,39

From Perene, 2009

Overhang + right side protection

Orientation	No Shading	d/h ≥ 0,25	d/h ≥ 0,50	d/h ≥ 0,75	d/h = 1
East	1	0,57	0,43	0,34	0,29
South	1	0,3	0,25	0,25	0,25
North	1	0,54	0,33	0,28	0,28
West	1	0,64	0,5	0,41	0,35

Overhang + left side protection

Orientation	No Shading	d/h ≥ 0,25	d/h ≥ 0,50	d/h ≥ 0,75	d/h = 1
East	1	0,62	0,47	0,39	0,33
South	1	0,32	0,28	0,28	0,28
North	1	0,52	0,31	0,25	0,25
West	1	0,61	0,46	0,37	0,32

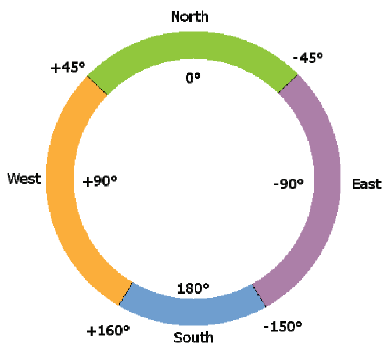
Overhang + both side protection

Orientation	No Shading	d/h ≥ 0,25	d/h ≥ 0,50	d/h ≥ 0,75	d/h = 1
East	1	0,56	0,4	0,31	0,24
South	1	0,09	0	0	0
North	1	0,32	0,06	0	0
West	1	0,59	0,43	0,34	0,27

Horizontal surfaces

	Roof without shading	Roof with shading or horizontal ventilation
Cm	1	0,3

From RTAA-DOM, 2009



Definition of orientations.

Annex E: Solar factor (SF)

Orientation		S	SE	E	NE	N	NW	W	SW
SF for vertical surface	W/m^2	104	138	168	197	191	202	175	138
SF for horizontal surface	W/m^2				264				

From Building Authority Hong Kong, 1995

Annex F: Material table

Thermal conductivity values of basic materials. The values should only be used if values from the manufacture are not available. If a material is not represented in the table, ASHRAE or other literature can be used.

Description	Density kg/m^3	λ W/m^oC
Asphalt, roofing	2240	1,226
Bitumen		1,298
Brick		
(a) dry (covered by plaster or tiles outside)	1760	0,807
(b) common brickwall (exposed to weather outside)		1,154
Concrete	2400	1,442
	64	0,144
Concrete Lightweight	960	0,303
	1120	0,346
	1280	0,476
Cork board	144	0,042
Fibre board	264	0,052
Glass, sheet	2512	1,053
Glass wool, mat or guilt	32	0,035
Gypsum plaster board	880	0,17
Hard board:		
(a)Standard	1024	0,216
(b)Medium	640	0,123
Metals:		
(a) Aluminum	2672	211
(b) Copper	8784	385
(c) Steel	7840	47,6
Mineral wool, felt	32-104	0,035-0,032
Plaster:		
(a) gypsum	1216	0,37
(b) perlite	616	0,115
(c) sand/cement	1568	0,533
(d) vermiculite	640-960	0,202-0,303
Polystyrene, expanded	16	0,035
Polyurethane, foam	24	0,024
PVC flooring	1360	0,713
Soil, loosely packed	1200	0,375
Stone, tile:		
(a) sand stone	2000	1,298

Description	**Density** **kg/m³**	**λ** **W/m°C**
(b) granite	2640	2,927
(c) marble/terrazzo/ceramic/mosaic	2640	1,298
Tile, roof	1890	0,836
Timber		
(a) across grain softwood	608	0,125
(b) hardwood	702	0,138
(c) plywood	528	0,138
Vermiculite, loose granules	80-112	0,065
Wood chipboard	800	0,144
Woodwool slab	400	0,086

Annex G: Surface film coefficient

	Direction of heat horizontal	down	Pitched ventilated roof space Down
R_{si}	0,126	0,17	0,46
R_{se}	0,074	0,04	

Where

R_{si} is the internal surface film coefficient

R_{se} is the external surface film coefficient

Annex H: Solar factor without horizontal shading (So)

So is determined in table 1-6 depending on the closing method, shading characteristics around the fenestration and the functions due to natural ventilation for thermal comfort. The general color definitions referred to in the tables, can be found in annex I.

For non air-conditioned rooms:

- Opening with no sun protection – table 1
- Opening closed with shutters or metal plates, table 2 and 2B
- Opening closed with a door or opaque movable part, which do not contribute to ventilation for thermal comfort – Table 3
- Opening closed with a window or a non-moving glass door, where the surface is a integrated part of the external opening surface – table 4
- Opening closed with a window or a moveable glass door without brick separations, where the moveable surface represents half of the external opening surface – table 5
- Transparent or translucent elements, with permanent shutters or metal plates, which do contribute to ventilation for thermal comfort – table 6

For air-conditioned rooms:

- Openings closed with transparent or translucent elements (shutters/metal plates, window or glass door – movable or non movable permanent glass elements) – table 6
- Openings closed with opaque movable elements (opaque shutters or metalplates, doors) – Table 3

Table 1: Solar factor without horizontal shading, So for openings with no sun protection

Type of protection	So
None (no other types then grid or iron bars)	1,00

Table 2: Solar factor without horizontal shading, So for openings closed with opaque shutters/metal plates or clear glass without reflective treatment.

Type of protection		So
Opaque shutters/metal plates (wood, metal, PVC...)	Shutters ”Light color”	0,28
	Shutters ”Medium color”	0,37
	Shutters ”Dark color”	0,46
	Shutters ”Very dark color”	0,53
Shutters of clear glass without reflective treatment	Shutters 4 mm clear glass	0,87
	Shutters 10 mm clear glass	0,83

Table 2B: Solar factor without horizontal shading, So for openings closed with transparent or translucent shutters/metal plates other than clear glass without reflective treatment.

Type of protection	Solar factor without horizontal shading, So						
	Shading coefficient of material (*)						
	0,70 - 0,79	0,60 - 0,69	0,50 - 0,59	0,40 - 0,49	0,30 - 0,39	0,20 - 0,29	0,10 - 0,19
Colored glass, non- refletive	0,86	0,81	0,76	0,71	0,66		
Shutter with reflection (12 - 20%)			0,73	0,68	0,63	0,58	0,53
Shutter with reflection (21 - 30%)				0,61	0,56	0,51	0,46
Shutter with reflection (>31 %)				0,57	0,54	0,49	0,44

(*) Data from manufature

Table 3: Solar factor without horizontal shading, So for opening closed with a door or opaque movable part (not included in the opening area of the outside)

Type of protection		**So**
Door or opaque element of wood or PVC (R > 0,1 m^2K/W)	Outside in ”Light color”	0,09
	Outside in ”Medium color”	0,14
	Outside in ”Dark color”	0,19
	Outside in ”Very dark color”	0,22
Metallic door or fixed opaque element with low resistance (R < 0,1 m^2K/W)	Outside in ”Light color”	0,15
	Outside in ”Medium color”	0,22
	Outside in ”Dark color”	0,30
	Outside in ”Very dark color”	0,35

Table 4: Solar factor without horizontal shading, So for opening closed with a window or a non moving glass door

Type of protection		**So**
Opening without shutters or sunblind	none	1,00
Opening protected with a non adjustable shutter or a vertical sunblind	Non openable shutters and sunblind's or all fixed shading which would not allow complete use of the opening for thermal comfort ventilation, will not be considered as contributing towards the solar factor, So.	1,00
Opening protected with a adjustable shutter or opaque sunblind	Shutter or sunblind in "Light color"	0,28
	Shutter or sunblind in "Medium color"	0,37
	Shutter or sunblind in "Dark color"	0,46
	Shutter or sunblind in "Very dark color"	0,53
Opening with a adjustable transparent sunblind	Sunblind in "light color"	0,36
	Sunblind in "Medium color"	0,44
	Sunblind in "Dark color"	0,52
	Sunblind in "Very dark color"	0,60

A transparent sunblind is a non dark sunblind characterized by a visible transmittance less than or equal to 0,20.

Table 5: Solar factor without horizontal shading, So for openings closed with a window or a movable glass door without brick separations, where the surface of the moveable part represents half of the opening surface.

Type of protection		**So**
No shutters or sunblinds	Metal	0,78
	Other materials	0,72
Opening protected with a non adjustable shutter or a vertical sunblind	Metal	0,78
	Other materials	0,72
Opening protected with a adjustable shutter or opaque sunblind	Shutter or sunblind in ”Light color”	0,19
	Shutter or sunblind in ”Medium color”	0,25
	Shutter or sunblind in ”Dark color”	0,30
	Shutter or sunblind in ”Very dark color”	0,34
Opening with a adjustable transparent sunblind	Sunblind in ”light color”	0,28
	Sunblind in ”Medium color”	0,33
	Sunblind in ”Dark color”	0,38
	Sunblind in ”Very dark color”	0,43

Table 6: Solar factor without horizontal shading, So for openings in air conditioned rooms closed with a transparent or translucent parts (metal plates/shutters, windows or glass doors, fixed glass parts)

Type of protection		Solar factor without horizontal shading, So				
		Opening with no protection	Openings protected with shutters (folding or roller shutters) or dark external sunblind			
			”Light color”	”Medium Color”	”Dark color”	”Very dark color”
Metal frame	”Light color” or ”Medium Color”	0,63	0,16	0,18	0,20	0,22
	”Dark color” or ”Very dark color”	0,61	0,12	0,14	0,16	0,18
Other metal works	”Light color” or ”Medium Color”	0,66	0,14	0,16	0,18	0,20
	”Dark color” or ”Very dark color”	0,64	0,10	0,12	0,14	0,16
Wood- or PVC works	”Dark color” or ”Very dark color”	0,52	0,10	0,12	0,14	0,16
	”Light color” or ”Medium Color”	0,51	0,08	0,10	0,12	0,14

Annex I: Absorption coefficient α

Color		**White, yellow, orange, pale, red**	**Dark red, light green, light blue, light grey**	**Brown, dark green, blue, grey**	**Black, dark brown, dark blue, dark grey**
General definition		**Light color**	**Medium color**	**Dark color**	**Very dark color**
Absorption coefficient α	Horizontal surface	α = 0,6	α = 0,6	α = 0,8	α = 1,0
	Vertical surface	α = 0,4	α = 0,6	α = 0,8	α = 1,0

Annex F: Example calculation OTTV and Solar factor

1 Example calculation of OTTV

The base of this example is a one story residential building. In figure 1-3 is a 3D drawing, a façade and a floor plan of the building. The building is located in climatic zone 1. It has a gross area of 637m2 whereas the building should comply with alternative 1(b) in the Building Energy Efficiency Code for Mauritius.

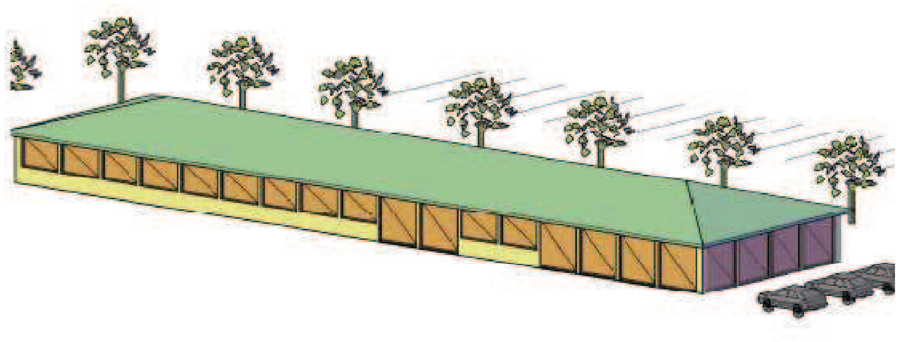


Figure 5: 3D drawing of the residential building used in the example.

Figure 6: Facade of the residential building used in the example.

Figure 7: Floor plan of the residential building used in the example.

This example will show how to calculate the overall thermal transfer value (OTTV) for a common residential building. It will consist of two separately calculations one for the walls and one for the roof.

1.1 OTTV for walls

$$OTTV = \frac{Q_{wc} + Q_{gc} + Q_{sol}}{A_i} = \frac{(A_w \cdot U_w \cdot TD_{eq}) + (A_f \cdot U_f \cdot DT) + (A_f \cdot SC \cdot SF)}{A_i}$$

The example will be shown in the following order:

1. Determine the wall and window areas
2. Calculating the U-value of the wall
3. Determine the heat conduction through opaque walls
4. Determine the heat conduction through windows and doors
5. Determine the solar radiation through window glass
6. Overall thermal transfer value (OTTV)

1.1.1 Determine the wall and window areas

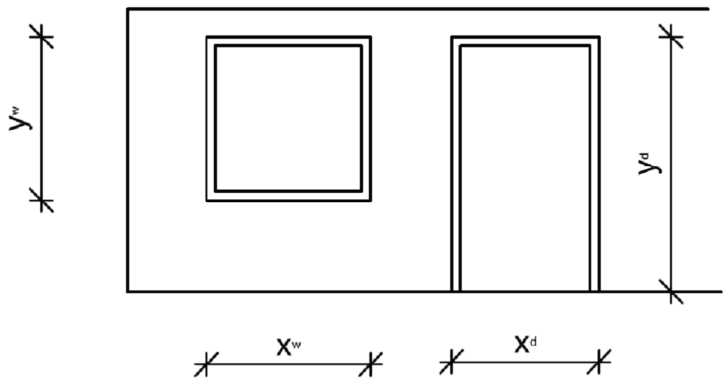


Figure 8: Principle section of the south-facing façade.

$$A_{f,win,south} = (x_w \cdot y_w) \cdot n_w$$
$$A_{f,door,south} = (x_d \cdot y_d) \cdot n_d$$

Where n is the number of doors or windows.

The same principle is used for the other three facades.

The table below holds the data for the windows of the complete building.

Table 7: Calculated areas, the U-values (U_f) and solar factor (SC_{win}) is from annex A, the windows is with double pane insulated glass.

Building component	Orientation	A_f [m^2]	U_f [$W/m^{2o}C$]	SC_{win}
Windows	N	54,6	2,73	0,7
Doors	N	25,2	1,43	0,63
Windows	W	8,4	2,73	0,7
Doors	W	12,6	1,43	0,63
Windows	E	16,8	2,73	0,7
Windows	S	46,2	2,73	0,7
Doors	S	37,8	1,43	0,63
Total		201,6		

The area (A_w) of the opaque wall can be calculated as in the following expression:

$$A_w = A_{i,south} - A_{f,south}$$
$$A_w = (51{,}6m \cdot 3{,}1m) - (46{,}2 - 37{,}8)m^2$$
$$= 75{,}96m^2$$

Table 8: Showing the areas and orientation of the walls.

Building component	Orientation	A_w [m^2]
North-facing wall	N	80,16
West-facing wall	W	18,06
East-facing wall	E	22,26
South-facing wall	S	75,96
Total		196,44

1.1.2 Calculating the U-value (U_w) of the wall

The wall is made from blocks illustrated in Figure 9. First step is to split the block in three layers, C, D and C. The C layer consists of only one material and is called at homogeneous layer. The D layer consists of two "materials", air and concrete, thus called an inhomogeneous layer.

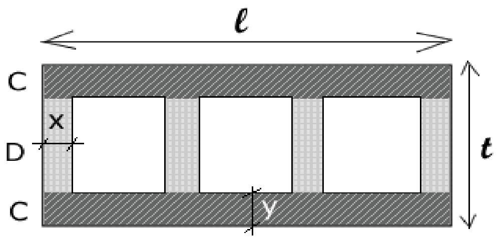


Figure 9: Block used for the construction of the walls.

The calculation will be split I three parts, one for each different layer and a combined calculation.

Data for the blocks

$$l = 450mm$$
$$x = 37{,}5mm$$
$$y = 35mm$$
$$t = 200mm$$
$$\lambda_{Concrete} = 1{,}44 \tfrac{W}{m^oC} \text{ (From annex F)}$$

Where lambda (λ) is the conductivity, in this case of concrete.

Resistance of the inhomogeneous layer (D)

First the fractions of the two materials are determined.

$$F_{concret} = \frac{4 \cdot x}{l} = \frac{4 \cdot 37{,}5mm}{450mm} = 0{,}33$$
$$F_{cavity} = 1 - F_{concrete} = 1 - 0{,}33 = 0{,}67$$

Then the resistance of the two materials is calculated.

$$R_{concrete} = \frac{d}{\lambda_{concrete}} = \frac{t - 2 \cdot y}{\lambda_{concrete}} = \frac{0{,}2m - 2 \cdot 0{,}035m}{1{,}44 \frac{W}{m^oC}} = 0{,}09 \frac{m^{2o}C}{W}$$

The cavity's resistance depends on the width of the cavity and can be read in annex B

$$R_{Cavity} = 0{,}18 \frac{m^{2o}C}{W}$$

The combined resistance of the entire layer D can be determined as the weighted average of the resistance of the two materials.

$$R_D = F_{concrete} \cdot R_{concrete} + F_{Cavity} \cdot R_{cavity}$$
$$R_D = 0{,}33 \cdot 0{,}09 \frac{m^{2o}C}{W} + 0{,}67 \cdot 0{,}18 \frac{m^{2o}C}{W} = 0{,}15 \frac{m^{2o}C}{W}$$

Resistance of the homogeneous layer (C)

This layer only consists of concrete, whereas the calculation is quite simple.

$$R_C = \frac{d}{\lambda_{concrete}} = \frac{y}{\lambda_{concrete}} = \frac{0{,}035m}{1{,}44 \frac{W}{m^oC}} = 0{,}024 \frac{m^{2o}C}{W}$$

U-value for the entire wall

The resistance for the three layers is summarized and the external and internal surface coefficient is added.

Table 9: The total resistance of a block wall.

Total resistance **Layer**		**R** **$m^{2o}C/W$**
R_{si}	=	0,074
Concrete (C)	=	0,024
Inhomogeneous layer (D)	=	0,15
- Concrete		
- Cavity		
Concrete (C)	=	0,024
R_{se}	=	0,126
Sum	=	0,40

The U-value can then be calculated.

$$U_W = \frac{1}{R} = \frac{1}{0{,}40\,\frac{m^2\,^oC}{W}} = 2{,}51\,\frac{W}{m^2\,^oC}$$

1.1.3 Determine the heat conduction through opaque walls

The heat gain through walls is determined by the equation below.

$$Q_{WC} = A_w \cdot U_w \cdot TD_{eq}$$

The area (A_w) and the U-value (U_w) are already known. The equivalent temperature difference (TD_{eq}) can be read in annex C. The factor takes density and orientation into account whereas we need to establish the weight of one square meter of opaque wall.

First the height of a wall only 1 block wide has to be determined. It is assume that mortar has the same density as concrete for simplification.

$$A = h \cdot l$$

Where

A is the wall area (m2)
h is the wall height (m)
l is the length of the block (m)

$$h = \frac{A}{l} = \frac{1m^2}{0{,}45m} = 2{,}22m$$

Then the volume of the wall is determined. The volume of the concrete and the volume of the air have to be calculated separately due to the difference in density.

$$V_{concrete} = 2 \cdot (y \cdot l \cdot h) + 4 \cdot [(t - 2 \cdot y) \cdot x \cdot h] = 2 \cdot (0{,}035m \cdot 0{,}45m \cdot 2{,}22m) + 4 \cdot [(0{,}2m - 2 \cdot 0{,}035m) \cdot 0{,}0375m \cdot 2{,}22m]$$
$$= 0{,}113\,\frac{m^3}{m^2}$$

$$V_{air} = (l - 4 \cdot x) \cdot (t - 2 \cdot y) \cdot h = (0{,}45m - 4 \cdot 0{,}0375m) \cdot (0{,}2m - 2 \cdot 0{,}035m) \cdot 2{,}22m = 0{,}087\,\frac{m^3}{m^2}$$

By multiplying the volumes respectively by the density of the materials the weight of 1 m^2 wall is determined.

The densities:

$$\rho_{concrete} = 2400\,\frac{kg}{m^3}\ \text{(from annex F)}$$
$$\rho_{air} = 1{,}18\,\frac{kg}{m^3}\ (\text{at } 20^\circ C)$$

The weight of 1 m^2 wall

$$m = V_{concrete} \cdot \rho_{concrete} + V_{air} \cdot \rho_{air} = 0{,}113 \tfrac{m^3}{m^2} \cdot 2400 \tfrac{kg}{m^3} + 0{,}087 \tfrac{m^3}{m^2} \cdot 1{,}18 \tfrac{kg}{m^3} = 272 \tfrac{kg}{m^2}$$

In Annex C the TD_{eq} values for the different orientations can be obtained.

$TD_{eq,south}$ = 3,05
$TD_{eq,north}$ = 4,30
$TD_{eq,east}$ = 5,84
$TD_{eq,west}$ = 5,06

The total heat gain through the opaque walls is presented in the table below.

Table 10: Total heat gain from opaque walls.

Description	A_w	U_w	Td_{eq}	Sum
	m^2	$W/m^2\,^oC$	^oC	W
North-facing wall	80,16	2,51	4,30	864,11
West-facing wall	18,06	2,51	5,06	229,33
East-facing wall	22,26	2,51	5,84	325,87
South-facing wall	75,96	2,51	3,05	580,45
Subtotal	196,44			**1999,75**

Example: "North wall"

$$Q_{wc,northwall} = A_w \cdot U_w \cdot TD_{eq} = 80{,}16 m^2 \cdot 2{,}51 \tfrac{W}{m^2 \cdot {}^o C} \cdot 4{,}30^o C = 864{,}11 W$$

1.1.4 Determined the heat conduction through windows and walls

The heat gain is determined by the formula below.

$$Q_{gc} = A_f \cdot U_f \cdot DT$$

The area (A_f) and the U-value (U_f) are already known. The temperature difference is calculated below. The building is located in climatic zone 1, whereas T_e = 30 ^oC.

$$DT = T_e - T_i = 30^o C - 24^o C = 6^o C$$

The Total heat gain from the openings is listed in the table below.

Table 11: Total heat gain through openings.

	A_f	U_f	DT	Sum
	m^2	W/m^2K	K	W
Windows, N	54,60	2,73	6,00	894,35
Doors, N	25,20	1,43	6,00	216,22
Windows, W	8,40	2,73	6,00	137,59
Doors, W	12,60	1,43	6,00	108,11
Windows, E	16,80	2,73	6,00	275,18

Windows, S	46,20	2,73	6,00	756,76
Doors, S	37,80	1,43	6,00	324,32
Subtotal	201,6		**Heat gain**	**2712,53**

Example: "Windows, N"

$$Q_{windows,N} = A_f \cdot U_f \cdot DT = 54{,}6m^2 \cdot 2{,}73\frac{W}{m^{2o}C} \cdot 6^{\circ}C = 894{,}35W$$

1.1.5 Determine the solar radiation through fenestration

The solar radiation through fenestration is calculated from the formula below.

$$Q_{sol} = A_f \cdot SC_{win} \cdot SSF \cdot SF$$

The area (A_f) and the shading coefficient (SC_{win}) is already known from Table 7.

The solar shading factor (SSF) is determined from the tables and figures in annex D. The factor depends on orientation, the relation between the size of the shading and the window and the direction of the shading.

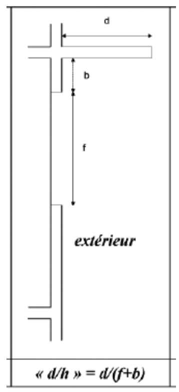


Figure 10: principle for calculating the relationship between window and overhang, see annex D.

In the case of the south-facing windows the relation between the overhang and the window is calculated from Figure 10

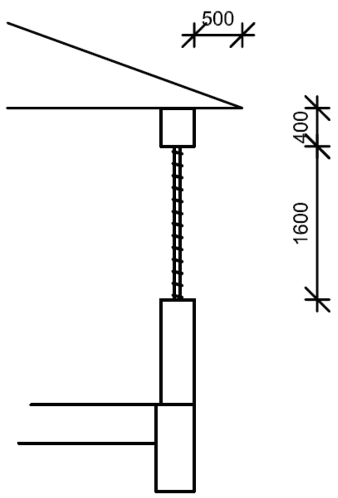


Figure 11: Section of south- facing window.

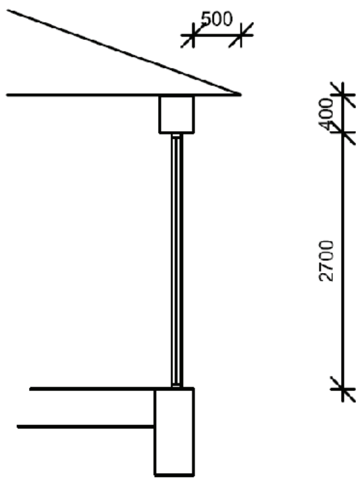


Figure 12: Section of south-facing door.

For south-facing windows: "only overhang"

$$\frac{d}{h} = \frac{0,5m}{1,6m + 0,4m} = 0,25 \Rightarrow SSF = 0,53$$

For south-facing doors: "only overhang"

$$\frac{d}{h} = \frac{0,5m}{2,7m + 0,4m} = 0,16 \Rightarrow SSF = 1$$

The results for the last three orientations can be found in table 12.

The solar factor (SF) of fenestration is determined from annex E and depends on the orientation and the direction of the surface. In this case all the windows are vertically installed, that makes the orientation the only variable. The solar factor (SF) can be obtained from annex E.

For at south-facing window the solar factor is 104 W/m^2.

The table below lists the heat gain from radiation through the windows and doors.

Table 12: Values for calculating the solar radiation through fenestration.

Description	A_f	SC_{win}	SSF	SF	Sum
	m^2	-	-	W/m^2	W
Windows, N	54,60	0,7	0,74	191	5402,01
Doors, N	25,20	0,63	1	191	3032,32
Windows, W	8,40	0,7	0,66	175	679,14
Doors, W	12,60	0,63	1	175	1389,15
Windows, E	16,80	0,7	1	168	1975,68
Windows, S	46,20	0,7	0,53	104	1782,58
Doors, S	37,80	0,63	1	104	2476,66
Subtotal	201,6			**Heat gain**	**16737,54**

1.1.6 Overall thermal transfer value (OTTV)

To calculate the OTTV the sum of the heat gains is distributed to the area of the fenestration and wall.

$$OTTV = \frac{Q_{Wc} + Q_{gc} + Q_{sol}}{A_f + A_w} = \frac{2000W + 2713W + 16738W}{202m^2 + 196m^2} = 54\,\tfrac{W}{m^2} > 45\,\tfrac{W}{m^2} \Rightarrow \text{Not acceptable!}$$

In this case the requirement of the energy efficiency code is not met. The largest contributor to the heat gain is the gain from radiation through fenestration, by reducing the fenestration area by 16 % the requirements could be met. There are other ways to bring down the heat gain. It could be lower U-values, lower solar factors for the fenestration, larger external shading etc.

1.2 OTTV for a roof construction

$$OTTV_r = \frac{Q_{rc} + Q_{gc} + Q_{sol}}{A_i} = \frac{(A_r \cdot U_r \cdot TD_{eqr}) + (A_s \cdot U_s \cdot DT) + (A_s \cdot SC_{win} \cdot SSF \cdot SF)}{A_i}$$

The example will be in the following order:

1. Determine the roof area
2. Calculating the U-value of the roof
3. Determined the heat conduction through opaque roof
4. Overall thermal transfer value (OTTV)

1.2.1 Determine the roof area

The roof area will be calculated as the horizontal area of the roof.

$$A_R = l \cdot b = 51{,}6m \cdot 12{,}6 = 650{,}2m^2$$

1.2.2 Calculating the U-value for the roof

The construction is a pitched roof with a horizontal ceiling slap of reinforced concrete.

The calculation is made similar to the calculation of the wall. First the resistance of the layers is determined. In this case the horizontal concrete slap is a homogeneous layer. In case of at flat roof the resistance is calculated as for walls, the only difference is the internal and external surface coefficients.

The homogeneous layer

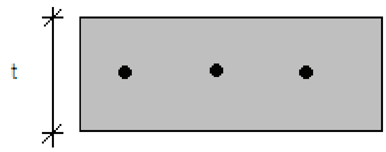


Figure 13: Section of reinforced concrete slap.

Where t = 200mm

From the material table in annex F the conductivity is read.

λ = 1,44 W/m°C

The resistance is calculated as below

$$R_{slap} = \frac{t}{\lambda} = \frac{0{,}2m}{1{,}44\,\frac{W}{m^{o}C}} = 0{,}14\,\frac{W}{m^{2o}C}$$

When a roof is ventilated, the construction from the ventilated cavity to the outside is considered to have one resistance. That makes the external surface film coefficient cero and the rest of the roof construction equal to the pitched ventilated roof space factor in annex H. (0,46 m^2K/W)

The total resistance and the U-value of the roof can then be calculated.

Table 13: The total resistance of the roof.

Total resistance			
Layer		**R**	
R_{si}	=	0,170	$m^{2o}C/W$
Ceiling slap	=	0,14	$m^{2}\,^{o}C/W$
Roof constrution	=	0,46	$m^{2}\,^{o}C/W$
R_{se}	=	0,00	$m^{2}\,^{o}C/W$
Sum	=	0,77	$m^{2}\,^{o}C/W$

The U-value can then be calculated.

$$U_r = \frac{1}{R} = \frac{1}{0{,}77\,\frac{m^{2o}C}{W}} = 1{,}30\,\frac{W}{m^{2o}C}$$

1.2.3 Determine the heat conduction through opaque roof

The heat gain through walls is determined by the formula below.

$$Q_{WC} = A_r \cdot U_r \cdot TD_{eqr}$$

The area (A_r) and the U-value (U_r) are already known and the equivalent temperature difference (TD_{eqr}) is the only unknown. TD_{eq} depends on the weight of one square meter roof and can be read in annex C.

To be able to calculate the weight of one square meter there is made a section of one square meter and the mass of the materials is calculated.

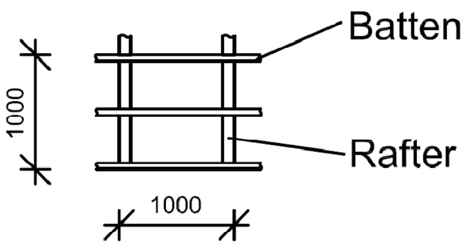


Figure 14: Principle section of 1 m² without tiles.

Figure 14 shows the principle section of one square meter. The roof consists of rafters (200x100mm, 2 ptc.), battens (60x45mm, 3 ptc.) and tiles (h = 40mm) covering one square meter. It is also needed to take the ceiling slap into account. This is 200mm thick and is covering one square meter.

In the table below lists the materials and its data. All material data can be found in annex H.

	Thickness mm	Width mm	n ptc	Density kg/m³	mass kg/m²
Ceiling slap	200	1000	-	2400	480
Roof construction					
Rafter	200	100	2	600	24
Batten	60	45	3	500	4,05
Tiles	40	1000	-	2100	84
Sum					592

Example: "Ceiling slap"

$$V_{ceiling} = 0{,}2m \cdot 1m \cdot 1m = 0{,}2m^3$$
$$m = \rho_{concrete} \cdot V_{ceiling} = 2400\tfrac{kg}{m^3} \cdot 0{,}2m^3 = 480kg$$

Example: "Rafter"

$$V_{rafter} = 0{,}2m \cdot 0{,}1m \cdot 1m \cdot 2 = 0{,}04m^3$$
$$m = \rho_{wood,600} \cdot V_{rafter} = 600\tfrac{kg}{m^3} \cdot 0{,}04m^3 = 24kg$$

In annex C the TD_{eqr} can be read. For the given weight of the wall (592kg/m^2) the TD_{eqr} is set to 9,61^{o}K

The heat conduction can then be calculated.

$$Q_{rC} = A_r \cdot U_r \cdot TD_{eqr} = 650{,}2m^2 \cdot 1{,}30\tfrac{W}{m^2K} \cdot 9{,}61^\circ K = 8122{,}9W$$

1.2.4 Overall thermal transfer value (OTTV)

$$OTTV_r = \frac{Q_r + Q_{gc} + Q_{sol}}{A_r} = \frac{A_r \cdot U_r \cdot TD_{eqr}}{A_r}$$

The heat gain from fenestration (Q_{gc}) and solar radiation (Q_{sol}) is cero, since there's no skylight.

$$OTTV_r = \frac{8122{,}9W}{650{,}2m^2} = 12{,}5\tfrac{W}{m^2} < 45\tfrac{W}{m^2} \Rightarrow OK$$

2 Example calculation of Solar factor

In this example, the solar factor (S) will be calculated for the walls, roof and fenestration.

The building has yellow render, light roof and an overhang of half a meter.

1. Calculating the solar factor for the walls
2. Calculating the solar factor for the roof
3. Calculating the solar factor for fenestration

2.1 Calculating the solar factor for walls

The solar factor for wall is defined as follows:

$$S = \frac{0{,}074 \cdot SSF \cdot \alpha}{R + 0{,}20}$$

To calculate the solar factor for the walls the resistance, the shading coefficient and the absorption coefficient have to be determined.

The resistance (R) has already been determined in the OTTV calculation and will be reused, see Table 9. In the equation for the solar factor only the resistance of the material is used. Thus it is necessary to deduct the internal (R_{si}) and external (R_{se}) film surface coefficient.

$$R = R_{Total} - R_{SI} - R_{SE} = (0{,}41 - 0{,}074 - 0{,}126)\tfrac{m^2K}{W} = 0{,}21\tfrac{m^2K}{W}$$

The shading coefficient SSF, depends on the relation between height of the wall and size of the shading. In annex D the d/h can be calculated and the SSF determined.

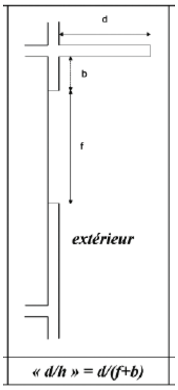


Figure 15: Principle for calculating the d/h relation.

$$\frac{d}{h} = \frac{0{,}5m}{3{,}1m} = 0{,}16 \Rightarrow SSF = 1$$

SSF is the same for all the walls due to the same d/h relation.

The absorption is determined from the color of the surface, in this case the walls have yellow render. In annex I the absorption can be determined as light color (α=0,4).

Finally the solar factor can be calculated.

$$S = \frac{0{,}074 \cdot SSF \cdot \alpha}{R + 0{,}20} = \frac{0{,}074 \cdot 1 \cdot 0{,}4}{0{,}21 + 0{,}20} = 0{,}07 < 0{,}09 \Rightarrow \text{OK}$$

To calculate the combined S value a weighted average due to the areas is calculated. In this case all walls have the same solar factor which makes the weighted average irrelevant, but for the learning objective its shown anyways.

$$S = \frac{\sum_{i=1}^{n} S_i \cdot A_i}{\sum_{i=1}^{n} A_i} = \frac{S_{north} \cdot A_{north} + S_{south} \cdot A_{south} + S_{east} \cdot A_{east} + S_{west} \cdot A_{west}}{A_{north} + A_{south} + A_{east} + A_{west}}$$

$$= \frac{0{,}07 \cdot 80{,}16m^2 + 0{,}07 \cdot 75{,}96m^2 + 0{,}07 \cdot 22{,}26m^2 + 0{,}07 \cdot 18{,}06m^2}{80{,}16m^2 + 75{,}96m^2 + 22{,}26m^2 + 18{,}06m^2} = 0{,}07$$

2.2 Calculating the solar factor for the roof

The solar factor for roof is defined as follows:

$$S = \frac{0{,}074 \cdot SSF \cdot \alpha}{R + 0{,}23}$$

To calculate the solar factor for the roof the resistance, the shading coefficient and the absorption coefficient have to be determined.

The resistance (R) has already been determined in the OTTV calculation and will be reused, see Table 13.

$$R = R_{Total} - R_{SI} - R_{SE} = (0{,}49 - 0{,}04 - 0{,}17)\,\tfrac{m^2K}{W} = 0{,}28\,\tfrac{m^2K}{W}$$

The shading coefficient (SSF) for a roof depends on whether the roof is shaded and ventilated. In this case the roof has a ventilated cavity and SSF can be determined from annex D to 0,3.

The absorption coefficient depends on the color of the roof. In this case the roof is light and has the general definition "light color" can be obtained from annex I, thus α=0,6.

The solar factor can then be calculated

$$S = \frac{0{,}074 \cdot SSF \cdot \alpha}{R + 0{,}23} = \frac{0{,}074 \cdot 0{,}3 \cdot 0{,}6}{0{,}28 + 0{,}21} = 0{,}026 > 0{,}03 \Rightarrow OK$$

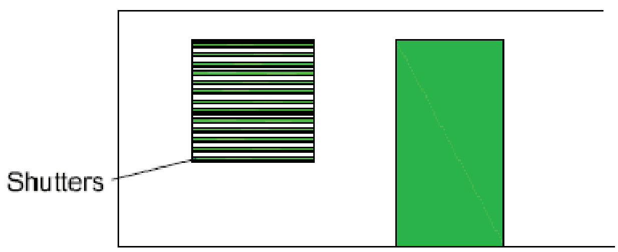
2.3 Calculating the solar factor for windows and doors

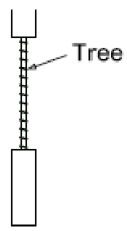
The solar factor for fenestration is defined as follows:

$$S = So \cdot SSF$$

In order to calculate the solar factor for the fenestration, the solar factor for a window without considering horizontal shading (So) and the coefficient of reduction (SSF), has to be determined.

So is determined by the type of shading and whether the building is air-conditioned. In this case the building is natural ventilated and the windows are shutters of wood in a dark green color. The doors are made of wood and have the same dark green color.





According to table 2 in annex H, So_w for the windows is 0,46 and for doors table 3 is used to determine the So_d to 0,19.

The SSF value is already know from Table 12 and is listed in Table 14. Under the table is two examples showing how the table is calculated.

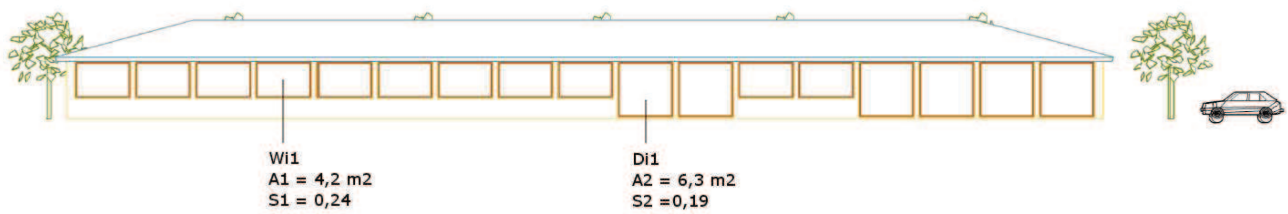
Table 14: Values for calculating the So for openings.

Description	A_i m^2	So_w -	SSF -	S_i -	S -	OK
Windows, N	54,60	0,46	0,74	0,34		
Doors, N	25,20	0,19	1	0,19	0,29	OK
Windows, W	8,40	0,46	0,66	0,30		
Doors, W	12,60	0,19	1	0,19	0,24	OK
Windows, E	16,80	0,46	1	0,46	0,46	OK
Windows, S	46,20	0,46	0,53	0,24		
Doors, S	37,80	0,19	1	0,19	0,22	OK
Subtotal	201,6					

Example "Windows,S":

$$S = So \cdot SSF = 0{,}46 \cdot 0{,}53 = 0{,}24$$

It is required to calculate the weighted average for each orientation to meet the limitations in the Energy Efficiency Code. The figure below shows how the south-facing façade is calculated.



$$S_{South} = \frac{\sum_{i=1}^{n} S_i + A_i}{\sum_{i=1}^{n} A_i} = \frac{n_1 \cdot S_1 \cdot A_1 + n_2 \cdot S_2 \cdot A_2}{n_1 \cdot A_1 + n_2 \cdot A_2} = \frac{11 \cdot 0{,}24 \cdot 4{,}2m^2 + 6 \cdot 0{,}19 \cdot 6{,}3m^2}{11 \cdot 4{,}2m^2 + 6 \cdot 6{,}3m^2} = 0{,}22 < 0{,}65 \Rightarrow OK$$

PART 2: Calculation of Total Annual Energy Consumption

1 Calculation methodology

As per section 6.1 of the Energy Efficiency Building Code, the energy consumption for residential buildings is to be calculated, for information (not compliance), and to allow data to be collated about the energy consumption of the residential buildings.

The energy consumption calculation is based on the energy consumed by fixed building services in the building, but not end-uses (cooking appliances, lighting, TV, etc). The energy consumption is based primarily on the cooling load of the building, auxiliary energy consumption (from fans, pumps and control gear), and energy used for hot water provision.

2 Definitions

For the purposes of this document, the following definitions apply:

2.1 Net Floor Area

The net floor area (**A**) within the boundary of the building should be used when calculating the total energy consumption per m^2. This is equal to the sum of all areas between the vertical building components (walls or partitions), excluding garages and non-conditioned storerooms.

2.2 Delivered v/s Primary Energy Consumption

Primary energy is the energy value of the fuel at source, whereas delivered energy is the net energy delivered to the building. The final annual energy consumption value calculated should reflect the "primary" energy consumption of the building. Calculating the primary energy allows the energy consumption based on different sources to be reduced to a common unit.

For instance, in certain cases, gas may be used for heating water and in other cases electricity may be used. The primary energy takes into account losses which occur during generation, transmission and distribution of energy. For energy which is generated on-site (e.g. on-site gas water heater), a conversion factor of 1.0 applies, whereas for centrally-generated energy (electricity from power stations), a conversion factor of 1.68 applies, in order to account for the losses that occur from energy generation to the energy delivered to the building.

Note: The precise energy conversion factor for centrally-generated energy (electricity from power stations) will need to be confirmed by CEB). For now, the value 1.68 is being used, which is the ratio of total delivered to primary energy according to the energy statistics for the year 2009 (Central Statistics Office).

3 Breakdown of energy consumption calculations

3.1 Energy consumption due to space cooling

The annual space cooling load estimation (based on internal gains due to occupancy, equipments, etc) should be calculated by the M&E Engineer, in order to determine the required capacity of the cooling system, *without over-sizing the cooling system*. At a *minimum*, the following internal heat gain components should be included in the calculation of the space cooling load:

Heat gains due to building occupants;

Heat gains due to lighting;

Heat gains due to appliances/equipment;

Heat gains due to warm outdoor air being introduced into the building through ventilation *(it should be noted that the external temperatures specified in Annex A, should be referred to, depending on the climate zone being considered).*

The total energy consumption due to space cooling should be calculated based on the capacity of the cooling system (provided by manufacturer), the efficiency of the cooling system (COP, Coefficient of Performance) and the annual operational hours.

The annual energy consumption due to space cooling should then be calculated as follows:

$E_{cooling}$ (kWh) = [Cooling System Capacity (kW) / CoP] x (Annual Operational Hours)

3.2 Miscellaneous power loads (Auxiliary power)

Auxiliary equipments such as fans, pumps and lifts add significantly to the energy consumption.

There are 5 equations which should be used, depending on the different scenarios.

Case 1

If the **motor and the machine are in the conditioned room**, the following calculations should be used:

E_{aux} (kWh) = 0.746 x (P / Eff) x Annual Operational Hours

where

0.746 = conversion factor for converting horsepower to kW

P = Horsepower rating from electrical power plans or manufacturer's data

Eff = Equipment motor efficiency

Case 2

If the **motor is outside and the machine is in the conditioned room,** the following calculations should be used:

E_{aux} (kWh) = 0.746 x P x Annual Operational Hours

where

P = Horsepower rating from electrical power plans or manufacturer's data

Case 3

If the **motor is belt driven and the motor and belt is outside and the machine is in the room**, the following calculations should be used:

E_{aux} (kWh) = 0.746 x P x Belt Eff x Annual Operational Hours

where

P = Horsepower rating from electrical power plans or manufacturer's data

Belt Eff = Belt transmission efficiency, as decimal fraction

Case 4

If the **motor is in the room and the machine is outside**, the following calculations should be used:

E_{aux} (kWh) = **0.746** x **[P/Motor Eff - P]** x **Annual Operational Hours**

where

P = Horsepower rating from electrical power plans or manufacturer's data

Motor Eff = Motor efficiency, as decimal fraction

Case 5

If the **motor is belt driven and the motor and belt is in the room and the machine is outside,** the following calculations should be used:

E_{aux} (kWh) = 0.746 x **[P/ (motor Eff) – P/ (Belt Eff)]** x **Annual Operational Hours**

where

P = Horsepower rating from electrical power plans or manufacturer's data

Motor Eff = Motor efficiency, as decimal fraction

Belt Eff = Belt transmission efficiency, as decimal fraction

Note that for residential buildings, Case 1 is used for calculation of auxiliary power.

3.3 Energy consumption due to hot water demand

The hot water requirement is based on the number of occupants in the building.

The daily consumption of ***hot*** *water, per person, should be taken as* ***65 Litres per day****.*

This assumes 30% of total water consumption per person is hot water, and that average total water consumption per person is 217 L/day (2009 statistical data from CWA).

The hot water energy consumption for residential buildings is calculated as follows:

E_{DHW} (kWh) = 0.28* x **Hot Water requirement (L/year)** x **Specific Heat of water** x **ΔT**

where

Specific Heat capacity of water, should be taken as **4.18/1000 MJ/kgC**

ΔT = temperature difference (deg. K that water is heated up), taken as **40℃** .

** To convert MJ into kWh, the conversion factor* ***1 MJ = 0.28 kWh*** *is used.*

3.4 Contribution from renewable energy sources

To include contribution due to solar hot water systems, photovoltaics and wind generators, the annual useful energy provided by the system, in kWh, should be obtained from the manufacturer. This contribution can be subtracted from the annual energy consumption of the building to obtain the final energy consumption.

4 Calculation of Total annual energy consumption

Using the calculations provided in the previous chapters, the estimated total annual energy consumption of the building should be calculated as follows:

TOTAL annual delivered energy consumption,

$\mathbf{E_{total}}$ **(kWh) =** $E_{cooling}$ (kWh) + E_{aux} (kWh) + E_{DHW} (kWh) - E_{renew} (kWh)

Where

$\mathbf{E_{cooling}}$ **(kWh)** = Energy consumption due to space cooling

$\mathbf{E_{aux}}$ **(kWh)** = Energy consumption due to auxiliary power

$\mathbf{E_{DHW}}$ **(kWh)** = Energy consumption due to hot water

$\mathbf{E_{renew}}$ **(kWh)** = Energy produced by renewable energy technologies

Total Annual Delivered Energy Consumption (kWh/m^2) = $\mathbf{E_{total}}$ (kWh) / A (m^2)

Total Primary Energy Consumption (kWh) =

(kWh(central generation) x 1.68) + (kWh(on-site generation) x 1.0)

5 References

CIBSE Guide B, Heating, ventilating, air conditioning and refrigeration (2005)

CIBSE Guide F, Energy Efficiency in Buildings (2004)

South African National Standard, SANS 204-1:2008

Digest of Environmental Statistics, Central Statistics Office (2010)

Annex A: Climatic data for zones 1 and 2

Mauritius is defined as having two Climatic Zones for the purpose of the Energy Efficiency Building Code.

Zone 1: Coastal Area, Altitude < 160 m

Zone 2: High Lands, Altitude ≥ 160 m

Rodrigues & other outer islands fall within Zone 1.

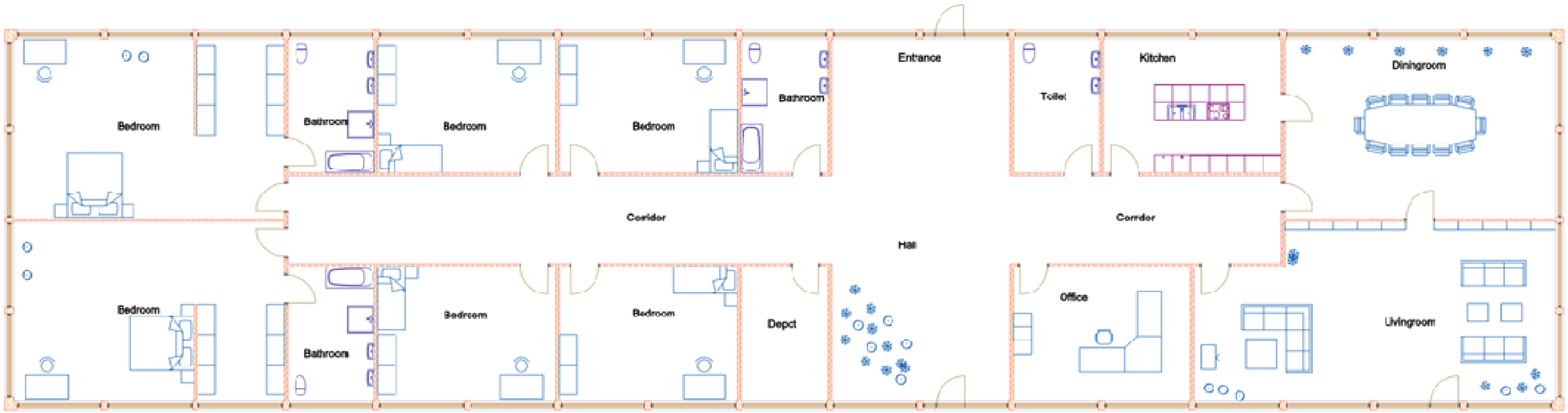
The design temperatures for each zone are given below:

	Wet Bulb (1%) °C	**Dry Bulb (1%) °C**	**Reference**
Climatic Zone 1 (Plaisance)	25,0	30,0	ASHRAE
Climatic Zone 2 (Vacoas)	23,0	27,7	MMT

Table 3: Design temperatures

Annex B: Example calculation of overall energy consumption

In order to illustrate how the calculation for energy consumption is to be carried out, an exemplary building is shown below.



Additional building details, for the purpose of this calculation, are as follows:

Building Location: Inland (Climate Zone 2)

Nett floor area = 650.2 m^2

Floor to ceiling height: 2.8 m in all rooms

Number of bedrooms: 6

Each bedroom has a split-unit air-conditioning system, with a **cooling capacity** of **3.5 kW.**

The COP of the air-conditioning units are **2.7**

Efficiency of fans (kitchen mechanical ventilation) = **0.85**

Horsepower of fan motor = **1 HP**

A **solar hot water system** will be installed on the building, and will meet **85%** of the hot water demand over the year.

Additional hot water demand is to be met using a **gas** water heater.

Calculations

1 Energy consumption due to space cooling

$E_{cooling}$ (kWh) = [Total Cooling Load (kW) / CoP] x **(operational hours)**

It is estimated that the air-conditioning system is in use for 980 hours over one year (4 hours per day over 8 months during the year).

$E_{cooling}$ (kWh) = { (3.5 x 6) / 2.7 } x 980 = 7,622 kWh

2 Energy consumption due to auxiliary power

E_{aux} (kWh) = **0.746** x **(P / Eff.)** x **Annual Operational Hours**

It is estimated that the mechanical ventilation system in the kitchen is in operation for 418 hours over one year (on average, 2 hours per day, for 4 out of 7 days each week).

Energy consumption due to fans,

E_{aux} (kWh) = 0.746 x (1.0 / 0.85) x 418 = 367 kWh

3 Energy consumption due to hot water

E_{DHW} (kWh) = 0.28 x **Hot Water requirement (L/year)** x **Specific Heat of water** x **ΔT**

Building Occupancy = 6 persons

Household hot water requirement = (65 x 6) = 390 L/day = 142,350 L/year

E_{DHW} (kWh) = 0.28 x **142,350** x **Specific Heat of water** x **ΔT**

= 0.28 x 142,350 x (4.18/1000) x 40

= 6,664 kWh

4 Energy contribution from renewable sources

The solar hot water system is to meet 85% of the annual hot water demand.

Therefore,

E_{renew} (kWh) = 0.85 x **6,664**

= 5,665 kWh

TOTAL delivered energy consumption,

E_{total} (kWh) = $E_{cooling}$ (kWh) + E_{aux} (kWh) + E_{DHW} (kWh) - E_{renew} (kWh)

= 8,989 kWh

Total Delivered Energy Consumption per unit floor area of building,

E_{total} (kWh/m^2) = E_{total} (kWh) / A (m^2)

= 8,989 / 650 = 13.83 kWh/m^2

Total Primary Energy Consumption (kWh)

= [($E_{cooling}$+ E_{aux}) x 1.68] + (E_{DHW} x 1.0) – (E_{renew} x 1.0)

= 20,086 kWh

= 30.90 kWh/m^2

Annex C: Spreadsheet showing inputs required

	Information required			Accompanying notes
1	Climate zone	Inland	▽	Select "Inland" or "Coastal" from drop-down menu
2	Net floor area	650.2	m^2	
3	No. of bedrooms	6		
4	No. of household occupants	6		
5	A/C operational hours per year	980	hrs/year	(based on an average of 4 hours of cooling per day over 8 months per year)
6	Total cooling capacity of all A/C in building	21	kW	
7	Efficiency of cooling system (CoP)	2.7		
8	Is mechanical ventilation used in the kitchens or bathrooms?	Kitchen	▽	Fill in inputs 8(a) and 8(b)
8(a)	Kitchen Mechanical ventilation fans rated power	1.00	HP or kW	
8(b)	Kitchen Mechanical ventilation fans efficiency	0.85		
~~8(c)~~	~~Bathrooms Mechanical ventilation fans rated power~~			
~~8(d)~~	~~Bathrooms Mechanical ventilation fans efficiency~~			
9	Are there any lifts in the building?	No	▽	
~~9(a)~~	~~Lift rated power~~			
~~9(b)~~	~~Lift motor efficiency~~			
10	Daily Hot Water Demand	390	L/day	
11	Main energy source used for heating water	Gas	▽	Select Gas or electricity from drop-down menu
12	Contribution from renewable energy:			
12(a)	Solar hot water panels?	Yes	▽	Select "Yes" for each renewable energy systems in the building
	Contribution (as % of hot water demand) =	85	%	
12(b)	Photovoltaics?	No	▽	"
	Contribution =		kWh/year	
12.(c)	Wind turbines?	No	▽	"
	Contribution =		kWh/year	
12(d)	Other renewable energy source (electric)	No	▽	Select Yes if there are any other renewable technology providing electrical energy
	Contribution =		kWh/year	
12(e)	Other renewable energy source (heat)	No	▽	Select Yes if there are any other renewable technology providing thermal energy
	Contribution =		kWh/year	

Notes: (i) Yellow cells need input from the user
(ii) The symbol ▽ means that the input can be selected from the drop-down menu.
The input can be selected by clicking on the green cells and then on the arrow that appears next to the cell.

Annex D: Spreadsheet showing energy consumption calculations

Calculations of energy consumption due to:

1 SPACE COOLING

$E_{cooling}$ (kWh) = [Cooling Load (kW) / CoP] x (operational hours)

Cooling system capacity (kW)	=	21	kW
CoP of cooling system	=	2.7	
Annual operational hours	=	980	hours
$E_{cooling}$ (kWh)	=	7,622	kWh

2 AUXILIARY POWER CONSUMPTION

E_{aux} (kWh) = 0.746 x (P / Eff) x Annual Operational Hours

<u>MECHANICAL VENTILATION SYSTEM</u>

<u>KITCHEN</u>

Horsepower rating from electrical power plans or manufacturer's data, P	=	1.00	
Equipment motor efficiency, Eff	=	0.85	
E_{aux} (kWh)	=	347	kWh

3 ENERGY CONSUMPTION DUE TO HOT WATER

E_{DHW} (kWh) = 0.28 x Hot Water Demand (L/year) x Specific Heat of water x ΔT

Hot Water Demand	=	142,350	L/year
Specific heat capacity of water	=	0.00418	MJ/kgK
ΔT	=	40	K
E_{DHW} (kWh)	=	6,664	kWh

4 ENERGY CONTRIBUTION FROM RENEWABLE SOURCES

Contribution from solar Hot Water Panels	=	5,664.62	kWh
Contribution from Photovoltaics	=	0	kWh
Contribution from Wind Turbines	=	0	kWh
Contribution from other renewable energy sources (electric)	=	0	kWh
Contribution from other renewable energy sources (heat)	=	0	kWh
E_{renew} (kWh)	=	5,665	kWh

Total annual delivered energy consumption	=	8,989	kWh
Total annual delivered energy consumption per unit floor area	=	13.83	kWh/m²
Total annual primary energy consumption	=	20,086	kWh
Total annual primary energy consumption per unit floor area	=	30.90	kWh/m²