VALIDATION OF THE PROGRAM GLASTA ACCORDING TO EN ISO 13788 (Annex C and D)

Introduction

Annex C of the standard EN ISO 13788[1] contains 6 examples of an interstitial condensation calculation and 1 example on drying of a wetted layer.
The following validation examples will be simulated with the software GLASTA

- C2 Example 1: Building component with condensation in one interface plane
- C3 Example 2: Building component with condensation in two interfaces*
- C4 Example 3: Building component containing a well ventilated cavity
- C5 Example 4: Building component in a warm humid climate
- C6 Example 5: Division of a layer with high thermal resistance
- D Example of the calculation of the drying of a wetted layer

* This validation example is excluded here as the data mentioned in EN ISO 13788 contains errors

Boundary conditions

Several of the validation examples make use of the boundary condition given in Annex C.1. Figure 1 shows the monthly mean external (side 1) and internal (side 2) temperature and relative humidity.

Month	External		Internal Normal occupancy		Internal High occupancy	
	θ_e °C	φ_e %	θ_e °C	φ_e %	θ_e °C	φ_e %
January	-1	85	20.0	39	20.0	49
February	0	84	20.0	40	20.0	50
March	4	78	20.0	44	20.0	54
April	9	72	20.0	49	20.0	59
May	14	68	22.0	54	22.0	64
June	18	69	24.0	58	24.0	68
July	19	73	24.5	59	24.5	69
August	19	75	24.5	59	24.5	69
September	15	79	22.5	55	22.5	65
October	10	83	20.0	50	20.0	60
November	5	88	20.0	45	20.0	55
December	1	88	20.0	41	20.0	51

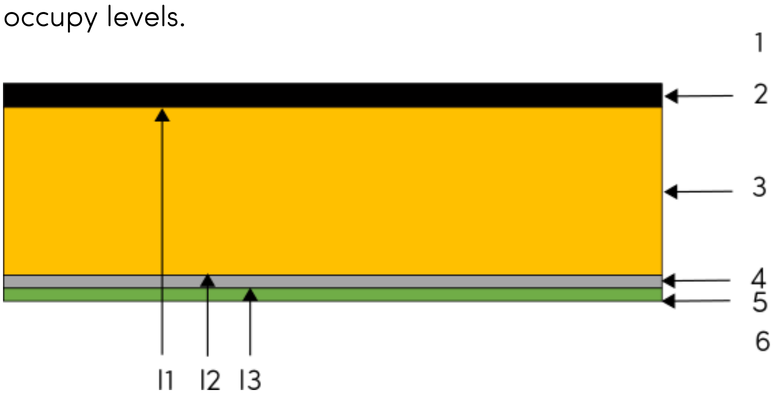
Figure 1. Boundary conditions

[1] EN ISO 13788:2012 Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods

C.2-Example 1: Condensation at 1 interface

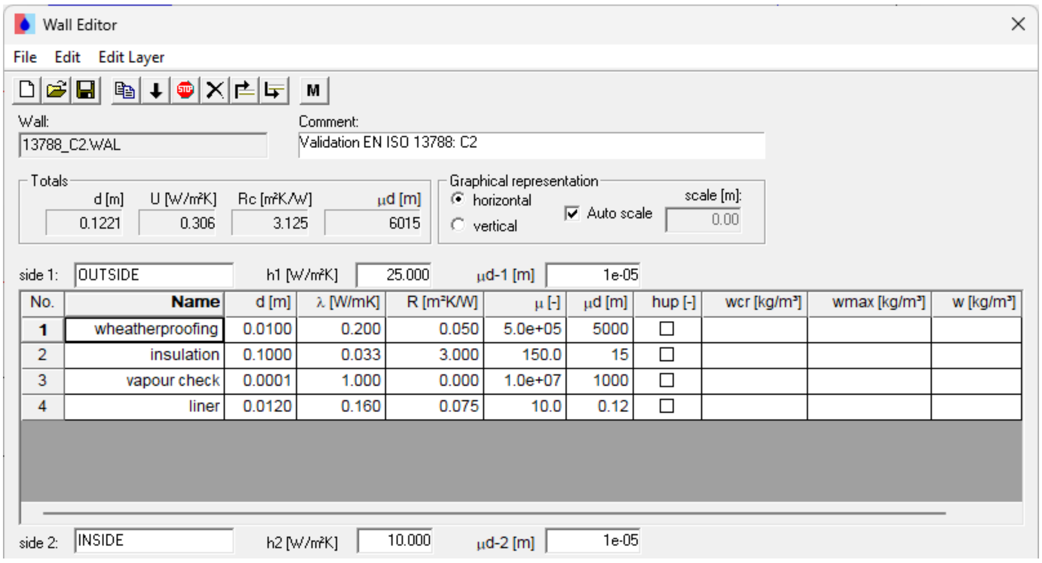
[ENISO13788_C2_normal.glp]() and [ENISO13788_C2_high.glp]()
[13788_C2.wal]()
[ENISO13788_C1_HIGH.boc]() and [ENISO13788_C1_NORMAL.boc]()

In this example, a flat roof with an impermeable weather proofing layer over the insulation is analysed. Figure 2 shows the roof built-up. The roof is analysed for both the normal and high occupy levels.



Key
1 external air
2 weatherproofing
3 insulation
4 vapour check
5 liner
6 inside air

Figure 2. Layers and interfaces in roof



No.	Name	d [m]	λ [W/mK]	R [m²K/W]	μ [-]	μd [m]	hup [-]	wcr [kg/m³]	wmax [kg/m³]	w [kg/m³]
1	wheatherproofing	0.0100	0.200	0.050	5.0e+05	5000	☐			
2	insulation	0.1000	0.033	3.000	150.0	15	☐			
3	vapour check	0.0001	1.000	0.000	1.0e+07	1000	☐			
4	liner	0.0120	0.160	0.075	10.0	0.12	☐			

Figure 3. Material properties in GLASTA

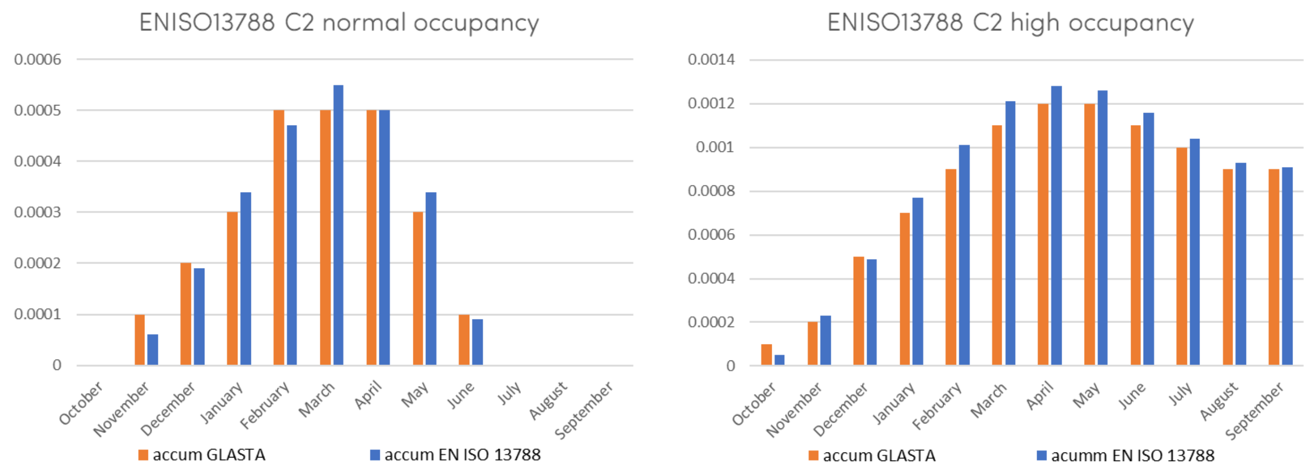


Figure 4. GLASTA results for example C.2 compared with the standard

Figure 4 and Figure 5 shows the condensation rate and the condensation accumulation rate obtained by GLASTA and listed in the standard, both for a situation with a normal and a high occupancy. The rates are practically identical.

Normal occupancy

Month	GLASTA results			table C.3 EN 13788	
	condensation rate g_c [kg/m²]	Wi-offset (kg/m²)	accumulation rate M_a [kg/m²]	condensation rate g_c [kg/m²]	accumulation rate M_a [kg/m²]
October	0	0	0	0	0
November	0.0001	0	0.0001	0.00006	0.00006
December	0.0001	0.0001	0.0002	0.00013	0.00019
January	0.0001	0.0002	0.0003	0.00015	0.00034
February	0.0001	0.0003	0.0005	0.00013	0.00047
March	0.0001	0.0005	0.0005	0.00008	0.00055
April	0	0.0005	0.0005	-0.00005	0.00050
May	-0.0001	0.0005	0.0003	-0.00016	0.00034
June	-0.0002	0.0003	0.0001	-0.00025	0.00009
July	-0.0001	0.0001	0	-0.00028	0.00000
August	0	0	0	0	0.00000
September	0	0	0	0	0.00000

High occupancy

Month	GLASTA results			table C.3 EN 13788	
	condensation rate g_c [kg/m²]	Wi-offset (kg/m²)	accumulation rate M_a [kg/m²]	condensation rate g_c [kg/m²]	accumulation rate M_a [kg/m²]
October	0.0001	0	0.0001	0.00005	0.00005
November	0.0002	0.0001	0.0002	0.00018	0.00023
December	0.0002	0.0002	0.0005	0.00026	0.00049
January	0.0003	0.0005	0.0007	0.00028	0.00077
February	0.0002	0.0007	0.0009	0.00024	0.00101
March	0.0002	0.0009	0.0011	0.0002	0.00121
April	0.0001	0.0011	0.0012	0.00007	0.00128
May	0.0000	0.0012	0.0012	-0.00002	0.00126
June	-0.0001	0.0012	0.0011	-0.0001	0.00116
July	-0.0001	0.0011	0.001	-0.00012	0.00104
August	-0.0001	0.001	0.0009	-0.00011	0.00093
September	0	0	0	-0.00002	0.00091

Figure 5. GLASTA results for example C.2 compared with the standard

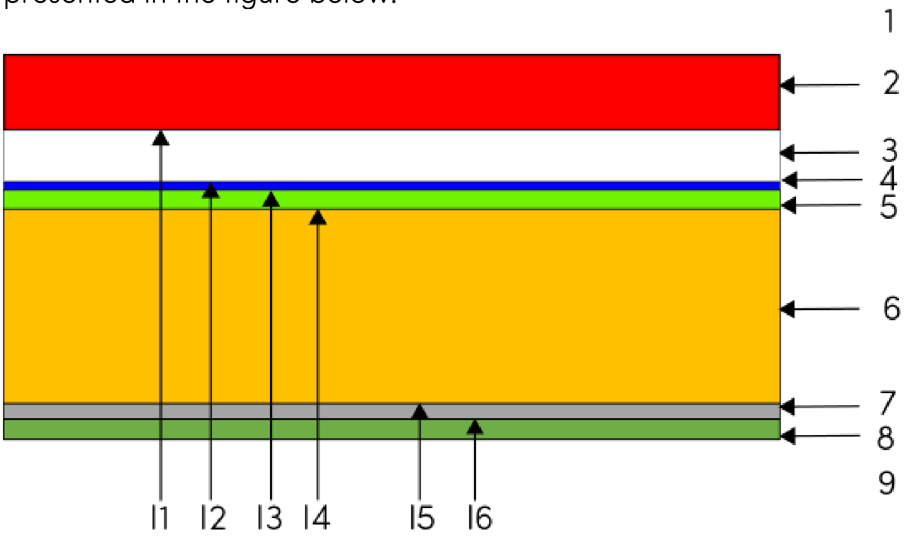
C.4-Example 3: Building component containing a well-ventilated cavity

In this validation example no condensation or drying in found. Consequently, this validation case is not relevant for validation purposes and is thus excluded here.

C.5-Example 4: Building component in a warm humid climate

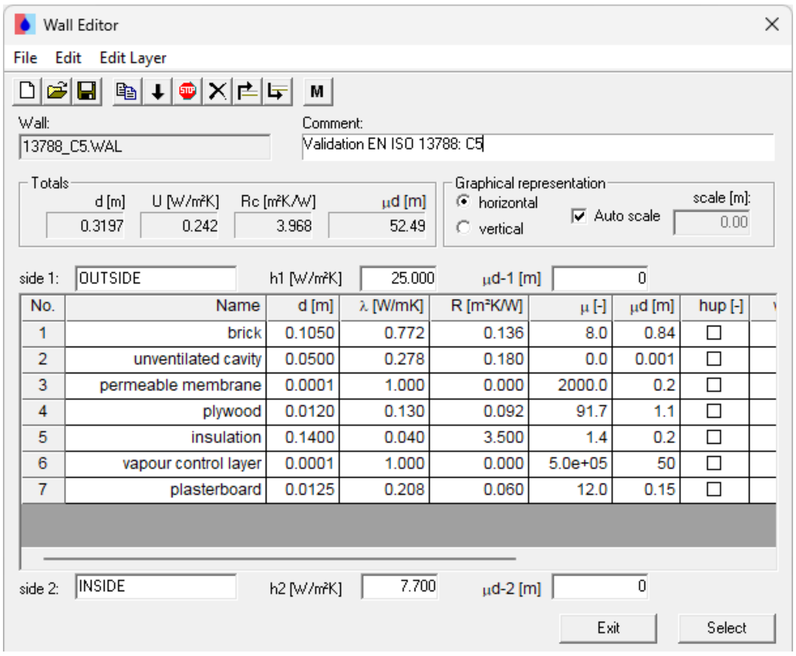
ENISO13788_C5.glp
13788_C5.wal
ENISO13788_C5.boc

In this example a timber framed wall is analysed in warm humid climate conditions. The wall is presented in the figure below.



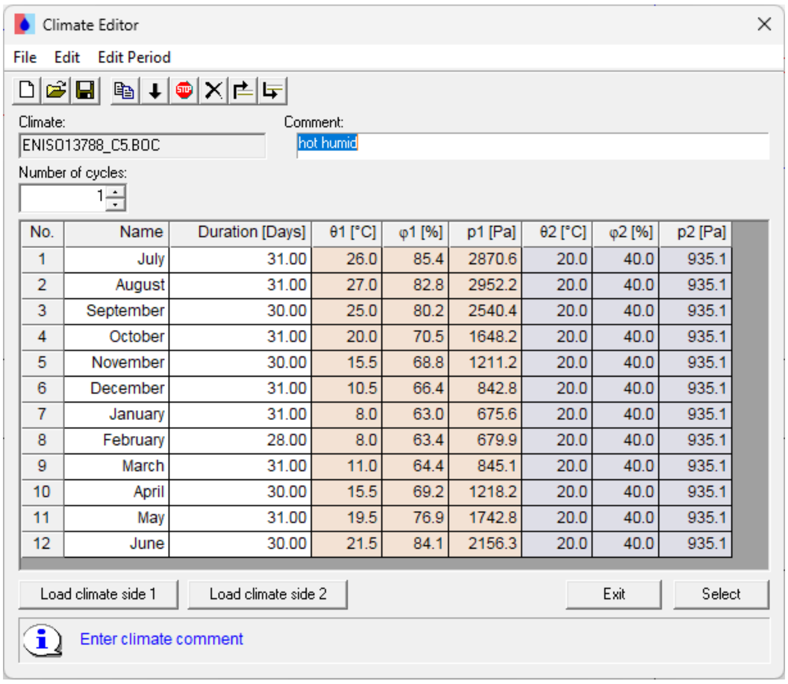
Key
1 external air
2 brick
3 unventilated cavity
4 permeable membrane
5 plywood
6 insulation
7 vapour control layer
8 plasterboard
9 internal air

Figure 6. Layers and interfaces in timber framed wall



No.	Name	d [m]	λ [W/mK]	R [m²K/W]	µ [-]	µd [m]	hup [-]
1	brick	0.1050	0.772	0.136	8.0	0.84	☐
2	unventilated cavity	0.0500	0.278	0.180	0.0	0.001	☐
3	permeable membrane	0.0001	1.000	0.000	2000.0	0.2	☐
4	plywood	0.0120	0.130	0.092	91.7	1.1	☐
5	insulation	0.1400	0.040	3.500	1.4	0.2	☐
6	vapour control layer	0.0001	1.000	0.000	5.0e+05	50	☐
7	plasterboard	0.0125	0.208	0.060	12.0	0.15	☐

Figure 7. Material properties in GLASTA



No.	Name	Duration [Days]	θ1 [°C]	φ1 [%]	p1 [Pa]	θ2 [°C]	φ2 [%]	p2 [Pa]
1	July	31.00	26.0	85.4	2870.6	20.0	40.0	935.1
2	August	31.00	27.0	82.8	2952.2	20.0	40.0	935.1
3	September	30.00	25.0	80.2	2540.4	20.0	40.0	935.1
4	October	31.00	20.0	70.5	1648.2	20.0	40.0	935.1
5	November	30.00	15.5	68.8	1211.2	20.0	40.0	935.1
6	December	31.00	10.5	66.4	842.8	20.0	40.0	935.1
7	January	31.00	8.0	63.0	675.6	20.0	40.0	935.1
8	February	28.00	8.0	63.4	679.9	20.0	40.0	935.1
9	March	31.00	11.0	64.4	845.1	20.0	40.0	935.1
10	April	30.00	15.5	69.2	1218.2	20.0	40.0	935.1
11	May	31.00	19.5	76.9	1742.8	20.0	40.0	935.1
12	June	30.00	21.5	84.1	2156.3	20.0	40.0	935.1

Figure 8. Warm humid climate

Figure 9 below compares the accumulated condensation calculated in GLASTA with the results from the standard. A good agreement is found.

Month	GLASTA results (interface 5)			table C.9 EN 13788	
	condensation rate g_c [kg/m^2]	Wi-offset (kg/m^2)	accumulation rate M_a [kg/m^2]	condensation rate g_c [kg/m^2]	accumulation rate M_a [kg/m^2]
July	0.0901	0	0.0901	0.0941	0.0941
August	0.1059	0.0901	0.196	0.1158	0.2099
September	0.0209	0.196	0.217	0.0211	0.231
Oktober	-0.16	0.217	0.057	-0.1701	0.0609
November	-0.0071	0.057	0	-0.2563	0
December	0.0000	0.0000	0	0	0
January	0	0	0	0	0
February	0.0000	0.0000	0	0	0
March	0.0000	0.0000	0	0	0
April	0	0	0	0	0
May	0	0	0	0	0
June	0	0	0	0	0

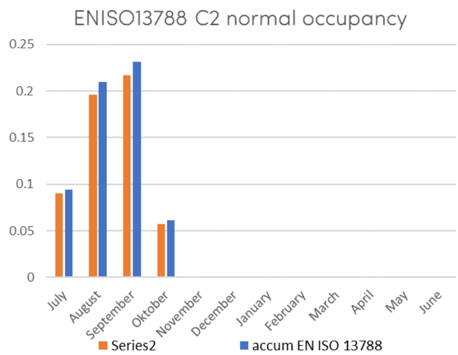


Figure 9. GLASTA results compared with the standard (condensation on interface 5)

C.6-Example 4: Building component in a warm humid climate

ENISO13788_C6.glp
13788_C6_SUBDIVIDED.wal
ENISO13788_C5.boc

In this example a wall built from lightweight blockwork with internal insulation is analysed. Both the blockwork and insulation have a thermal resistance greater than 0.25 m^{2}K/W, so the blockwork is divided in 10 layers and the insulation in 2 layers (see section 6.4.1 in EN ISO 13788)

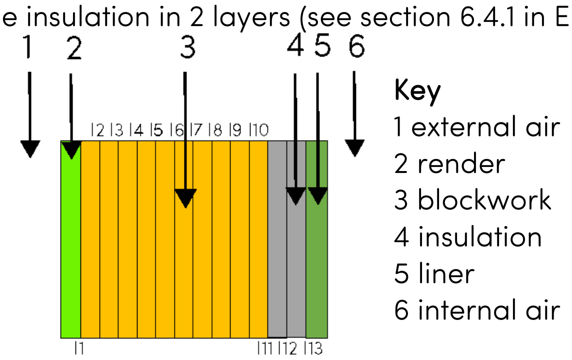
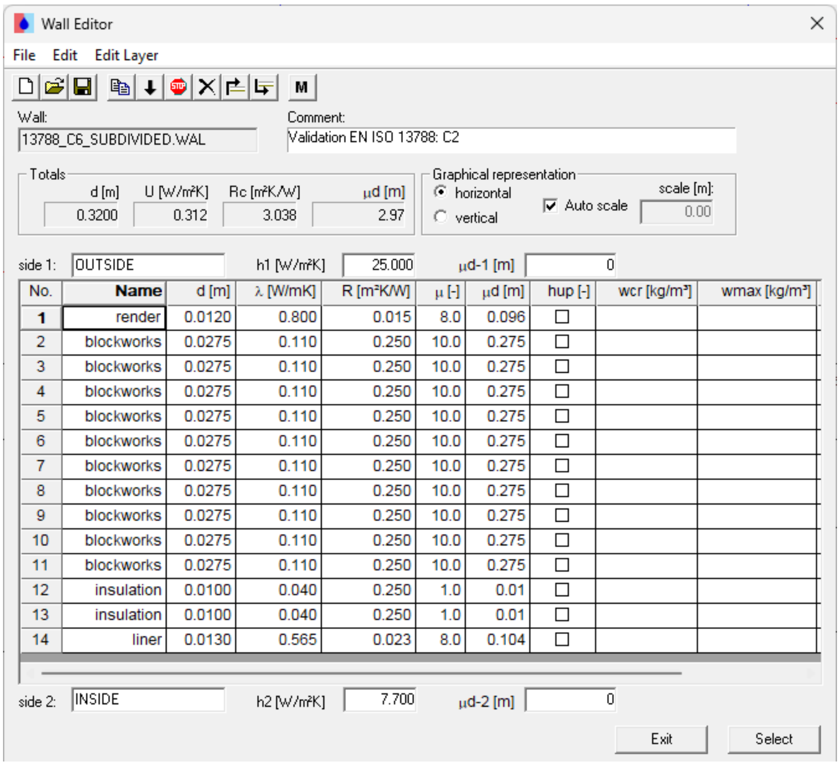
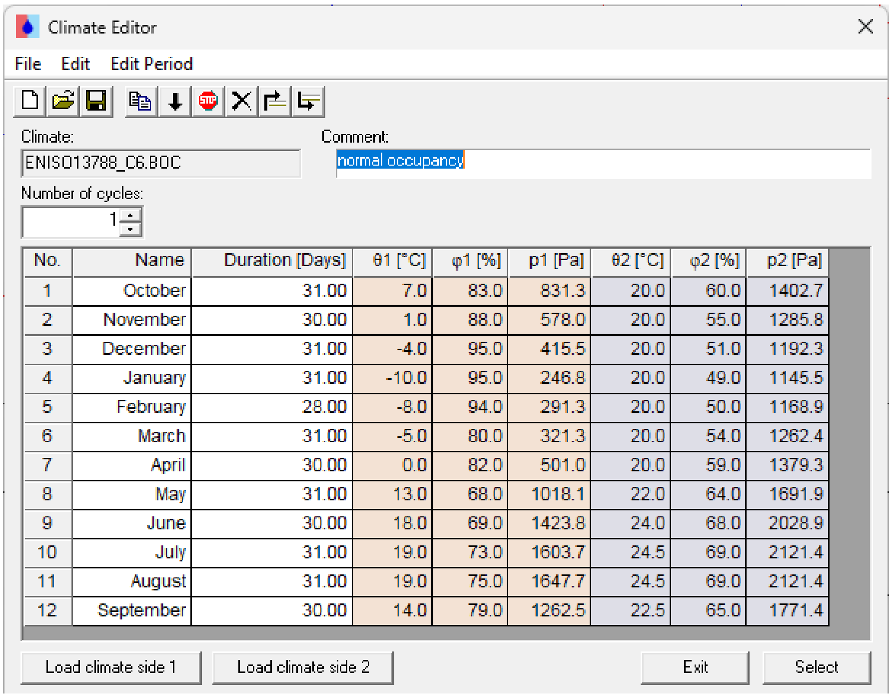


Figure 10. Layers and interfaces



No.	Name	d [m]	λ [W/mK]	R [m²K/W]	µ [-]	µd [m]	hup [-]	wcr [kg/m³]	wmax [kg/m³]
1	render	0.0120	0.800	0.015	8.0	0.096	☐		
2	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
3	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
4	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
5	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
6	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
7	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
8	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
9	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
10	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
11	blockworks	0.0275	0.110	0.250	10.0	0.275	☐		
12	insulation	0.0100	0.040	0.250	1.0	0.01	☐		
13	insulation	0.0100	0.040	0.250	1.0	0.01	☐		
14	liner	0.0130	0.565	0.023	8.0	0.104	☐		

Figure 11. Material properties GLASTA



No.	Name	Duration [Days]	θ1 [°C]	φ1 [%]	p1 [Pa]	θ2 [°C]	φ2 [%]	p2 [Pa]
1	October	31.00	7.0	83.0	831.3	20.0	60.0	1402.7
2	November	30.00	1.0	88.0	578.0	20.0	55.0	1285.8
3	December	31.00	-4.0	95.0	415.5	20.0	51.0	1192.3
4	January	31.00	-10.0	95.0	246.8	20.0	49.0	1145.5
5	February	28.00	-8.0	94.0	291.3	20.0	50.0	1168.9
6	March	31.00	-5.0	80.0	321.3	20.0	54.0	1262.4
7	April	30.00	0.0	82.0	501.0	20.0	59.0	1379.3
8	May	31.00	13.0	68.0	1018.1	22.0	64.0	1691.9
9	June	30.00	18.0	69.0	1423.8	24.0	68.0	2028.9
10	July	31.00	19.0	73.0	1603.7	24.5	69.0	2121.4
11	August	31.00	19.0	75.0	1647.7	24.5	69.0	2121.4
12	September	30.00	14.0	79.0	1262.5	22.5	65.0	1771.4

Figure 12. Climate conditions

interface 2

Month	GLASTA results			table C.12 EN 13788	
	condensation rate g_c [kg/m²]	Wi-offset (kg/m²)	accumulation rate M_a [kg/m²]	condensation rate g_c [kg/m²]	accumulation rate M_a [kg/m²]
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January	0.018	0	0.018	0.0249	0.0249
February	0.0101	0.018	0.0281	0.0056	0.0305
March	-0.0281	0.0281	0	-0.0109	0.0196
April	0	0	0	-0.0931	0
May	0	0	0	0	0
June	0	0	0	0	0
July	0	0	0	0	0
August	0	0	0	0	0
September	0	0		0	0

interface 3

Month	GLASTA results			table C.12 EN 13788	
	condensation rate g_c [kg/m²]	Wi-offset (kg/m²)	accumulation rate M_a [kg/m²]	condensation rate g_c [kg/m²]	accumulation rate M_a [kg/m²]
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January	0.0231	0	0.0231	0.0249	0.0249
February	0.0053	0.0231	0.0284	0.0057	0.0306
March	-0.0040	0.0284	0.0243	-0.0109	0.0197
April	-0.0243	0.0243	0	-0.0932	0
May	0	0	0	0	0
June	0	0	0	0	0
July	0	0	0	0	0
August	0	0	0	0	0
September		0	0	0	0

Figure 13. GLASTA results compared with the standard

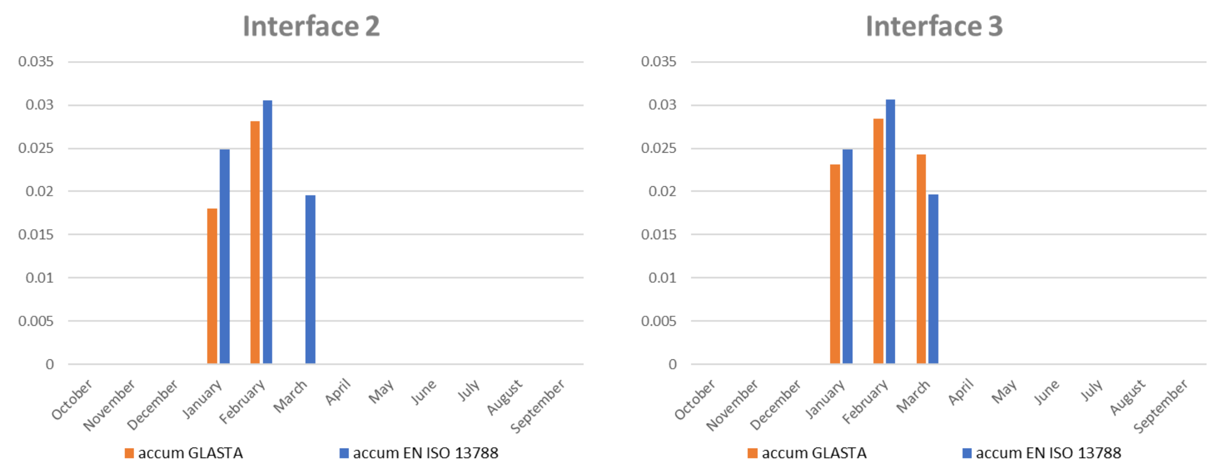
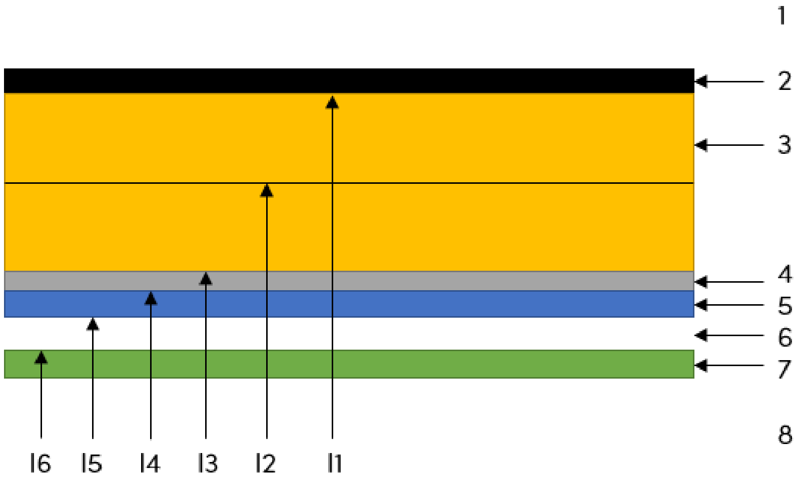


Figure 14. GLASTA results compared with the standard

D – Example of the calculation of the drying of a wetted layer

ISO13788_ANNEX_D_DRYING_2_layers.glp
ISO13788_ANNEX_D_WET.wal
ISO13788_ANNEX_D_SEPT.boc

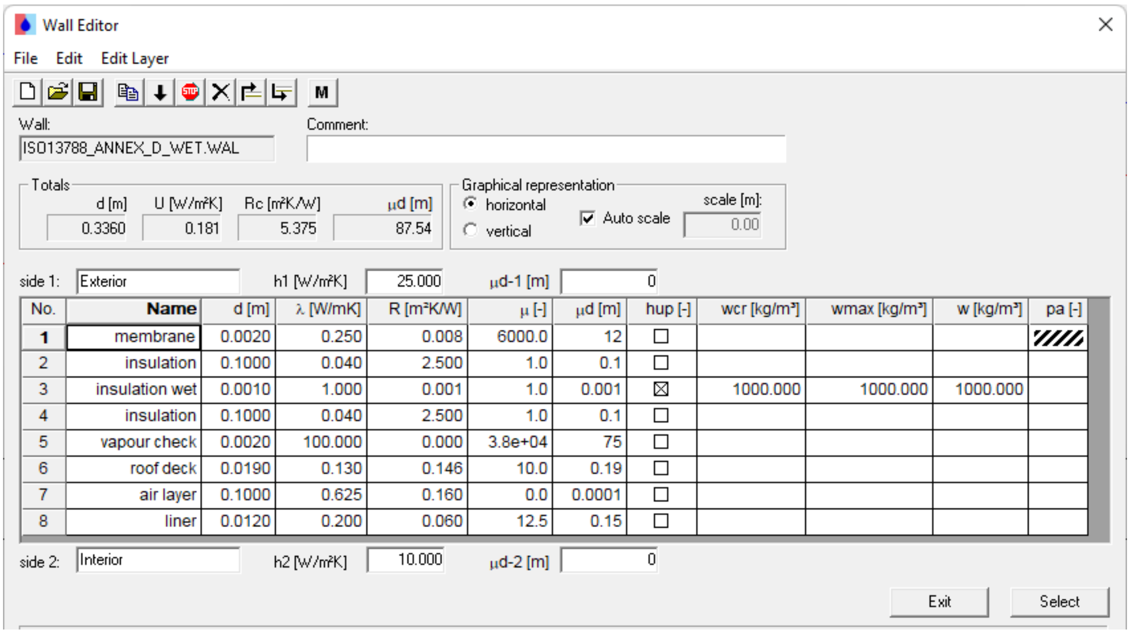
This example assumes that the insulation, layer 3 in the flat roof shown in the figure below, has been wetted by precipitation during construction before the installation of the weatherproof membrane. To do this, the insulation layer is divided into two and it is assumed that there is excess moisture content of 1 kg/m^2 at interface I2.
The climate conditions correspond to C.1 with high occupancy.



Key
1 external air
2 membrane
3 insulation
4 vapour check
5 roof deck
6 unventilated cavity
7 liner
8 inside air

Figure 15. Layers and interfaces in roof

The material properties used for each layer in GLASTA are shown in table below:



No.	Name	d [m]	λ [W/mK]	R [m²K/W]	μ [-]	μd [m]	hup [-]	wcr [kg/m³]	wmax [kg/m³]	w [kg/m³]	pa [-]
1	membrane	0.0020	0.250	0.008	6000.0	12	☐				
2	insulation	0.1000	0.040	2.500	1.0	0.1	☐				
3	insulation wet	0.0010	1.000	0.001	1.0	0.001	☒	1000.000	1000.000	1000.000	
4	insulation	0.1000	0.040	2.500	1.0	0.1	☐				
5	vapour check	0.0020	100.000	0.000	3.8e+04	75	☐				
6	roof deck	0.0190	0.130	0.146	10.0	0.19	☐				
7	air layer	0.1000	0.625	0.160	0.0	0.0001	☐				
8	liner	0.0120	0.200	0.060	12.5	0.15	☐				

Figure 16. Material properties and initial moisture content in GLASTA

I2 is modelled in GLASTA as a small layer (d=0.001m) with an intial moisture content of 1000 kg/m^2 which corresponds to 1 kg/m^2. The critical moisture content w_{crit} is defined equal to the initial moisture content w. Consequently, the moisture transport in this layer corresponds to vapour transport only. The results below compare the drying at interface 1 during the first year.

interface 1

Month	GLASTA results		table D.2 EN 13788	
	g_c [kg/m²]	M_a [kg/m²]	g_c [kg/m²]	M_a [kg/m²]
			-	0
September	0.9833	0.9833	0.99128	0.99128
Oktober	-0.0084	0.9749	-0.00845	0.98283
November	-0.0021	0.9728	-0.00208	0.98075
December	-0.0001	0.9727	-0.00013	0.98062
January	-0.0001	0.9726	-0.00007	0.98055
February	-0.0007	0.9719	-0.00073	0.97982
March	-0.0052	0.9667	-0.00521	0.97461
April	-0.0127	0.954	-0.01266	0.96195
May	-0.0225	0.9315	-0.02254	0.93941
June	-0.0282	0.9033	-0.0282	0.91121
July	-0.0274	0.8759	-0.02735	0.88386
August	-0.0254	0.85050	-0.02539	0.85847

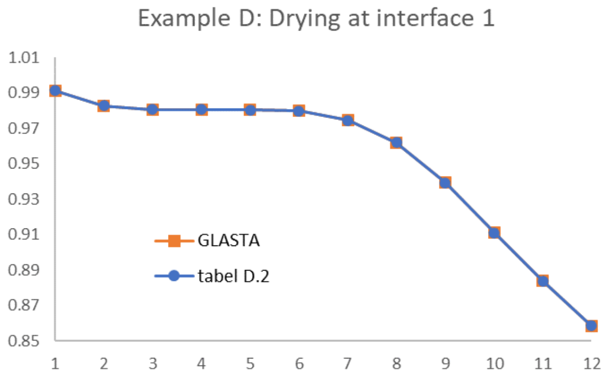


Figure 17. GLASTA results compared with the standard (first year)

The graph below shows that the roof is dried out after a period of 83 months which is in line with the results from EN ISO 13788.

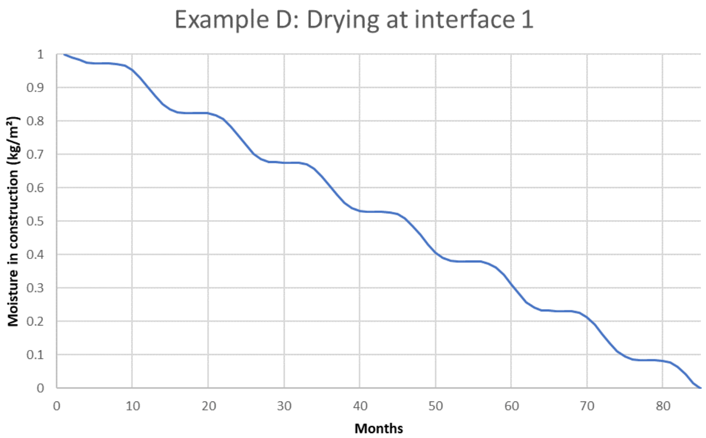


Figure 18. GLASTA results compared with the standard (first year)