International Energy Agency

Long-Term Performance of Super-Insulating-Materials in Building Components & Systems

Energy in Buildings and Communities Programme

Bijan Adl-Zarrabi, Pär Johansson (Editors)

Appendix A 1

International Energy Agency, EBC Annex 65

Long-Term Performance of Super-Insulating-Materials in Building Components & Systems

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Report of Subtask III: Practical Applications

Retrofitting at the Building Scale – Field scale

03 January 2020

APPENDIX A & APPENDIX B

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Appendix A: 29 case studies with basic information

#	Country	City	Type of building	New/retro.	Year	Climate	SIM type:	SIM (m^2):	Finalized	Follow up	Moni-tored
1	Canada	Whitehorse	Office	Retro	1988	Cold	VIP	27	2011	Y	Y
2	China	Qingdao	High rise hotel	Retrofitting	1960	Oceanic, mild	VIP	20,000	2001	N	N
3	China	Suzhou	Commercial	Retrofitting	-	Warm	VIP	-	Y	N	N
4	China	Taicang	Government	Retrofitting		Warm	VIP	50,000	Y	N	N
5	France	Nantes	Office	New	1952	Medium tempered	VIP	40	Y 2014	Y	Y
6	Germany	Bottrop	Single family house	Retrofit	1962	Cold / wet	VIP	60	Y	N	Y
7	Germany	Darmstadt	Special building	New	2013	middle European climate	Silica based		Y	N	N
8	Germany	Eitting	Office	New	2013	cold / wet	VIP	45	2014	N	N
9	Germany	Marktredwitz	Commercial	New	2008	cold , wet	Aerogel	200	2009	N	Y
10	Germany	Rheinfelden	Single family house	Retrofit	1861	middle European climate	Silica based		Y	N	Y
11	Germany	Rosenheim	Single family house	New	2010	moderate Climate	VIP	110	2010		Y
12	Germany	Stuttgart	Office	New	2014	Cold / wet	VIP	80	2014	N	Y
13	Greece	Athens	Mock-up	Retrofit	2011	Mediterranean	VIP	16	Y	Y	Y
14	Italy	Milan	Academic building	Retrofit	1965	Temperate	Aerogel	7	Y	Y	Y

15	Italy	Turin	Mock-up	New	2007-2008	Temperate	VIP	1.8	2013	Y	Y
16	Japan	Fukushima		New	2011		VIP	2,576			Y
17	Japan	Osaka		Retrofit	2010		VIP	128	Y		Y
18	Japan	Shiga	Special	New	2006		VIP	96			Y
19	Japan	Osaka					VIP	3.3			
20	Korea	Seongnam	Residential building	New	2012	Warm	VIP	250	Y	N	Y
21	Korea	Seoul	Public building	New	2011	Warm	VIP	15,000	Y	N	N
22	Korea	Jeju	Public building	New	2011	Warm	VIP	2,500	Y	N	N
23	Sweden	Gothenburg	District heating	New	2012	Oceanic, mild	VIP	N/A	2017	Y	Y
24	Sweden	Gothenburg	Residential	Retrofit	1930	Oceanic, mild	VIP	83	2010	Y	Y
25	Sweden	Stockholm	Mock-up	Retrofit	2014	3 temp. Diffs.: 10; 20; 30 degree	VIP	12	Under progress	Y	Y
26	Switzerland	Oberhallau	Residential / Public	Retrofit	1608	Temperate wet	Aerogel	200	2008	N	N
27	Switzerland	Rheinfelden	Office	Retrofit	1965	middle European	Silica & VIP		2015	N	N
28	UK	London	Residential	Retrofit	Unknown	UK standard	VIP	13	2010	N	Y
29	UK	Nottingham	Single family house	New	2010	Cold/Wet	aerogel	80	Y	Y	Y
30	UK	Watford	Residential	Retrofit	1910	cold , wet	Aerogel	60	2009	Y	Y
31	UK	London	Single family house	Retrofit	1840	cold wet	Aerogel & VIP	80	2013	Y	Y

Appendix A 2

32	USA	Boston	Residential	Retrofit	1920	cold , wet	Aerogel	2,000	2009	N	Y

Appendix B: VIPs performance and operating conditions at building scale for the service life planning

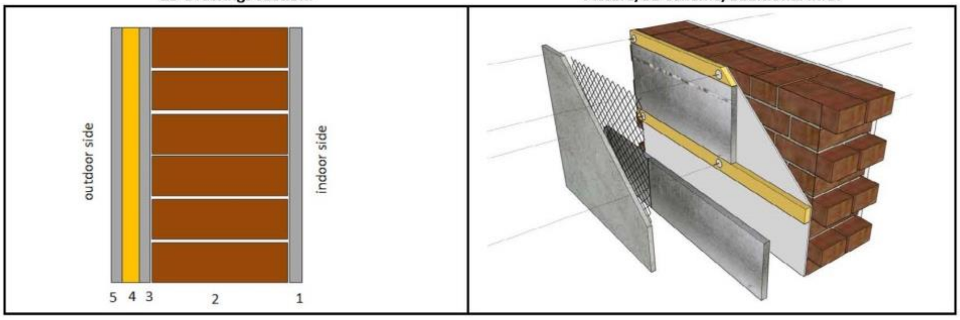
Table of Contents

1.1 Configuration 1- Brick Wall in Turin (POLITO)

This configuration represents a typical case of refurbishment of an old wall (built before 1945) made of solid brick. This wall structure represents a common technology for the existing residential Italian building stock (corresponding to about 30 % of the overall residential buildings). Details of the wall section are shown in Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-1.

Component type	Wall	Orientation	All orientation	slope	vertical=90°

2D Drawings section: / Picture/3D scheme/additional info:



Component stratigraphy:

Layer:	Material:
indoor	
1	SILICATE PLASTER
2	BRICK WALL
3	SILICATE PLASTER
4	LEVELLING PLASTER
5	VIP
6	SILICATE PLASTER
7	
8	
9	
10	
outdoor	

Basic values - termophysical properties

layer	s thickness	ρ Bulk density	pt Porosity	c Specific Heat Capacity	λ_{eff} Thermal Conductivity, Design Value	R Thermal resistance	μ Water Vapour Diffusion Resistance Factor	Wc Reference Water Content	SW Free Water Saturation	WA Water Absorption Coefficient	DF Drying Factor	ε Long wave radiation emissivity	α Short wave radiation absorption coefficient
	m	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	kg/m³	kg/m³	kg/m²s^0.5	-	-	-
1	0.020	1303	0.51	1134	0.4405	0.045	11	66.1	404.8	0.087			
2	0.500	1400	0.35	1000	0.5500	0.909	19	11.4	319.0	0.177			
3	0.020	1303	0.51	1134	0.4405	0.045	11	66.1	404.8	0.087			
4	0.005	1249	0.53	1253	0.3193	0.016	14	58.2	362.0	0.020			
5	0.020	200	0.90	850	0.0044	4.495	340,000	18.7	73.1	-			
6	0.010	1303	0.51	1134	0.4405	0.023	11	66.1	404.8	0.087		0.9	0,3/0,6/0,9
7													
8													
9													
10													

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-1. Summary data-sheet of the analysed wall.

1.1.1 Outdoor weather conditions:

The outdoor weather conditions of Turin (Italy) (lat. 45°4'41'' Long. 7°40'34'') were selected for the numerical simulations (Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-2 and Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-3). Data were extracted from Wufi® 6.0. database (Turin - year 2004).

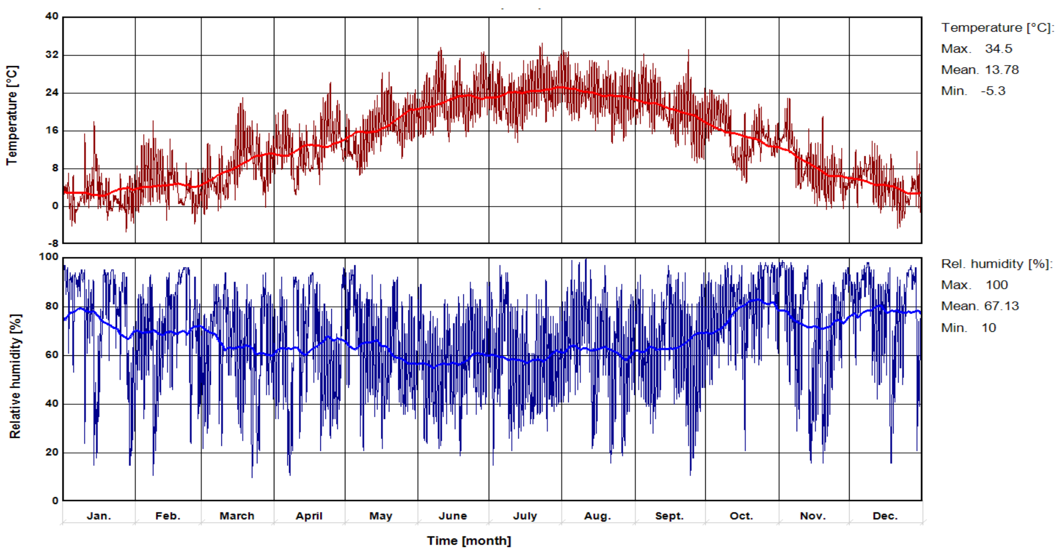


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-2. Outdoor temperature (red), outdoor relative humidity (blue), (graphical output from Wufi® 6.0).

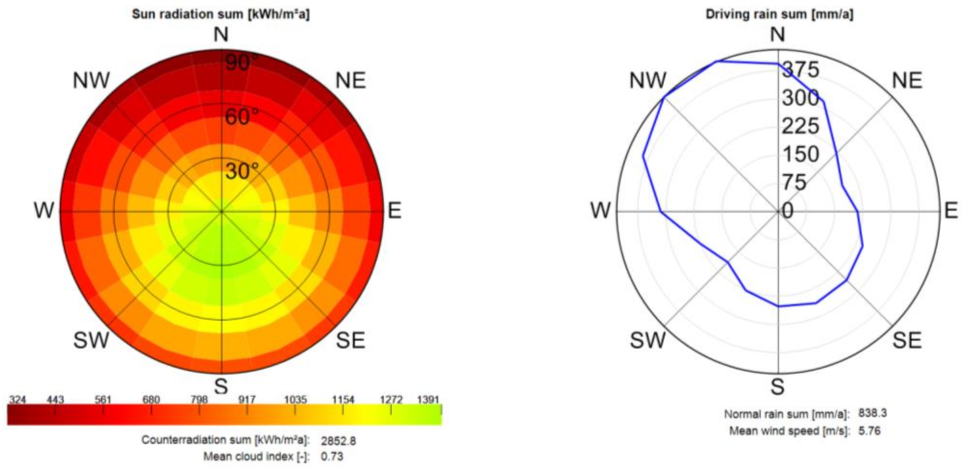


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-3. Solar radiation (left), driving rain and mean wind speed (right) (graphical output from Wufi® 6.0).

1.1.2 Indoor climate conditions:

The indoor climate conditions defined in EN 15026:2007 (Hygrothermal performance of building components and building elements. Assessment of moisture transfer by numerical simulation) [86] were assumed:

- Heating season (15th October- 15th April): T = 20 °C and medium and high moisture load;
- Cooling season (15th April- 15th October): T = 25 °C and medium and high moisture load.

1.1.3 Design alternatives:

Simulation were carried out on different wall designs, considering four orientations (north, east, south and west), three different external finishing colours, (bright, medium and dark finishing, with a solar absorption coefficient α of respectively 0.3, 0.6 and 0.9), two different moisture load (medium and high) and two different VIP thickness (10 and 20 mm). The resulting combinations lead to fourteen design alternatives that are summarised in Table Erreur ! **Il n'y a pas de texte répondant à ce style dans ce document.**.1.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.1. Summary of the different wall configurations.

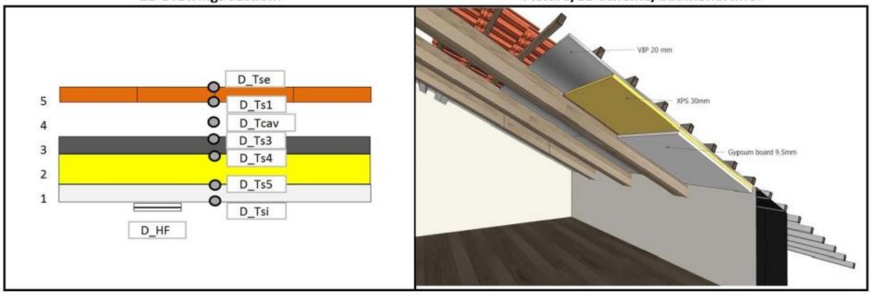
Configuration name	Orientation	Solar absorption coefficient (α)		Moisture load	Thickness
1. N_B_m_20		Bright	0.3		
1. N_M_m_20	NORTH	Medium	0.6		
1. N_D_m_20		Dark	0.9		
1. E_B_m_20		Bright	0.3		
1. E_M_m_20	EAST	Medium	0.6		
1. E_D_m_20		Dark	0.9		
1. S_B_m_20		Bright	0.3	medium	20 mm
1. S_M_m_20	SOUTH	Medium	0.6		
1. S_D_m_20		Dark	0.9		
1. W_B_m_20		Bright	0.3		
1. W_M_m_20	WEST	Medium	0.6		
1. W_D_m_20		Dark	0.9		
1. W_D_h_10	WEST	Dark	0.9	high	10 mm
1. W_D_h_20					20 mm

1.2 Configuration 2- Pitched Roof – wood frame in Turin (POLITO)

The selected building component is a typical, traditional pitched roof with wood frame covered by clay tiles. An energy retrofit has been assumed by using VIPs and XPS panels placed on the indoor side of the attic. Furthermore, an internal gypsum board finishing layer is located below the insulating layer. Specifications about the roof section are shown in Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-4.

Component type	Roof	Orientation	All orientation	slope	28°

2D Drawings section: | Picture/3D scheme/additional info:



Component stratigraphy:

Layer:	Material:
indoor	
1	Gypsum board
2	XPS
3	VIP
4	Air cavity
5	Roof tiles
outdoor	

Basic values - termophysical properties

layer	s thickness	ρ Bulk density	pt Porosity	c Specific Heat Capacity	λ_{eff} Thermal Conductivity, Design Value	R Thermal resistance	μ Water Vapour Diffusion Resistance Factor	Wc Reference Water Content	SW Free Water Saturation	WA Water Absorption Coefficient	DF Drying Factor	ε Long wave radiation emissivity	α Short wave radiation absorption coefficient
	m	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	kg/m³	kg/m³	kg/m²s^0.5	-	-	-
1	0.0095	770	0.65	1000	0.250	0.04	10	7.16	551	0.277		0.9	
2	0.03	32	0.91	1500	0.034	0.88	227.32	0.006	905	8E-06			
3	0.02	200	0.9	850	0.00445	4.50	340000	18.71	73.08	-			
4	0.097	1.2	0.999	1020	0.590	0.16	0.15	0.0138	0.0173	1E-07			
5	0.02	1700	0.32	840	0.700	0.03	28.29	0.5	239.86	0.0312		0.9	0.5
6													
7													
8													
9													
10													

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-4. Summary sheet of the analysed roof.

1.2.1 Outdoor weather conditions:

Weather conditions are the same used for simulating Configuration 1 (1.1).

1.2.2 Indoor climate:

Indoor weather conditions are the same used for simulating Configuration 1 (1.1).

1.2.3 Design alternatives:

Simulation were carried out on different roof design alternatives, considering four orientations (north, east, south and west) and three different external finishing colour, (bright, medium and dark finishing, with a solar absorption coefficient *α* of respectively 0.3, 0.6 and 0.9). The resulting combinations provided twelve design alternatives that are summarised in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.2.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.2. Summary of the different roof configurations.

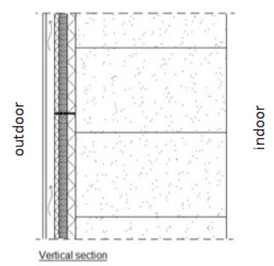
Configuration name	**Orientation**	**Solar absorption coefficient (α)**		**Moisture load**	**Thickness**
2. N_B_m_20	NORTH	Bright	0.3	medium	20 mm
2. N_M_m_20		Medium	0.6		
2. N_D_m_20		Dark	0.9		
2. E_B_m_20	EAST	Bright	0.3		
2. E_M_m_20		Medium	0.6		
2. E_D_m_20		Dark	0.9		
2. S_B_m_20	SOUTH	Bright	0.3		
2. S_M_m_20		Medium	0.6		
2. S_D_m_20		Dark	0.9		
2. W_B_m_20	WEST	Bright	0.3		
2. W_M_m_20		Medium	0.6		
2. W_D_m_20		Dark	0.9		

1.3 Configuration 3- Ventilated wall in Stockholm (KTH)

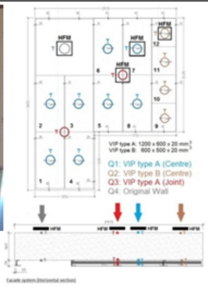
The building component represents a wall of light aggregate concrete with glued on exterior insulation of VIPs embedded in two layers of EPS sheets. Outside cladding consists of 12 mm façade boards with 2 mm rendering. The façade cladding is mounted with L-shaped profiles and is ventilated by the means of a 20 mm air gap.

Component type	Wall	Orientation	SOUTH=0° EAST=-90° WEST=90°	Inclination	vertical=90°

2D Drawings section:



Picture/3D scheme/additional info:



The renovated wall in a climatic chamber

Component section:

Layer:	Material:
indoor	
1	Aerated concrete blocks
2	EPS
3	VIP envelope
4	VIP core
5	VIP envelope
6	EPS
7	Air gap
8	Board
9	Rendering
outdoor	

Basic values - termophysical properties

layer	s thickness	ρ Bulk density	pt Porosity	c Specific Heat Capacity	λ_{eff} Thermal Conductivity, Design Value	R Thermal resistance	μ Water Vapour Diffusion Resistance Factor	Wc Reference Water Content	SW Free Water Saturation	WA Water Absorption Coefficient	DF Drying Factor	ε Long wave radiation emissivity	α Short wave radiation absorption coefficient
	mm	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	%	kg/m³	kg/m²s^0.5	-	-	-
Aerated concrete blocks	160	400	0.81	850	0.1		7	RF 80%					
EPS	10	15	0.95	1500	0.04		30	RF 80%					
VIP envelope	0.0003	1000	0.001	1000	200		200000	0					
VIP	50	200	0.95	1000	0.005		1.1	0					
VIP envelope	0.0003	1000	0.001	1000	200		200000	0					
EPS	20	15	0.95	1500	0.04		30	RF 80%					
Air gap (ventilated)	20	1.3	0.999	1000	0.13		0.56						
boards	13	1610	0.15	850	0.13		83.3	RF 80%					
Rendering	15	1360	0.49	850	0.9		8.1	RF 80%				0.9	0.5

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-5. Summary sheet of the analysed wall configuration.

1.3.1 Outdoor weather conditions:

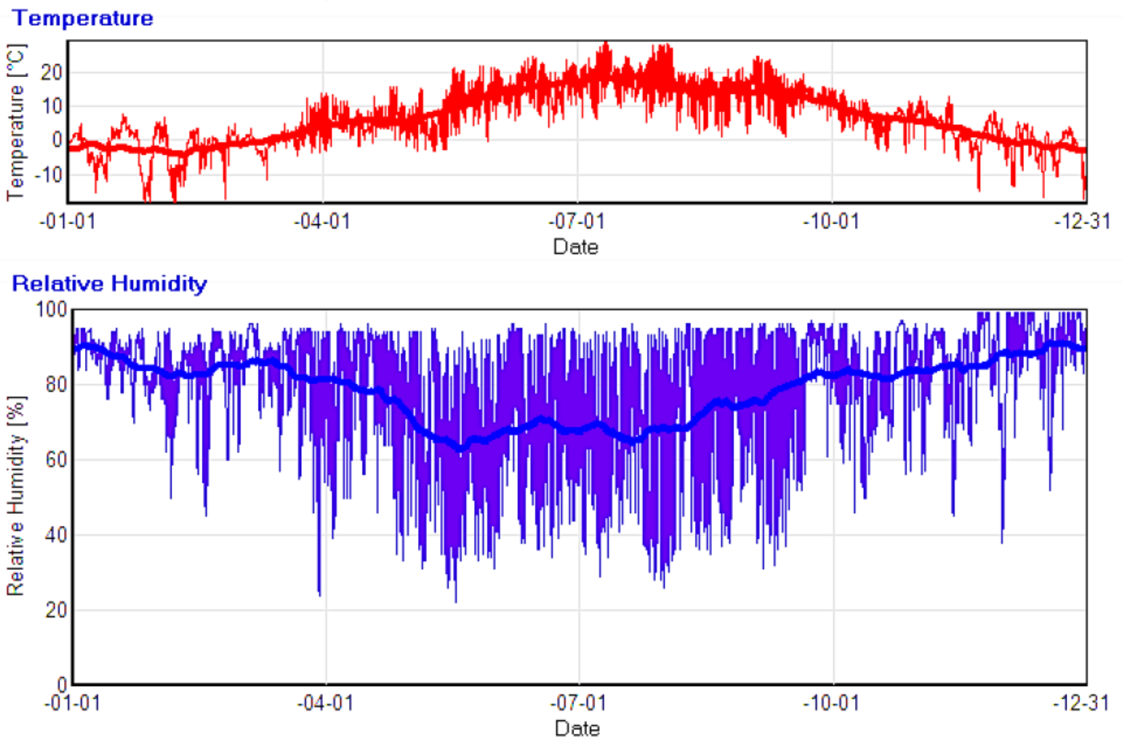


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-6. Summary sheet of the analysed wall configuration.

1.3.2 Indoor climate:

The indoor climate condition of EN 15026:2007 was used for the simulations

1.3.3 Design alternatives:

One design alternative for four orientations.

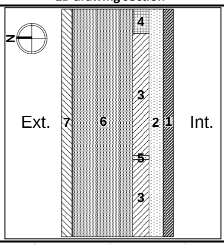
1.4 Configuration 4- Internal wall insulation in Nancy (CSTB)

Two interior wall configurations were selected to represent two kinds of wall structure: masonry block and wood frame. VIP panels were placed against the structure while a plaster board was located on the internal side, separated from the VIP by an air gap. A strip of aerogel fibre mat was placed above the VIP to simulate the presence of a filler. An air space of 0.5 mm between two VIPs allowed to simulate a junction between two VIP. For wood frame configuration, a ventilated cladding was supposed on external side. It was not simulated because assumption was made that it was sufficiently ventilated so that conditions were the same on both sides of the cladding.

1.4.1 *Configuration A1: masonry block structure*

Componant type	Wall	Orientation	North	Inclination	Vertical = 90°

2D drawing section



Picture / 3D scheme / additional info:

Component statigraphy

Layer:	Material:
indoor	
1	Plaster board
2	Air cavity
3	VIP
4	Aerogel fiber mat
5	Air cavity (junction)
6	Masonry block
7	Hydraulic Coating
outdoor	

Basic values - thermophysical properties

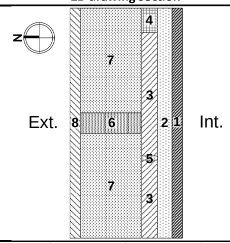
	s	ρ	pt	c	λ_{eff}	R	μ	Wc	SW	WA	DF	ε	α
layer	thickness	Bulk density	Porosity	Specific Heat Capacity	Thermal conductivity, Design value	Thermal Resistance	Water vapour Diffusion Resistance Factor	Reference water content	Free water saturation	Water absorption Coefficient	Drying factor	Long wave radiation emissivity	Short wave radiation absorption coefficient
	m	kg/m^3	m^3/m^3	J/kgK	W/mK	m^2K/W	-	kg/m^3	kg/m^3	kg/m^2s^0,5	-	-	-
Plaster Board	0,013	850	0,65	850	0,2	0,065	8,5	6,3	400	0,287	-	0,9	0,6
Air cavity	0,018	1,3	0,999	1000	0,13	0,138	0,56	-	-	-	-	-	-
VIP	0,02	200	0,9	850	0,00445	4,494	340000	-	-	-	-	-	-
Aerogel fiber mat	0,02	146	0,92	1000	0,014	1,429	4,7	6,6	213	0,0004	-	-	-
Air cavity (0,5 mm thick)	0,02	1,3	0,999	1000	0,13	0,154	0,56	-	-	-	-	-	-
Masonry block	0,16	1900	0,29	850	1	0,16	28	25	250	0,045	-	-	-
Hydraulic coating	0,015	1900	0,24	850	1	0,015	10	45	210	0,03	-	0,9	0,6

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-7. Summary sheet of the analysed masonry wall configuration.

1.4.2 Configuration B1: Wood frame

Componant type	Wall	Orientation	North	Inclination	Vertical = 90°

2D drawing section



Picture / 3D scheme / additional info:

Component statigraphy

Layer:	Material:
indoor	
1	Plaster board
2	Air cavity
3	VIP
4	Aerogel fiber mat
5	Air cavity (junction)
6	Spruce
7	Fiber wood insulation
8	Plywood
outdoor	

Basic values - thermophysical properties

	s	ρ	pt	c	λ_{eff}	R	μ	Wc	SW	WA	DF	ε	α
layer	thickness	Bulk density	Porosity	Specific Heat Capacity	Thermal conductivity, Design value	Thermal Resistance	Water vapour Diffusion Resistance Factor	Reference water content	Free water saturation	Water absorption Coefficient	Drying factor	Long wave radiation emissivity	Short wave radiation absorption coefficient
	m	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	kg/m³	kg/m³	kg/m²s^0,5	-	-	-
Plaster Board	0,013	850	0,65	850	0,2	0,065	8,5	6,3	400	0,287	-	0,9	0,6
Air cavity	0,018	1,3	0,999	1000	0,13	0,138	0,56	-	-	-	-	-	-
VIP	0,02	200	0,9	850	0,00445	4,494	340000	-	-	-	-	-	-
Aerogel fiber mat	0,02	146	0,92	1000	0,014	1,429	4,7	6,6	213	0,0004	-	-	-
Air cavity (0,5 mm thick)	0,02	1,3	0,999	1000	0,13	0,154	0,56	-	-	-	-	-	-
Spruce	0,14	600	0,72	1600	0,13	1,077	130	80	600	0,0004			
Fiber wood insulation	0,14	53	0,96	2100	0,039	3,58974359	1,35	7	180	0,042			
Plywood	0,012	650	0,9	1500	0,13	0,09230769	169	92	636	0,001			

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-8. Summary sheet of the analysed wood frame wall configuration.

1.4.3 Outdoor weather conditions:

The weathers conditions of continental climate of Nancy (France) has been chosen for the simulations.

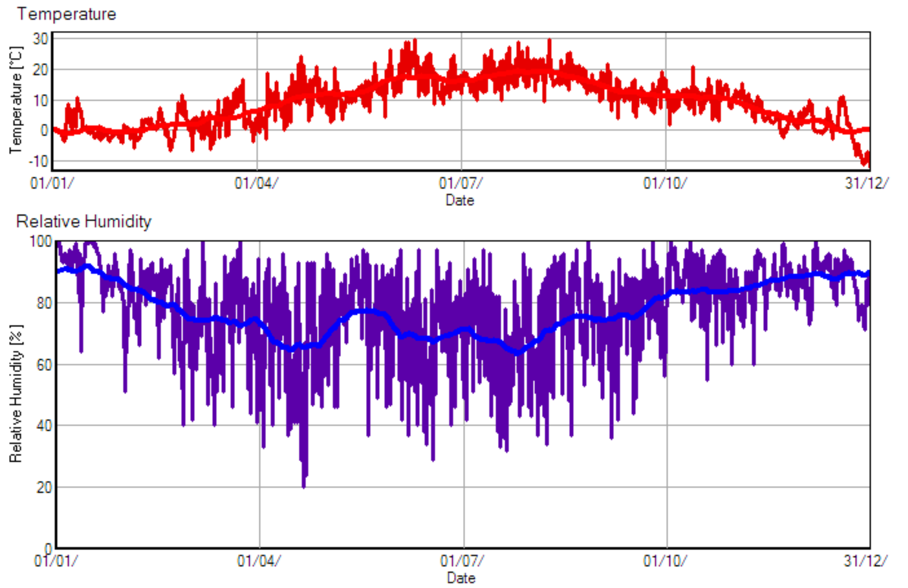


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-9. Outdoor temperature (upper), outdoor relative humidity (below).

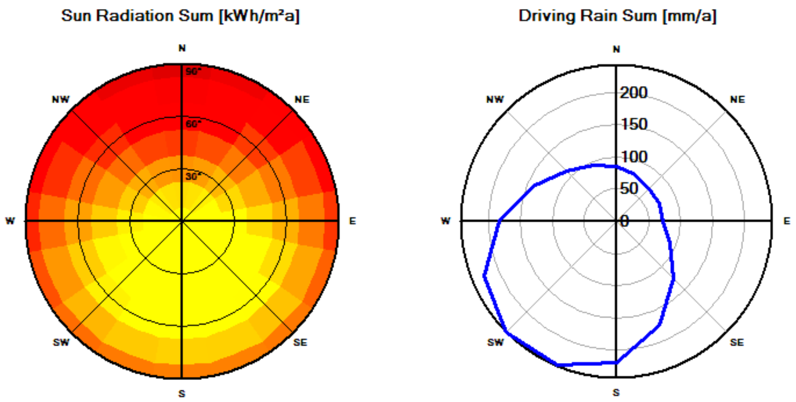


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-10.-: Solar radiation (left), driving rain and mean wind speed (right).

North orientation of the wall is considered. Driving rain absorption is only supposed for masonry block configurations. For wood frame configurations, it was supposed that the cladding (not taken into account in simulations) protects the wall from driving rain.

1.4.4 Indoor climate:

Two kind of indoor climate have been considered. Firstly, indoor climate conditions of EN 15026:2007 (Hygrothermal performance of building components and building elements. Assessment of moisture transfer by numerical simulation) were assumed. Two levels of moisture loads were investigated: medium moisture load and high moisture load.

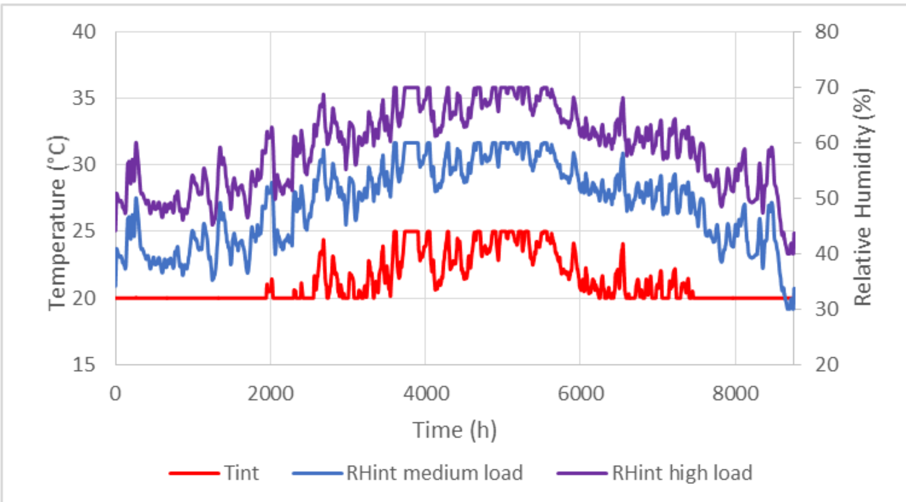
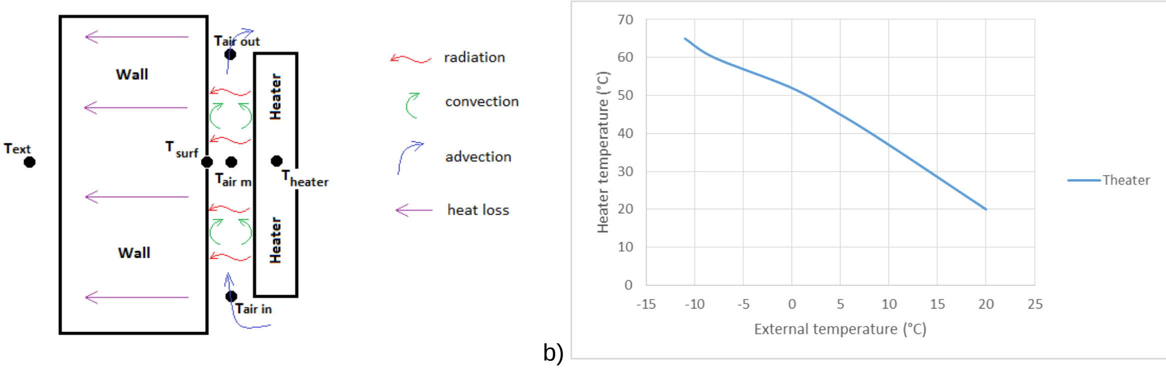


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-11: Indoor climate conditions in case of room with medium or high moisture load boundaries.

Secondly, surface temperature and humidity of a wall backwards a thermal heater were assumed. The surface temperature was calculated from a simplified thermal balance taking into account radiation from the radiator to the wall, convection, indoor air advection between wall and radiator and conduction through the wall as described on Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-12 (a). The average temperature of the heater was defined from the heating curve shown on Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-12 (b).



a) b)

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-12. a) Thermal phenomenon involved in thermal balance of a wall backwards heat b) heating curve of the heater modelled.

The surface relative humidity was defined from the indoor relative humidity according to EN 15026:2007 [86] (medium load), and previously calculated surface temperature. Temperature and relative humidity of the wall backwards a thermal heater is presented on Figure 4.26.

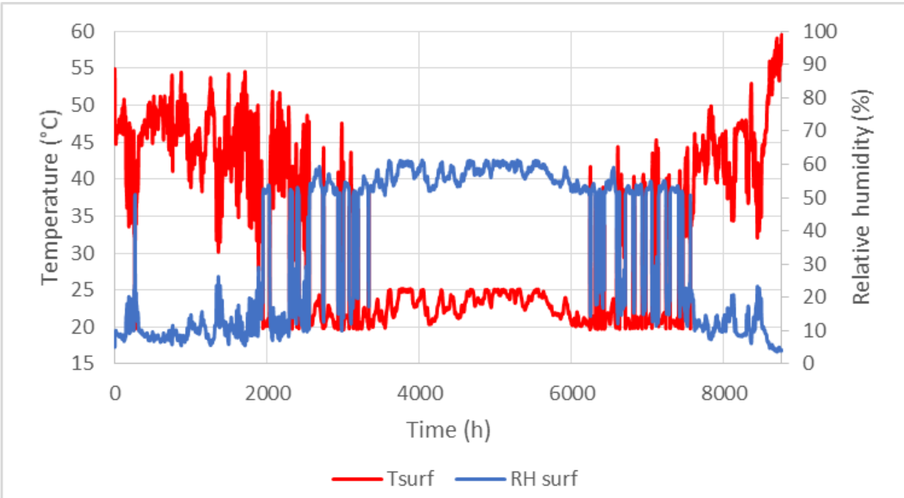


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-13. Indoor climate conditions in case of wall backwards heater boundary.

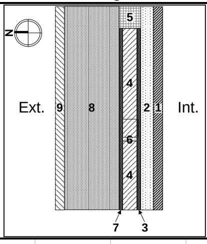
1.4.5 Design alternatives:

For each configuration, two variants were proposed: either the VIP was unprotected (A1 and B1) as mentioned previously, or it was protected by a 5 mm thick layer of EPS (A2 and B2). In this case, the continuity of EPS at the junction between two VIP is supposed. These variants are described in the following tables.

1.4.6 Configuration A2: masonry block structure and EPS layer as VIP protection

Componant type	Wall	Orientation	North	Inclination	Vertical = 90°

2D drawing section | **Picture / 3D scheme / additional info:** | **Component statigraphy**



Layer:	Material:
indoor	
1	Plaster board
2	Air cavity
3	EPS
4	VIP
5	Aerogel fiber mat
6	Air cavity (junction)
7	EPS
8	Masonry block
9	Hydraulic Coating
outdoor	

Basic values - thermophysical properties

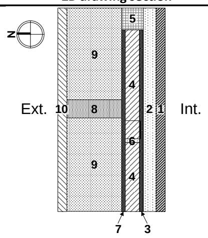
	s	ρ	pt	c	λ_{eff}	R	μ	Wc	SW	WA	DF	ε	α
layer	thickness	Bulk density	Porosity	Specific Heat Capacity	Thermal conductivity, Design value	Thermal Resistance	Water vapour Diffusion Resistance Factor	Reference water content	Free water saturation	Water absorption Coefficient	Drying factor	Long wave radiation emissivity	Short wave radiation absorption coefficient
	m	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	kg/m³	kg/m³	kg/m²s^0,5	-	-	-
Plaster Board	0,013	850	0,65	850	0,2	0,065	8,5	6,3	400	0,287	-	0,9	0,6
Air cavity	0,018	1,3	0,999	1000	0,13	0,138	0,56	-	-	-	-	-	-
EPS	0,005	30	0,95	1500	0,04	0,125	50	-	-	-	-	-	-
VIP	0,02	200	0,9	850	0,00445	4,494	340000	-	-	-	-	-	-
Aerogel fiber mat	0,03	146	0,92	1000	0,014	2,143	4,7	6,6	213	0,0004	-	-	-
Air cavity (0,5 mm thick)	0,02	1,3	0,999	1000	0,13	0,154	0,56	-	-	-	-	-	-
EPS	0,005	30	0,95	1500	0,04	0,125	50	-	-	-	-	-	-
Masonry block	0,16	1900	0,29	850	1	0,16	28	25	250	0,045	-	-	-
Hydraulic coating	0,015	1900	0,24	850	1	0,015	10	45	210	0,03	-	0,9	0,6

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-14. Summary sheet of the analysed masonry wall configuration.

1.4.7 Configuration B2: Wood frame and EPS layer as VIP protection

Componant type	Wall	Orientation	North	Inclination	Vertical = 90°

2D drawing section | **Picture / 3D scheme / additional info:** | **Component statigraphy**



Layer:	Material:
indoor	
1	Plaster board
2	Air cavity
3	EPS
4	VIP
5	Aerogel fiber mat
6	Air cavity (junction)
7	EPS
8	Spruce
9	Fiber wood insulation
10	Plywood
outdoor	

Basic values - thermophysical properties

	s	ρ	pt	c	λ_{eff}	R	μ	Wc	SW	WA	DF	ε	α
layer	thickness	Bulk density	Porosity	Specific Heat Capacity	Thermal conductivity, Design value	Thermal Resistance	Water vapour Diffusion Resistance Factor	Reference water content	Free water saturation	Water absorption Coefficient	Drying factor	Long wave radiation emissivity	Short wave radiation absorption coefficient
	m	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	kg/m³	kg/m³	kg/m²s^0,5	-	-	-
Plaster Board	0,013	850	0,65	850	0,2	0,065	8,5	6,3	400	0,287	-	0,9	0,6
Air cavity	0,018	1,3	0,999	1000	0,13	0,138	0,56	-	-	-	-	-	-
EPS	0,005	30	0,95	1500	0,04	0,125	50	-	-	-	-	-	-
VIP	0,02	200	0,9	850	0,00445	4,494	340000	-	-	-	-	-	-
Aerogel fiber mat	0,02	146	0,92	1000	0,014	1,429	4,7	6,6	213	0,0004	-	-	-
Air cavity (0,5 mm thick)	0,02	1,3	0,999	1000	0,13	0,154	0,56	-	-	-	-	-	-
EPS	0,005	30	0,95	1500	0,04	0,125	50	-	-	-	-	-	-
Spruce	0,14	600	0,72	1600	0,13	1,077	130	80	600	0,0004			
Fiber wood insulation	0,14	53	0,96	2100	0,039	3,58974359	1,35	7	180	0,042			
Plywood	0,012	650	0,9	1500	0,13	0,09230769	169	92	636	0,001			

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-15. Summary sheet of the analysed wood frame wall configuration.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.3. Summary of internal wall configurations.

configuration name	**Wall design**	**Indoor condition**
4.A11_RM	A11 / Masonry block and VIP unprotected	RM / Room with medium moisture load
4.A11_RH		RH / Room with high moisture load
4.A11_WH		WB / wall surface behind a thermal heater
4.A12_RM	A12 / Masonry block and VIP protected	RM / Room with medium moisture load
4.A12_RH		RH / Room with high moisture load
4.A12_WH		WB / wall surface behind a thermal heater
4.B11_RM	B11 / Wood frame and VIP unprotected	RM / Room with medium moisture load
4.B11_RH		RH / Room with high moisture load
4.B11_WH		WB / wall surface behind a thermal heater
4.B12_RM	B12 / Wood frame and VIP protected	RM / Room with medium moisture load
4.B12_RH		RH / Room with high moisture load
4.B12_WH		WB / wall surface behind a thermal heater

Then, simulations were carried out for 4 different wall design alternatives (A11, A12, B11, B12) and 3 different indoor conditions: room with medium moisture load (RM), room with high moisture load (RH), wall surface backwards a heater placed in a room with medium moisture load (WH). The resulting twelve design alternatives are summarised in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.3.

1.5 Configuration 5– Flat roof in Nice (EDF)

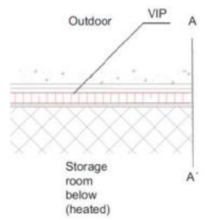
(Results based on the publication project: Antoine BATARD and al., “Prediction method of the long-term thermal performance of Vacuum Insulation Panels installed in building thermal insulation applications”, 2017)

The building component is a flat roof. Its configuration corresponds to the case study located in Regensdorf near Zurich (Switzerland) and studied by Brunner and Simmler [1].

Proposal of the building component to be investigated - Part "A"

Component type	Flat roof	Orientation	N-E-S-W	Slope	orizontal=0°

2D Drawings section:



Picture/3D scheme/additional info:

Additional info:

Component stratigraphy:

Layer:	Material:
indoor	
1	Concrete
2	Bituminous water barrier
3	PSE
4	VIP
5	PSE
6	Bituminous water barrier
7	Gravel
8	
9	
10	
outdoor	

Basic values - termophysical properties

layer	d thickness	ρ Bulk density	pt Porosity	c Specific Heat Capacity	λ_{eff} Thermal Conductivity, Design Value	R Thermal resistance	μ Water Vapour Diffusion Resistance Factor	Wc Reference Water Content	SW Free Water Saturation	WA Water Absorption Coefficient	DF Drying Factor	ε Long wave radiation emissivity	α Short wave radiation absorption coefficient
	m	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	kg/m³	kg/m³	kg/m²s^0.5	-	-	-
1	0.030	2200	0.122	100	2.000	0.015	We use the water vapour diffusion coefficient.	-	122	-	-	-	-
2	0.010	1100	0.001	1000	0.230	0.043		-	1	-	-	-	-
3	0.007	70	0.98	2300	0.050	0.140		-	980	-	-	-	-
4	0.020	190	0.935	800	0.006	3.333		-	935	-	-	-	-
5	0.005	70	0.98	2300	0.050	0.100		-	980	-	-	-	-
6	0.010	1100	0.001	1000	0.230	0.043		-	1	-	-	-	-
7	0.200	1800	0.2	1000	1.250	0.160		-	200	-	-	-	-
8													
9													
10													

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-16. Summary sheet of the analysed flat roof.

1.5.1 Boundary conditions:

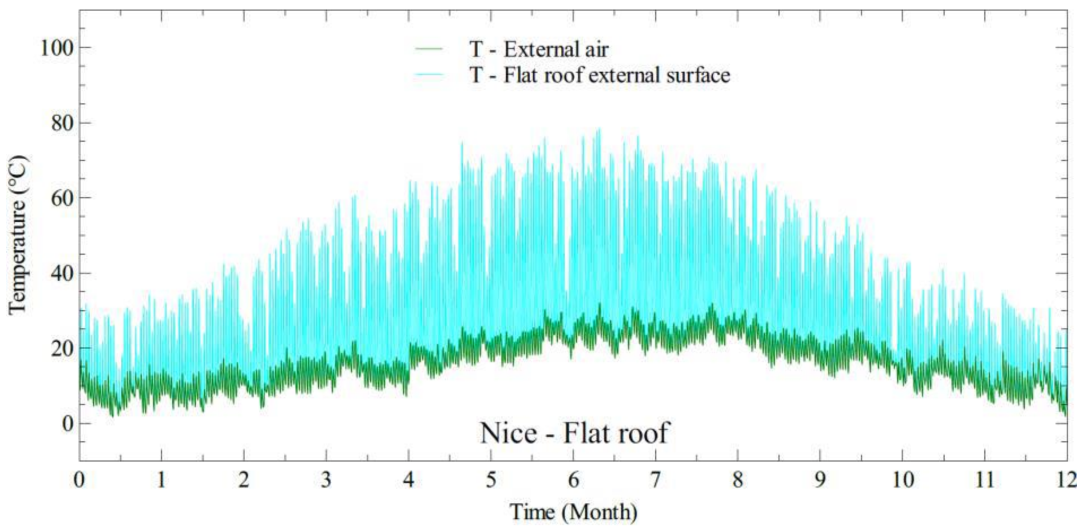


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-17. Yearly time profile of temperatures of external air and at the external wall surface.

It can be observed from Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-17 that the temperature at the walls' external surface (light blue) strongly differs to the external air temperature (green). This difference is very significant for all the year for the flat roof in Nice. For this configuration, the temperature at the walls' external surface exceeds 60 °C during spring and summer days. The temperature peaks can reach very high values up to 80 °C in summer whereas the external air temperature doesn't exceed 35 °C.

1.5.2 Indoor climate:

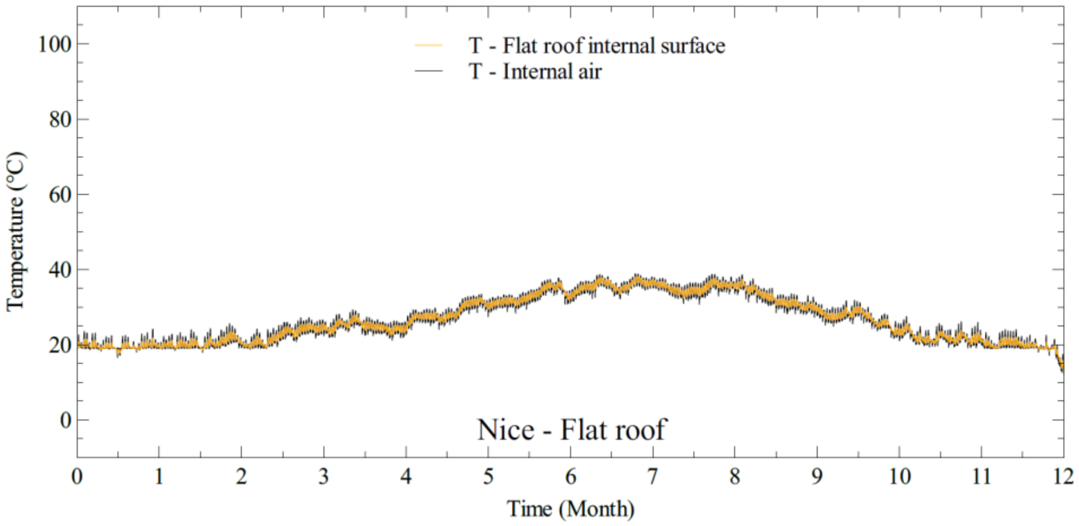


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-18. Yearly time profile of temperatures of internal air and at the internal wall surface.

It can be observed from Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-18 that the temperature at the internal walls' surface (orange) is very similar to the internal air temperature (black).

The impact of radiation exchanges strongly depends on the absorption coefficients, on the climate, on the orientation, on the insulation application and on the systems. In contrast, the temperatures at the internal walls' surface can be reasonably approximated by the internal air temperature.

1.5.3 Design alternatives:

In total, simulations were carried out for 3 different climate conditions and for three different external finishing colour, (bright, medium and dark finishing, with a solar absorption coefficient α of respectively 0.3, 0.6 and 0.9). Only the worst case has been retained: Nice with α = 0.9.

1.6 Configuration 6 – Flat roof/roof terrace – Holzkirchen and Freiburg (FIW)

The following Configurations 6 to 10 represent exemplary wall and roof configurations with VIP in Germany. The configurations are based on using VIP with a thickness of 20 mm, covered with a 5 mm layer of XPS. For each configuration the following variations are considered:

- Test reference years at Freiburg and Holzkirchen;
- Orientation from South to West;
- Normal and high moisture load of the internal room according to EN 15026:2007

The hygrothermal calculation was performed with Wufi®Pro 5.2 (Release: 5.2.0.972.DB.24.76), running the calculation for three years (until steady state conditions are reached): the results for the third year were considered for data analysis.

A numerical code was used to describe the configurations consisting of number of configuration (C6 – C10), the location (FR = Freiburg, HO = Holzkirchen), the moisture load of the internal room (NM = normal moisture load, HM = high moisture load) and the orientation of the building element (SO = south, WE = west). An exemplary description of the Configuration 6 (flat roof), in Freiburg, normal moisture load and south orientation is: C6-FR-NM-SO.

The description of the Configurations C6 – C10 is based on Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-19 including the relevant material data. For reasons of simplicity the thermal conductivity of the VIP is set to 0.004 W/mK (typical rated value) without ageing effects in the three year calculation and the water vapour diffusion coefficient is set to infinity. The other data used are mostly taken from the Wufi® material data base and are partly complemented and adapted.

Proposal of the building component to be investigated - Part "A"

Component type	-	Orientation	-	Slope	-

2D Drawings section and Picture/3D scheme/additional info

-

Component stratigraphy:

Layer:	Material:	Layer:	Material:
1	VIP	8	Internal plaster, Gypsum
2	XPS	9	Exterior plaster
3	Vapour control layer	10	Concrete, C35/C45
4	Underlay membrane	11	Concrete, C12/C15
5	Wood (spruce)	12	Watertight barrier, V13
6	Gypsum fibre board	13	Gravel
7	Sand-lime brick	14	Air layer

Basic values - termophysical properties

	d	*ρ*	*pt*	*c*	*λ eff*	*R*	*μ*	*Wc*	*SW*	*WA*	*DF*	*ε*	*α*
layer	thickness	Bulk density	Porosity	Specific Heat Capacity	Thermal Conductivity, Design Value	Thermal resistance	Water Vapour Diffusion Resistance Factor	Reference Water Content	Free Water Saturation	Water Absorption Coefficient	Drying Factor	Long wave radiation emissivity	Short wave radiation absorption coefficient
	mm	kg/m³	m³/m³	J/kgK	W/mK	m²K/W	-	kg/m³	kg/m³	kg/m²s^0.5	-	-	-
1	20/30/40	200	0.99	850	0.004	-	∞	-	-	-	-	-	-
2	5	40	0.95	1500	0.03	-	100	-	-	-	-	-	-
3	1	130	0.001	2300	2.3	-	50000	-	-	-	-	-	-
4	1	130	0.001	2300	2.3	-	200	-	-	-	-	-	-
5	20	455	0.73	1500	0.09	-	130	-	-	-	-	-	-
6	13	850	0.65	850	0.2	-	8.3	-	-	-	-	-	-
7	115	1900	0.29	850	1	-	28	-	-	-	-	-	-
8	15	850	0.65	850	0.2	-	8.3	-	-	-	-	-	-
9	20	*Taken from the Wufi® data base as a sytem consisting of four layers*							-	-	-	-	-
10	175	2200	0.18	850	1.6	-	248	-	-	-	-	-	-
11	0	2200	0,118	850	1,6	-	92	-	-	-	-	-	-
12	20	2400	0.001	1000	0.5	-	100000	-	-	-	-	-	-
13	50	1400	0.3	1000	0.7	-	1	-	-	-	-	-	-
14	50	1.3	0.999	1000	0.28	-	0.32	-	-	-	-	-	-

Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-19. Material data for the layers of the Configurations C6 – C10.

The configurations are described by a sequence of numbers according to Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-19. Each sequence of numbers starts with the exterior layer and ends with the internal layer of the configuration.

The utilization of 20 mm thick VIP can be described as the lower limit of panel thicknesses and represents therefore a kind of worst-case scenario. The achieved U-values are in the range of ca. 0.18 W/m^2K and therefore represent typical thermal performance in Germany. If thicker VIP panels are used, much lower U-values can be achieved and the climatic stress varies. Due to the greater volume of the panels, then also the internal pressure increase as the main ageing factor of VIP will be proportionally lower. To have an impression of the thermal performance of the configurations the U-values are given also for VIP with 30 mm and 40 mm thickness – however, only VIP with 20 mm thickness are considered for calculation of climatic boundary conditions.

The chosen configuration for a flat roof, resp. roof terrace based on a ceiling made of concrete is given in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.4. The building element is assumed to be horizontal.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.4. Configuration 6 – Flat roof terrace.

<table>
<tr><th>C6</th><th colspan="2">Outside climate - 11/13/12/2/1/2/10/8 – Interior climate</th></tr>
<tr><td>Specialities of the model:</td><td colspan="2">Moisture spring with 1 % of driving rain on the inner 5 mm of layer 14</td></tr>
<tr><td rowspan="2">U-value
[W/m²K]</td><td>VIP 20 mm</td><td>0,173</td></tr>
<tr><td>VIP 30 mm</td><td>0,121</td></tr>
</table>

	VIP 40 mm	0,093

1.6.1 Outdoor weather conditions:

The outdoor weather conditions refer to the locations Freiburg and Holzkirchen that offer different climatic impact. Compared to Holzkirchen, Freiburg offers a much higher mean temperature (Freiburg, 10.4°C vs. Holzkirchen, 6.6°C). On the other hand the humidity impact is higher in Holzkirchen that is characterized by the mean relative humidity (Freiburg, 74 % ϕ vs. Holzkirchen 81 % ϕ) and a more intense driving rain load. The orientation of the building element in Freiburg was considered south, to guarantee maximum temperature stress. For the worst case with respect of moisture impact, the orientation in Holzkirchen for the case with high internal moisture load was also switched to west, as the driving rain load in Holzkirchen is directed to West.

Due to the expected interdependency between permeation of dry air gases and water vapour from the climatic boundary conditions, the chosen reference locations are expected to be of influence on the ageing behaviour of VIP in the specific configurations.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.5. Summarized exterior climatic analysis of the location Freiburg (Wufi®).

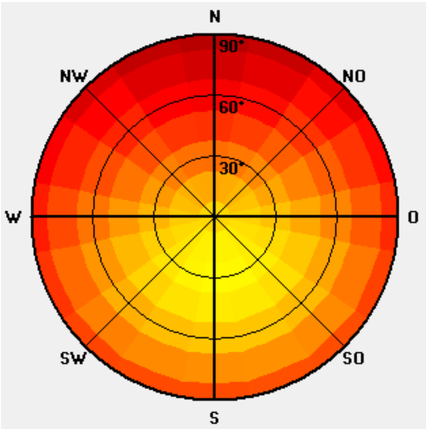
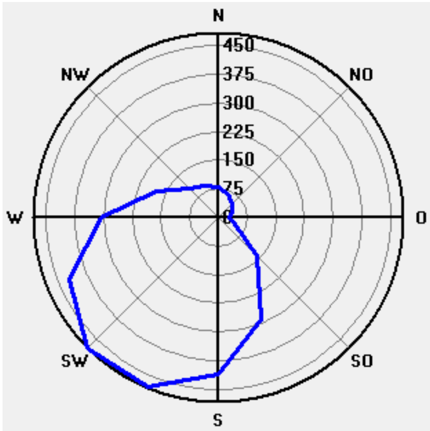
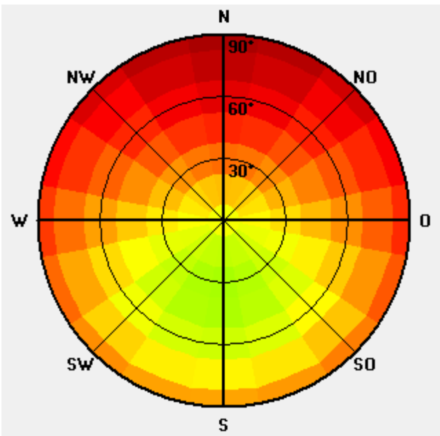
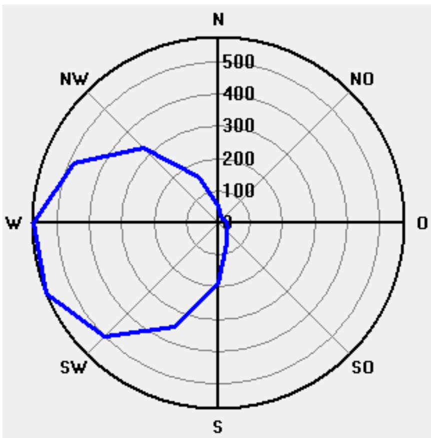
Mean temperature [°C]:	10,4	Mean relative humidity [%]:	74
Max. temperature [°C]:	32,5	Max. relative humidity [%]:	100
Min. temperature [°C]:	-10,7	Min. relative humidity [%]:	12
Downward terrestrial radiation [kWh/m²a]:	2431,3	Mean wind speed [m/s]:	2,77
Mean degree of overclouding [-]:	0,65	Normal rain sum [mm/a]:	940
Sum of solar radiation [kWh/m²a]		Sum of driving rain [mm/a]	
			

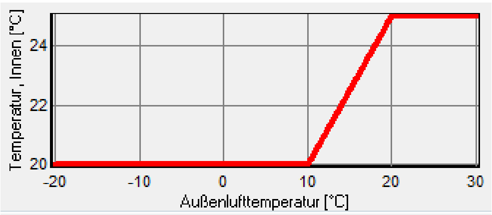
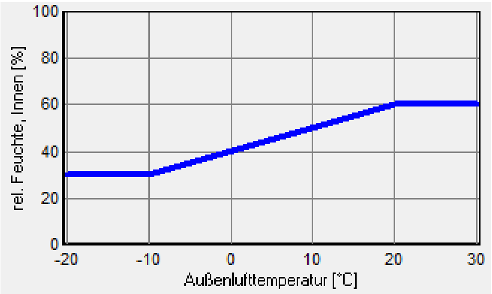
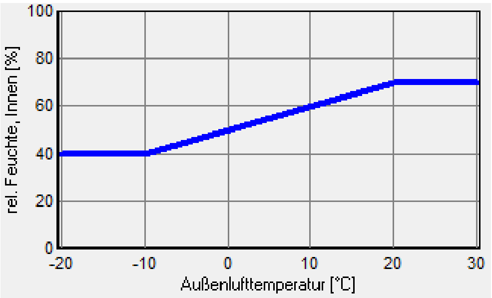
Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.6. Summarized exterior climatic analysis of the location Holzkirchen (Wufi®).

Mean temperature [°C]:	6,6	Mean relative humidity [%]:	81
Max. temperature [°C]:	32,1	Max. relative humidity [%]:	98
Min. temperature [°C]:	-20,1	Min. relative humidity [%]:	24
Downward terrestrial radiation [kWh/m²a]:	2668,4	Mean wind speed [m/s]:	2,33
Mean degree of overclouding [-]:	-	Normal rain sum [mm/a]:	1185
Sum of solar radiation [kWh/m²a]		Sum of driving rain [mm/a]	
			

1.6.2 *Indoor climate:*

The indoor climate was set according to EN 15026:2007, discriminating between normal and high moisture load. The applied values are connected to the exterior temperature and relative humidity at the chosen locations in Freiburg and Holzkirchen assuming the functionalities given in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.7. The indoor climate was applied for the Configurations C6 – C10 in the same way.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.7. Interdependency between exterior and interior climate for normal and high moisture load according to EN 15026:2007 [86].

	Interior temperature as a function of exterior temperature for normal and high moisture load
	Interior relative humidity as a function of exterior temperature for normal moisture load
	Interior relative humidity as a function of exterior temperature for high moisture load

1.6.3 *Design alternatives:*

The observed design alternatives consider variations of location, internal moisture load and orientation of the building.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.8. Design alternatives for the flat roof / roof terrace.

C6-FR-NM-SO	Flat roof – Freiburg – normal moisture load – south orientation
C6-HO-NM-SO	Flat roof – Holzkirchen – normal moisture load – south orientation
C6-HO-HM-WE	Flat roof – Holzkirchen – high moisture load – west orientation

1.7 Configuration 7 – Pitched roof – Holzkirchen and Freiburg (FIW)

The chosen configuration for a pitched roof with wooden roof sheathing and gypsum fibre board on the internal side is given in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.9. The pitched roof has an angle of 30°. Outdoor and indoor climate are applied according to Configuration 6.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.9. Configuration7 – Flat roof terrace.

C7	**Outside climate - 5/2/1/2/3/6 - Interior climate**	
Specialities of the model:	Moisture spring based on air infiltration on the inner 5 mm of layer 6	
U-value [W/(m² K)]	VIP 20 mm	0,174
	VIP 30 mm	0,121
	VIP 40 mm	0,093

1.7.1 Design alternatives:

The observed design alternatives consider variations of location, internal moisture load and orientation of the building.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.10. Design alternatives for the pitched roof.

C7-FR-NM-SO	Pitched roof – Freiburg – normal moisture load – south orientation
C7-HO-NM-SO	Pitched roof – Holzkirchen – normal moisture load – south orientation
C7-HO-HM-WE	Pitched roof – Holzkirchen – high moisture load – west orientation

1.8 Configuration 8 – External thermal insulation composite system (ETICS) – Holzkirchen and Freiburg (FIW)

The chosen configuration for an external thermal insulation composite system installed on a sand-lime brick wall is given in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.11. The wall is assumed to be vertical. Outdoor and indoor climate are applied according to Configuration 6.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.11. Configuration 8 – External thermal insulation composite system (ETICS).

C8	**Outside climate - 9/2/1/2/7/8– Interior climate**	
Specialities of the model:	Moisture spring with 1 % of driving rain on the outer 5 mm of layer 8	
U-value [W/(m² K)]	VIP 20 mm	0,174
	VIP 30 mm	0,121
	VIP 40 mm	0,093

1.8.1 Design alternatives:

The observed design alternatives consider variations of location, internal moisture load and orientation of the building.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.12. Design alternatives for the external thermal insulation composite system (ETICS).

C8-FR-NM-SO	ETICS – Freiburg – normal moisture load – south orientation
C8-HO-NM-SO	ETICS – Holzkirchen – normal moisture load – south orientation
C8-HO-HM-WE	ETICS – Holzkirchen – high moisture load – west orientation

1.9 Configuration 9 – Internal insulation – Holzkirchen and Freiburg (FIW)

The chosen configuration for an internal insulation of a sand-lime brick wall is given in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.13. The wall is assumed to be vertical. Outdoor and indoor climate are applied according to Configuration 6.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.13. Configuration 9 – Internal insulation.

C9	**Outside climate - 9/7/8/2/1/2/3/6– Interior climate**	
Specialities of the model:	-	
U-value [W/(m^2 K)]	VIP 20 mm	0,172
	VIP 30 mm	0,120
	VIP 40 mm	0,092

1.9.1 Design alternatives:

The observed design alternatives consider variations of location, internal moisture load and orientation of the building.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.14. Design alternatives for the external thermal insulation composite system (ETICS).

C9-FR-NM-SO	Internal insulation – Freiburg – normal moisture load – south orientation
C9-HO-NM-SO	Internal insulation – Holzkirchen – normal moisture load – south orientation
C9-HO-HM-WE	Internal insulation – Holzkirchen – high moisture load – west orientation

1.10 Configuration 10 – ventilated façade – Holzkirchen and Freiburg (FIW)

The chosen configuration represents a ventilated façade installed in front of a sand-lime brick wall (Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.15). Outdoor and indoor climate are applied according to Configuration 6.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.15. Configuration 10 – Ventilated façade.

C10	**Outside climate - 5/14/3/1/2/9/7/8 - Interior climate**	
Specialities of the model:	Air exchange of 100 h^{-1} in layer 14	
U-value [W/(m^2 K)]	VIP 20 mm	0,164
	VIP 30 mm	0,116
	VIP 40 mm	0,090

1.10.1 Design alternatives:

The observed design alternatives consider variations of location, internal moisture load and orientation of the building.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.16. Design alternatives for the external thermal insulation composite system (ETICS).

C10-FR-NM-SO	Ventilated façade – Freiburg – normal moisture load – south orientation
C10-HO-NM-SO	Ventilated façade – Holzkirchen – normal moisture load – south orientation
C10-HO-HM-WE	Ventilated façade – Holzkirchen – high moisture load – west orientation

1.11 Results and discussion

In the following sections the results of the numerical simulations performed for each of the proposed configurations are presented and critically analysed.

1.11.1 Configuration 1- Brick wall in Turin (POLITO)

For the sake of brevity, only the results of one design alternative are shown in detail. The results referring to the case of west dark vertical façade, with medium internal moisture load, and panel thickness of 20 mm (case: 1. W_D_m_20) are shown.

The time profiles of the temperature *T*, relative humidity *φ* and water vapour pressure p_v over an entire year are plotted in Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-20, Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-21 and Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-22 respectively. Each plot shows the data relative to the external VIP side (*e*), the internal VIP side (*i*), and the average value (*avg*).

Furthermore, the cumulative frequency distributions of *T, φ* and p_v are represented in Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-23, Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-24 and Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-25, respectively.

The overview of the results related to all the design alternatives are resumed in Table 1.17 that reports the frequency values within specific ranges of temperature, relative humidity and water vapour pressure. Cells are coloured in gradient greyscale to highlight the highest values among the various design alternatives.

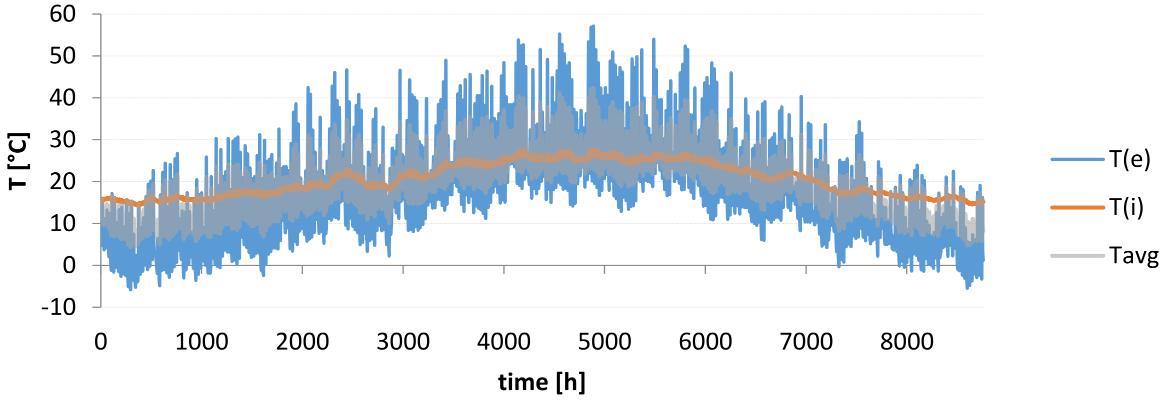


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-20. Yearly time profile of temperatures for the west dark vertical façade, medium internal moisture load, VIP thickness 20 mm.

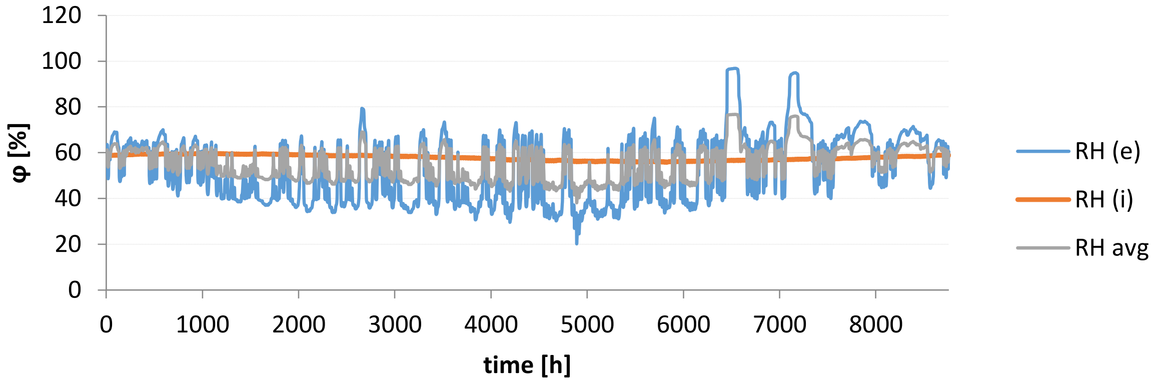


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-21. Yearly time profile of ϕs for west dark vertical façade, medium internal moisture load, VIP thickness 20 mm.

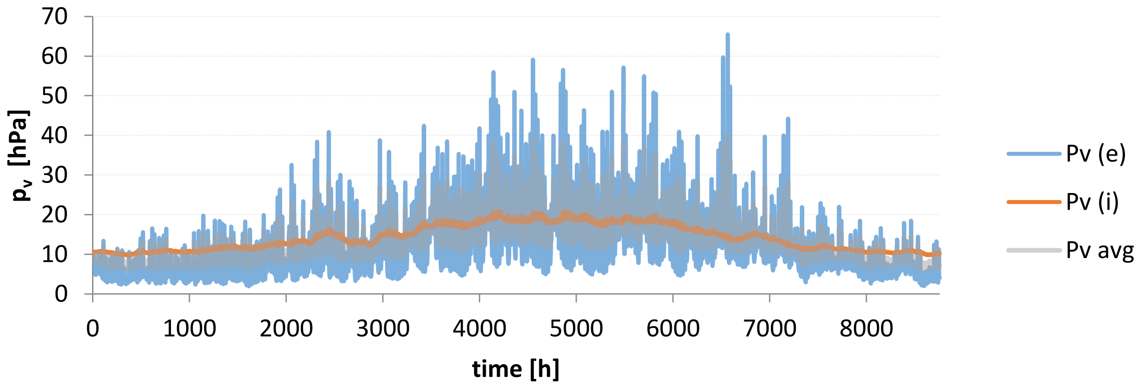


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-22. Yearly time profile of vapour pressures for west dark vertical façade, medium internal moisture load, VIP thickness 20 mm.

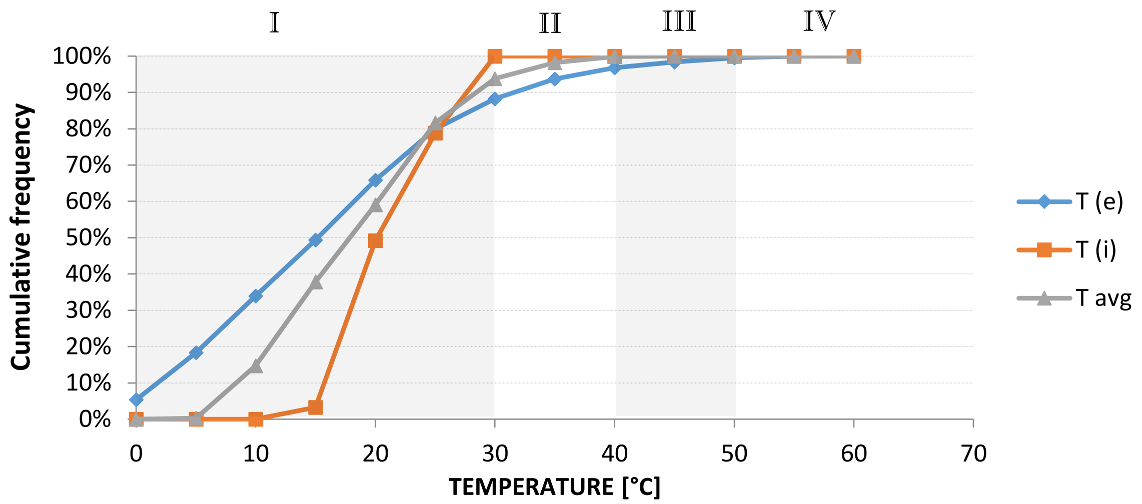


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-23. Temperature cumulative frequency for west dark vertical façade, medium internal moisture load, VIP thickness 20 mm.

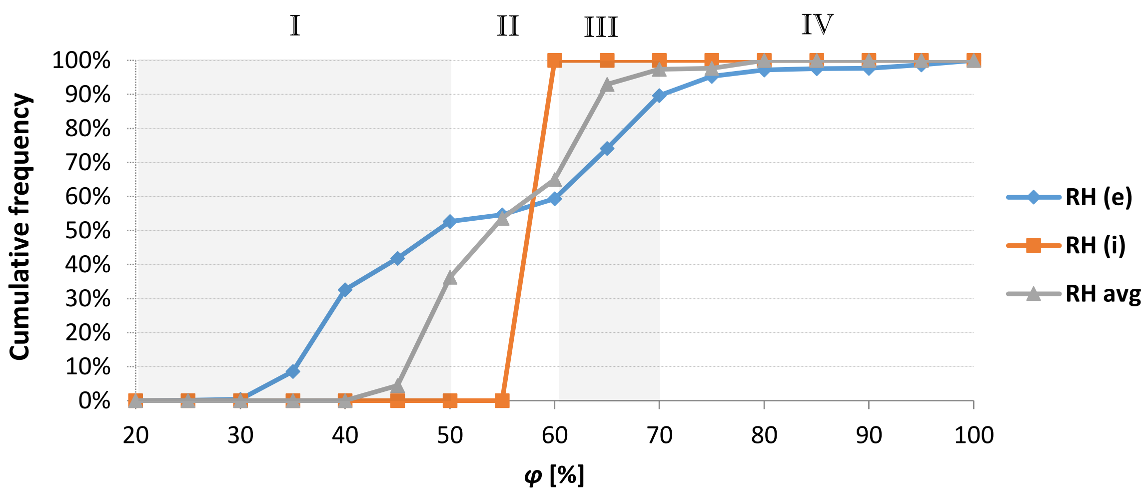


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-24. Relative humidity cumulative frequency for west dark vertical façade, medium internal moisture load, VIP thickness 20 mm.

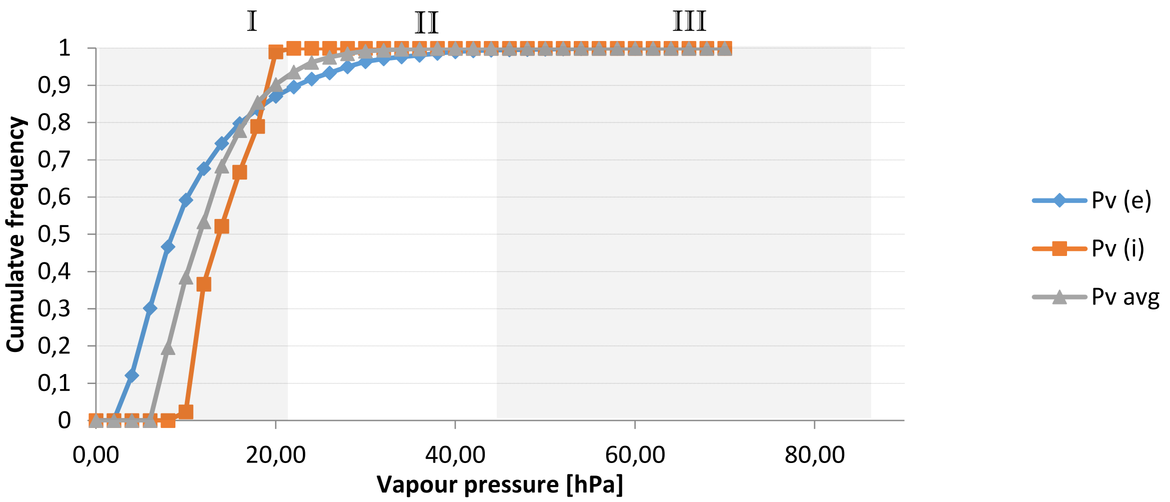


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-25. Vapour pressure cumulative frequency for west dark vertical façade, medium internal moisture load, VIP thickness 20 mm.

Table 1.17. A: Summary of the frequency distribution at the faces of a VIP 20 mm thick. Simulations refer to a medium internal moisture load. (1 % of frequency corresponds to 3.65 days/year of exposure).

Configuration	**Moisture load**	**VIP thickness**	**Orientation**	**Solar adsorption coefficient**	**Side**	Temperature ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
						I (≤30 °C)	II (30÷40 °C)	III (40÷50 °C)	IV (>50 °C)	MAX [°C]	I (≤50 %)	II (50÷60 %)	III (60÷70 %)	IV (>70 %)	MAX [%]	I (≤21,2 hPa)	II (21,2÷44,3 hPa)	III (44,3÷86 hPa)	MAX [hPa]
1.N_B_m_20	medium	20mm	North	0.3	avg.	100.0%	0.0%	0.0%	0.0%	**30.1**	0.2%	21.6%	70.5%	7.6%	**79.4%**	95.5%	4.5%	0.0%	**30.3**
					ext.	98.1%	1.9%	0.0%	0.0%	**35.1**	15.6%	7.1%	46.7%	30.7%	**97.8%**	91.6%	8.4%	0.0%	**42.6**
					int.	100.0%	0.0%	0.0%	0.0%	**25.5**	0.0%	25.3%	74.7%	0.0%	**61.9%**	100.0%	0.0%	0.0%	**19.8**
1. N_M_m_20				0.6	avg.	99.6%	0.4%	0.0%	0.0%	**31.4**	2.3%	29.6%	62.3%	5.8%	**78.7%**	95.1%	4.9%	0.0%	**33.9**
					ext.	95.9%	4.1%	0.0%	0.0%	**37.3**	24.2%	7.1%	44.9%	23.8%	**97.2%**	90.9%	9.0%	0.1%	**49.6**
					int.	100.0%	0.0%	0.0%	0.0%	**25.9**	0.0%	44.7%	55.3%	0.0%	**61.4%**	100.0%	0.0%	0.0%	**19.9**
1. N_D_m_20				0.9	avg.	98.2%	1.8%	0.0%	0.0%	**32.7**	9.1%	33.4%	53.2%	4.2%	**78.0%**	94.4%	5.6%	0.0%	**37.8**
					ext.	92.7%	7.3%	0.0%	0.0%	**39.5**	32.9%	7.7%	40.7%	18.7%	**96.6%**	90.1%	9.8%	0.1%	**57.4**
					int.	100.0%	0.0%	0.0%	0.0%	**26.3**	0.0%	61.8%	38.2%	0.0%	**60.8%**	100.0%	0.0%	0.0%	**20.0**
1. E_B_m_20			East	0.3	avg.	99.9%	0.1%	0.0%	0.0%	**30.3**	1.1%	29.0%	67.9%	1.9%	**78.4%**	95.7%	4.3%	0.0%	**30.1**
					ext.	97.2%	2.8%	0.0%	0.0%	**35.3**	21.9%	8.1%	47.2%	22.8%	**96.2%**	92.4%	7.6%	0.0%	**42.1**
					int.	100.0%	0.0%	0.0%	0.0%	**25.7**	0.0%	39.9%	60.1%	0.0%	**61.6%**	100.0%	0.0%	0.0%	**19.8**
1. E_M_m_20				0.6	avg.	98.0%	2.0%	0.0%	0.0%	**34.5**	13.0%	33.7%	51.7%	1.5%	**77.7%**	94.9%	5.1%	0.0%	**34.1**
					ext.	92.9%	6.9%	0.2%	0.0%	**43.2**	36.4%	7.8%	41.5%	14.4%	**96.1%**	91.7%	8.2%	0.1%	**50.2**
					int.	100.0%	0.0%	0.0%	0.0%	**26.3**	0.0%	65.0%	35.0%	0.0%	**60.7%**	100.0%	0.0%	0.0%	**20.0**
1. E_D_m_20				0.9	avg.	94.7%	5.3%	0.0%	0.0%	**39.1**	31.2%	32.0%	35.8%	1.1%	**76.9%**	93.6%	6.4%	0.0%	**41.0**
					ext.	88.3%	10.1%	1.6%	0.0%	**51.5**	49.7%	7.2%	34.5%	8.6%	**95.7%**	90.3%	9.3%	0.4%	**64.1**
					int.	100.0%	0.0%	0.0%	0.0%	**27.0**	0.0%	100.0%	0.0%	0.0%	**59.9%**	100.0%	0.0%	0.0%	**20.3**

Table 1.17. B: Summary of the frequency distribution at the faces of a VIP 20 mm thick. Simulations refer to a medium internal moisture load. (1 % of frequency corresponds to 3.65 days/year of exposure).

Configuration	**Moisture load**	**VIP thickness**	**Orientation**	**Solar adsorption coefficient**	**Side**	Temperature ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
						I (≤30 °C)	II (30÷40 °C)	III (40÷50 °C)	IV (>50 °C)	MAX [°C]	I (≤50 %)	II (50÷60 %)	III (60÷70 %)	IV (>70 %)	MAX [%]	I (≤21,2 hPa)	II (21,2÷44,3 hPa)	III (44,3÷86 hPa)	MAX [hPa]
1. S_B_m_20	high	20 mm	South	0.3	avg.	99.6%	0.4%	0.0%	0.0%	**31.5**	2.0%	32.6%	59.1%	6.2%	**78.0%**	96.1%	3.9%	0.0%	**30.0**
					ext.	96.7%	3.3%	0.0%	0.0%	**37.7**	25.6%	8.7%	43.2%	22.5%	**96.9%**	92.0%	8.0%	0.0%	**41.5**
					int.	100.0%	0.0%	0.0%	0.0%	**25.7**	0.0%	43.8%	56.2%	0.0%	**61.3%**	100.0%	0.0%	0.0%	**19.6**
1. S_M_m_20				0.6	avg.	97.4%	2.6%	0.0%	0.0%	**34.4**	23.7%	35.5%	37.4%	3.4%	**77.2%**	94.5%	5.5%	0.0%	**33.3**
					ext.	91.9%	7.8%	0.3%	0.0%	**43.2**	48.6%	6.8%	29.7%	14.9%	**96.8%**	89.9%	10.0%	0.1%	**50.7**
					int.	100.0%	0.0%	0.0%	0.0%	**26.3**	0.0%	89.6%	10.4%	0.0%	**60.3%**	100.0%	0.0%	0.0%	**19.7**
1. S_D_m_20				0.9	avg.	93.9%	6.1%	0.0%	0.0%	**38.0**	54.6%	22.2%	21.0%	2.1%	**76.4%**	92.6%	7.4%	0.0%	**41.5**
					ext.	85.8%	11.7%	2.6%	0.0%	**49.4**	67.1%	4.6%	19.3%	9.0%	**96.6%**	87.5%	12.2%	0.3%	**67.8**
					int.	100.0%	0.0%	0.0%	0.0%	**27.0**	0.0%	100.0%	0.0%	0.0%	**59.0%**	100.0%	0.0%	0.0%	**19.9**
1. W_B_m_20			West	0.3	avg.	99.1%	0.9%	0.0%	0.0%	**32.7**	2.4%	27.2%	64.2%	6.2%	**78.2%**	95.8%	4.2%	0.0%	**31.1**
					ext.	96.2%	3.8%	0.0%	0.0%	**40.0**	22.5%	7.1%	45.2%	25.2%	**97.0%**	91.6%	8.4%	0.0%	**43.4**
					int.	100.0%	0.0%	0.0%	0.0%	**26.0**	0.0%	40.9%	59.1%	0.0%	**61.5%**	100.0%	0.0%	0.0%	**20.0**
1. W_M_m_20				0.6	avg.	96.7%	3.3%	0.0%	0.0%	**37.4**	17.0%	31.2%	47.1%	4.6%	**77.5%**	93.9%	6.1%	0.0%	**33.2**
					ext.	92.1%	6.7%	1.2%	0.0%	**48.1**	38.5%	7.6%	37.8%	16.2%	**96.9%**	89.7%	10.2%	0.1%	**47.9**
					int.	100.0%	0.0%	0.0%	0.0%	**26.9**	0.0%	69.8%	30.2%	0.0%	**60.7%**	100.0%	0.0%	0.0%	**20.3**
1. W_D_m_20				0.9	avg.	93.8%	6.0%	0.1%	0.0%	**42.4**	36.3%	28.7%	32.4%	2.6%	**76.8%**	92.4%	7.6%	0.0%	**40.1**
					ext.	88.3%	8.5%	2.8%	0.4%	**57.2**	52.7%	6.7%	30.2%	10.4%	**96.9%**	88.6%	10.8%	0.6%	**65.5**
					int.	100.0%	0.0%	0.0%	0.0%	**27.7**	0.0%	100.0%	0.0%	0.0%	**59.7%**	100.0%	0.0%	0.0%	**20.9**
1. W_D_h_20	medium			0.9	avg.	93.8%	6.0%	0.1%	0.0%	**42.4**	3.4%	50.3%	39.3%	7.0%	**82.0%**	89.3%	10.7%	0.0%	**41.5**
					ext.	88.3%	8.5%	2.8%	0.4%	**57.2**	52.7%	6.7%	30.2%	10.4%	**96.9%**	88.6%	10.8%	0.6%	**65.5**
					int.	100.0%	0.0%	0.0%	0.0%	**27.8**	0.0%	0.0%	100.0%	0.0%	**68.5%**	77.5%	22.5%	0.0%	**25.0**
1. W_D_h_10		10 mm		0.9	avg.	93.5%	6.2%	0.3%	0.0%	**43.2**	0.6%	51.2%	38.1%	10.1%	**83.1%**	88.2%	11.8%	0.0%	**42.6**
					ext.	88.4%	8.5%	2.6%	0.4%	**56.6**	53.0%	6.9%	30.1%	10.0%	**96.8%**	88.7%	10.8%	0.5%	**64.5**
					int.	100.0%	0.0%	0.0%	0.0%	**30.0**	0.0%	0.0%	43.5%	56.5%	**71.1%**	73.9%	26.1%	0.0%	**29.1**

1.11.1.1 Simulations done considering the medium moisture load

1.11.1.1.1 Temperature ranges

All the design alternatives of Configuration 1 lie in range I and II.

Range III is reached by few of design alternatives, in particular:

- 1. S_D_m_20 (south exposure and dark surface finishing) on the VIP external surface, where the temperature spans from 40 °C and 50 °C for about 2.6 % of the time (≈ 9.5 days/year, (T_{MAX} = 49.4 °C);
- 1. W_D_m_20 (west exposure and dark surface finishing) on the VIP external surface, where the range III was reached for about 2.8 % of the time (≈ 10 days). For this design alternative also the range IV is reached, even for a very short percentage of time (about 0.4 % ≈ 1.5 days, T_{MAX} = 57.2 °C).

1.11.1.1.2 Relative Humidity ranges

The relative humidity reaches range III for almost all the design alternatives. Many design alternatives also reach the range IV, with the highest frequencies in case of bright and medium finishing colours :

- 1. S_B_m_20 (south exposure and bright surface finishing) on the VIP external surface, cumulative frequency equal to about 22.5 % of time ≈ 82 days;
- 1. E_B_m_20 (east exposure and bright surface finishing) on the VIP external surface, cumulative frequency equal to about 22.8 % ≈ 83 days;
- 1. N_M_m_20 (north exposure and medium surface finishing) on the VIP external surface, cumulative frequency equal to about 23.8 % ≈ 87 days;
- 1. W_B_m_20 (west exposure and bright surface finishing) on the VIP external surface, cumulative frequency equal to about 25.2 % ≈ 92 days (φ_{MAX} = 97.0 %);
- 1. N_B_m_20 (north exposure and bright surface finishing) on the VIP external surface, cumulative frequency equal to about 30.7 % ≈ 112 days (φ_{MAX} = 97.8%).
- 1. W_D_m_20 (west exposure and dark surface finishing) on the VIP external surface, reaches the range IV in the 10.4 % of time ≈ 38 days, with a maximum value of relative humidity equal to around 96.7 %.

1.11.1.1.3 Vapour Pressure ranges

Few design alternatives reach range III. It is worth noting that these are the same design alternatives that lie in ranges III and IV as far as the temperature is concerned. In particular the cases with vapour pressure between 44.3 hPa and 86 hPa are:

- 1. S_D_m_20 (south exposure and dark surface finishing) on the VIP external surface, cumulative frequency equal to about 0.3 % ≈ 1 day ($p_{v\,MAX}$ = 67.8 hPa);
- 1. E_D_m_20 (east exposure and dark surface finishing) on the VIP external surface, cumulative frequency equal to about 0.4 % ≈ 1.5 days ($p_{v\,MAX}$ = 64.1 hPa);
- 1. W_D_m_20 (west exposure and dark surface finishing) on the VIP external surface, cumulative frequency equal to about 0.6 % ≈ 2 days ($p_{v\,MAX}$ = 65.5 hPa).

1.11.1.2 Simulations done considering the medium moisture load

Considering all the three analysed parameters (temperature, relative humidity and vapour pressure), it comes out that the worst configuration is 1. W_D_m_20. For this configuration also, the simulation results obtained with high moisture loads are shown. The effect was a global increase in relative humidity, especially on the internal surface (7.0 % of time ≈ 25.5 days in Range IV, instead of 22 days) and in the middle of the VIP (100 % of time in Range III, instead of 0 %), with relative humidity peak values equal to 82 % and 68.5 % respectively. A similar trend was observed for the vapour pressure, in particular for the internal side of VIP, where the range II was reached in 22.5 % of time (≈ 82 days) with a peak value equal to 25.0 hPa, instead of 20.9 hPa.

1.11.2 Configuration 2- Pitched roof – wood frame in Turin (POLITO)

For the sake of brevity, only the results of one design alternative are shown in detail. In particular, the results refer to the case south dark pitched roof, with medium internal moisture load, and panel thickness of 20 mm (case: 2. S_D_m_20).The time profiles of the temperature *T*, relative humidity φ and water vapour pressure p_v are plotted in Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-26, Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-27 and Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-28, respectively. Each plot shows the data relative to the external VIP side (*e*), the internal VIP side (*i*), and the average value (*avg*) .

Furthermore an analysis on the cumulative frequency distribution of *T*, φ and p_v were represented in Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-29, Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-30 and Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-31, respectively.

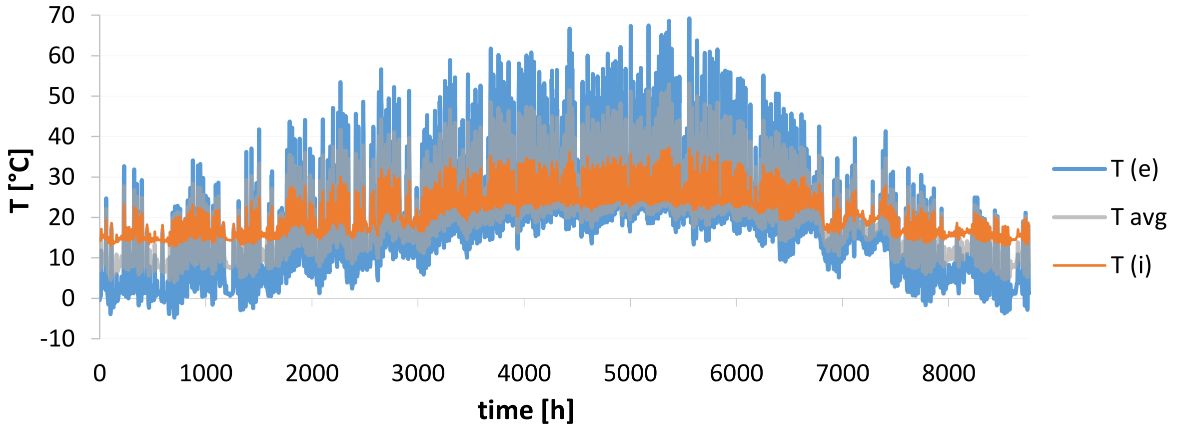


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-26. Yearly time profile for the south dark pitched roof, medium internal moisture load, VIP thickness 20 mm.

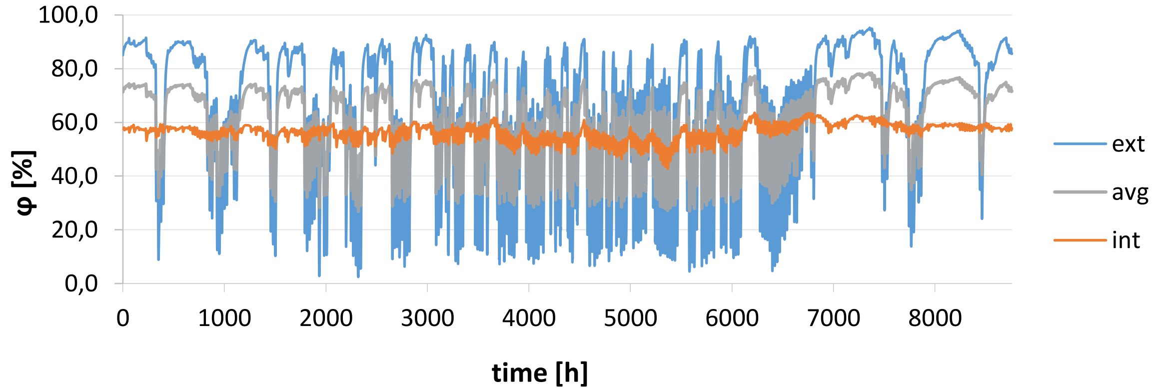


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-27. Yearly time profile of φs for the south dark pitched roof, medium internal moisture load, VIP thickness 20 mm.

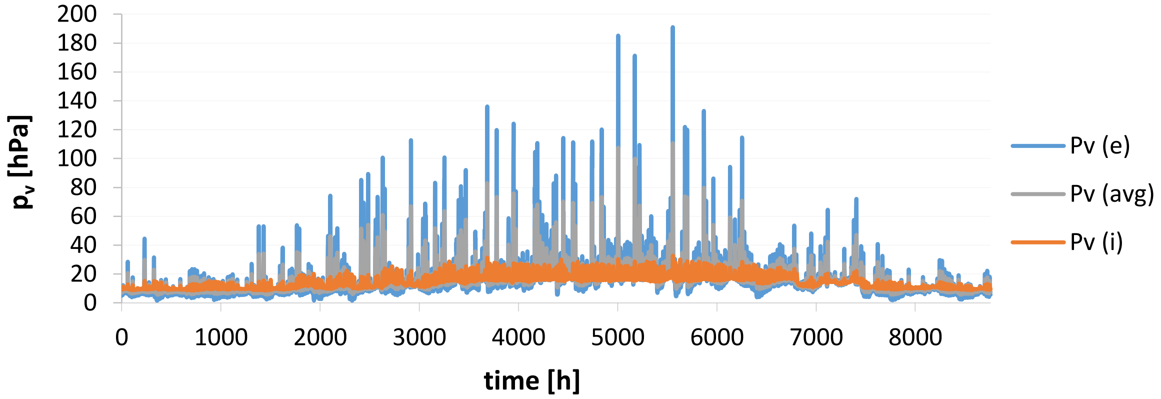


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-28. Yearly time profile of vapour pressures for the south dark pitched roof, medium internal moisture load, VIP thickness 20 mm.

The overview of the results related to all the design alternatives are resumed in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.18 that reports the frequency values within specific ranges of temperature, relative humidity and water vapour pressure. Cells are coloured in gradient greyscale to highlight the highest values among the various design alternatives.

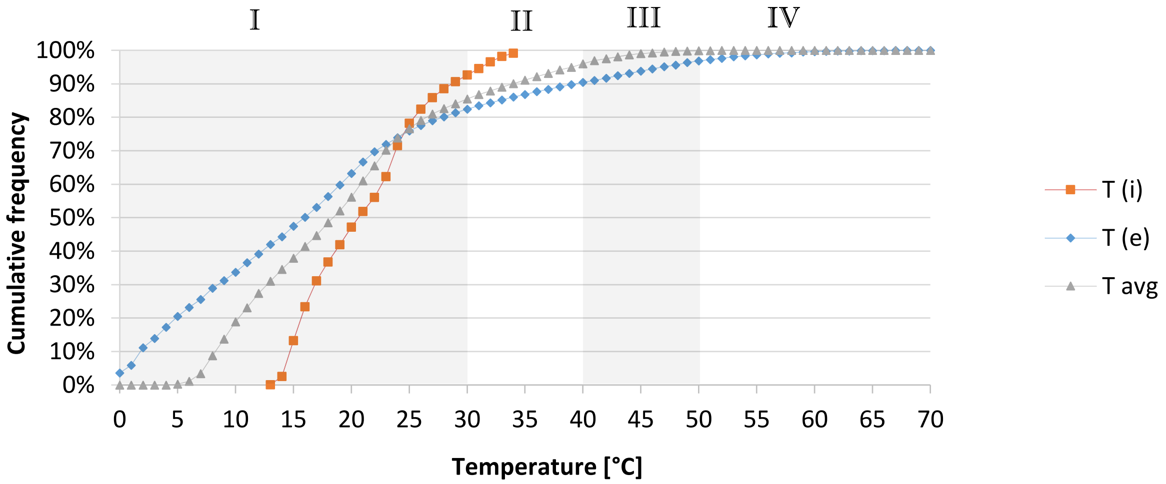


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-29. Temperature cumulative functions for the south dark pitched roof, medium internal moisture load, VIP thickness 20 mm.

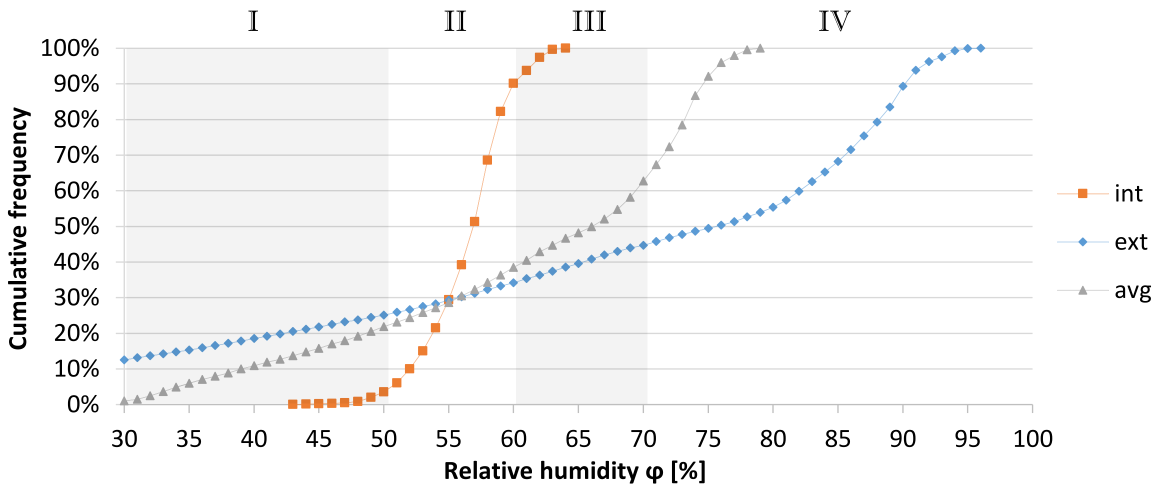


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-30. Relative humidity cumulative functions for the south dark pitched roof, medium internal moisture load, VIP thickness 20 mm.

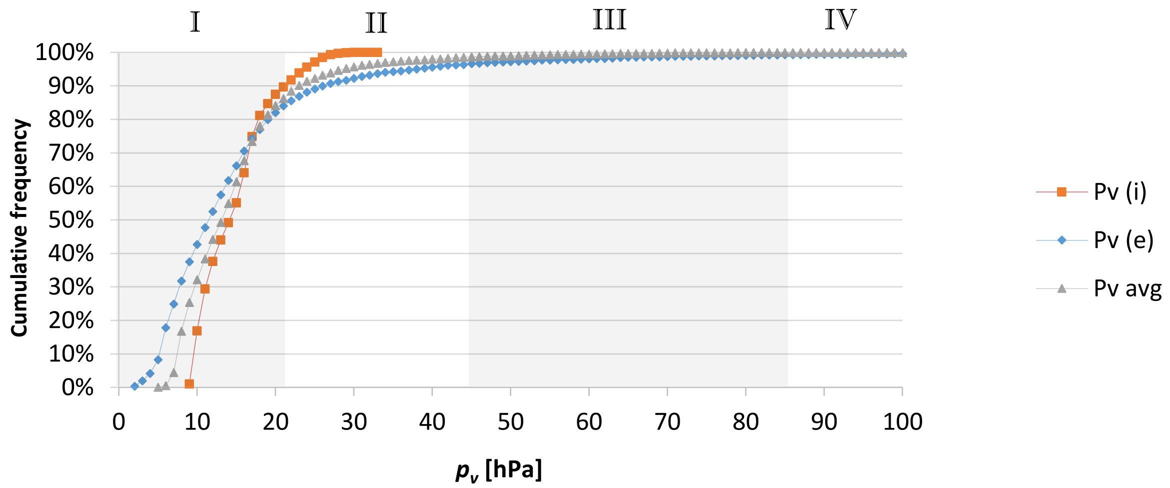


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-31. Vapour pressure cumulative functions for the south dark pitched roof, medium internal moisture load, VIP thickness 20 mm.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.18. A: Summary of the frequency distribution at the faces of a VIP 20 mm thick. Simulations refer to a medium internal moisture load. (1 % of frequency corresponds to 3.65 days/year of exposure).

Configuration	Moisture load	VIP thickness	Orientation	Solar adsorption coefficient	Side	Temperature ranges					Relative Humidity Ranges					Vapour Pressure Ranges				
						I (≤30 °C)	II (30÷40 °C)	III (40÷50 °C)	IV (>50 °C)	MAX [°C]	I (≤50 %)	II (50÷60 %)	III (60÷70 %)	IV (>70 %)	MAX [%]	I (≤21,2 hPa)	II (21,2÷44,3 hPa)	III (44,3÷86 hPa)	IV(≥86 hPa)	MAX [hPa]
2.N_B_m_20	medium	20mm	North	0.3	ext.	97.0%	3.0%	0.0%	0.0%	36.2	6.0%	4.7%	6.0%	83.3%	95.8	85.5%	14.3%	0.2%	0.0%	49.4
					int.	100.0%	0.0%	0.0%	0.0%	28.2	0.0%	10.4%	89.6%	0.0%	67.7	98.0%	2.0%	0.0%	0.0%	22.3
					avg.	98.5%	1.5%	0.0%	0.0%	32.2	3.0%	7.5%	47.8%	41.7%	81.7	89.7%	10.3%	0.0%	0.0%	35.6
2. N_M_m_20				0.6	ext.	89.6%	8.6%	1.8%	0.0%	45.7	13.4%	6.4%	9.0%	71.1%	95.6	85.0%	13.2%	1.7%	0.0%	78.4
					int.	99.4%	0.6%	0.0%	0.0%	30.9	0.0%	42.7%	57.3%	0.0%	66.3	93.5%	6.5%	0.0%	0.0%	25.2
					avg.	94.5%	4.6%	0.9%	0.0%	38.3	6.7%	24.6%	33.2%	35.6%	81.0	88.9%	10.9%	0.3%	0.0%	51.8
2. N_D_m_20				0.9	ext.	85.0%	8.4%	5.5%	1.2%	55.7	18.9%	7.3%	9.9%	63.9%	95.4	84.7%	12.6%	2.4%	0.2%	113.0
					int.	94.8%	5.2%	0.0%	0.0%	34.1	1.5%	68.9%	29.6%	0.0%	64.7	91.4%	8.6%	0.0%	0.0%	27.9
					avg.	89.9%	6.8%	2.7%	0.6%	44.9	10.2%	38.1%	19.8%	32.0%	80.1	87.7%	11.3%	1.0%	0.0%	69.4
2. E_B_m_20			East	0.3	ext.	95.5%	4.5%	0.0%	0.0%	37.6	8.3%	5.4%	8.4%	77.9%	95.7	85.3%	14.2%	0.4%	0.0%	55.5
					int.	100.0%	0.0%	0.0%	0.0%	28.7	0.0%	18.2%	81.8%	0.0%	66.5	97.2%	2.8%	0.0%	0.0%	22.8
					avg.	97.7%	2.3%	0.0%	0.0%	33.1	4.1%	11.8%	45.1%	39.0%	81.1	89.3%	10.7%	0.0%	0.0%	39.0
2. E_M_m_20				0.6	ext.	88.5%	8.1%	3.3%	0.1%	51.3	16.1%	7.8%	9.3%	66.8%	95.6	85.0%	12.7%	2.2%	0.1%	99.9
					int.	98.1%	1.9%	0.0%	0.0%	32.6	0.0%	60.3%	39.7%	0.0%	65.3	92.9%	7.1%	0.0%	0.0%	26.5
					avg.	93.3%	5.0%	1.7%	0.0%	41.9	8.1%	34.0%	24.5%	33.4%	80.4	88.5%	10.8%	0.6%	0.0%	62.4
2. E_D_m_20				0.9	ext.	83.7%	8.0%	5.3%	3.0%	65.0	22.9%	8.6%	9.9%	58.6%	95.4	84.9%	11.8%	2.6%	0.3%	151.7
					int.	93.4%	6.6%	0.0%	0.0%	36.7	3.1%	81.6%	15.3%	0.0%	64.2	90.8%	9.2%	0.0%	0.0%	30.0
					avg.	88.5%	7.3%	2.6%	1.5%	50.8	13.0%	45.1%	12.6%	29.3%	79.8	87.5%	11.2%	1.3%	0.0%	90.0

Table 1.18. B: Summary of the frequency distribution at the faces of a VIP 20 mm thick. Simulations refer to a medium internal moisture load. (1 % of frequency corresponds to 3.65 days/year of exposure).

						Temperature ranges					Relative Humidity Ranges					Vapour Pressure Ranges				
Configuration	**Moisture load**	**VIP thickness**	**Orientation**	**Solar adsorption coefficient**	**Side**	**I (≤30 °C)**	**II (30÷40 °C)**	**III (40÷50 °C)**	**IV (>50 °C)**	**MAX [°C]**	**I (≤50 %)**	**II (50÷60 %)**	**III (60÷70 %)**	**IV (>70 %)**	**MAX [%]**	**I (≤21,2 hPa)**	**II (21,2÷44,3 hPa)**	**III (44,3÷86 hPa)**	**IV(≥86 hPa)**	**MAX [hPa]**
2. S_B_m_20	medium	20 mm	South	0.3	ext.	94.7%	5.3%	0.0%	0.0%	40.3	9.0%	5.4%	8.8%	76.8%	95.7	85.5%	14.1%	0.4%	0.0%	54.6
					int.	100.0%	0.0%	0.0%	0.0%	29.3	0.0%	22.4%	77.6%	0.0%	66.5	96.1%	3.9%	0.0%	0.0%	22.9
					avg.	97.4%	2.6%	0.0%	0.0%	34.8	4.5%	13.9%	43.2%	38.4%	81.1	89.5%	10.5%	0.0%	0.0%	38.6
2. S_M_m_20				0.6	ext.	87.2%	8.8%	3.8%	0.2%	54.9	17.3%	8.3%	10.5%	63.9%	95.4	84.4%	13.1%	2.4%	0.0%	116.7
					int.	97.8%	2.2%	0.0%	0.0%	33.4	0.1%	70.8%	29.1%	0.0%	64.7	92.2%	7.8%	0.0%	0.0%	27.3
					avg.	92.5%	5.5%	1.9%	0.1%	44.2	8.7%	39.6%	19.8%	31.9%	80.1	87.9%	11.3%	0.7%	0.0%	72.0
2. S_D_m_20				0.9	ext.	82.4%	8.0%	6.4%	3.2%	69.2	25.1%	9.1%	10.6%	55.3%	95.2	84.2%	12.2%	2.8%	0.3%	191.0
					int.	92.6%	7.4%	0.0%	0.0%	37.3	3.5%	86.6%	9.9%	0.0%	63.6	90.1%	9.9%	0.0%	0.0%	32.7
					avg.	87.5%	7.7%	3.2%	1.6%	53.2	14.3%	47.8%	10.2%	27.6%	79.4	86.7%	11.8%	1.4%	0.0%	110.6
2. W_B_m_20			West	0.3	ext.	95.3%	4.7%	0.0%	0.0%	39.1	6.9%	4.5%	7.7%	80.9%	95.7	85.4%	14.1%	0.5%	0.0%	54.4
					int.	100.0%	0.0%	0.0%	0.0%	29.0	0.0%	14.7%	85.3%	0.0%	67.0	96.6%	3.4%	0.0%	0.0%	23.1
					avg.	97.7%	2.3%	0.0%	0.0%	34.1	3.5%	9.6%	46.5%	40.4%	81.4	89.5%	10.5%	0.0%	0.0%	38.5
2. W_M_m_20				0.6	ext.	88.7%	8.3%	3.0%	0.0%	50.9	14.4%	7.1%	9.5%	69.1%	95.5	84.7%	13.1%	2.2%	0.0%	85.5
					int.	98.6%	1.4%	0.0%	0.0%	32.5	0.0%	56.9%	43.1%	0.0%	64.9	92.8%	7.2%	0.0%	0.0%	25.6
					avg.	93.6%	4.8%	1.5%	0.0%	41.7	7.2%	32.0%	26.3%	34.5%	80.2	88.3%	11.3%	0.4%	0.0%	55.3
2. W_D_m_20				0.9	ext.	83.8%	8.2%	5.9%	2.0%	62.6	21.3%	8.6%	10.6%	59.4%	95.3	84.3%	12.5%	2.7%	0.3%	151.8
					int.	93.8%	6.2%	0.0%	0.0%	35.8	2.2%	81.7%	16.1%	0.0%	64.0	90.6%	9.4%	0.0%	0.0%	29.1
					avg.	88.8%	7.2%	2.9%	1.0%	49.2	11.8%	45.1%	13.4%	29.7%	79.6	87.3%	11.3%	1.3%	0.0%	90.4

1.11.2.1 Simulations done considering the medium moisture load

1.11.2.1.1 Temperature ranges

More than half of the design alternatives of Configuration 2 lies in range I and II. range III is reached only by about 45 % of them and range IV by more than 30 %. In particular:

- 2. W_D_m_20 (west exposure and dark surface finishing) on the VIP external surface, where temperatures higher than 50 °C were observed for about 2.0 % of the time (≈ 7 days/year, T_{MAX} = 62.6 °C);
- 2. E_D_m_20 (east exposure and dark surface finishing) on the VIP external surface, where range IV was reached for about 3.0 % of the time (≈ 11 days,T_{MAX} = 65.0 °C);
- 2. S_D_m_20 (south exposure and dark surface finishing) on the VIP external surface, where the temperatures were within range IV for about 3.2 % of the time (≈ 12 days, T_{MAX} = 69.2 °C).

1.11.2.1.2 Relative Humidity ranges

The analysis on the relative humidity shows that almost all the configurations reach range III, and 67 % of them also arrived to range IV (with high frequency values). Again, as for Configuration 1, the cases with bright and medium finishing colours are the most critical:

- 2. N_M_m_20 (north exposure and medium surface finishing) on the VIP external surface, frequency equal to about 71.1 % of time ≈ 259 days (φ_{MAX} = 95.6 %);
- 2. S_B_m_20 (south exposure and bright surface finishing) on the VIP external surface, frequency equal to about 76.8 % ≈ 280 days (φ_{MAX} = 95.7 %);
- 2. E_B_m_20 (east exposure and bright surface finishing) on the VIP external surface, frequency equal to about 77.9 % ≈ 284 days (φ_{MAX} = 95.7 %);
- 2. W_B_m_20 (west exposure and bright surface finishing) on the VIP external surface, frequency equal to about 80.9 % ≈ 295 days (φ_{MAX} = 95.7 %);
- 2. N_B_m_20 (north exposure and bright surface finishing) on the VIP external surface, frequency equal to about 83.3 % ≈ 304 days (φ_{MAX} = 95.8 %).

1.11.2.1.3 Vapour Pressure ranges

Few design alternatives reach range IV. It is worth noting that these are the same design alternatives that lie in ranges IV as far as the temperature is concerned. In particular the cases with vapour pressure higher than 86 hPa are:

- 2. E_D_m_20 (east exposure and dark surface finishing) on the VIP external surface, frequency equal to about 0.3 % ≈ 1 day ($p_{v\,MAX}$ = 151.7 hPa);
- 2. W_D_m_20 (west exposure and dark surface finishing) on the VIP external surface, frequency equal to about 0.3 % ≈ 1 day ($p_{v\,MAX}$ = 151.8 hPa);
- 2. S_D_m_20 (south exposure and dark surface finishing) on the VIP external surface, frequency equal to about 0.3 % ≈ 1 day ($p_{v\,MAX}$ = 191.0 hPa).

1.11.3 Configuration 3- Ventilated wall in Stockholm (KTH)

The different orientations show different results on the outer surface of the wall configuration with the wall facing south having much greater fluctuations in both relative humidity and temperature. The results are however strikingly similar when it comes to the conditions within the wall configuration. The results for the North facing wall are shown in figures from Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-32 to Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-37 and are summarised in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.19.

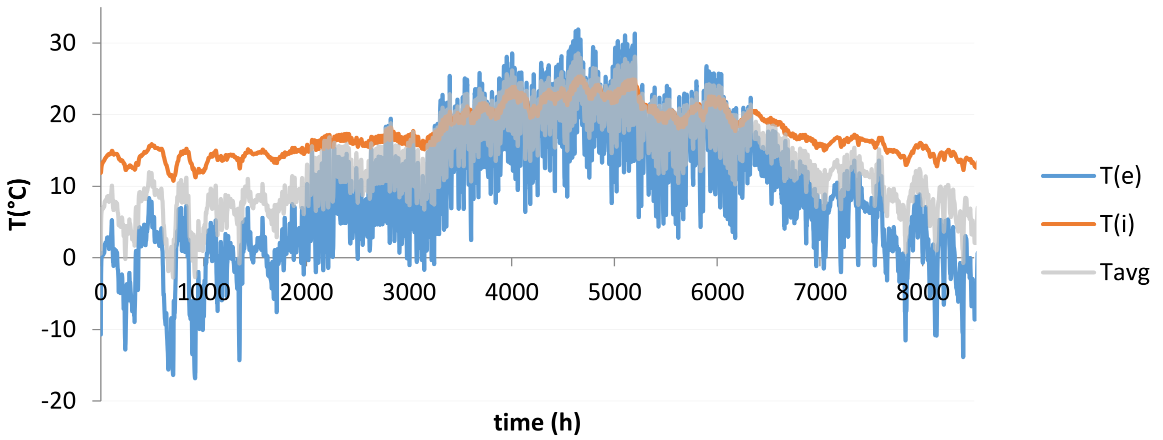


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-32. Yearly time profile of temperatures on the inside and outside of the VIP panel for the façade towards North.

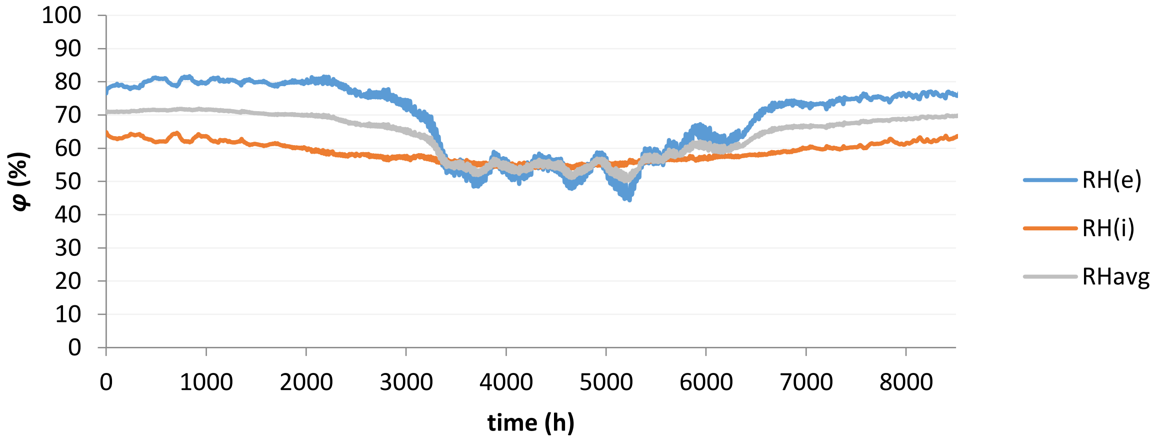


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-33. Yearly time profile of relative humidity on the inside and outside of the VIP panel for the façade towards North.

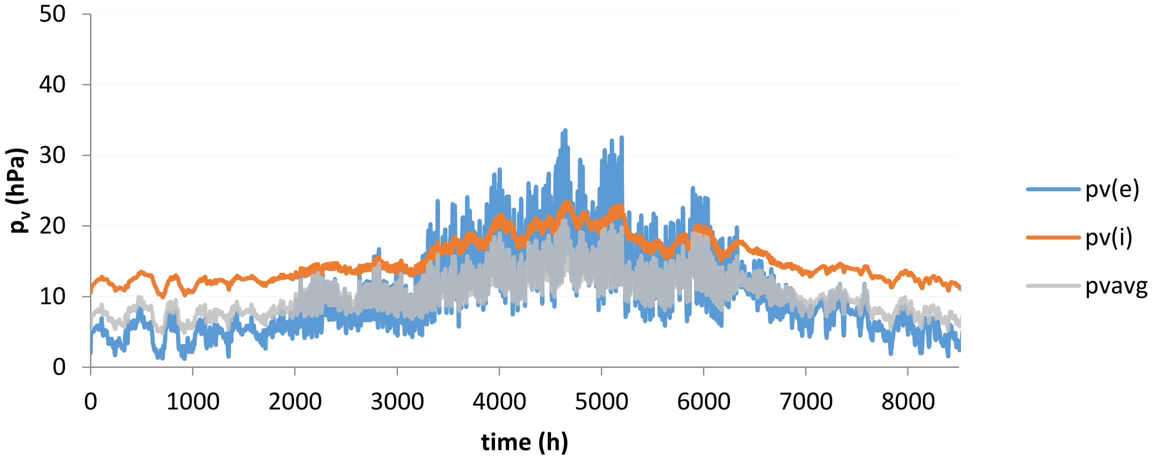


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-34. Yearly time profile of vapour pressure on the inside and outside of the VIP panel for the façade towards North.

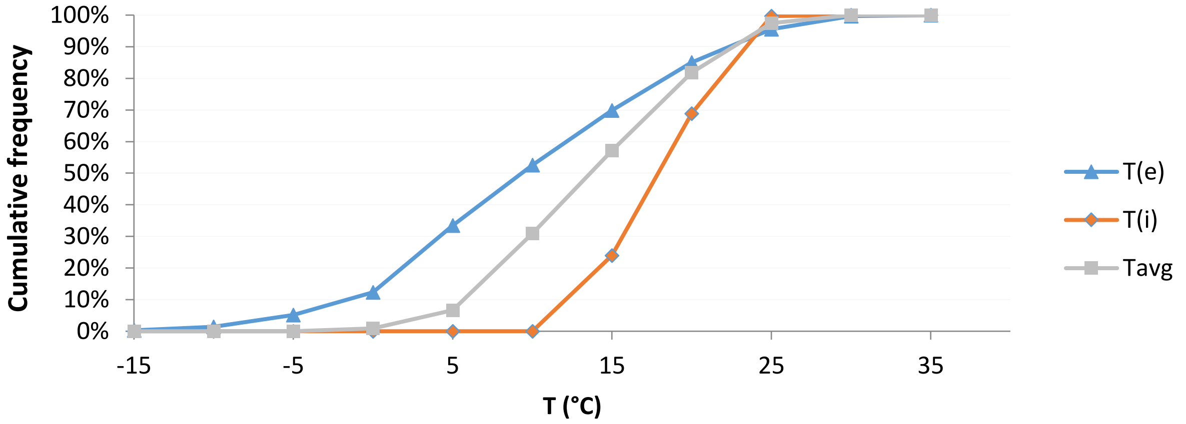


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-35. Temperature cumulative functions for the inside and outside of the VIP panel for the façade towards North.

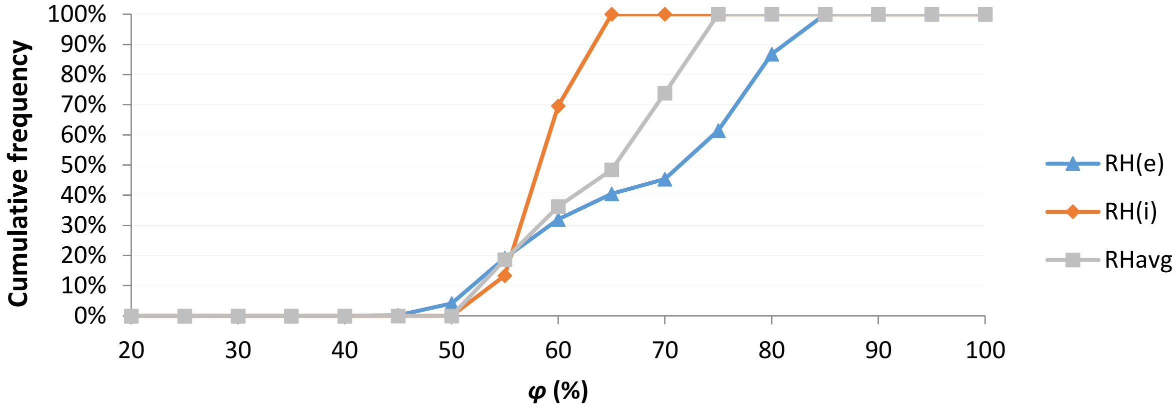


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-36. Relative humidity cumulative functions for the inside and outside of the VIP panel for the façade towards North.

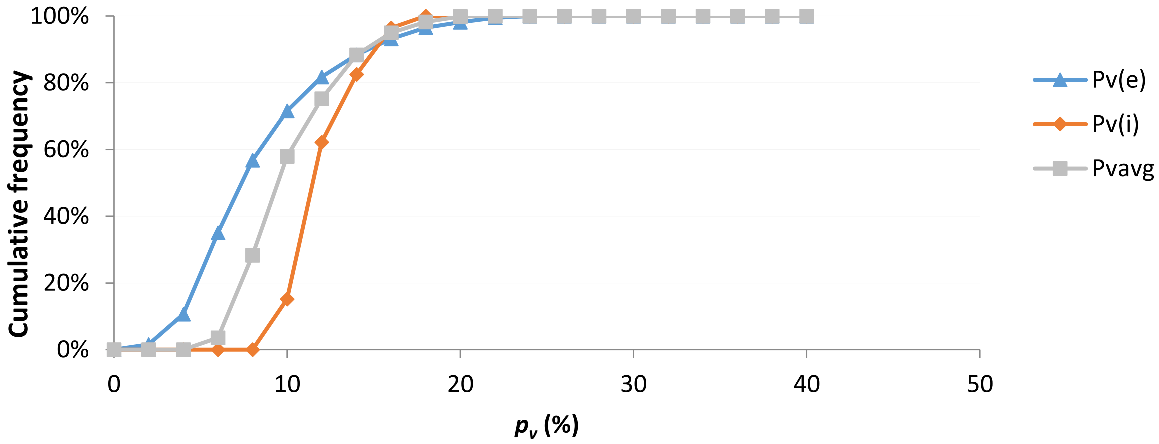


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-37. Vapour pressure cumulative functions for the inside and outside of the VIP panel for the façade towards North.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.19. Summary of the frequency distribution results for the inside and outside of the VIP panel for the façade towards North.

Configuration	Orientation	Side	Temperature ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
			I (≤30 °C)	II (30÷40 °C)	III (40÷50 °C)	IV (>50 °C)	MAX [°C]	I (≤50 %)	II (50÷60 %)	III (60÷70 %)	IV (>70 %)	MAX [%]	I (≤21,2 hPa)	II (21,2÷44,3 hPa)	III (44,3÷86 hPa)	MAX [hPa]
3.N	NORTH	avg.	100.0%	0.0%	0.0%	0.0%	28.6	0.0%	36.2%	37.6%	26.2%	71.9	99.9%	0.1%	0.0%	20.8
		ext.	100.0%	0.0%	0.0%	0.0%	31.9	4.1%	27.8%	13.4%	54.7%	81.7	98.2%	1.8%	0.0%	24.4
		int.	100.0%	0.0%	0.0%	0.0%	25.3	0.0%	69.6%	30.4%	0.0%	64.8	100.0%	0.0%	0.0%	17.4
3.E	EAST	avg.	99.1%	9.0%	0.0%	0.0%	34.8	15.6%	23.7%	43.9%	16.9%	71.5	91.9%	8.1%	0.0%	42.8
		ext.	96.5%	3.3%	0.2%	0.0%	43.8	27.0%	11.3%	3.9%	57.7%	82.3	97.1%	2.9%	0.0%	41.7
		int.	100.0%	0.0%	0.0%	0.0%	26.2	0.0%	67.1%	32.9%	0.0%	64	100.0%	0.0%	0.0%	64
3.S	SOUTH	avg.	98.3%	17.0%	0.0%	0.0%	35.4	24.1%	25.0%	50.2%	8.0%	70.6	90.9%	9.1%	0.0%	44.5
		ext.	94.4%	5.0%	0.6%	0.0%	44.8	34.7%	8.4%	23.1%	33.8%	81.1	94.8%	5.2%	0.0%	50.4
		int.	100.0%	0.0%	0.0%	0.0%	26.3	0.0%	74.1%	25.9%	0.0%	63.5	100.0%	0.0%	0.0%	63.5
3.W	WEST	avg.	98.8%	1.2%	0.4%	0.0%	35.7	17.1%	23.6%	42.5%	16.8%	71.5	92.5%	7.5%	0.0%	45.4
		ext.	95.8%	3.8%	0.4%	0.0%	45.4	26.0%	12.9%	43.0%	56.8%	82.4	96.3%	3.6%	0.1%	45.5
		int.	100.0%	0.0%	0.0%	0.0%	26.5	0.0%	66.7%	33.3%	0.0%	64.1	92.5%	7.5%	0.0%	64.1

1.11.4 Configuration 4- Internal wall insulation in Nancy (CSTB)

The vertical internal wall has been analysed for different design alternatives in terms of internal conditions and wall components (for more details see Section 1.1).

For the sake of brevity only the graphical results of one wall configuration are reported. In particular, the results refer to the case of concrete frame wall, VIP unprotected and internal conditions of a room with high moisture load (4.A11_RH).The results of the time evolution of temperature *T*, relative humidity *φ* and water vapour pressure p_v are plotted in Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-38, Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-39 and Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-40 respectively. Each plot shows the data relative to the internal VIP side (int), three positions of external VIP side (at the bottom ext_b, at the top ext_t and in the middle ext_m) and the average value (avg.). These different locations are shown on Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-41. (red circles).

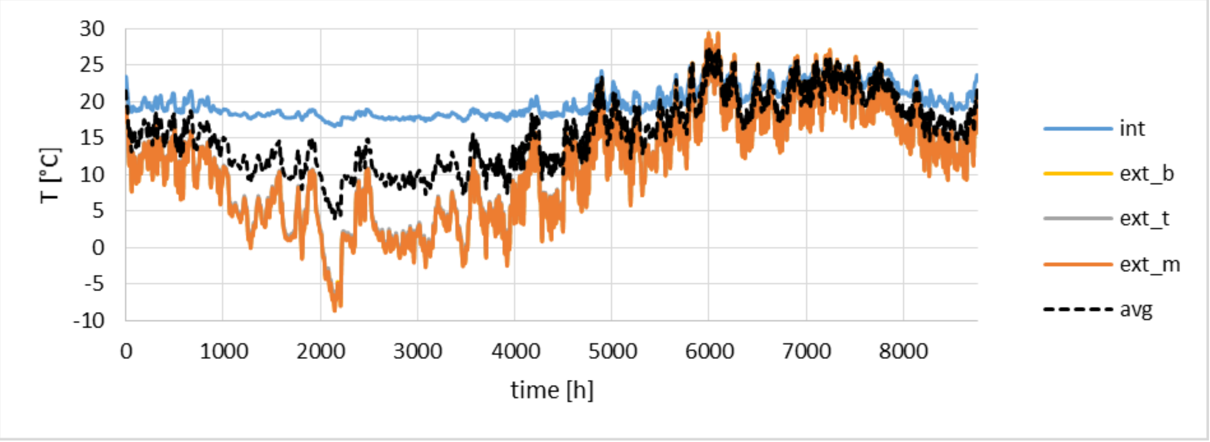


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-38. Yearly time profile of temperatures for concrete frame internal load, VIP unprotected and high room moisture load, VIP thickness 20 mm.

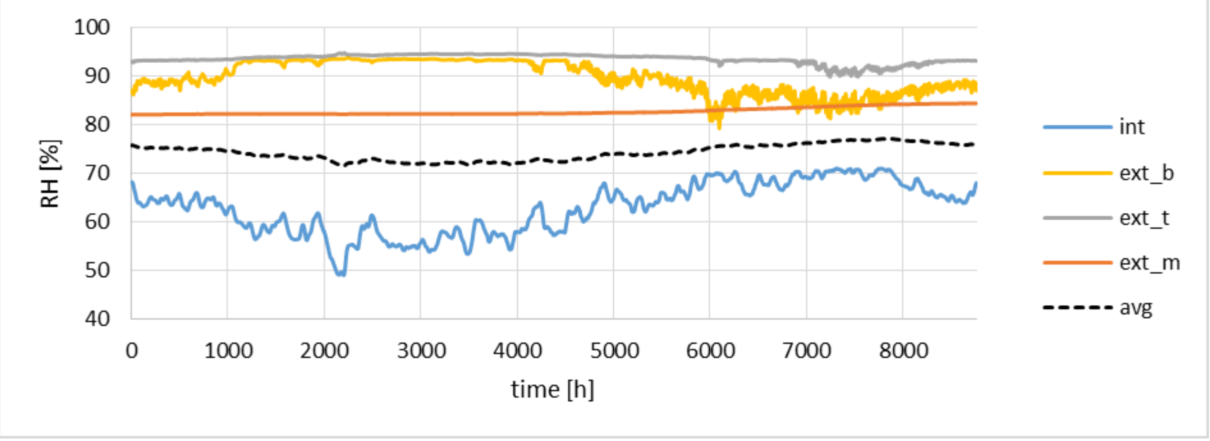


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-39. Yearly time profile of relative humidity for concrete frame internal load, VIP unprotected and high room moisture load, VIP thickness 20 mm.

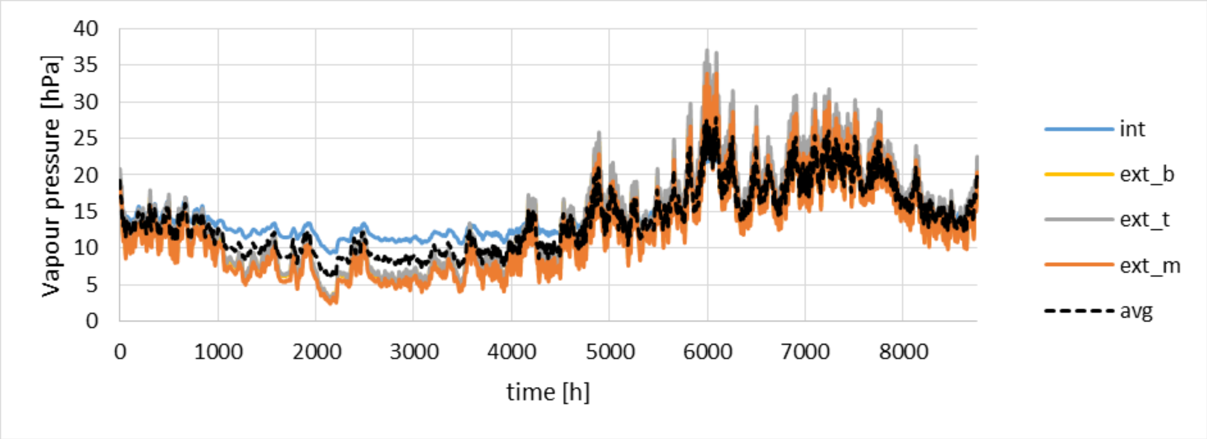


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-40. Yearly time profile of vapour pressure for concrete frame internal load, VIP unprotected and high room moisture load, VIP thickness 20 mm.

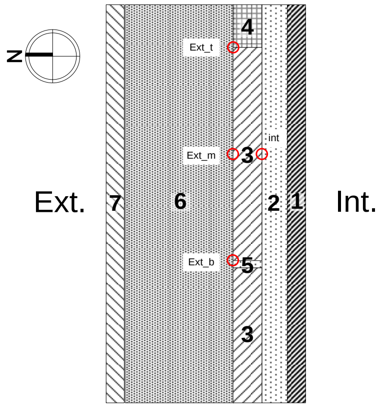


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-41. Locations of plotted results.

Furthermore, the cumulative frequency distribution of *T*, *φ* and p_v were presented in Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-42, Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-43 and Figure Erreur **! Il n'y a pas de texte répondant à ce style dans ce document.**-44, respectively.

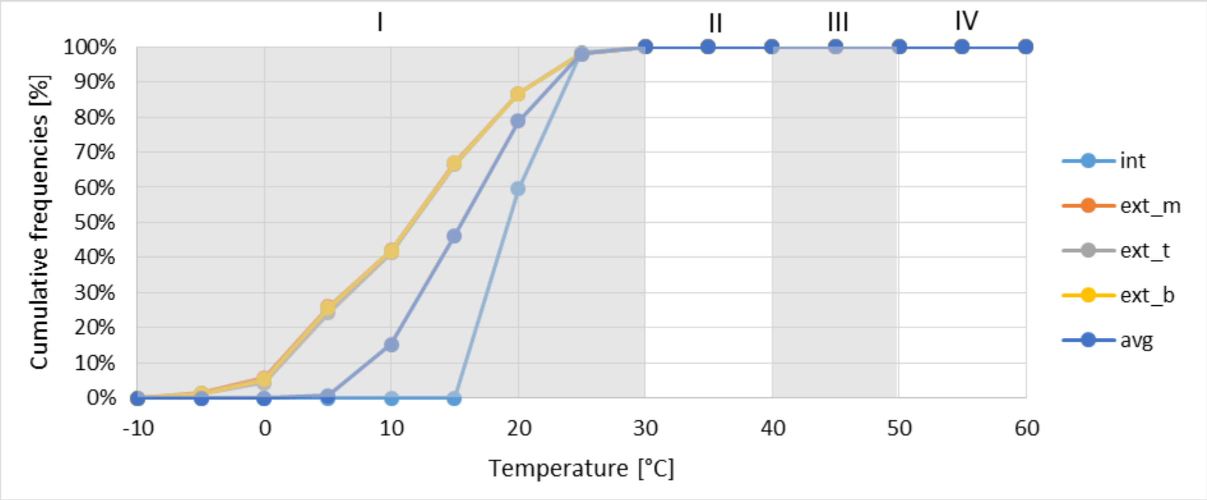


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-42. Temperatures cumulative functions for concrete frame internal load, VIP unprotected and high room moisture load, VIP thickness 20 mm.

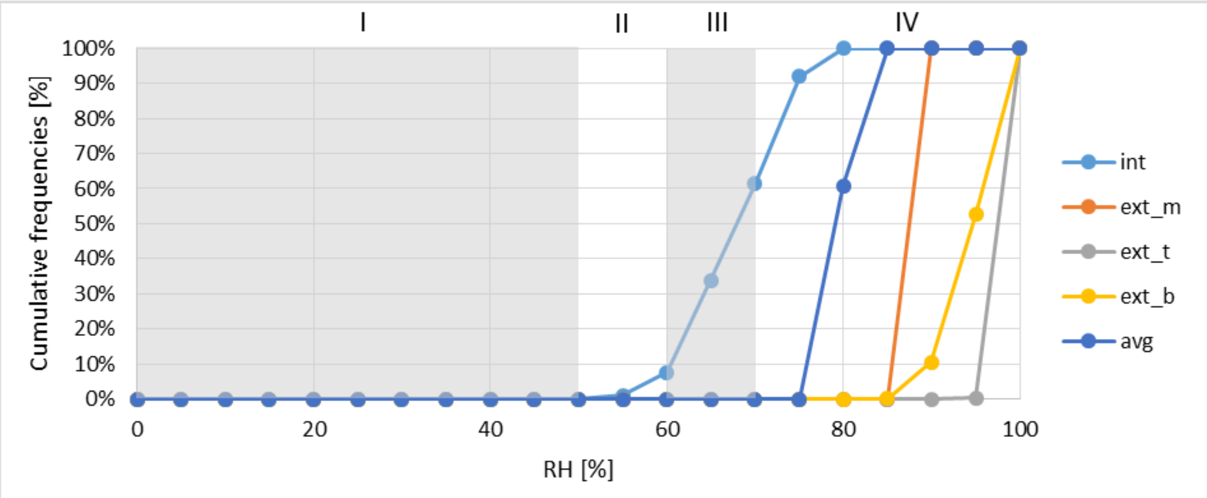


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-43. Relative humidity cumulative functions for concrete frame internal load, VIP unprotected and high room moisture load, VIP thickness 20 mm.

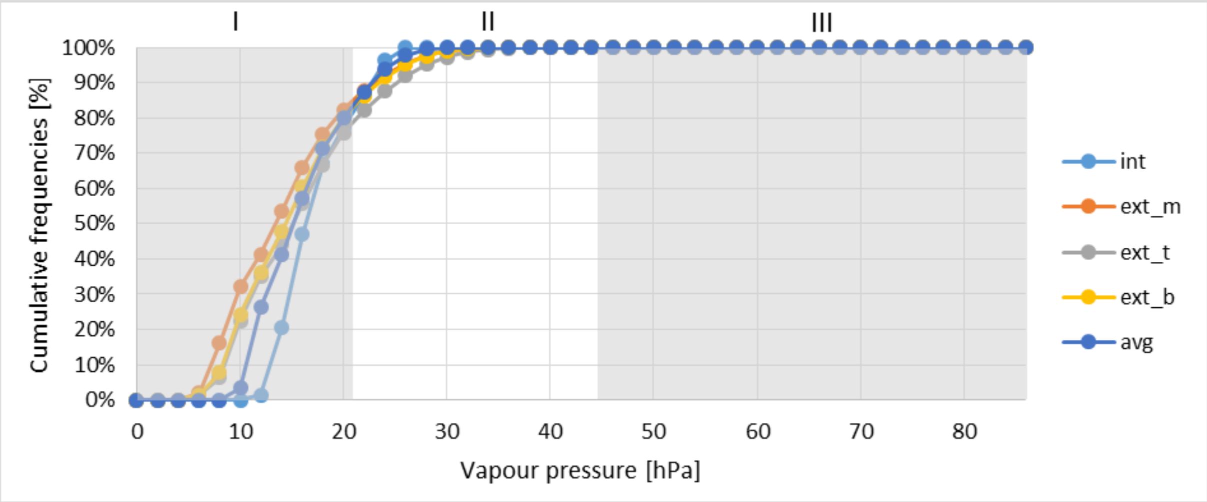


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-44. Vapour pressure cumulative functions for concrete frame internal load, VIP unprotected and high room moisture load, VIP thickness 20 mm.

The overview of the results related to all the design alternatives are resumed in Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.20, that summarise the frequency values within specific ranges of temperature, relative humidity and water vapour pressure.

Table **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**.20. A: Summary of the frequency distribution results at the edges of VIP 20 mm thick, internal North wall in Nancy.

Configuration	**Wall design**	**Indoor condition**	**Side**	Temperature Ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
				I (≤30°C)	II (30;40°C	III (40;50°C)	IV (>50°C)	MAX [°C]	I (≤50%)	II (50;60%)	III (60;70%)	IV (>70%)	MAX [%]	I (≤21,2 hPa)	II (21,2;44,3 hPa)	III (44,3;86 hPa)	MAX [hPa]
4.A11_RM	A11	RM	avg	100,0%	0,0%	0,0%	0,0%	**27,4**	0,0%	0,0%	96,1%	3,9%	**70,2**	96,8%	3,2%	0,0%	**25,3**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,4**	0,0%	0,0%	0,0%	100,0%	**80,3**	92,6%	7,4%	0,0%	**32,8**
			ext_t	100,0%	0,0%	0,0%	0,0%	**29,2**	0,0%	0,0%	0,1%	99,9%	**93,6**	94,1%	5,9%	0,0%	**29,9**
			ext_b	100,0%	0,0%	0,0%	0,0%	**29,4**	0,0%	0,0%	0,0%	100,0%	**93,2**	93,9%	6,1%	0,0%	**29,4**
			int	100,0%	0,0%	0,0%	0,0%	**25,5**	36,0%	54,2%	9,9%	0,0%	**61,3**	100,0%	0,0%	0,0%	**19,6**
4.A11_RH		RH	avg	100,0%	0,0%	0,0%	0,0%	**27,4**	0,0%	0,0%	0,0%	100,0%	**77,1**	91,7%	8,3%	0,0%	**27,8**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,3**	0,0%	0,0%	0,0%	100,0%	**84,3**	90,6%	9,4%	0,0%	**33,9**
			ext_t	100,0%	0,0%	0,0%	0,0%	**28,9**	0,0%	0,0%	0,0%	100,0%	**94,7**	85,6%	14,4%	0,0%	**37,1**
			ext_b	100,0%	0,0%	0,0%	0,0%	**29,4**	0,0%	0,0%	0,0%	100,0%	**93,6**	89,6%	10,4%	0,0%	**33,3**
			int	100,0%	0,0%	0,0%	0,0%	**25,5**	1,0%	32,8%	58,1%	8,1%	**71,0**	91,1%	8,9%	0,0%	**22,8**
4.A11_WH		WH	avg	100,0%	0,0%	0,0%	0,0%	**27,5**	42,9%	16,2%	41,0%	0,0%	**68,8**	98,0%	2,0%	0,0%	**23,9**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,4**	0,0%	0,0%	0,0%	100,0%	**78,2**	93,8%	6,2%	0,0%	**31,8**
			ext_t	100,0%	0,0%	0,0%	0,0%	**29,2**	0,0%	0,0%	1,5%	98,5%	**92,8**	95,9%	4,1%	0,0%	**27,6**
			ext_b	100,0%	0,0%	0,0%	0,0%	**29,4**	0,0%	0,0%	0,6%	99,4%	**93,1**	95,2%	4,8%	0,0%	**27,6**
			int	53,3%	24,2%	22,2%	0,3%	**51,8**	55,9%	33,9%	10,2%	0,0%	**61,7**	99,3%	0,7%	0,0%	**28,7**

Table 1.20. B: Summary of the frequency distribution results at the edges of VIP 20 mm thick, internal North wall in Nancy.

Configuration	**Wall design**	**Indoor condition**	**Side**	Temperature Ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
				I (≤30°C)	II (30;40°C	III (40;50°C)	IV (>50°C)	MAX [°C]	I (≤50%)	II (50;60%)	III (60;70%)	IV (>70%)	MAX [%]	I (≤21,2 hPa)	II (21,2;44,3 hPa)	III (44,3;86 hPa)	MAX [hPa]
4.A12_RM	A12	RM	avg	100,0%	0,0%	0,0%	0,0%	**27,4**	0,0%	0,0%	100,0%	0,0%	**69,5**	97,3%	2,7%	0,0%	**24,9**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,3**	0,0%	0,0%	0,0%	100,0%	**79,1**	93,2%	6,8%	0,0%	**32,1**
			ext_t	100,0%	0,0%	0,0%	0,0%	**28,9**	0,0%	0,0%	0,3%	99,7%	**88,0**	95,1%	4,9%	0,0%	**28,9**
			ext_b	100,0%	0,0%	0,0%	0,0%	**29,1**	0,0%	0,0%	0,6%	99,4%	**96,8**	95,5%	4,5%	0,0%	**27,3**
			int	100,0%	0,0%	0,0%	0,0%	**25,5**	33,8%	55,6%	10,6%	0,0%	**61,5**	100,0%	0,0%	0,0%	**19,7**
4.A12_RH		RH	avg	100,0%	0,0%	0,0%	0,0%	**27,4**	0,0%	0,0%	0,0%	100,0%	**76,2**	92,5%	7,5%	0,0%	**27,4**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,3**	0,0%	0,0%	0,0%	100,0%	**83,0**	91,2%	8,8%	0,0%	**33,4**
			ext_t	100,0%	0,0%	0,0%	0,0%	**28,7**	0,0%	0,0%	0,0%	100,0%	**94,1**	86,5%	13,5%	0,0%	**35,4**
			ext_b	100,0%	0,0%	0,0%	0,0%	**29,0**	0,0%	0,0%	0,0%	100,0%	**98,9**	91,9%	8,1%	0,0%	**29,4**
			int	100,0%	0,0%	0,0%	0,0%	**25,5**	0,0%	29,3%	61,3%	9,4%	**71,3**	91,1%	8,9%	0,0%	**22,9**
4.A12_WH		WH	avg	100,0%	0,0%	0,0%	0,0%	**27,5**	43,5%	17,8%	38,6%	0,0%	**68,4**	98,4%	1,6%	0,0%	**23,6**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,3**	0,0%	0,0%	34,6%	65,4%	**77,5**	94,3%	5,7%	0,0%	**31,2**
			ext_t	100,0%	0,0%	0,0%	0,0%	**28,9**	0,0%	0,0%	5,3%	94,7%	**85,8**	96,0%	4,0%	0,0%	**27,7**
			ext_b	100,0%	0,0%	0,0%	0,0%	**29,1**	0,0%	0,0%	25,8%	74,2%	**85,4**	96,0%	4,0%	0,0%	**26,9**
			int	53,7%	26,3%	19,8%	0,2%	**51,0**	54,7%	33,8%	11,6%	0,0%	**62,0**	99,4%	0,6%	0,0%	**28,0**

Table 1.20. C: Summary of the frequency distribution results at the edges of VIP 20 mm thick, internal North wall in Nancy.

Configuration	Wall design	Indoor condition	Side	Temperature Ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
				I (≤30°C)	II (30;40°C	III (40;50°C)	IV (>50°C)	MAX [°C]	I (≤50%)	II (50;60%)	III (60;70%)	IV (>70%)	MAX [%]	I (≤21,2 hPa)	II (21,2;44,3 hPa)	III (44,3;86 hPa)	MAX [hPa]
			int	53,7%	26,3%	19,8%	0,2%	**51,0**	54,7%	33,8%	11,6%	0,0%	**62,0**	99,4%	0,6%	0,0%	**28,0**
4.B11_RM	B11	RM	avg	100,0%	0,0%	0,0%	0,0%	**27,1**	23,4%	53,3%	23,3%	0,0%	**62,2**	99,7%	0,3%	0,0%	**22,3**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,2**	7,4%	45,4%	39,0%	8,3%	**77,4**	96,3%	3,7%	0,0%	**31,2**
			ext_t	100,0%	0,0%	0,0%	0,0%	**28,5**	3,5%	53,9%	42,0%	0,6%	**71,5**	97,2%	2,8%	0,0%	**27,7**
			ext_b	100,0%	0,0%	0,0%	0,0%	**28,9**	27,4%	62,5%	10,1%	0,0%	**66,9**	98,5%	1,5%	0,0%	**26,6**
			int	100,0%	0,0%	0,0%	0,0%	**25,4**	41,3%	54,7%	4,1%	0,0%	**60,5**	100,0%	0,0%	0,0%	**19,5**
4.B11_RH		RH	avg	100,0%	0,0%	0,0%	0,0%	**27,3**	0,0%	27,9%	67,3%	4,8%	**70,5**	95,1%	4,9%	0,0%	**25,1**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,8**	1,3%	25,5%	33,9%	39,3%	**83,1**	90,5%	9,5%	0,0%	**34,4**
			ext_t	100,0%	0,0%	0,0%	0,0%	**28,9**	0,0%	6,7%	51,5%	41,8%	**81,0**	90,4%	9,6%	0,0%	**32,1**
			ext_b	100,0%	0,0%	0,0%	0,0%	**28,9**	8,5%	54,0%	37,3%	0,2%	**70,6**	97,4%	2,6%	0,0%	**28,1**
			int	100,0%	0,0%	0,0%	0,0%	**25,5**	2,0%	38,6%	56,6%	2,9%	**70,4**	91,0%	9,0%	0,0%	**22,6**
4.B11_WH		WH	avg	67,4%	32,6%	0,0%	0,0%	**37,9**	63,1%	36,9%	0,0%	0,0%	**60,0**	99,9%	0,1%	0,0%	**22,8**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,2**	45,3%	26,7%	27,7%	0,3%	**71,1**	97,6%	2,4%	0,0%	**28,7**
			ext_t	98,7%	1,3%	0,0%	0,0%	**31,1**	51,2%	23,2%	25,7%	0,0%	**67,6**	97,9%	2,1%	0,0%	**26,4**
			ext_b	100,0%	0,0%	0,0%	0,0%	**28,9**	53,3%	45,5%	1,3%	0,0%	**62,8**	99,3%	0,7%	0,0%	**24,9**
			int	52,7%	18,8%	26,8%	1,7%	**55,1**	57,2%	37,0%	5,9%	0,0%	**60,9**	99,4%	0,6%	0,0%	**28,2**

Table 1.20. D: Summary of the frequency distribution results at the edges of VIP 20 mm thick, internal North wall in Nancy.

Configuration	**Wall design**	**Indoor condition**	**Side**	Temperature Ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
				I (≤30°C)	II (30;40°C	III (40;50°C)	IV (>50°C)	MAX [°C]	I (≤50%)	II (50;60%)	III (60;70%)	IV (>70%)	MAX [%]	I (≤21,2 hPa)	II (21,2;44,3 hPa)	III (44,3;86 hPa)	MAX [hPa]
4.B12_RM	B12	RM	avg	100,0%	0,0%	0,0%	0,0%	**27,1**	23,7%	55,9%	20,4%	0,0%	**61,3**	99,9%	0,1%	0,0%	**21,9**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,1**	8,9%	48,1%	40,4%	2,6%	**73,1**	97,2%	2,8%	0,0%	**29,0**
			ext_t	100,0%	0,0%	0,0%	0,0%	**28,6**	1,7%	53,6%	44,7%	0,0%	**69,7**	97,6%	2,4%	0,0%	**26,8**
			ext_b	100,0%	0,0%	0,0%	0,0%	**28,9**	1,0%	84,4%	14,5%	0,0%	**64,4**	99,5%	0,5%	0,0%	**23,4**
			int	100,0%	0,0%	0,0%	0,0%	**25,5**	39,9%	55,1%	5,1%	0,0%	**60,7**	100,0%	0,0%	0,0%	**19,5**
4.B12_RH		RH	avg	100,0%	0,0%	0,0%	0,0%	**27,3**	0,0%	30,3%	69,7%	0,0%	**69,4**	96,1%	3,9%	0,0%	**24,5**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,7**	0,8%	30,2%	33,0%	36,0%	**80,0**	91,8%	8,2%	0,0%	**32,7**
			ext_t	100,0%	0,0%	0,0%	0,0%	**29,0**	0,0%	1,7%	55,9%	42,4%	**79,3**	91,8%	8,2%	0,0%	**32,7**
			ext_b	100,0%	0,0%	0,0%	0,0%	**28,9**	0,0%	5,2%	94,8%	0,0%	**69,4**	97,8%	2,2%	0,0%	**25,1**
			int	100,0%	0,0%	0,0%	0,0%	**25,6**	1,7%	37,1%	57,1%	4,2%	**70,6**	91,1%	8,9%	0,0%	**22,7**
4.B12_WH		WH	avg	68,9%	31,1%	0,0%	0,0%	**37,4**	63,5%	36,5%	0,0%	0,0%	**59,5**	99,9%	0,1%	0,0%	**22,6**
			ext_m	100,0%	0,0%	0,0%	0,0%	**29,1**	46,7%	30,0%	23,3%	0,0%	**67,7**	98,4%	1,6%	0,0%	**26,9**
			ext_t	100,0%	0,0%	0,0%	0,0%	**29,7**	51,1%	20,9%	28,1%	0,0%	**65,8**	98,2%	1,8%	0,0%	**25,7**
			ext_b	100,0%	0,0%	0,0%	0,0%	**28,9**	50,9%	45,5%	3,6%	0,0%	**66,2**	99,7%	0,3%	0,0%	**22,5**
			int	52,8%	19,6%	26,3%	1,3%	**54,4**	56,4%	36,8%	6,8%	0,0%	**61,1**	99,5%	0,5%	0,0%	**28,0**

1.11.5 *Configuration 5- Flat roof in Nice (EDF)*

(Results based on the PhD thesis of Antoine BATARD : Modelling of long-term thermal behaviour of vacuum insulation panels : (VIP) [2].

The insulation system, associated to its local temperature and humidity solicitations, is simulated with a detailed heat and mass transfer software. The coupling heat and mass transfers is considered. The following figures show the temperature, relative humidity and water vapour pressure evolutions at the VIPs' surfaces.

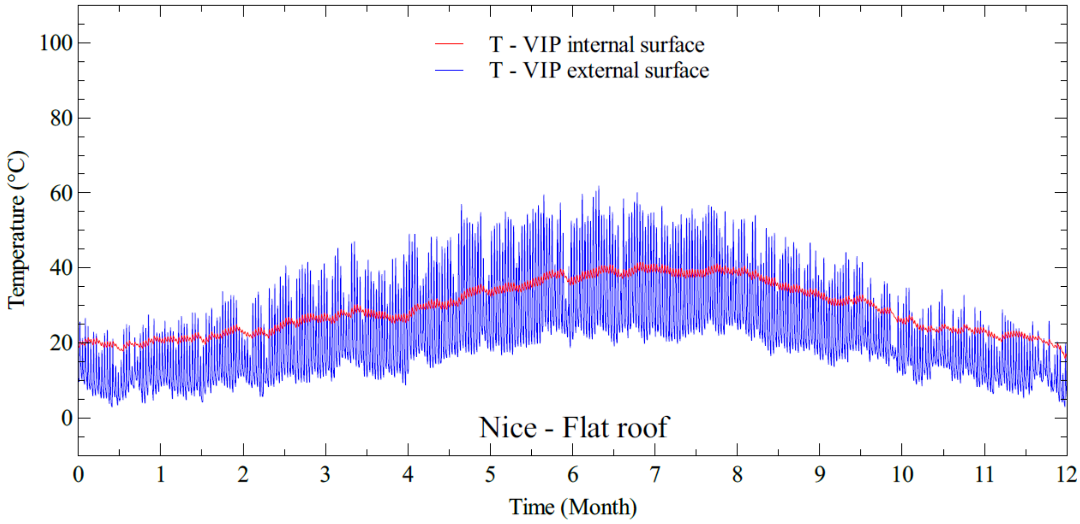


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-45 : Temperatures evolution over one year, at the VIPs' internal and external surfaces, for flat roof in Nice.

The variations of relative humidity at the VIPs' external surface are always higher than those at the VIPs' internal surface. Relative humidity isn't the most pertinent variable to be studied because it depends on the temperature.

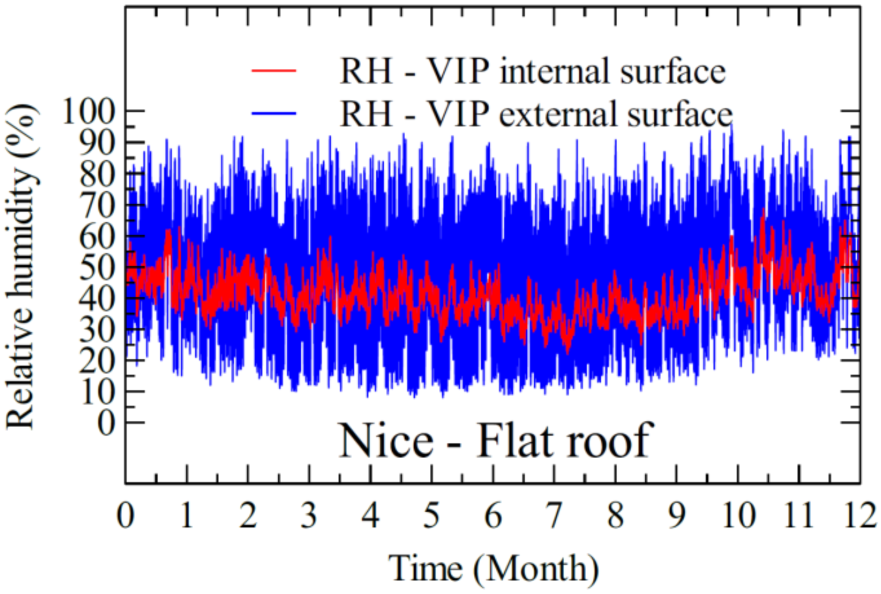


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-46 : Relative humidity evolution over one year, at the VIPs' internal and external surfaces, for flat roof in Nice.

Water vapour partial pressures at the VIPs' internal surface are always higher than those at the VIPs' external surface. Pressures fluctuate between 500 Pa and 3500 Pa and are always higher in summer than in winter.

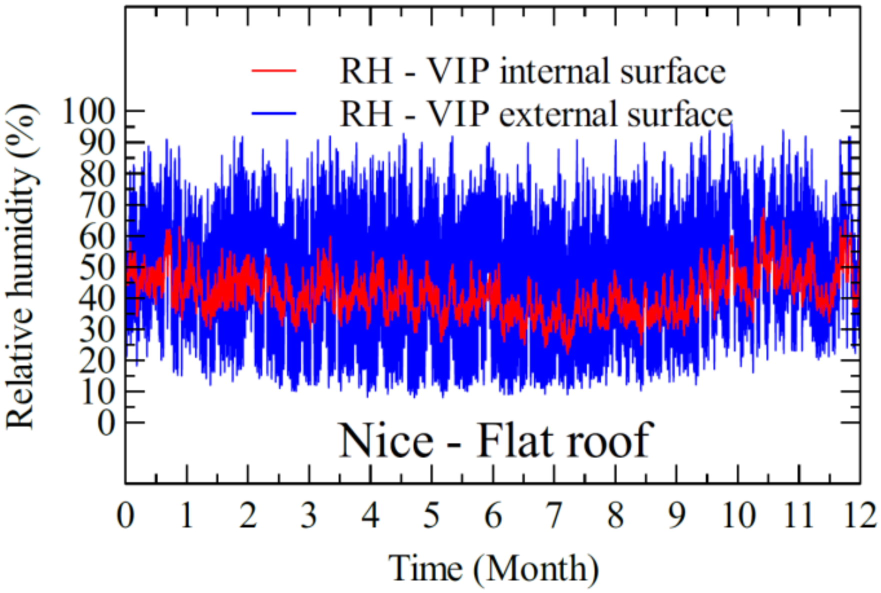


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-47 : Relative humidity evolution over one year, at the VIPs' internal and external surfaces, for flat roof in Nice.

Water vapour partial pressures at the VIPs' internal surface are always higher than those at the VIPs' external surface. Pressures fluctuate between 500 Pa and 3500 Pa and are always higher in summer than in winter.

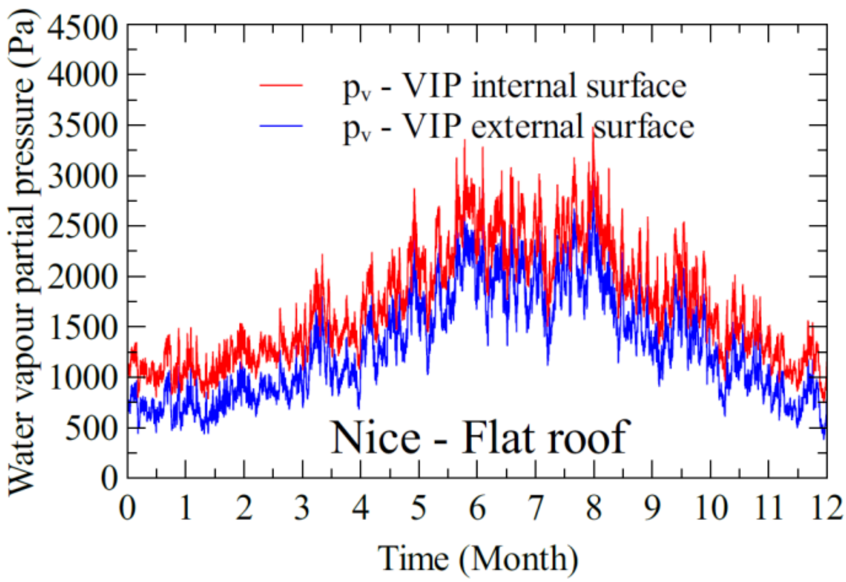


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-48 : Water vapour partial pressure evolution over one year, at the VIPs' internal and external surfaces, for flat roof in Nice.

All the solicitations of the VIPs surfaces over one year can be represented on a diagram “temperature/vapour pressure”. Each point corresponds to one hour where the VIPs surfaces are submitted to the “temperature/vapour pressure” couple. It can be observed from the obtained clouds of points that globally when temperature is high, the vapour pressure is high. The highest vapour pressures are obtained at the VIPs' internal surface. Very high temperatures are observed but they don't correspond to extreme humidity. All vapour pressures are lower than 3500 Pa. This is much less than the vapour pressures that are commonly used for short-term accelerated tests.

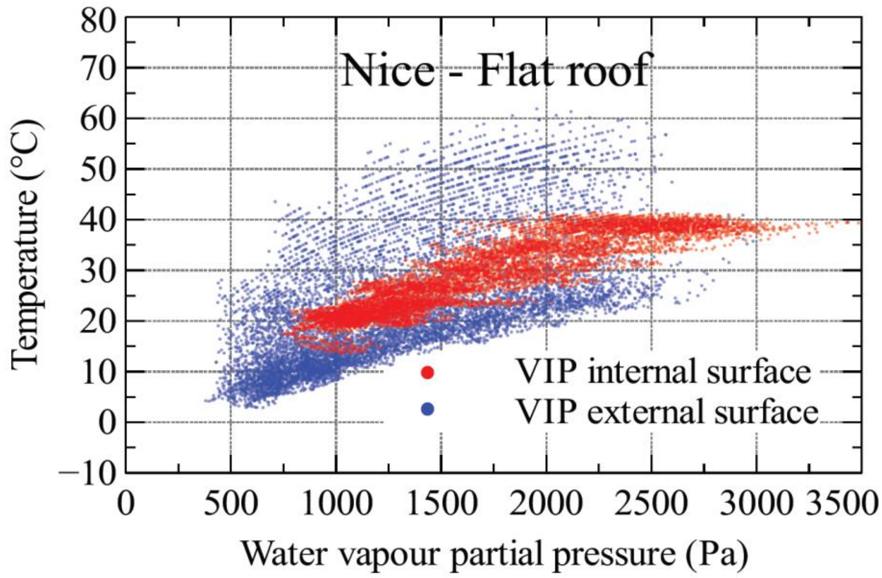


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-49 : Diagram "temperature/water vapour partial pressure" of all solicitations exposed to VIPs over one year, for flat roof in Nice.

The following figures show the cumulative percentage of hours over 1 year, where VIPs are submitted to temperatures and vapour pressure below a certain value. This representation can be useful to determine the number of hours when VIPs are submitted to high temperatures or humidity, but doesn't take into account the coupling effect of the two solicitations. The red curves represent the solicitations at the VIPs' internal surface, and the blue curves at the VIPs' external surface.

VIPs are exposed to temperatures higher than 30 °C and to vapour pressure higher than 1800 Pa during about 40 % of percent of the year.

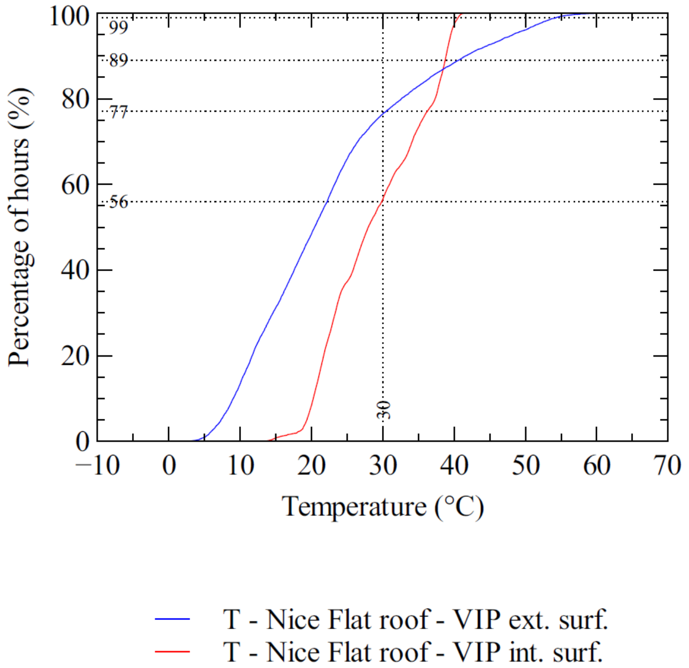


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-50 : Cumulative percentage of hours where VIPs are exposed to temperatures below a certain value.

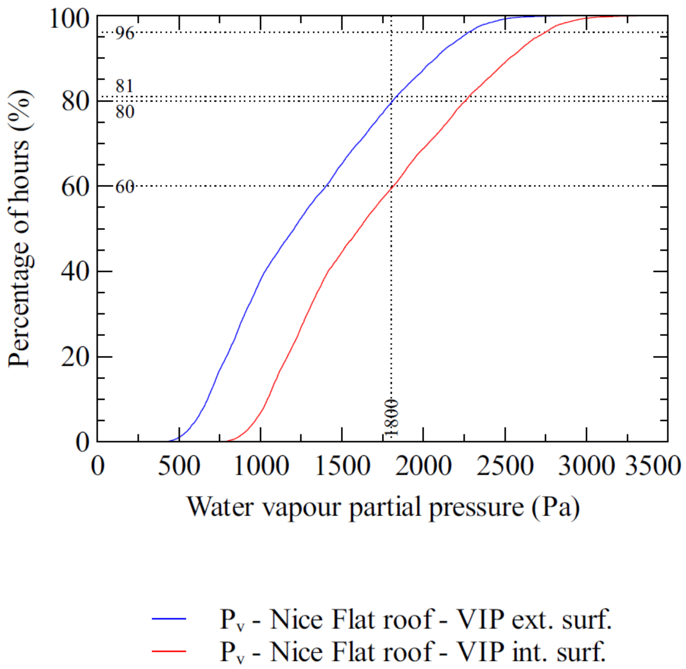


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-51 : Cumulative percentage of hours where VIPs are submitted to water vapour partial pressures below a certain value.

Table 1.21. Summary of the frequency distribution results at the VIP surfaces, flat roof in Nice.

Side	**Temperature ranges**					**Relative Humidity Ranges**					**Vapour Pressure Ranges**			
	I (≤30 °C)	**II (30÷40 °C)**	**III (40÷50 °C)**	**IV (>50 °C)**	**MAX [°C]**	**I (≤50 %)**	**II (50÷60 %)**	**III (60÷70 %)**	**IV (>70 %)**	**MAX [%]**	**I (≤21,2 hPa)**	**II (21,2÷44,3 hPa)**	**III (44,3÷86 hPa)**	**MAX [hPa]**
avg.	66.8%	26.3%	4.9%	2.1%	**51.9**	65.9%	12.4%	9.7%	12.1%	**84.0**	83.2%	16.8%	0.0%	**32.3**
ext.	76.4%	12.2%	7.3%	4.1%	**61.9**	43.5%	14.9%	18.2%	23.4%	**96.0**	91.8%	8.2%	0.0%	**29.8**
int.	57.1%	40.4%	2.5%	0.0%	**41.9**	88.3%	9.8%	1.1%	0.8%	**72.0**	74.6%	25.4%	0.0%	**34.8**

1.11.6 Configuration 6 – Flat roof/roof terrace – Holzkirchen and Freiburg (FIW)

For Configuration 6 to 10 the results are presented in similar way. Yearly values and cumulative frequency distributions of temperature, relative humidity and water vapour pressure are given for the location Holzkirchen, South orientation and normal internal moisture load.

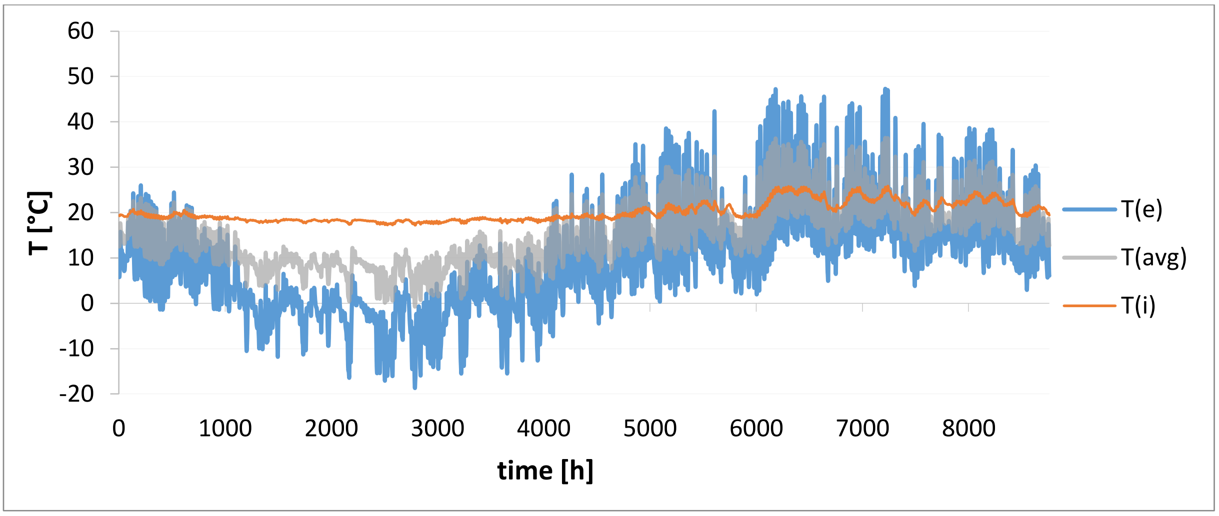


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-52 . Yearly time profile (from 1st October – 30th September) of temperatures for Configuration C6-HO-NM-SO.

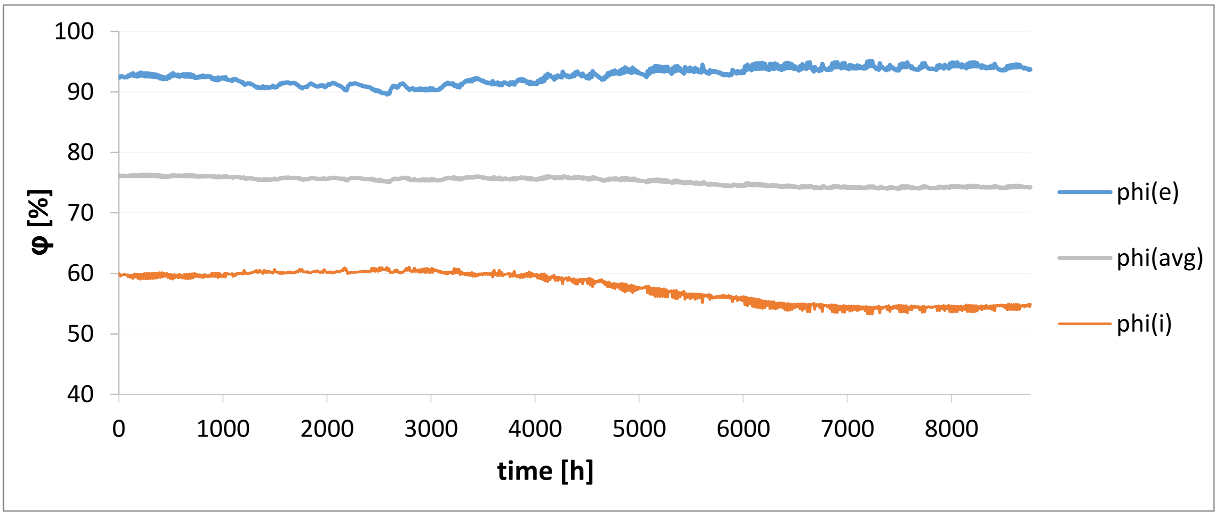


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-53. Yearly time profile (from 1st October – 30th September) of relative humidity for Configuration C6-HO-NM-SO.

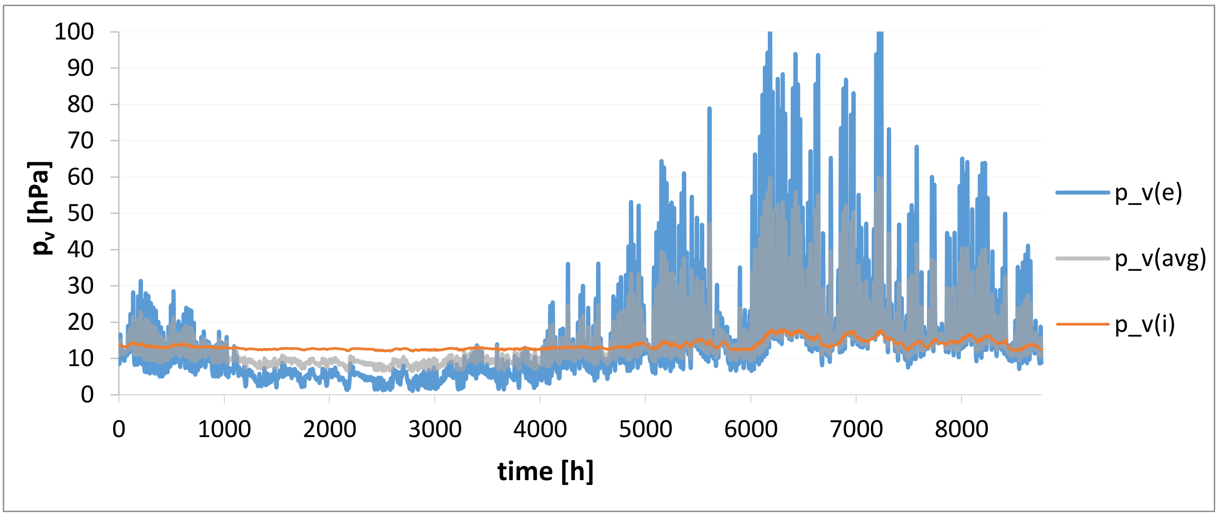


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-54. Yearly time profile (from 1st October – 30th September) of water vapour pressure for Configuration C6-HO-NM-SO.

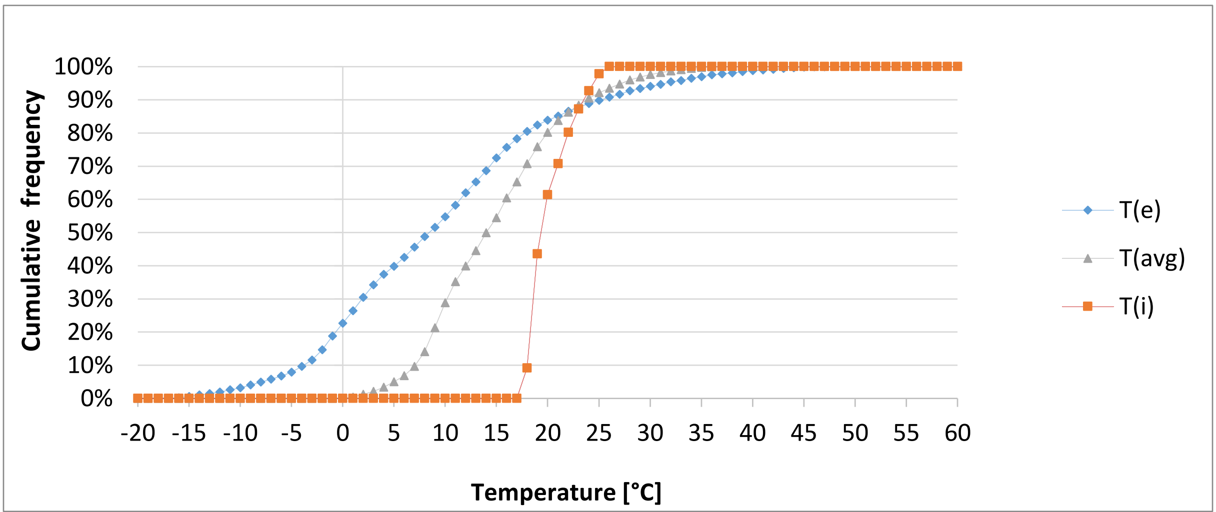


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-55. Temperature cumulative functions for Configuration C6-HO-NM-SO.

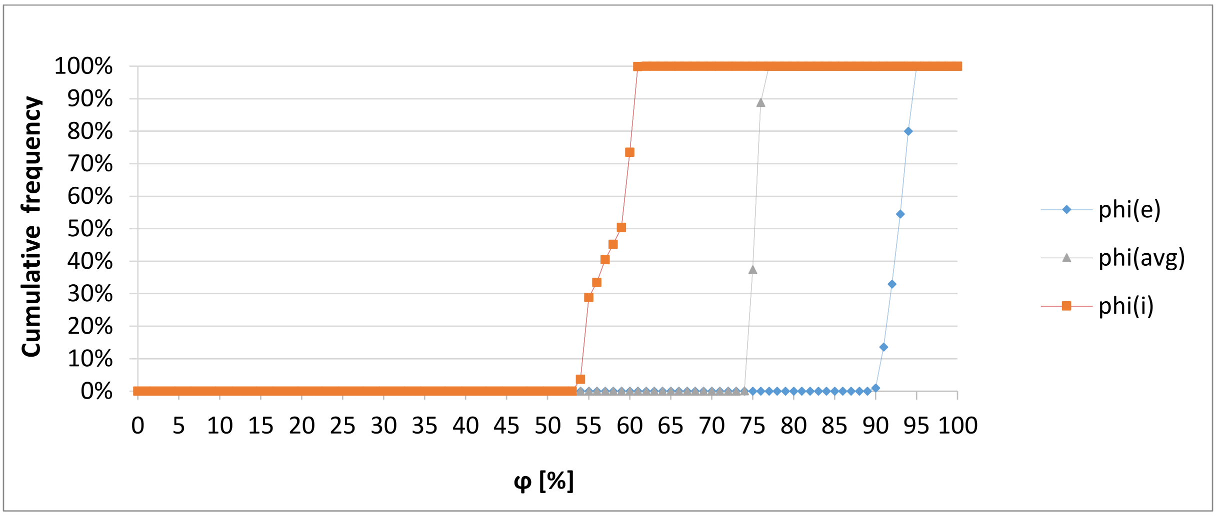


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-56. Relative humidity cumulative functions for Configuration C6-HO-NM-SO.

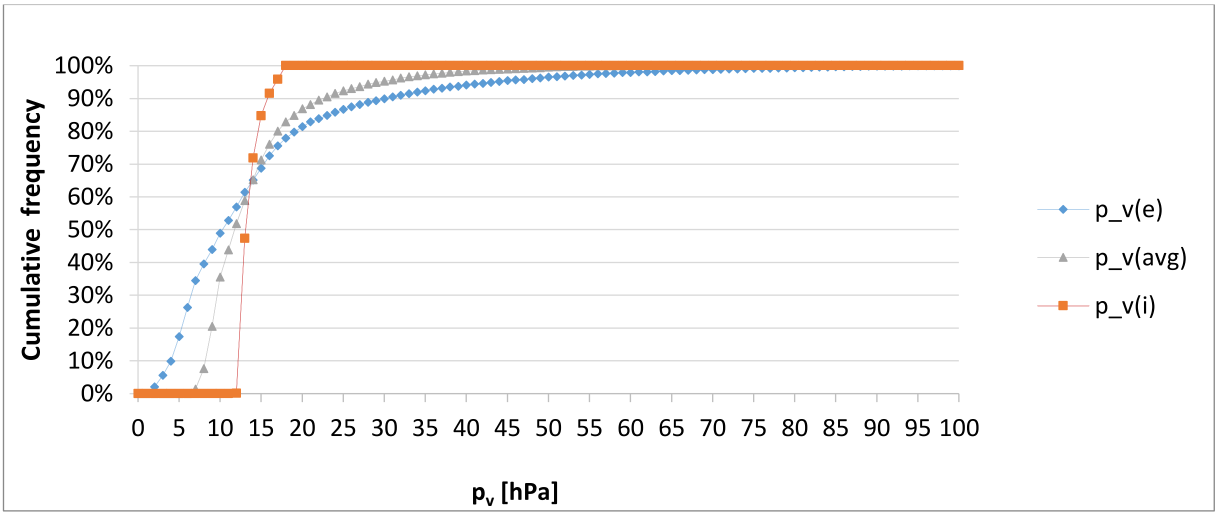


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-57. Water vapour pressure cumulative functions for Configuration C6-HO-NM-SO.

1.11.7 Configuration 7 – Pitched roof – Holzkirchen (FIW)

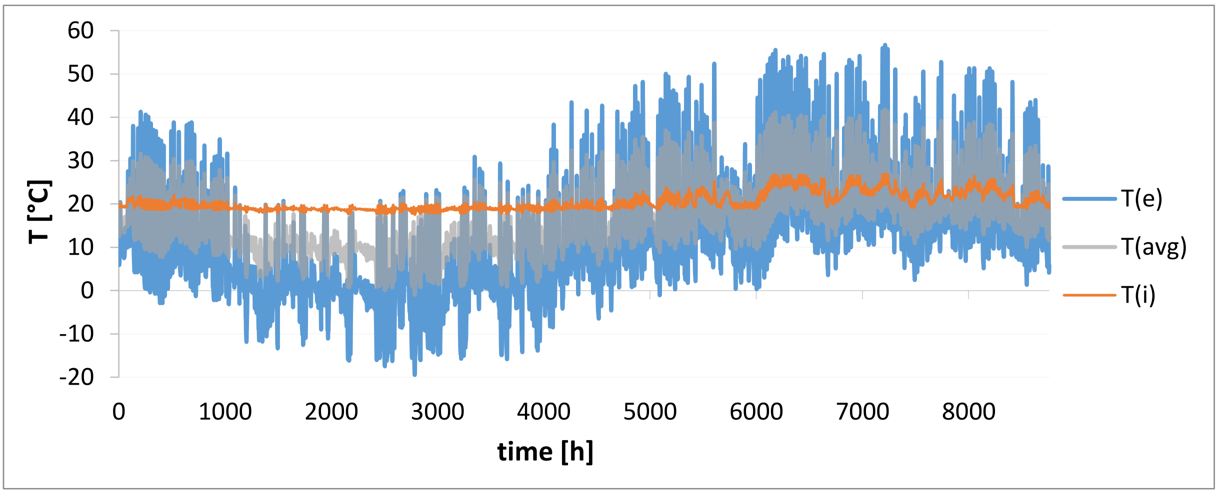


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-58. Yearly time profile (from 1st October – 30th September) of temperature for Configuration C7-HO-NM-SO.

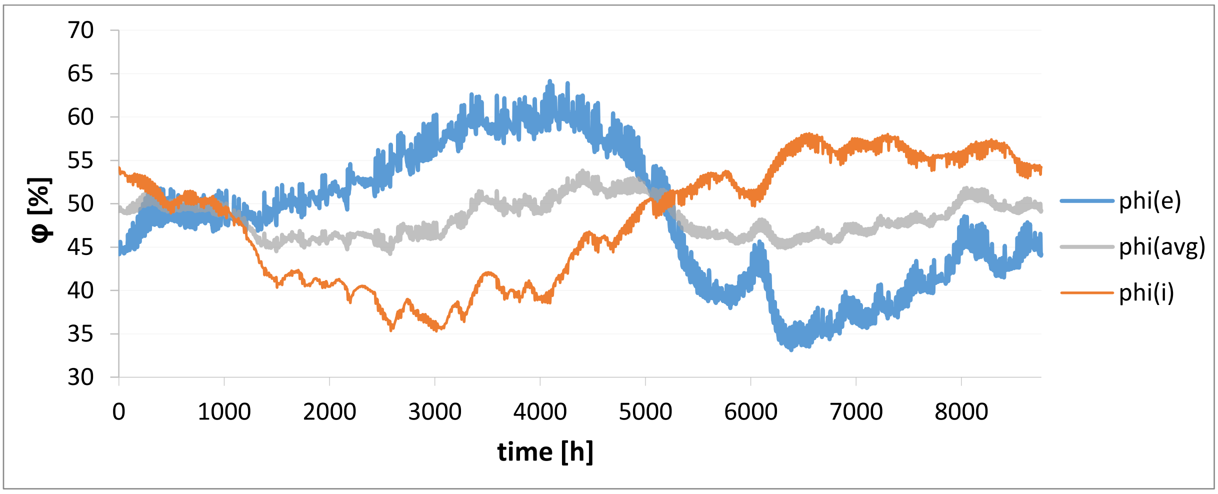


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-59. Yearly time profile (from 1st October – 30th September) of relative humidity for Configuration C7-HO-NM-SO.

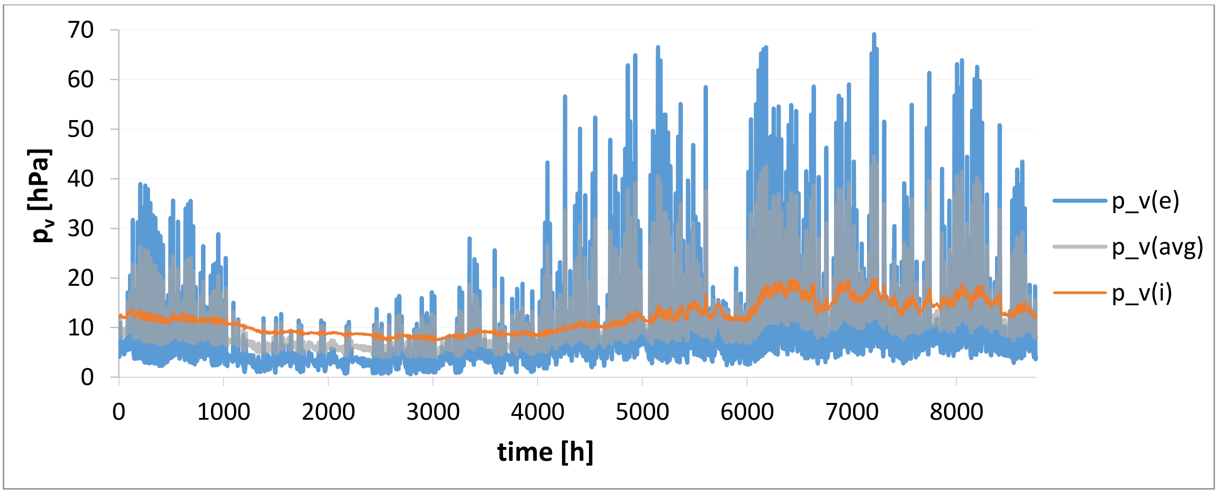


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-60. Yearly time profile (from 1st October – 30th September) of water vapour pressure for Configuration C7-HO-NM-SO.

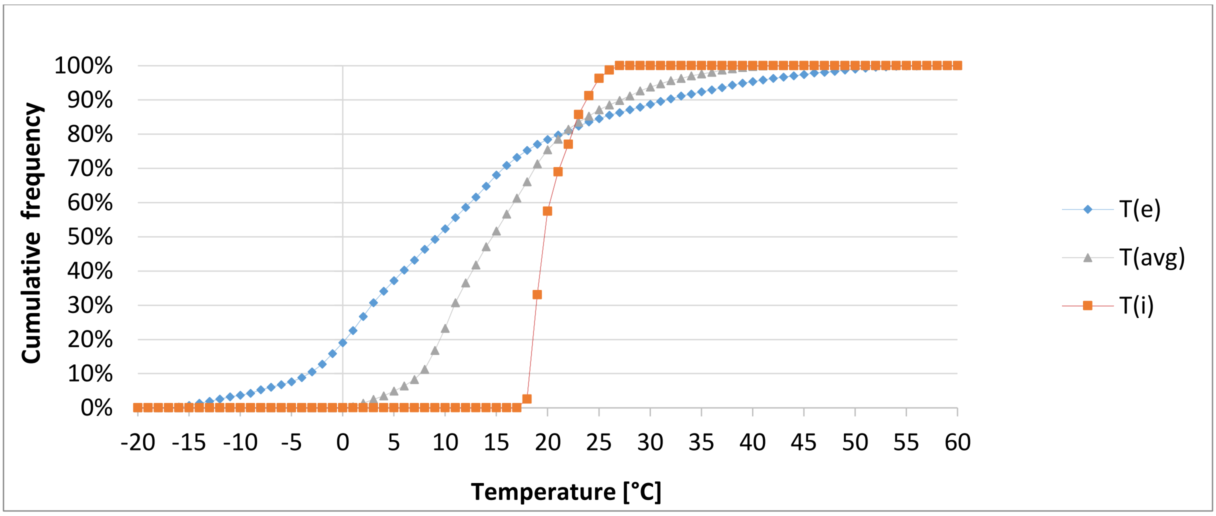


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-61. Temperature cumulative functions for Configuration C7-HO-NM-SO.

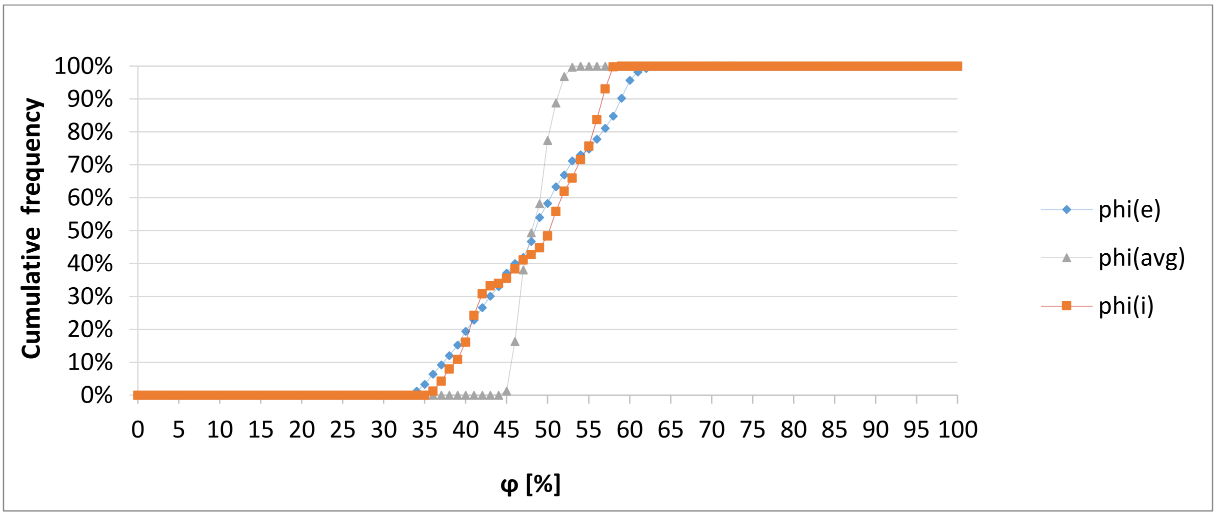


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-62. Relative humidity cumulative functions for Configuration C7-HO-NM-SO.

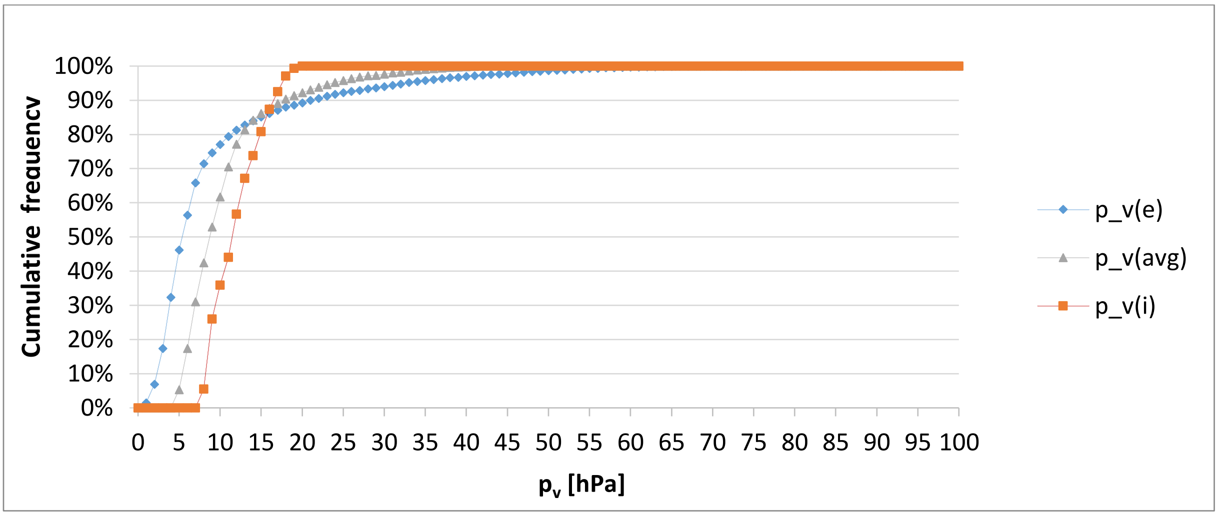


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-63. Water vapour pressure cumulative functions for Configuration C7-HO-NM-SO.

1.11.8 *Configuration 8 – External thermal insulation composite system (ETICS) – Holzkirchen (FIW)*

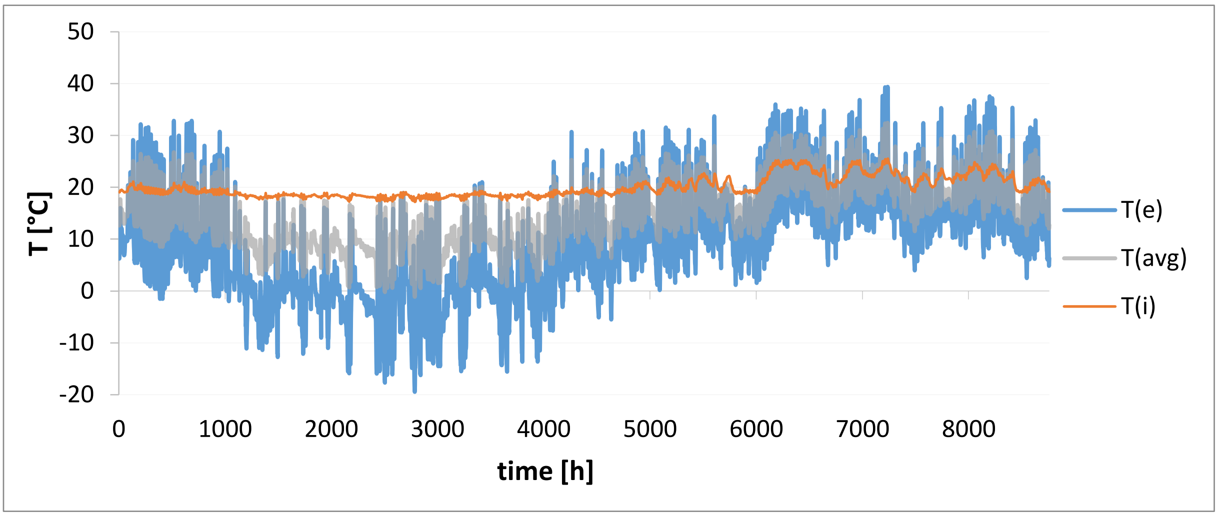


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-64. Yearly time profile (from 1st October – 30th September) of temperature for Configuration C8-HO-NM-SO.

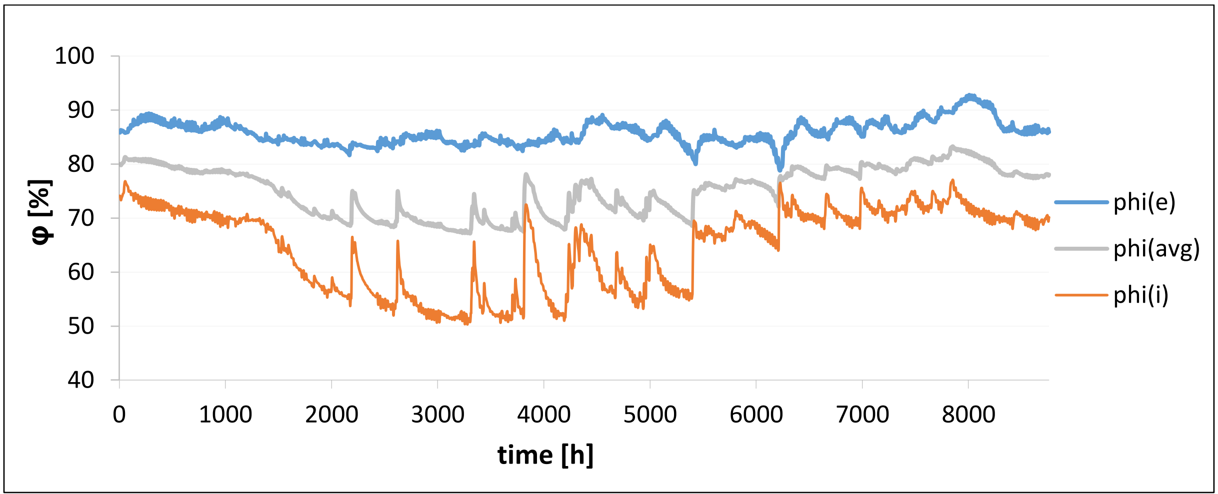


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-65. Yearly time profile (from 1st October – 30th September) of relative humidity for Configuration C8-HO-NM-SO.

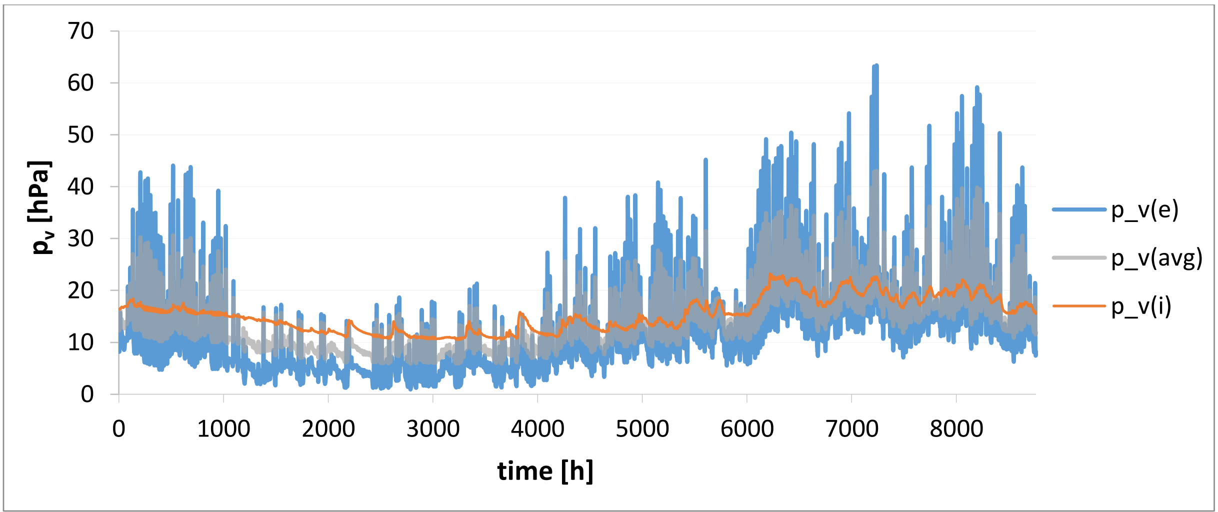


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-66. Yearly time profile (from 1st October – 30th September) of water vapour pressure for Configuration C8-HO-NM-SO.

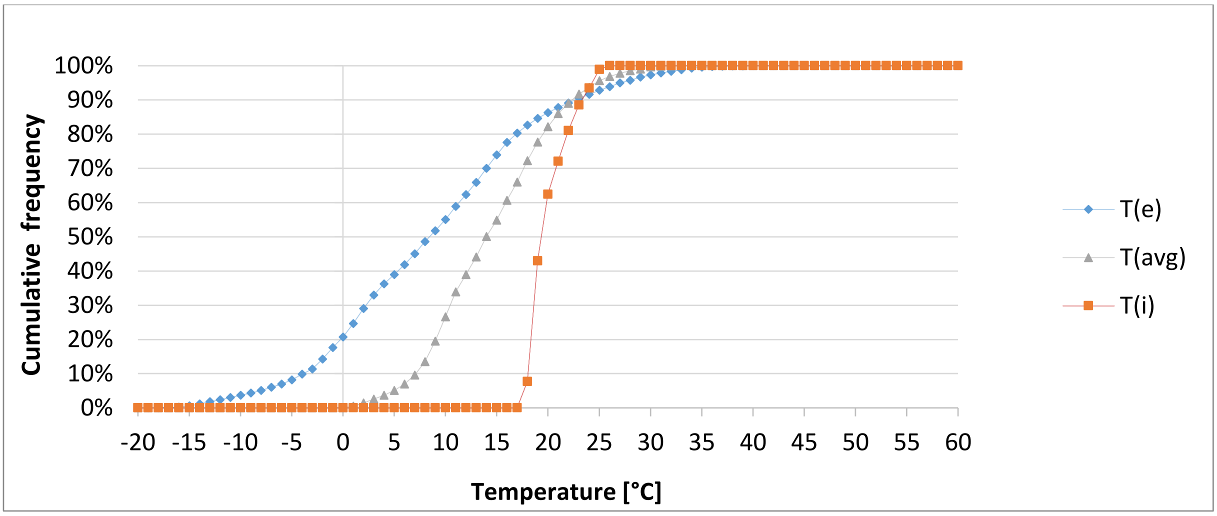


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-67. Temperature cumulative functions for Configuration C8-HO-NM-SO.

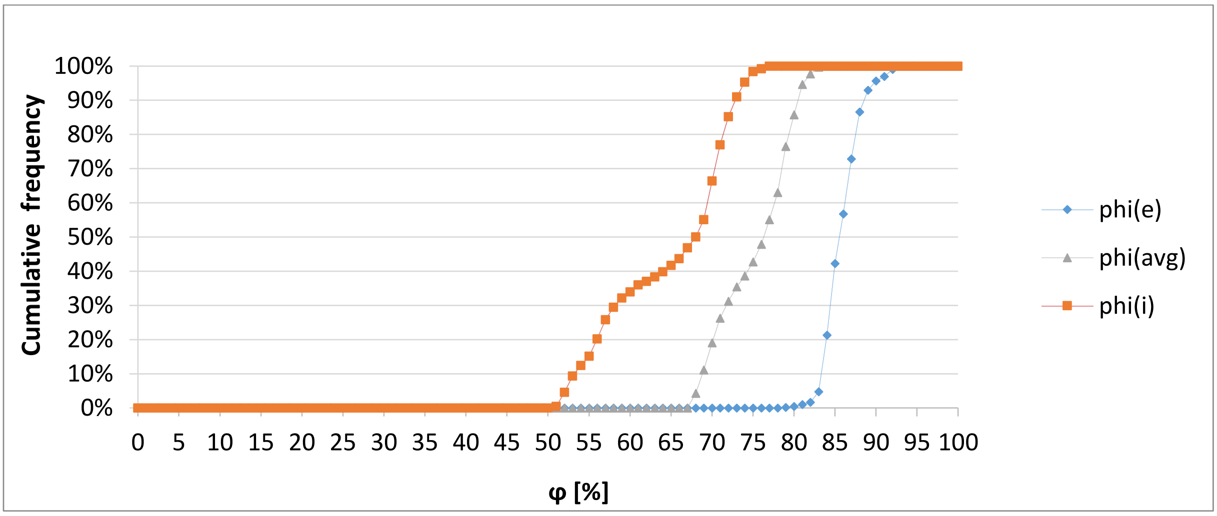


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-68. Relative humidity cumulative functions for Configuration C8-HO-NM-SO.

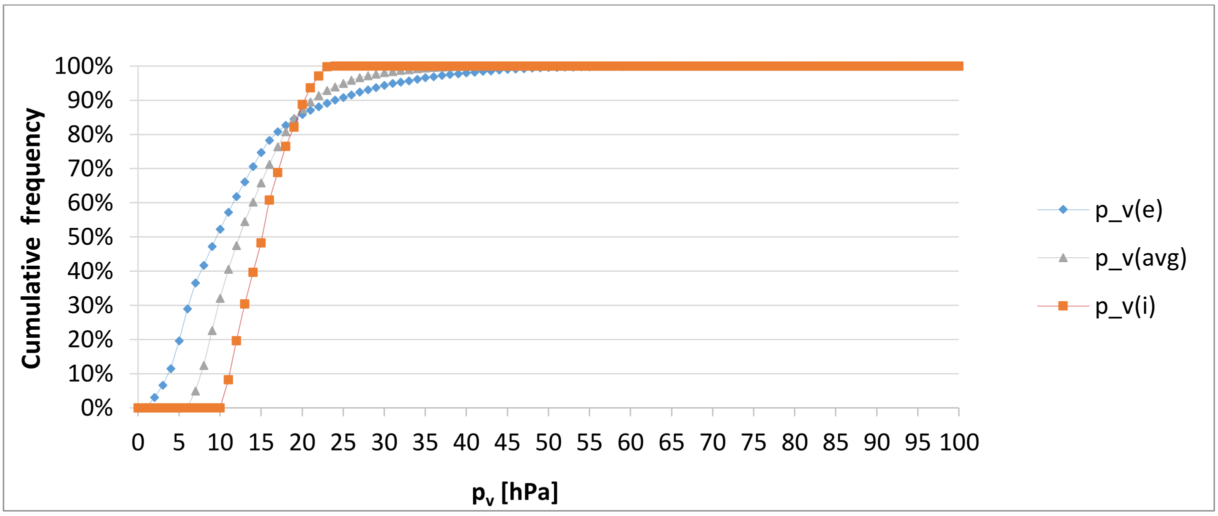


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-69. Water vapour pressure cumulative functions for Configuration C8-HO-NM-SO.

1.11.9 Configuration 9 – Internal insulation – Holzkirchen (FIW)

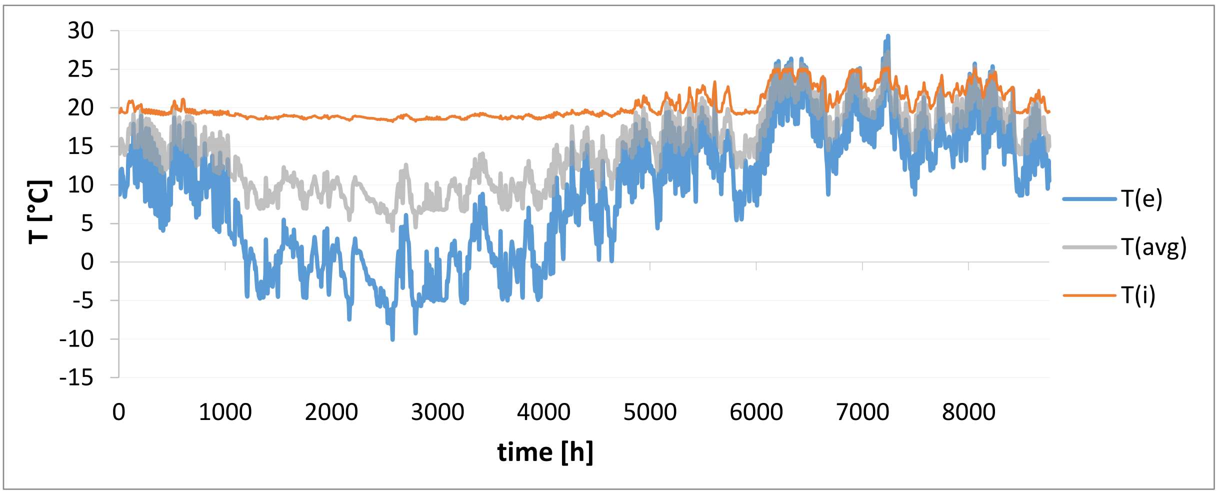


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-70. Yearly time profile (from 1st October – 30th September) of temperature for Configuration C9-HO-NM-SO.

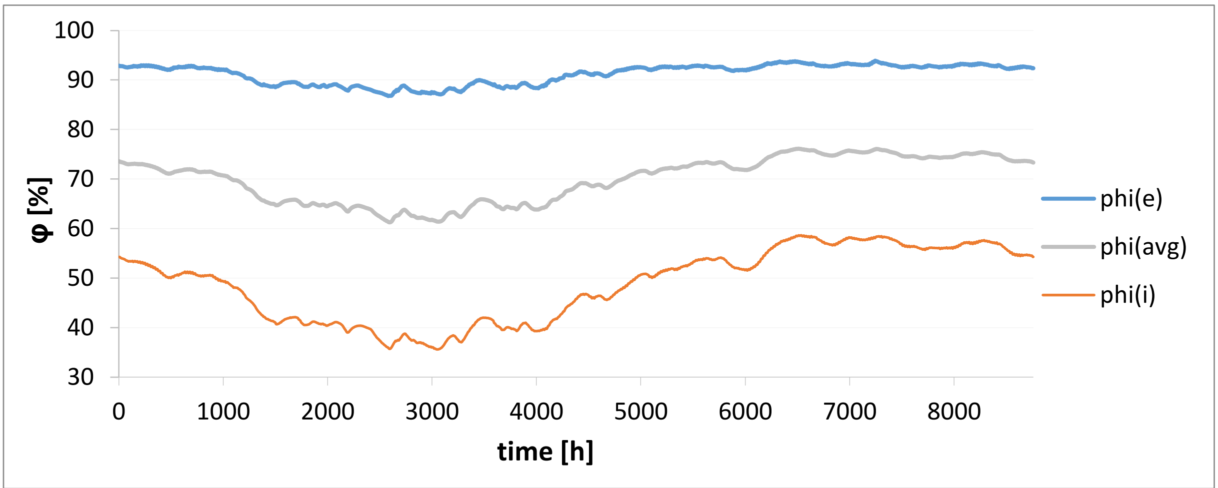


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-71. Yearly time profile (from 1st October – 30th September) of relative humidity for Configuration C9-HO-NM-SO.

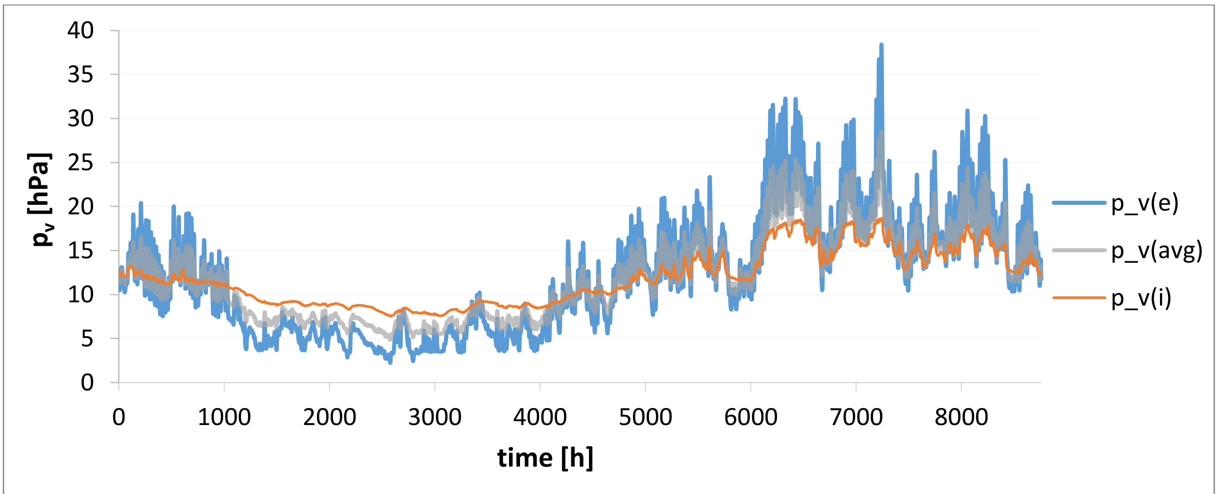


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-72. Yearly time profile (from 1st October – 30th September) of water vapour pressure for Configuration C9-HO-NM-SO.

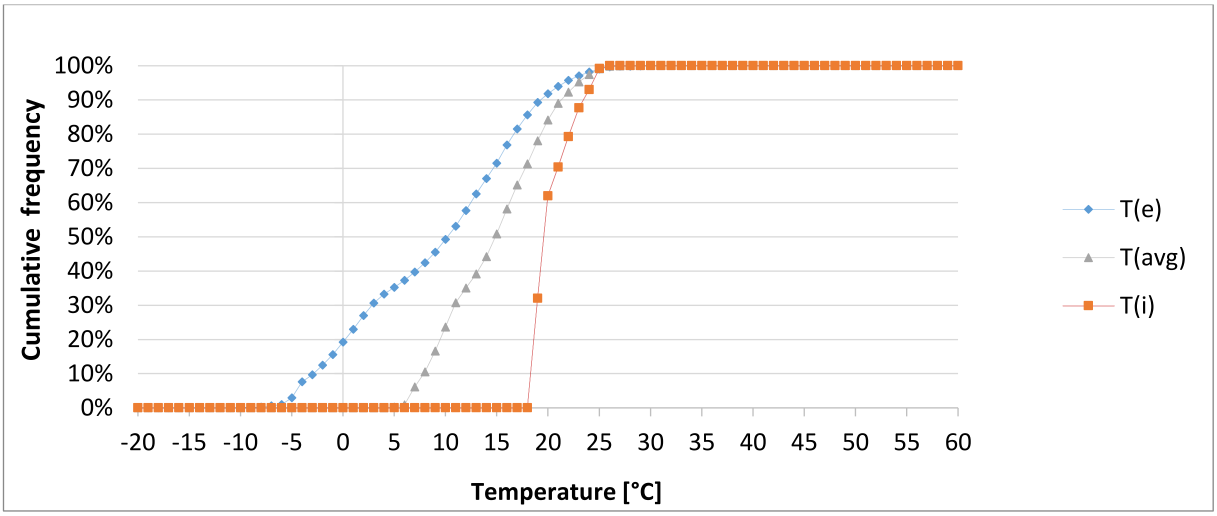


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-73. Temperature cumulative functions for Configuration C9-HO-NM-SO.

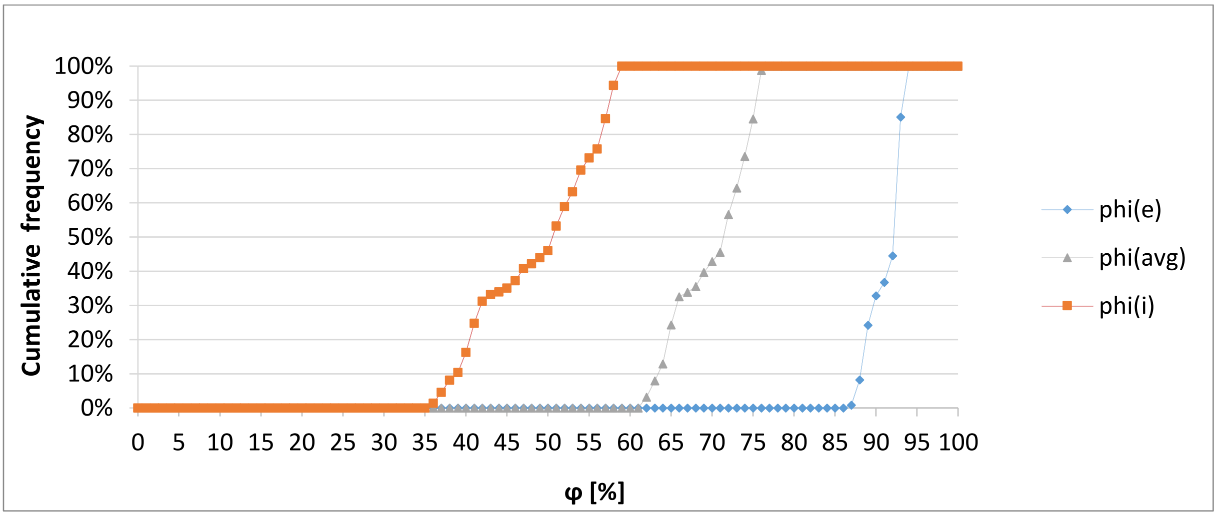


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-74. Relative humidity cumulative functions for Configuration C9-HO-NM-SO.

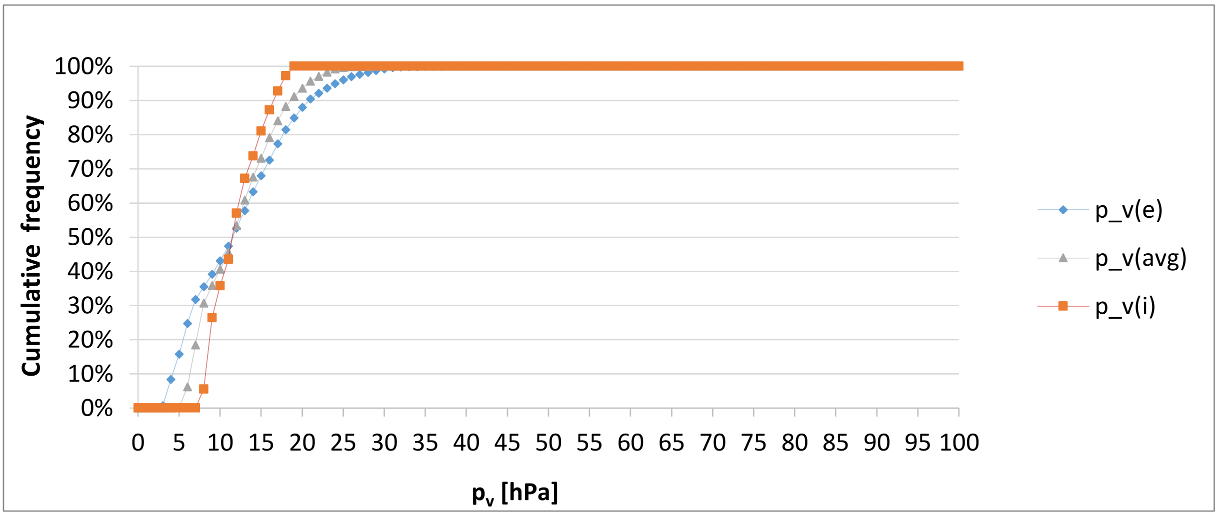


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-75. Water vapour pressure cumulative functions for Configuration C9-HO-NM-SO

1.11.10 Configuration 10 – Ventilated façade – Holzkirchen (FIW)

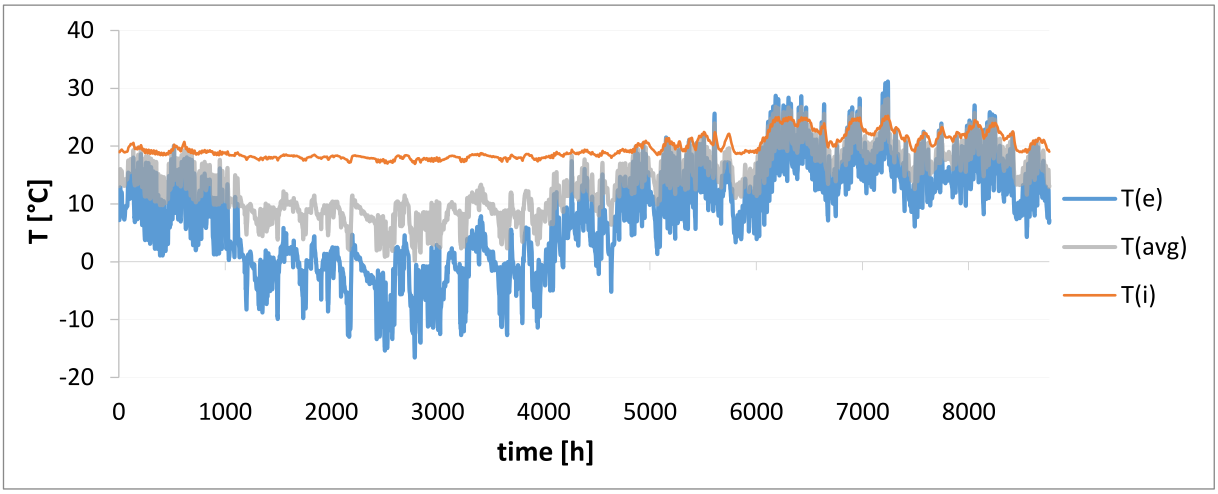


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-76. Yearly time profile (from 1st October – 30th September) of temperature for Configuration C10-HO-NM-SO.

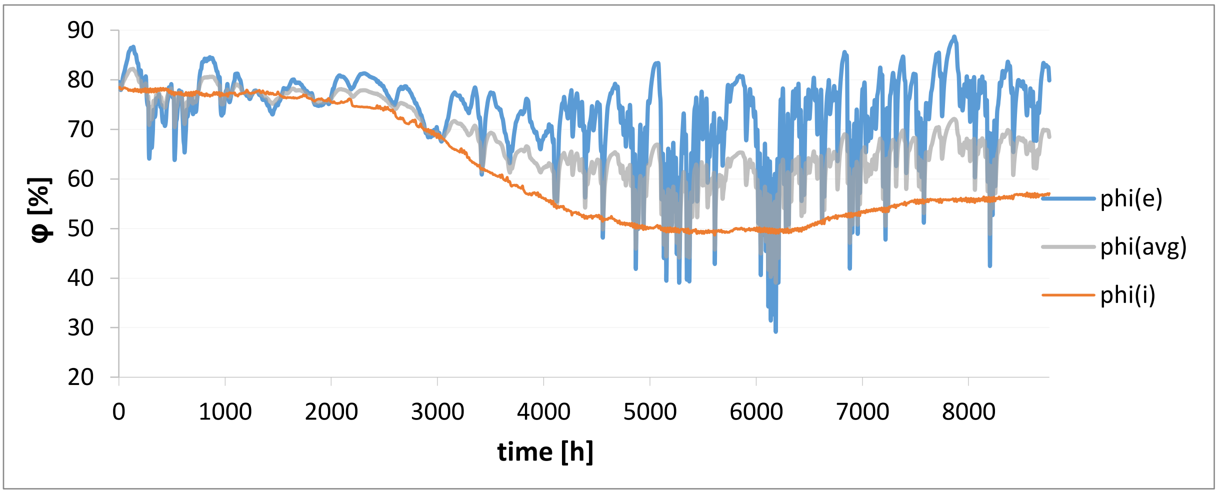


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-77. Yearly time profile (from 1st October – 30th September) of relative humidity for Configuration C10-HO-NM-SO.

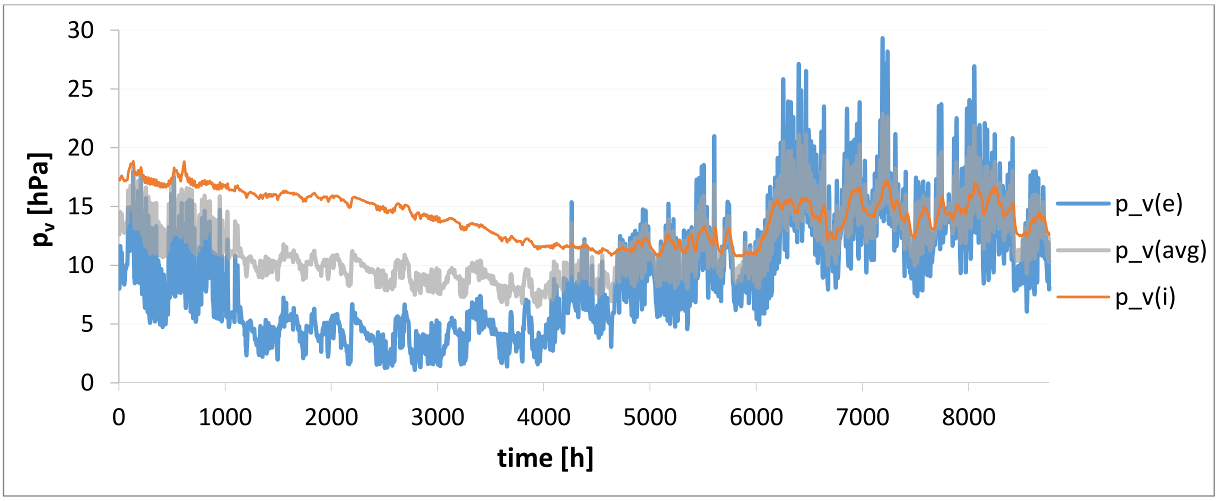


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-78. Yearly time profile (from 1st October – 30th September) of water vapour pressure for Configuration C10-HO-NM-SO.

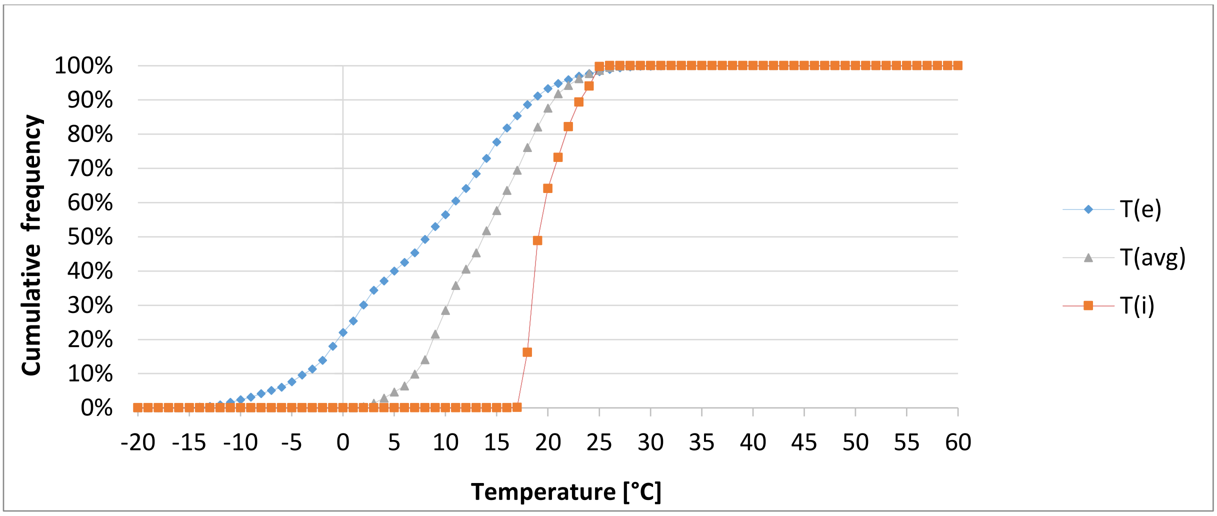


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-79. Temperature cumulative functions for Configuration C10-HO-NM-SO.

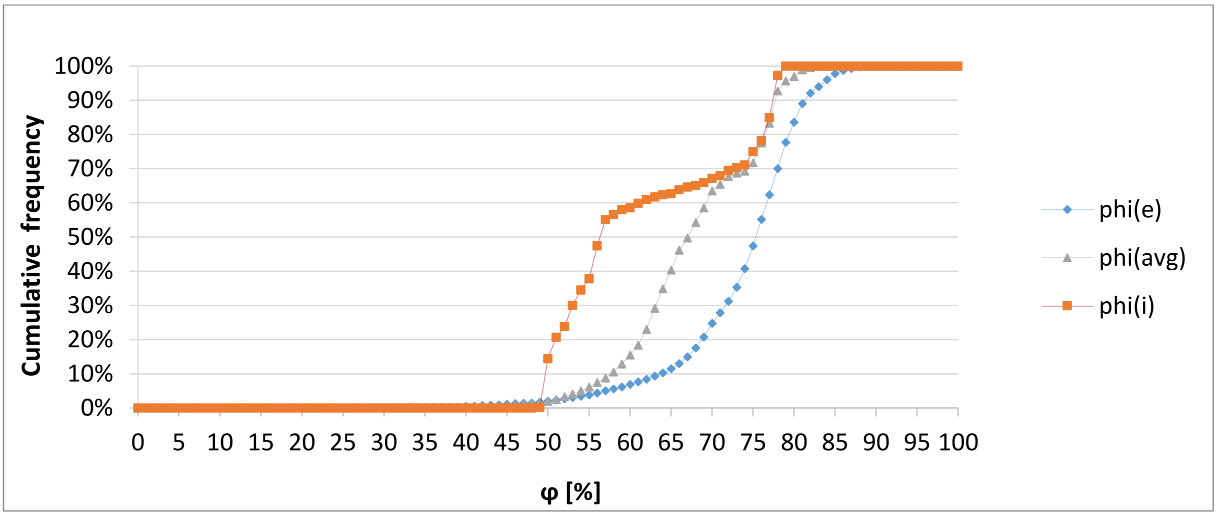


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-80. Relative humidity cumulative functions for Configuration C10-HO-NM-SO.

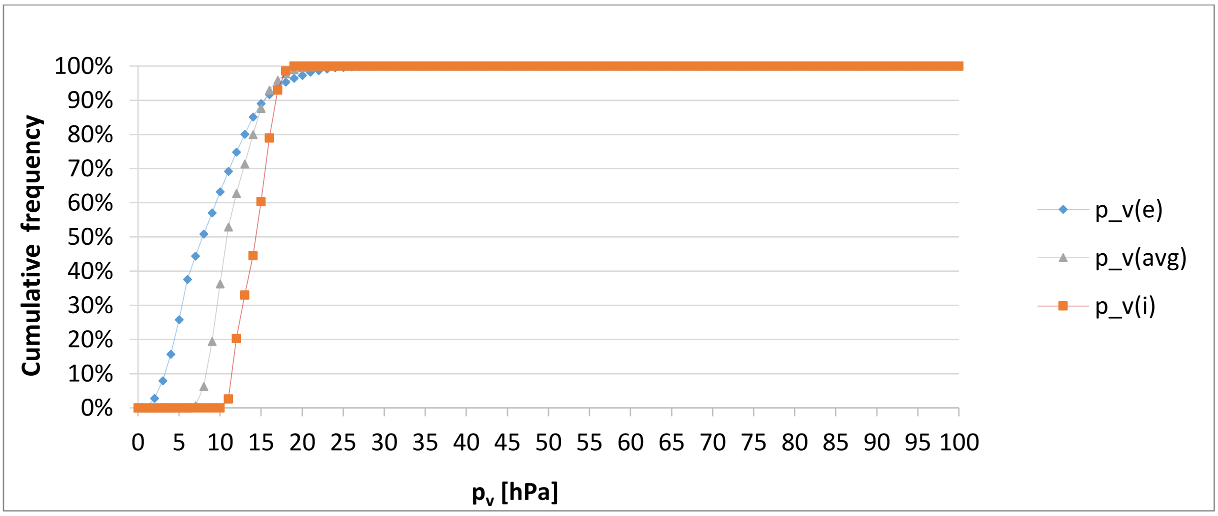


Figure **Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.**-81. Water vapour pressure cumulative functions for Configuration C10-HO-NM-SO

Table 1.22.A Summary of boundary conditions of Configurations 6 – 10 (Holzkichen and Freiburg).

Configuration	Location in Germany	Moisture load	VIP thickness	Orientation	Side	Temperature ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
						I (≤30 °C)	II (30÷40 °C)	III (40÷50 °C)	IV (>50 °C)	MAX [°C]	I (≤50 %)	II (50÷60 %)	III (60÷70 %)	IV (>70 %)	MAX [%]	I (≤21,2 hPa)	II (21,2÷44,3 hPa)	III (44,3÷86 hPa)	MAX [hPa]
C6-FR-NM-SO	Freiburg	normal	20mm	South	avg.	98.10%	1.90%	0.00%	0.00%	34.6	0.00%	0.00%	0.00%	100.00%	77.7	89.20%	10.50%	0.20%	52.3
					ext.	94.80%	4.90%	0.30%	0.00%	44.1	0.00%	0.00%	0.00%	100.00%	94.6	84.60%	11.50%	3.90%	86.3
					int.	100.00%	0.00%	0.00%	0.00%	25.7	0.00%	43.70%	56.30%	0.00%	63.5	100.00%	0.00%	0.00%	18.5
C6-HO-NM-SO	Holzkirchen	normal		South	avg.	97.60%	2.40%	0.00%	0.00%	36.4	0.00%	0.00%	0.00%	100.00%	76.3	89.40%	9.50%	1.00%	60
					ext.	94.00%	4.70%	1.30%	0.00%	47.3	0.00%	0.00%	0.00%	100.00%	95.1	83.90%	11.60%	4.20%	102.4
					int.	100.00%	0.00%	0.00%	0.00%	25.9	0.00%	73.60%	26.40%	0.00%	61	100.00%	0.00%	0.00%	18
C6-HO-HM-WE	Holzkirchen	high		West	avg.	97.60%	2.40%	0.00%	0.00%	36.4	0.00%	0.00%	0.00%	100.00%	81.2	88.00%	10.80%	1.20%	61.2
					ext.	94.00%	4.70%	1.30%	0.00%	47.3	0.00%	0.00%	0.00%	100.00%	95.1	83.90%	11.60%	4.20%	102.4
					int.	100.00%	0.00%	0.00%	0.00%	25.8	0.00%	0.00%	100.00%	0.00%	69.9	100.00%	0.00%	0.00%	20.3
C7-FR-NM-SO	Freiburg	normal		South	avg.	94.40%	5.60%	0.00%	0.00%	39.4	0.70%	97.30%	2.10%	0.00%	61.5	93.10%	6.80%	0.00%	47.5
					ext.	90.90%	5.80%	3.20%	0.10%	52.3	27.40%	35.80%	35.90%	1.00%	71.6	90.60%	7.20%	2.10%	75.7
					int.	100.00%	0.00%	0.00%	0.00%	26.6	37.50%	62.50%	0.00%	0.00%	60	100.00%	0.00%	0.00%	20.2
C7-HO-NM-SO	Holzkirchen	normal		South	avg.	93.80%	6.00%	0.20%	0.00%	41.8	77.40%	22.60%	0.00%	0.00%	53.8	93.80%	6.20%	0.00%	44.5
					ext.	88.80%	6.60%	3.70%	1.00%	56.7	58.30%	37.40%	4.30%	0.00%	64.2	90.50%	7.30%	2.10%	69.2
					int.	100.00%	0.00%	0.00%	0.00%	26.9	48.40%	51.60%	0.00%	0.00%	58.1	100.00%	0.00%	0.00%	19.8
C7-HO-HM-WE	Holzkirchen	high		West	avg.	97.60%	2.40%	0.00%	0.00%	36.4	0.00%	0.00%	0.00%	100.00%	81.2	88.00%	10.80%	1.20%	61.2
					ext.	94.00%	4.70%	1.30%	0.00%	47.3	0.00%	0.00%	0.00%	100.00%	95.1	83.90%	11.60%	4.20%	102.4
					int.	100.00%	0.00%	0.00%	0.00%	25.8	0.00%	0.00%	100.00%	0.00%	69.9	100.00%	0.00%	0.00%	20.3
C8-FR-NM-SO	Freiburg	normal		South	avg.	99.80%	0.20%	0.00%	0.00%	31.5	0.00%	0.00%	0.00%	100.00%	92.9	85.50%	14.50%	0.00%	43.7
					ext.	98.40%	1.60%	0.00%	0.00%	37.9	0.00%	0.00%	0.00%	100.00%	93.9	89.30%	10.20%	0.60%	59.9
					int.	100.00%	0.00%	0.00%	0.00%	25.3	0.00%	0.00%	0.00%	100.00%	92.7	64.40%	35.60%	0.00%	27.6

Table 1.22. B: Summary of boundary conditions of Configurations 6 – 10 (Holzkichen and Freiburg).

Configuration	Location in Germany	Moisture load	VIP thichness	Orientation	Side	Temperature ranges					Relative Humidity Ranges					Vapour Pressure Ranges			
						I (≤30 °C)	II (30÷40 °C)	III (40÷50 °C)	IV (>50 °C)	MAX [°C]	I (≤50 %)	II (50÷60 %)	III (60÷70 %)	IV (>70 %)	MAX [%]	I (≤21,2 hPa)	II (21,2÷44,3 hPa)	III (44,3÷86 hPa)	MAX [hPa]
C8-HO-NM-SO	Holzkirchen	normal	20mm	South	avg.	99.70%	0.30%	0.00%	0.00%	**32.4**	0.00%	0.00%	19.00%	81.00%	**83.3**	91.30%	8.70%	0.00%	**43**
					ext.	97.30%	2.70%	0.00%	0.00%	**39.4**	0.00%	0.00%	0.00%	100.00%	**92.8**	88.10%	10.90%	1.00%	**63.4**
					int.	100.00%	0.00%	0.00%	0.00%	**25.5**	0.00%	33.90%	32.50%	33.60%	**77.1**	97.10%	2.90%	0.00%	**23.2**
C8-HO-HM-WE	Holzkirchen	high		West	avg.	99.30%	0.70%	0.00%	0.00%	**33.9**	0.00%	0.00%	0.00%	100.00%	**94.4**	85.40%	14.30%	0.30%	**53.5**
					ext.	97.50%	2.40%	0.10%	0.00%	**42.3**	0.00%	0.00%	0.00%	100.00%	**95.4**	89.60%	8.80%	1.60%	**77.3**
					int.	100.00%	0.00%	0.00%	0.00%	**25.5**	0.00%	0.00%	0.00%	100.00%	**94.6**	65.70%	34.30%	0.00%	**29.8**
C9-FR-NM-SO	Freiburg	normal		South	avg.	100.00%	0.00%	0.00%	0.00%	**26**	0.00%	0.00%	33.70%	66.30%	**77**	96.10%	3.90%	0.00%	**26.1**
					ext.	100.00%	0.00%	0.00%	0.00%	**26.9**	0.00%	0.00%	0.00%	100.00%	**94.1**	90.20%	9.80%	0.00%	**33.4**
					int.	100.00%	0.00%	0.00%	0.00%	**25.1**	37.20%	60.20%	2.50%	0.00%	**60.2**	100.00%	0.00%	0.00%	**19**
C9-HO-NM-SO	Holzkirchen	normal		South	avg.	100.00%	0.00%	0.00%	0.00%	**27.3**	0.00%	0.00%	42.80%	57.20%	**76.1**	97.10%	2.90%	0.00%	**28.5**
					ext.	100.00%	0.00%	0.00%	0.00%	**29.3**	0.00%	0.00%	0.00%	100.00%	**93.9**	92.10%	7.90%	0.00%	**38.4**
					int.	100.00%	0.00%	0.00%	0.00%	**25.2**	46.00%	54.00%	0.00%	0.00%	**58.6**	100.00%	0.00%	0.00%	**18.7**
C9-HO-HM-WE	Holzkirchen	high		West	avg.	100.00%	0.00%	0.00%	0.00%	**27.2**	0.00%	0.00%	17.10%	82.90%	**81.2**	95.00%	5.00%	0.00%	**30**
					ext.	100.00%	0.00%	0.00%	0.00%	**29.2**	0.00%	0.00%	0.00%	100.00%	**94.5**	92.50%	7.50%	0.00%	**38.3**
					int.	100.00%	0.00%	0.00%	0.00%	**25.2**	10.30%	34.50%	55.20%	0.00%	**68.3**	100.00%	0.00%	0.00%	**21.7**
C10-FR-NM-SO	Freiburg	normal		South	avg.	100.00%	0.00%	0.00%	0.00%	**28.4**	2.20%	18.10%	37.80%	41.90%	**81.7**	99.90%	0.10%	0.00%	**23.4**
					ext.	99.90%	0.10%	0.00%	0.00%	**31.6**	7.50%	11.90%	25.50%	55.10%	**85.8**	99.20%	0.80%	0.00%	**28.5**
					int.	100.00%	0.00%	0.00%	0.00%	**25.2**	0.00%	45.60%	11.70%	42.70%	**80.6**	99.80%	0.20%	0.00%	**22.3**
C10-HO-NM-SO	Holzkirchen	normal		South	avg.	100.00%	0.00%	0.00%	0.00%	**28.2**	1.90%	13.50%	48.10%	36.50%	**82.2**	99.90%	0.10%	0.00%	**22.9**
					ext.	99.90%	0.10%	0.00%	0.00%	**31.2**	2.00%	4.90%	17.80%	75.30%	**88.7**	98.70%	1.30%	0.00%	**29.3**
					int.	100.00%	0.00%	0.00%	0.00%	**25.3**	14.40%	44.20%	8.60%	32.90%	**78.5**	100.00%	0.00%	0.00%	**18.8**
C10-HO-HM-WE	Holzkirchen	high		West	avg.	100.00%	0.00%	0.00%	0.00%	**28.2**	0.00%	1.30%	11.60%	87.10%	**86**	99.10%	0.90%	0.00%	**25.5**
					ext.	99.90%	0.10%	0.00%	0.00%	**31.2**	1.90%	4.80%	16.70%	76.50%	**88.8**	98.70%	1.30%	0.00%	**29.5**
					int.	100.00%	0.00%	0.00%	0.00%	**25.3**	0.00%	0.00%	13.00%	87.00%	**85.7**	96.80%	3.20%	0.00%	**22.8**

1.12 References

1 : S. Brunner, H. Simmler. In situ performance assessment of vacuum insulation panels in a flat roof construction. Vacuum 82-7 (2008) 700-707.

2 : A. Batard : Modelling of long-term thermal behaviour of vacuum insulation panels : (VIP), PhD Thesis, 2017, https://tel.archives-ouvertes.fr/tel-01692551/document