EVALUATION OF INSULATION SYSTEMS BY IN SITU TESTING

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RESUME

La performance énergétique des bâtiments est devenue aujourd'hui un sujet d'une importance capitale. Afin d'avoir une compréhension précise des déperditions au travers des parois d'un bâtiment, nous avons développé des essais en taille réelle (dit in situ), qui permettent l'étude des performances thermiques dynamiques de tout système d'isolation. Les cellules de tests employées sont des toitures inclinées dotées de deux murs pignons, elles ont les mêmes dimensions intérieures et extérieures et sont construites à l'identique avec les mêmes matériaux. Placés sur un même site ouvert, elles disposent d'un système de chauffage identique qui permet de maintenir au même niveau de température le volume intérieur de chaque cellule. A partir de cette température intérieure, de la consommation d'énergie et des conditions météorologiques, il est possible de déterminer l'efficacité thermique ou énergétique de chaque solution testée. Cet article présente les résultats obtenus sur deux sites en Europe où étaient placées ces cellules de test isolées par un isolant mince multi réflecteur ou une laine minérale. Les résultats obtenus sont comparés à des simulations TRNSYS.

1. INTRODUCTION

At the beginning of the XXIst century, the climatic global warning is a crucial subject which mobilizes the scientific community. We estimate today that in order to act in a significant manner on the greenhouse effect, it is necessary to divide by four the equivalent emission of CO_2 before 2050 which means for the building sector a reduction by 3/4th of the energy demand. In fact, the residential and service industry buildings represent 46% of the energetic bill in France and one of the main sources of emission of greenhouse effect gas. The requirements on building products contributing to energy saving are often reinforced thanks to new regulations. Nowadays, the estimations of energy saving of a building are made with dedicated software which allow the studies on the impact of the different solutions set up to minimize the building energetic requirement. Insulation products are one of them and their thermal efficiencies are estimated by standardized guarded hot plate or hot box measurements [1,2,3]. In comparison, a detailed report from the Building Research Establishment Ltd [4] has concluded about the existence of important differences, in certain cases equivalent to almost 30%, between the calculation of the coefficient of thermal transmission U under the norm ISO 6946 [5] and the measurements in situ made by the Alba Building Science company on the walls of buildings built between 1995 et 1999.
In such context, the European Multifoil Manufacturers association (EMM) tries to characterize insulation systems using a different approach which should allow estimating the energy reduction due to the insulation system installed and used in real conditions. The EMM members develop thin multi reflective insulation products and it is already admit that this kind of insulation tested using standardized lab measurements [1,2,6,7,8] present lower thermal resistance than a classical insulation solution. On the other hand, in situ tests have shown that it is possible to obtain good performances on wall [9] or in roof in summer conditions [10,11] when the walls are insulated with thin reflective insulation products.

In situ tests developed by EMM and presented here allow determining the energy performance of different insulating systems under climatic boundary conditions. A given realistic tests cell placed in 2 different European site will be detailed and results obtained with two insulations systems comparing a non insulated identical cell will be presented: a traditional one (200 mm of mineral wool) and a thin multi reflective insulation product (IRMM). Finally, comparison with TRNSYS software calculation will be done.

2. EXPERIMENTAL PART

2.1 Structural description of the test cells

Three test cells in wood frame representative of an attic that can be converted, with a roof surface about 35 m², outside dimensions of 4 x 7 m² on floor level and a height of 3 m were used for the described tests (figure 1). Each cell is built without windows and controlled ventilation. The access to each test volume is done through an insulated airlock placed on the gable wall; the thermal exchanges therefore take place through walls insulated with the tested material. The gable walls and the airlock opening adjoining are made of 23 mm thick plywood. The roof (36° pitch), is a traditional one made up of rafter of 8 x 11 cm with a space gap of 48 cm, the roofing is made of clay tiles. The roof ridge has a north/south orientation. The floor, made up of a wood paving with an under floor gap, is over-insulated with 20 cm of PSE and 10 cm of mineral wool. The airlock entries and under floor spaces are maintained with the same temperature than the one inside the cells (23°C).

Figure 1: View of the test cells : left, French test center; right : Spain test center.

A meteorological station, located nearby the cells is equipped to realize the permanent record of the following parameters temperature T_{ext}, hygrometry %RH, pressure P, global solar radiation R_G, and wind speed F_W.
This experiment setup was installed around Europe on 2 sites places in 2 different countries (Spain near Valladolid and France in Limoux)

2.2 Insulation and layout

Insulation products tested are (figure 2):

- Non commercial thin (45 mm) multi reflective insulation product (MF) with a core thermal resistance of 1.25 m²K/W measured with standards methods [1,2,3].
- mineral wool of 200 mm (MW) with a declared thermal conductivity of 0,040 W/mK (R_D = 5 m²K/W). An additional and continuous vapor control layer made of polyethylene foil (0.2 mm) was placed between mineral wool and plasterboard.
- the last cell had no insulation above the plasterboard.

A HPV under tile liner was placed under the tiles in each cell and the air gaps between the tiles and this HPV membrane were ventilated. The layout of the cells was realized in a way to ensure the total and identical air tightness of the cells (blowerdoor test measurements [12]) and in order to obtain an interior volume closest as possible (Table I). The layout has been realized under the manufacturer instructions [13,14], the one with mineral wool in Limoux has been controlled by the official organism APAVE. IR cameras pictures made outside and inside the cells do not reveal difference between each kind of insulated cells.

Table 1: Airtightness results and surface and volume of the cells

		Surface (m²)	Volume (m^3)	n_{50} (/h)
Spain	MF cell	43,93	28,15	5,29
	No ins cell	44,59	28,79	5,72
	MW cell	44,51	28,72	5,57
France	MF cell	44,19	28,93	4,5
	No ins cell	44,71	30,18	4,4
	MW cell	45,31	30,32	4,35

2.3 Instruments inside the testing cells

Each cell has been equipped with two temperature sensors located at 1.50m above the floor. The sensors are placed in an open grey PVC tube in order to protect them from air movements which might be susceptible to affect the measurements. The temperature homogeneity was controlled in each cell. During the test, parameters are measured on a constant rate (one per minute).
During this tests in winter condition, the maintenance at a constant interior temperature is obtained thanks to two fan heaters rated at 1 kW output each in the wood frame cells and thanks to electric oil filled radiator in concrete blocks cells. Current and voltage measurements using calibrated transducers allow, in each cell, the determination of the exact energy consumption.

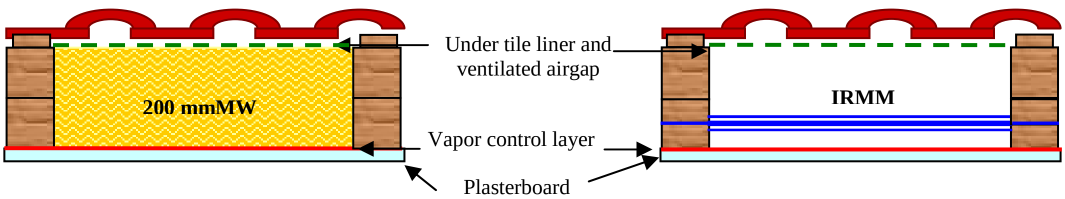

Figure 2: Scheme of roof constructions (for the non insulated cell, the same configuration was realized without any insulation)

3. CELLS CALIBRATION

In order to verify that the 3 cells on each test center are identical a preliminary calibration step is necessary. In order to do so, the energy consumption needed to maintain the same internal temperature into the cells with an identical insulation (200 mm of MW), during a period of five days was recorded. In both cases, the difference was inferior to 5% regarding the average consumption. The cells are therefore considered as identical.

4. ENERGY CONSUMPTION RESULTS

In situ test was performed between the 29th January 2008 and the 12th March 2008 in Spanish test center (with a 7 day period with data troubles) and between the 14th January 2008 and 22nd February 2008 in the French one (with two days with data recording troubles). The weather conditions encountered during this period and the energy consumption results needed to maintain a set point at 23°C are presented in Table 2.

Table 2: weather conditions and the energy consumption results on the 2 tests centers

FRENCH TEST CENTER						
Date	Temp (°C)	Wind speed (m/s)	Solar radiation (W/m²)	kWh MF	kWh MW	kWh No ins.
14/01/08 9:00	6,91	0,71	47,50	6,45	5,45	23,54
15/01/08 9:00	7,20	1,64	62,66	6,43	5,55	23,49
16/01/08 9:00	7,69	4,68	49,76	6,70	5,91	26,33
17/01/08 9:00	11,95	3,96	67,97	5,05	4,29	18,60
18/01/08 9:00	13,12	4,21	46,29	3,94	3,30	15,84
19/01/08 9:00	9,80	1,00	42,33	4,99	4,15	19,24
20/01/08 9:00	5,86	0,09	94,88	6,63	5,73	25,19
21/01/08 9:00	INVALID DATA					
22/01/08 9:00	10,78	5,71	26,20	5,15	4,85	20,70
23/01/08 9:00	5,94	1,03	83,72	6,19	5,44	24,50
24/01/08 9:00	7,97	1,02	94,18	6,47	5,72	23,09
25/01/08 9:00	INVALID DATA					
26/01/08 9:00	4,36	0,02	106,17	7,31	6,46	27,56
27/01/08 9:00	8,00	0,87	106,97	6,61	5,94	23,81
28/01/08 9:00	5,88	0,92	107,59	6,65	5,87	25,49
29/01/08 9:00	5,15	1,30	79,60	7,06	6,24	26,28
30/01/08 9:00	6,73	3,72	36,66	6,55	5,94	25,68
31/01/08 9:00	3,33	1,49	26,68	7,38	6,51	28,85
01/02/08 9:00	7,07	1,25	68,61	6,26	5,62	23,11
02/02/08 9:00	3,19	1,73	92,41	7,43	6,67	29,57
03/02/08 9:00	6,97	1,41	97,97	6,70	6,00	23,78
04/02/08 9:00	5,16	8,34	91,00	6,94	6,08	27,26
05/02/08 9:00	6,65	0,13	128,27	6,72	5,97	24,77
06/02/08 9:00	10,93	3,95	102,14	4,87	4,33	17,02
07/02/08 9:00	8,12	0,12	133,18	5,56	4,89	21,42
08/02/08 9:00	7,44	4,14	138,24	6,25	5,58	23,19
09/02/08 9:00	6,93	1,97	138,62	6,30	5,60	23,58
10/02/08 9:00	6,22	1,60	137,64	6,55	5,79	24,54
11/02/08 9:00	8,94	2,44	134,56	6,25	5,62	23,38
12/02/08 9:00	6,91	1,71	144,15	6,22	5,46	23,58
13/02/08 9:00	8,50	1,95	143,57	6,17	5,48	22,61
14/02/08 9:00	6,87	1,31	115,38	5,90	5,10	22,09
15/02/08 9:00	6,12	0,37	152,56	6,43	5,83	24,62
16/02/08 9:00	7,71	1,05	161,24	6,34	5,71	22,82
17/02/08 9:00	8,87	1,97	176,31	5,42	4,73	20,59
18/02/08 9:00	10,49	1,20	148,89	5,19	4,59	17,92
19/02/08 9:00	12,02	1,74	103,04	3,91	3,47	14,21
20/02/08 9:00	9,76	0,77	42,82	4,41	3,81	16,49
21/02/08 9:00	11,38	0,77	154,30	4,09	3,70	16,67
	7,75	1,95	99,57	223,46	197,39	841,42
	AVERAGE			SUM		

SPAIN TEST CENTER						
Date	Temp (°C)	Wind speed (m/s)	Solar radiation (W/m²)	kWh MF	kWh MW	kWh No ins.
29/01/08 9:00	1,51	0,24	152,82	8,88	9,06	30,81
30/01/08 9:00	1,44	0,38	97,79	9,08	9,21	31,29
31/01/08 9:00	2,52	0,30	157,27	9,05	8,87	29,93
01/02/08 9:00	6,03	1,46	57,26	7,68	7,35	26,08
02/02/08 9:00	4,38	1,17	144,94	8,21	7,42	28,56
03/02/08 9:00	6,99	3,00	49,90	7,48	6,83	27,22
04/02/08 9:00	6,16	1,29	130,35	7,44	6,76	25,81
05/02/08 9:00	7,46	1,14	74,17	6,57	5,89	22,62
06/02/08 9:00	5,74	0,43	165,90	7,01	6,13	23,38
07/02/08 9:00	5,09	0,21	166,90	7,44	6,67	24,21
08/02/08 9:00	4,59	0,17	164,42	7,10	6,31	24,64
09/02/08 9:00	4,32	0,24	172,50	7,27	7,00	24,97
10/02/08 9:00	3,45	0,22	170,31	7,45	7,26	26,04
11/02/08 9:00	3,75	0,23	174,30	7,59	7,39	27,10
12/02/08 9:00	3,38	0,47	170,93	7,67	7,38	27,33
13/02/08 9:00	2,80	0,40	173,84	7,96	7,76	28,59
14/02/08 9:00	7,29	0,49	113,83	6,76	6,57	22,98
15/02/08 9:00	5,31	0,27	125,39	6,25	5,99	23,32
16/02/08 9:00	5,96	0,24	166,95	6,68	6,54	23,57
17/02/08 9:00	6,87	0,65	140,67	6,58	6,38	23,03
18/02/08 9:00	7,60	0,65	83,84	6,07	5,75	21,86
19/02/08 9:00	8,38	0,13	55,08	5,60	5,29	20,24
20/02/08 9:00	7,83	0,35	111,04	5,48	5,13	20,62
21/02/08 9:00	7,06	0,52	195,91	5,87	5,56	21,70
22/02/08 9:00	7,41	0,35	199,26	5,90	5,74	21,40
23/02/08 9:00	10,24	0,42	141,79	5,33	5,18	18,00
24/02/08 9:00	9,63	0,30	85,40	4,98	4,73	17,90
25/02/08 9:00	7,95	0,49	189,18	5,15	4,77	19,00
26/02/08 9:00	8,22	0,49	124,73	5,61	5,44	19,84
27/02/08 9:00	10,36	0,62	116,47	4,89	4,66	17,38
28/02/08 9:00						
29/02/08 9:00						
01/03/08 9:00						
02/03/08 9:00						
03/03/08 9:00	INVALID DATA					
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05/03/08 9:00						
06/03/08 9:00						
07/03/08 9:00						
08/03/08 9:00	7,20	0,85	222,45	6,67	6,51	23,31
09/03/08 9:00	7,04	2,01	170,01	6,78	6,63	25,03
10/03/08 9:00	8,39	3,46	42,27	6,73	6,60	26,54
11/03/08 9:00	12,79	2,44	210,80	4,36	4,21	15,97
	6,33	0,77	138,78	229,55	218,96	810,25
	AVERAGE			SUM		

At the end of the test period:

- MF cells present energy consumption of 223.46 kWh on the French test center and 232.64 on the Spanish one.
- MW cells present energy consumption of 197.39 kWh on the French test center and 218.96 on the Spanish one.
- Non insulated cells present energy consumption of 841.42 kWh on the French test center and 810.25 on the Spanish one.

The table 3 gives the U values of the cells based on these results and the energy saving due to insulation systems.

Table 3: U values of the cells and energy saving

	U value (W/m²K)			Energy saving	
	MF cell	MW cell	No ins cell	MF cell	MW cell
French test center	0,39	0,34	1,68	77%	80%
Spain test center	0,37	0,35	1,32	72%	73%

This table shows that under these real weather conditions, MF product despite its low thermal resistance can provide a high energy saving.

5. COMPARISON WITH TRNSYS SOFTWARE RESULTS

Simulation under TRNSYS software was performed using the exact geometry of the cells and the weather conditions registered on each test center. U values of each walls calculated thanks to EN ISO 6946 standard are given in the table 4.

Table 4: Calculation of the standardized U-values of each walls

	MF cell	MW cell
Walls	0.379	0.186
Roofs	0.455	0.191

The simulation results are compared with measurements in table 5. For mineral wool, simulation results fit with the measurements in both test centers using a level of air infiltration of 0.73 vol/h when thermal bridges are not considered and a level of air infiltration of 0.46 vol/h when thermal bridges are considered.

For MF cell, simulations overestimated the energy needed to maintain the temperature set point into the cells. Moreover, as presented in table 1, air tightness of MF cells is very close to the MW ones and if the same level of infiltration find for MW cells is applied to the MF one, the difference between simulations and measurements can reach 70 %.

This difference may come to the wrong estimation of the performance of air gaps surrounding the MF product due to impact of the radiation on the energy transfer in the system MF + airgaps. This raises the question of the efficiency of classic models and the needs of new suitable models to determine the correct resistive characteristics of the cavities in the presence of reflective walls.

We plan to model this kind of system using CFD tools coupling the different heat transfer modes in three dimensional simulations. An accurate model of inhomogenous radiative walls heat flux including diffuse and specular reflexion and suitable for coupling has been developed. The Monte Carlo method used in precedents works [15] makes it possible to model efficiently the radiosities between elements of walls and their sensitivity to the temperature field.

Table 5: Measurements and simulation results

Spanish test site								
	Mineral Wool				Multi foil			
Configuration	In situ (kWh)	Trnsys (kWh)	Diff. (Trnsys-In situ)	Air change to fit measurements (h^{-1})	In situ (kWh)	Trnsys (kWh)	Diff. (Trnsys-In situ)	Air change to fit measurements (h^{-1})
Without thermal bridges	218,96	121,11	-45%	0,73	229,546	243,83	6%	-
Thermal bridges (Sext)		156,51	-29%	0,46		328,99	43%	-

French test site								
	Mineral Wool				Multi foil			
Configuration	In situ (kWh)	Trnsys (kWh)	Diff. (Trnsys-In situ)	Air change to fit measurements (h^{-1})	In situ (kWh)	Trnsys (kWh)	Diff. (Trnsys-In situ)	Air change to fit measurements (h^{-1})
Without thermal bridges	197,39	128,09	-35%	0,50	223,46	257,08	15%	-
Thermal bridges (Sext)		163,21	-17%	0,24		344,27	54%	-

6. CONCLUSION

Thin multi reflective insulation products show higher performance where they are tested in situ following the protocol presented in this paper. In order to understand the difference between these results and the performance obtained using standards measurement and calculations, fine studies on air gaps surrounding the products are necessary to determine the correct thermal characteristics of the system MF + air gaps.
The protocol detailed in this paper allows the direct determination of the energy saving using a given insulation system in comparison with a non insulated cell. The thin multi reflective insulation solution allows a significant energy saving; associated with an efficient heating system (heat pump…), this solution can be an interesting alternative for old buildings where the space for thick insulation was not anticipated.

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