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Design of a new full-scale facility for building envelope test: FACT (FACade Tool)

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Abstract

In the last years, several innovations have been introduced in the field of building envelope research and development. To bridge the gap between research and commercially available products, one of the key step is to evaluate these technologies in 1:1 scale and under real boundary conditions. For this purpose, test in outdoor full-scale facilities in complement with dynamic numerical simulation, allow to assess the performances of these complex envelope components, systems or whole building. In this framework a new versatile facility, named FACT (FACade Tool), is under construction in the south-eastern France (CEA- INES platform – Le Bourget du Lac) for building envelope components test. This new full-scale tool will be dedicated to infield evaluation of: opaque and transparent elements, light-weight and massive façades, different thickness and heights and different geometry of the indoor environment. In this paper it is presented the design phase, the concept and the working principle of the facility. The layout definition was supported by preliminary simulations and the results of this modelling activity are discussed in order to guide the construction of the facility and to outline the experimental protocol for the next campaigns in FACT.

Peer-review under responsibility of KES International.
Keywords: outdoor facility; experiment; test room; design facility; FACT; full-scale facility; building envelope

1. Introduction

Several achievements in the building technology field have been registered in the last years; such as super-insulation material, switchable glazing, multi-functional façade, semi-transparent photovoltaic modules, pv/thermal hybrid

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collector in façade components [1]. According to the new European calls, these innovations will form the backbone of the energy system for 2030-2050 [2], but still a limited widespread of these technologies is registered, mainly due to the reluctance to novelty in the construction market, the additional construction costs and the practical difficulties in the integration in the building. To bridge the gap between research and market, outdoor full-scale facilities, permit to evaluate infield in a 1:1 scale building envelope technologies and to overcome the difference between design phase and real building energy consumptions [3,4]. Moreover a new research line is followed on building envelope with an adaptive behavior. These technologies are able to modify their thermophysical properties responsively interacting with the outdoor boundary conditions and the user [1]. Often these type of building envelopes present a high degree of integration with the system. Due to the complexity of the problem, both for new buildings and the refurbished ones, the optimization and the definition of the envelope technology properties need to be assessed with an experimental activity. In fact, particularly for the adaptive building envelope, measurement in a mockup reproducing the building in a real scale and exposed to real dynamic boundary conditions, permits to verify the real behaviour of these complex technologies as well as to collect data to validate dedicated simulation tools. As far as it regards building energy refurbishment one of the most challenging aspects is related to find the right technological solutions which permits to integrate the new building envelope system into the existing building, to avoid thermal bridges and to verify the compatibility of materials [5].

On the one hand the experimental activity in test cells exposed to real boundary conditions cannot be substituted with indoor laboratory facilities, on the other hand some negative aspects are presented in this type of test: the cost and test duration, the effectiveness of the measurement is not obvious, a lack of standards to build test cells and to perform measurement do not permit to have internationally shared protocols.

The IEA ECB Annex 58 project (2011-2015) on "Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements" focused on the state of the art of full scale testing, on dynamic data analysis, on the development of common quality procedures and models [6–10]. A recently published work on existing outdoor test cells, reports a classification of outdoor facility showing an extensive use of these utilities in the scientific community [11–13].

In Europe among real scale facilities a small number of them present the property of being modular, such as Kubik (Tecnalia – Spain) [11], VERU (Fraunhofer - Germany), The Cube (DTU - Denmark) [14] and BEST lab (EDF - France). The aim of this paper is to present a new modular outdoor facility, FACT (FACade Tool). The design phase, the concept and the working principle of this real scale facility under construction in CEA – INES, are described. The design process was supported by preliminary simulations, to help the definition of the facility, and the purposes of the test. Results of this modelling activity are discussed in order to outline the experimental campaigns that will be implemented in FACT starting from next autumn. Within three different European financed projects (HomeSkin, WALL IN ONE and Conipher) will be soon installed in FACT parallel experimental activities on building envelope components to evaluate both the performance and the technological integration of: aerogel based systems (i.e. internal and outer plaster) and a modular cladding system for façade refurbishment with PV.

Nomenclature and acronym

FACT	FACade Tool facility
MAE	Mean Absolute Error (°C)
WWR	Window Wall Ratio (-)
PASSYS	Passive Solar Systems and Component Testing
IEQ	Indoor Environmental Quality

2. FACT test facility

2.1. FACT description

FACT is a new test facility under construction in CEA – INES, Le Bourget du Lac, a research platform in the south-eastern France. The design phase of FACT started in 2014 and the construction site in January 2016 while the end of the work is expected for July 2016. The acronym “FACT” stands for FACade Tool facility, and the design of this tool is aimed to constitute a new versatile facility for building envelope test completing the already existing experimental platform which counts the presence of four detached houses
(INCAS), four test cells (PASSYS) and 10 roof test benches.

The design of the facility focused on the possibility to do measurement of the energy performance and on the impact on IEQ of building envelope on the indoor environment and this type of facility undergoes the real scale facility rather than house facility classification. FACT project was particularly challenging because the aim was to allow to test with the maximum flexibility;

- opaque and transparent façade,
- building envelope integrated with HVAC system, PV/ST and BIPV,
- lightweight and massive façade.

Furthermore also the geometry of the experiments need to allow to evaluate:

- different façades thickness between 10 cm and 60 cm,
- different height of façade i.e. single floor or two floors as for the double skin façade up to 8 m (Fig. 1),
- different geometry of the indoor environment enclosed with the tested façades. The dimension of test cells can be modified, in order to perform measurement of single office and open space.

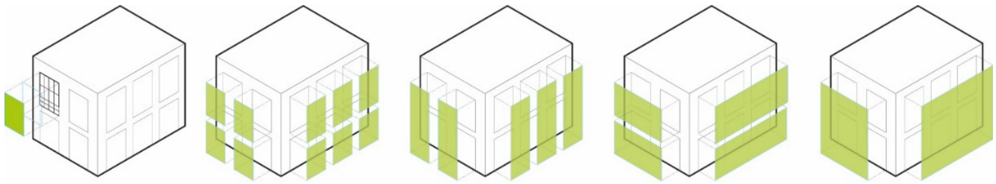


Fig. 1. The metallic structure permits to hang on FACT different configurations façade. From left: working principle of FACT, single façades test, full height and large façade test, full FACT façades test.

2.2. FACT geometry

The facility is a two floors building with a total height of 8.34 m, and external gross dimension of 7.8 m x 9.8 m. It is composed of 2 fixed technique rooms and 10 test cells. In Fig. 2 the plan of the two floors are schematically reported. Test cells 1 to 5 are positioned in the ground floor and test cells 6 to 10 in the first floor. Each test cell presents two façades of test with an area of 7.70 m² (2.3 m width x 3.3 m height) except for cellules 4 and 9 which present only one façade of test south exposed.

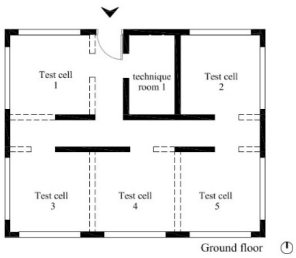


Fig. 2. FACT ground floor (left) and first floor (right). Each floor hosts 1 technique room and a maximum of 5 test cells.

The different possible configurations of test are reported in Fig. 1 and as it is shown in the schematic view the surface of tested façade can vary. The rooftop of FACT is prepared to host renewable technologies such as solar and photovoltaic panels as well as horizontal technologies for building envelope such as green roof, cool roof, sky dome, on a surface of 68 m ².

The metallic structure of the facility (Fig. 3 center) is connected to a concrete foundation on a crawl space of 1.5 m. A primary metallic structure is coupled with a secondary frame able to support the tested façade for a maximum of 4 tons. If necessary the secondary frame is removable in order to perform test on transparent façade.

2.3. FACT envelope and equipment

The FACT envelope is constituted of polyurethane panels, which are divided in fixed, semi-fix and movable part. The internal partitions, ceiling, floor and vertical walls, can be completely removed and substitute according the experimental campaign needs. A fixed partition with an electrical panel, a communication network, and the sensors cable access is positioned in every test cell. According to the test configuration, the floor and ceiling of the tested environment are modular and they can be removed. Specific joints are designed in order to modify easily the configuration. The envelope is fixed to the metallic structure which is connected to a concrete slab of foundation.

An HVAC system with a reversible heat pump maintains the indoor air temperature in the cellules. The humidity control is not yet implemented but the space for technical equipment is previewed.

The regulation system was designed to maintain in each test cells the desired set point temperature (± 0.5 °C). A variable mechanical air flow rate can be defined for each cellules in the range of 0.5 and 3 vol/h.

Fig. 3. FACT during the building phase. External view (left), the secondary structure (center) and façade installation (right).

3. Preliminary evaluation on FACT

3.1 Methods and materials

The preliminary simulation activity was parallel to the design phase and aimed at verifying the project and to define the test conditions in the facility. Given the large possibilities of test in FACT these first simulations set, focused on the comparison between the test cells. The main variables which make the comparison critic are: the envelope tested, the different expositions of test cells, and the geometry i.e. the first floor test cells have heat losses and gains through the ceiling on the contrary ground floor test cells heat losses through the floor. For these reasons the results of the simulations are represented to show the combinations of test cells with the most similar behavior.

A simplified geometry of FACT was modelled with Google Sketch Up 2016 and Open studio plug-in. The model was run in EnergyPlus v.8.4.0 and a Meteonorm v.7 typical year weather data of Chambery (France) was used [11]. The model will be validated against real first experimental data which will be collected during summer – autumn 2016. The dynamic simulation were carried out over the year with a computation of 4 time steps per hour and hourly reported results. A free floating condition was assumed, meaning that the indoor air temperature in the cellules was not controlled and no HVAC system was modelled. In all the environments of the facility a mechanical ventilation air flow rate of 0.5 vol/h was provided.

Five different possible configurations of FACT were so far investigated:

- **Configuration 1 –** The whole building envelope is modelled as opaque. Ten different test cells constitute the indoor geometry of FACT.

- **Configuration 2 –** Ten test cells are simulated and the building envelope is modelled with a percentage of transparent surface. The Window to Wall Ratio parameter (WWR) [7] assesses the percentage of transparent envelope. According to literature values the WWR was varied between 20%, 50% and 80% of the opaque surface of the façade, in order to have a low, medium and a highly glazed configurations. For the corner cells, which present two façades exposed to outdoor boundary conditions, only one façade is modelled with window; for cells 1, 2, 6 and 7 the north façade and for cellules 3, 4, 5, 8, 9, 10 the south ones. Respectively the configurations are named as: configuration 2.1 has a WWR of 20%, configuration 2.2 has a WWR of 50% , configuration 2.3 has a WWR of 80% .

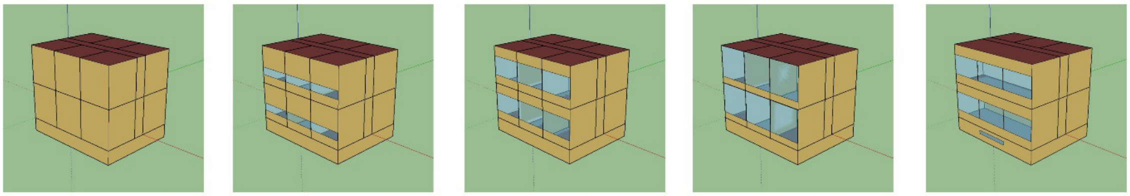
- **Configuration 3 –** An open space configuration is modelled in the south exposed façades of FACT. Cellules 3, 4 and 5 for ground floor and cellules 8, 9 and 10 first floor are merged in a unique environment. An average value of 50% for WWR is assumed. The test cells exposed to north are not included in the open space.

For configuration 2.2, 2.3 and 3 with higher WWR, in order to maintain the indoor air temperature in acceptable range the natural ventilation schedule was increased during the summer season up to 3 vol/h.

The building envelope input of FACT are reported in Table 1. The roof is constituted of insulation material in polyurethane foam panels of 24 cm with a thermal resistance greater than 10 m^2K/W. Walls are constituted of polyurethane panels of 18 and 20 cm, internal and external respectively, with a thermal resistance of 9 and 7 m^2K/W. The floor on a crawl space is constituted of a concrete slab insulated on both side, with two polyurethane panels of 20 cm each. Internal finishing was hypothesized for tertiary building use; a gypsum plaster board (2 cm) for walls and ceiling and linoleum for the floor. For configuration 2.1 (WWR 20%) the glazing is a double unit with a clear glass of 6 mm an argon filled cavity (16 mm) and a low – e coating glass (4 mm). Instead of the clear glass for the configurations 2.2 and 2.3, which present higher transparent area, a reflective glazing was model, in order to reduce solar heat gains. To wrap up the conditions of simulation are reported in Table 2.

Some assumptions are done to simplify the simulation: internal gains, window frame, thermal bridges and air infiltration are not considered. These two last assumptions, which could substantially influence the results, were not taken into account because they will be evaluated specifically for each experimental set-up by means of measurement coupled with specific model.

For each configuration the mean indoor air temperature is simulated. The results are processed to evaluate the Mean Absolute Error (MAE) defined in equation 1. This index was calculated hourly, for each combination of comparison, meaning cellule 1 vs cellule 2, cellule 1 vs cellule 3 etc., for a total of 90 combinations. The MAE is the mean absolute difference between the air temperature of cellule *n* and cellule *n+1*. The higher is the MAE the greater is the indoor air temperature difference between the compared cellules. If the indoor air temperature of cellule *n* is the same of cellule *n+1* the MAE is zero. The results of MAE are represented in a square symmetric matrix 10 rows by 10 columns as elements in order to have compact view of the results.



Configuration 1 **Configuration 2.1** **Configuration 2.2** **Configuration 2.3** **Configuration 3**

Fig. 4. Simulated geometry of FACT for the different configurations.

For each configurations the analysis is carried out for winter, spring, summer and autumn seasons: *winter* with results of December, January and February, *spring* with results of March, April, May, *summer* with results of June, July and August and *autumn* with results of September, October and November. In Fig. 5 the layout of the matrix is reported and two areas are highlighted: the “A” area is related to MAEs between test cells positioned at the same floor and the “B” area is related to MAEs between test cells positioned at different floor.

$$MAE_{n,n+1} = \frac{1}{n}\sum_{i=1}^{n}\left|t_n - t_{n+1}\right| \qquad (1)$$

Three classes are defined to evaluate the feasibility of comparison between the cellules and the MAEs values are plotted in matrix (Fig.5) with colored cells representing:

- Green: good reliability for $MAE_{n,n+1}$ range between 0°C and 1°C
- Yellow: medium reliability for $MAE_{n,n+1}$ range between 1°C and 2°C
- Red: low reliability for $MAE_{n,n+1}$ greater than 2°C

The range were defined considering that during the operational phase of FACT the value of air temperature measured will be affected by a certain incertitude of measurement and the possible oscillation of indoor air temperature due to the control system of the HVAC. An aggregate elaboration is provided for the most critical season, showing the average value of MAEs for the south and north exposition. Given the results of the matrixes, the average value of MAEs is calculated between test cells with the same exposition.

Table 1. Input data for simulation of the FACT envelope.

Structure name (outdoor to indoor)	Thickness [mm]	Thermal resistance[m^2K/W]
Roof (polyurethane panels + gypsum plaster board)	260	10.4
External wall (polyurethane panel + gypsum plaster board)	220	9
Internal vertical partition (polyurethane panel + gypsum plaster board)	200	7
Internal horizontal partition (linoleum + polyurethane panel gypsum plaster board)	200	7
Floor (polyurethane panel + concrete slab+ polyurethane panel + linoleum)	630	14.8
Window DGU (6/16/4 mm)	24	0.8
Window reflective DGU (6/16/4 mm)	24	0.8

Table 2. Configurations, envelope and ventilation schedule definition.

Configuration	*Envelope*	*Ventilation schedule*

Configuration 1	100% opaque	0.5 vol/h
Configuration 2.1	WWR 20% - DGU	0.5 vol/h
Configuration 2.2	WWR 50% Reflective DGU	0.5 vol/h (Oct-May) 3 vol/h (May-Sept)
Configuration 2.3	WWR 80% Reflective DGU	0.5 vol/h (Oct-May)3 vol/h (May-Sept)
Configuration 3	WWR 50%Reflective DGU	0.5 vol/h (Oct-May) 3 vol/h (May-Sept)

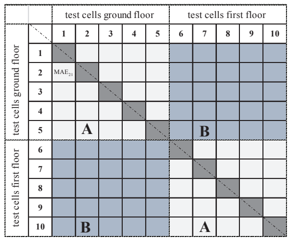


Fig. 5. Example of matrix.

3.2 Results

To introduce the results it is important to point out that the outputs of the model discussed hereafter are achieved simulating step by step the facility during the design phase. The presented results are the final optimized solution obtained after different improvement stage. At the beginning of the work a great air temperature difference between ground floor and first floor test cells was simulated. After several attempts it was possible to find out that the reason of this discrepancy was due to the assembly of the floors i.e. ground floor presented a concrete slab floor and the first floor an insulated sandwich panel. This difference corresponded to a higher thermal inertia of the building envelope in the ground floor than first floor which made the building envelope test cells 1, 2, 3, 4 and 5 with a higher thermal mass than the 6, 7, 8, 9 and 10. For this reason the following results propose a final solution with the concrete slab insulated on both sides.

Example of the simulations outputs are reported in Fig.7. In the left picture indoor air temperature trend for configuration 2.1 during summer period are plotted. It is possible to notice that the north cells 1, 2, 6 and 7 have a similar trend on the contrary higher temperature are measured for south exposed cells. In the Fig. 5 right a comparison, for the different configurations, of indoor are temperatures trend between test cell 1 and 3 is done. For configuration 1 (with no windows) no particular differences are revelaed between north exposed test cell the and south one. On the contrary for the other configurations i.e. with higher WWR values, the differece between test cell 1 and 3 increases.

At a first glance the matrixes in Fig. 7 show that the number of red elements (corresponding to a bad reliability) are directly proportional to the increasing of WWR. This means that the comparison between the test cells with large glazed surface is more difficult, with no real surprise.

For configuration 1 (opaque envelope) no particular difference are registered between the cellules and most of elements are in the green category, meaning that the difference between air temperature of the test cells is lower than 1°C. As a general comment the air temperature is lower for first floor test cells compared to the ground floor ones. This means that test cells in the first floor, have higher heat losses due to the presence of the roof (also visible in Fig. 6). During winter season the higher differences (yellow elements) are calculated in the comparison between north exposed test cells of the first floor (6 and 7) and south exposed test cells of ground floor (3, 4 and 5). The same consideration is valid also for autumn.

For configuration 2.1 it is possible to notice that the influence of the exposition is greater than for configuration 1. During all the seasons, results of MAEs between south exposed test cells and north test cells are greater than 2°C following in the lower category (the red one). On the contrary the comparison between north exposed test cells is possible regardless the floor i.e. test cells 1, 2, 6 and 7. For winter and autumn seasons between the test cells 4, 8 and 10, results show a medium class (yellow elements) corresponding to a medium reliability. This behavior is explained considering the lower surface exposed to outdoor of test cell 4 if compared to the corner cells. The highest value of MAE, 7.9°C, is calculated during autumn between the comparison of north test cells (6 and 7) and the south exposed test cell 4. For all the configurations south exposed test cells during autumn present a largely higher temperature than the north ones, this means that the solar heat gains are higher due to the lower angle of the sun.

For configuration 2.2 and 2.3 the same considerations outlined for configuration 2.1 are still valid, but the MAEs values are higher.

As far as it regards the configuration 3 the representation in matrix is not possible because actually the comparison is only between two spaces: the south open space at the ground floor and the south open space at the first floor. The comparison is shown in Fig. 7 and a good reliability is calculated during all the seasons.
Lastly an aggregate representation of the results are reported in Table 3 showing the average MAEs for autumn, the most critical season, and for summer. It is possible to notice that the higher values of MAEs are calculated for south exposed test cells than the north ones. Results present good reliability also for configuration 2.3

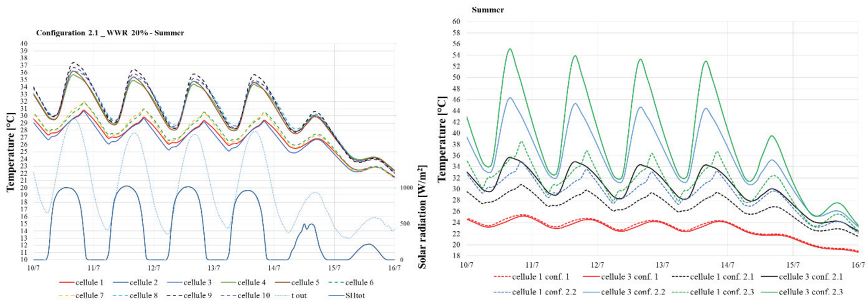


Fig. 6. Indoor air temperature trend in each test cells with boundary condition (solar radiation on the horizontal plane and outdoor air temperature). Configuration 2.1 summer season (left).

Configuration 1 -Winter (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.1	0.6	0.6	0.5	0.7	0.7	0.4	0.4	0.4
2	0.1		0.5	0.6	0.5	0.8	0.7	0.6	0.5	0.6
3	0.6	0.5		0.1	0.1	1.2	1.3	0.7	0.8	0.8
4	0.6	0.6	0.1		0.1	1.3	1.3	0.8	0.8	0.8
5	0.5	0.5	0.1	0.1		1.2	1.2	0.7	0.8	0.5
6	0.7	0.8	1.2	1.3	1.2		0.1	0.5	0.5	0.5
7	0.7	0.7	1.3	1.3	1.2	0.1		0.5	0.5	0.5
8	0.4	0.6	0.7	0.8	0.7	0.5	0.5		0.1	0.1
9	0.4	0.5	0.8	0.8	0.8	0.5	0.5	0.1		0.1
10	0.4	0.6	0.8	0.8	0.5	0.5	0.5	0.1	0.1	

Configuration 1 - Spring (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.4	0.3	0.4	0.2	0.3	0.3	0.6	0.4	0.6
2	0.4		0.5	0.3	0.5	0.6	0.6	1.0	0.7	1.0
3	0.3	0.5		0.3	0.1	0.4	0.4	0.5	0.3	0.6
4	0.4	0.3	0.3		0.4	0.6	0.6	0.8	0.6	0.9
5	0.2	0.5	0.1	0.4		0.4	0.4	0.5	0.3	0.4
6	0.3	0.6	0.4	0.6	0.4		0.1	0.4	0.2	0.4
7	0.3	0.6	0.4	0.6	0.4	0.1		0.4	0.3	0.4
8	0.6	1.0	0.5	0.8	0.5	0.4	0.4		0.3	0.1
9	0.4	0.7	0.3	0.6	0.3	0.2	0.3	0.3		0.3
10	0.6	1.0	0.6	0.9	0.4	0.4	0.4	0.1	0.3	

Configuration 1 - Summer (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.4	0.3	0.7	0.3	0.2	0.2	0.3	0.3	0.3
2	0.4		0.3	0.3	0.3	0.6	0.5	0.7	0.4	0.7
3	0.3	0.3		0.4	0.2	0.4	0.5	0.5	0.3	0.6
4	0.7	0.3	0.4		0.5	0.8	0.8	0.9	0.5	1.0
5	0.3	0.3	0.2	0.5		0.5	0.4	0.5	0.3	0.3
6	0.2	0.6	0.4	0.8	0.5		0.2	0.2	0.3	0.2
7	0.2	0.5	0.5	0.8	0.4	0.2		0.3	0.3	0.2
8	0.3	0.7	0.5	0.9	0.5	0.2	0.3		0.4	0.2
9	0.3	0.4	0.3	0.5	0.3	0.3	0.3	0.4		0.5
10	0.3	0.7	0.6	1.0	0.3	0.2	0.2	0.2	0.5	

Configuration 1 -Autumn (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.2	0.5	0.4	0.4	0.6	0.6	0.3	0.3	0.3
2	0.2		0.6	0.4	0.5	0.5	0.5	0.4	0.4	0.4
3	0.5	0.6		0.1	0.1	1.0	1.1	0.6	0.7	0.6
4	0.4	0.4	0.1		0.1	0.9	0.9	0.5	0.6	0.5
5	0.4	0.5	0.1	0.1		1.0	1.1	0.6	0.7	0.5
6	0.6	0.5	1.0	0.9	1.0		0.1	0.5	0.4	0.5
7	0.6	0.5	1.1	0.9	1.1	0.1		0.5	0.4	0.5
8	0.3	0.4	0.6	0.5	0.6	0.5	0.5		0.2	0.1
9	0.3	0.4	0.7	0.6	0.7	0.4	0.4	0.2		0.1
10	0.3	0.4	0.6	0.5	0.5	0.5	0.5	0.1	0.1	

Configuration 2.1 -Winter (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.2	6.5	7.1	6.5	0.5	0.5	5.7	6.3	5.7
2	0.2		6.4	7.0	6.4	0.6	0.6	5.6	6.2	5.6
3	6.5	6.4		0.6	0.1	7.0	7.0	0.8	0.7	0.8
4	7.1	7.0	0.6		0.6	7.6	7.6	1.4	0.8	1.4
5	6.5	6.4	0.1	0.6		7.0	7.0	0.8	0.6	0.8
6	0.5	0.6	7.0	7.6	7.0		0.1	6.2	6.7	6.2
7	0.5	0.6	7.0	7.6	7.0	0.1		6.2	6.7	6.2
8	5.7	5.6	0.8	1.4	0.8	6.2	6.2		0.6	0.1
9	6.3	6.2	0.7	0.8	0.6	6.7	6.7	0.6		0.6
10	5.7	5.6	0.8	1.4	0.8	6.2	6.2	0.1	0.6	

Configuration 2.1 - Spring (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.2	5.4	5.8	5.4	0.5	0.5	5.6	6.0	5.6
2	0.2		5.5	5.9	5.6	0.6	0.7	5.8	6.2	5.8
3	5.4	5.5		0.5	0.1	4.9	4.9	0.3	0.7	0.4
4	5.8	5.9	0.5		0.4	5.3	5.3	0.5	0.4	0.5
5	5.4	5.6	0.1	0.4		4.9	4.9	0.3	0.7	0.3
6	0.5	0.6	4.9	5.3	4.9		0.1	5.1	5.6	5.2
7	0.5	0.7	4.9	5.3	4.9	0.1		5.1	5.5	5.2
8	5.6	5.8	0.3	0.5	0.3	5.1	5.1		0.5	0.1
9	6.0	6.2	0.7	0.4	0.7	5.6	5.5	0.5		0.4
10	5.6	5.8	0.4	0.5	0.3	5.2	5.2	0.1	0.4	

Configuration 2.1 -Summer (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.3	3.3	3.6	3.4	0.4	0.5	3.6	3.9	3.7
2	0.3		3.5	3.8	3.6	0.6	0.7	3.7	4.1	3.8
3	3.3	3.5		0.4	0.2	2.9	2.9	0.4	0.6	0.4
4	3.6	3.8	0.4		0.3	3.2	3.2	0.5	0.4	0.5
5	3.4	3.6	0.2	0.3		3.0	3.0	0.4	0.6	0.4
6	0.4	0.6	2.9	3.2	3.0		0.2	3.2	3.5	3.2
7	0.5	0.7	2.9	3.2	3.0	0.2		3.1	3.4	3.2
8	3.6	3.7	0.4	0.5	0.4	3.2	3.1		0.4	0.2
9	3.9	4.1	0.6	0.4	0.6	3.5	3.4	0.4		0.3
10	3.7	3.8	0.4	0.5	0.4	3.2	3.2	0.2	0.3	

Configuration 2.1 -Autumn (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.2	7.0	7.6	7.0	0.4	0.4	6.3	6.9	6.3
2	0.2		7.0	7.5	6.9	0.5	0.4	6.3	6.8	6.2
3	7.0	7.0		0.6	0.1	7.3	7.3	0.7	0.6	0.7
4	7.6	7.5	0.6		0.6	7.9	7.9	1.3	0.7	1.3
5	7.0	6.9	0.1	0.6		7.3	7.3	0.7	0.6	0.7
6	0.4	0.5	7.3	7.9	7.3		0.1	6.6	7.2	6.6
7	0.4	0.4	7.3	7.9	7.3	0.1		6.7	7.2	6.6
8	6.3	6.3	0.7	1.3	0.7	6.6	6.7		0.6	0.1
9	6.9	6.8	0.6	0.7	0.6	7.2	7.2	0.6		0.6
10	6.3	6.2	0.7	1.3	0.7	6.6	6.6	0.1	0.6	

Configuration 2.2 -Winter (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.2	8.4	9.1	8.4	0.4	0.4	7.8	8.4	7.7
2	0.2		8.3	9.0	8.3	0.5	0.5	7.6	8.3	7.6
3	8.4	8.3		0.7	0.1	8.8	8.8	0.7	0.8	0.7
4	9.1	9.0	0.7		0.7	9.4	9.4	1.3	0.7	1.4
5	8.4	8.3	0.1	0.7		8.7	8.7	0.7	0.8	0.7
6	0.4	0.5	8.8	9.4	8.7		0.1	8.1	8.7	8.1
7	0.4	0.5	8.8	9.4	8.7	0.1		8.1	8.7	8.1
8	7.8	7.6	0.7	1.3	0.7	8.1	8.1		0.7	0.1
9	8.4	8.3	0.8	0.7	0.8	8.7	8.7	0.7		0.7
10	7.7	7.6	0.7	1.4	0.7	8.1	8.1	0.1	0.7	

Configuration 2.2 - Spring (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.3	8.2	8.9	8.3	0.6	0.6	8.4	9.1	8.4
2	0.3		8.3	8.9	8.3	0.6	0.7	8.5	9.1	8.5
3	8.2	8.3		0.8	0.1	7.7	7.6	0.3	1.0	0.3
4	8.9	8.9	0.8		0.8	8.3	8.3	0.8	0.3	0.8
5	8.3	8.3	0.1	0.8		7.7	7.7	0.3	0.9	0.3
6	0.6	0.6	7.7	8.3	7.7		0.1	7.8	8.5	7.8
7	0.6	0.7	7.6	8.3	7.7	0.1		7.8	8.5	7.8
8	8.4	8.5	0.3	0.8	0.3	7.8	7.8		0.8	0.1
9	9.1	9.1	1.0	0.3	0.9	8.5	8.5	0.8		0.8
10	8.4	8.5	0.3	0.8	0.3	7.8	7.8	0.1	0.8	

Configuration 2.2 -Summer (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.3	5.9	6.5	6.0	0.6	0.6	6.1	6.7	6.1
2	0.3		6.0	6.5	6.0	0.6	0.6	6.1	6.7	6.2
3	5.9	6.0		0.8	0.2	5.4	5.4	0.3	0.9	0.3
4	6.5	6.5	0.8		0.7	6.0	5.9	0.8	0.3	0.7
5	6.0	6.0	0.2	0.7		5.5	5.4	0.4	0.9	0.3
6	0.6	0.6	5.4	6.0	5.5		0.2	5.6	6.2	5.6
7	0.6	0.6	5.4	5.9	5.4	0.2		5.5	6.1	5.6
8	6.1	6.1	0.3	0.8	0.4	5.6	5.5		0.8	0.2
9	6.7	6.7	0.9	0.3	0.9	6.2	6.1	0.8		0.7
10	6.1	6.2	0.3	0.7	0.3	5.6	5.6	0.2	0.7	

Configuration 2.2 - Autumn (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.2	9.6	10.3	9.6	0.3	0.4	9.0	9.7	9.0
2	0.2		9.5	10.3	9.5	0.4	0.4	8.9	9.6	8.9
3	9.6	9.5		0.8	0.1	9.9	9.9	0.6	0.9	0.7
4	10.3	10.3	0.8		0.8	10.6	10.6	1.4	0.7	1.4
5	9.6	9.5	0.1	0.8		9.8	9.8	0.6	0.9	0.6
6	0.3	0.4	9.9	10.6	9.8		0.1	9.2	9.9	9.2
7	0.4	0.4	9.9	10.6	9.8	0.1		9.2	9.9	9.2
8	9.0	8.9	0.6	1.4	0.6	9.2	9.2		0.8	0.1
9	9.7	9.6	0.9	0.7	0.9	9.9	9.9	0.8		0.8
10	9.0	8.9	0.7	1.4	0.6	9.2	9.2	0.1	0.8	

Configuration 2.3 -Winter (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.2	10.7	11.4	10.7	0.4	0.4	10.1	10.8	10.1
2	0.2		10.6	11.3	10.5	0.5	0.5	10.0	10.7	9.9
3	10.7	10.6		1.0	0.1	11.0	11.0	0.6	1.2	0.6
4	11.4	11.3	1.0		1.1	11.7	11.7	1.4	0.7	1.4
5	10.7	10.5	0.1	1.1		10.9	10.9	0.6	1.2	0.6
6	0.4	0.5	11.0	11.7	10.9		0.1	10.3	11.1	10.3
7	0.4	0.5	11.0	11.7	10.9	0.1		10.4	11.1	10.3
8	10.1	10.0	0.6	1.4	0.6	10.3	10.4		1.1	0.1
9	10.8	10.7	1.2	0.7	1.2	11.1	11.1	1.1		1.1
10	10.1	9.9	0.6	1.4	0.6	10.3	10.3	0.1	1.1	

Configuration 2.3 -Spring (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.4	10.4	11.1	10.4	0.7	0.7	10.5	11.2	10.5
2	0.4		10.4	11.1	10.4	0.6	0.6	10.4	11.2	10.5
3	10.4	10.4		1.3	0.1	9.8	9.7	0.3	1.3	0.3
4	11.1	11.1	1.3		1.2	10.5	10.5	1.3	0.3	1.2
5	10.4	10.4	0.1	1.2		9.8	9.7	0.3	1.3	0.3
6	0.7	0.6	9.8	10.5	9.8		0.1	9.8	10.6	9.8
7	0.7	0.6	9.7	10.5	9.7	0.1		9.8	10.6	9.8
8	10.5	10.4	0.3	1.3	0.3	9.8	9.8		1.3	0.1
9	11.2	11.2	1.3	0.3	1.3	10.6	10.6	1.3		1.2
10	10.5	10.5	0.3	1.2	0.3	9.8	9.8	0.1	1.2	

Configuration 2.3 - Summer (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.5	7.6	8.3	7.6	0.7	0.8	7.6	8.4	7.7
2	0.5		7.5	8.2	7.5	0.6	0.6	7.6	8.3	7.6
3	7.6	7.5		1.2	0.2	7.0	6.9	0.3	1.3	0.3
4	8.3	8.2	1.2		1.1	7.7	7.7	1.3	0.3	1.1
5	7.6	7.5	0.2	1.1		7.0	7.0	0.3	1.2	0.3
6	0.7	0.6	7.0	7.7	7.0		0.2	7.0	7.8	7.0
7	0.8	0.6	6.9	7.7	7.0	0.2		7.0	7.7	7.0
8	7.6	7.6	0.3	1.3	0.3	7.0	7.0		1.3	0.2
9	8.4	8.3	1.3	0.3	1.2	7.8	7.7	1.3		1.2
10	7.7	7.6	0.3	1.1	0.3	7.0	7.0	0.2	1.2	

Configuration 2.3 -Autumn (MAE)

	1	2	3	4	5	6	7	8	9	10
1		0.3	12.2	12.9	12.1	0.4	0.4	11.6	12.3	11.5
2	0.3		12.0	12.8	12.0	0.4	0.3	11.4	12.2	11.4
3	12.2	12.0		1.2	0.1	12.3	12.3	0.6	1.4	0.6
4	12.9	12.8	1.2		1.2	13.0	13.1	1.5	0.6	1.5
5	12.1	12.0	0.1	1.2		12.2	12.2	0.6	1.3	0.6
6	0.4	0.4	12.3	13.0	12.2		0.1	11.7	12.4	11.6
7	0.4	0.3	12.3	13.1	12.2	0.1		11.7	12.4	11.6
8	11.6	11.4	0.6	1.5	0.6	11.7	11.7		1.3	0.1
9	12.3	12.2	1.4	0.6	1.3	12.4	12.4	1.3		1.2
10	11.5	11.4	0.6	1.5	0.6	11.6	11.6	0.1	1.2	

Configuration 3 – Winter (MAE)	Configuration 3 – Spring (MAE)	Configuration 3 – Summer (MAE)	Configuration 3 – Autumn (MAE)
0.4	0.2	0.2	0.5

MAE $_{n,n+1}$ > 2 °C		1 °C < MAE $_{n,n+1}$ < 2 °C		0 °C < MAE $_{n,n+1}$ < 1 °C	

Fig. 7 Simulation results, for different configurations and seasons.

Table 3. Aggregate results of the simulations. Average value of MAEs, for south and north exposed cellules, for autumn and summer season.

	Autumn - South MAE [°C]	*Autumn - North* MAE [°C]	*Summer - South* MAE [°C]	*Summer - North* MAE [°C]
Configuration 1	0.4	0.4	0.5	0.4
Configuration 2.1	0.7	0.3	0.4	0.4
Configuration 2.2	0.7	0.3	0.6	0.5
Configuration 2.3	0.9	0.3	0.8	0.6

4. Discussion of the characterization protocol and future steps in FACT

In the previous paragraph the preliminary results of a simulation activity on FACT are analyzed and discussed. The results show that for some configurations, the MAEs of the indoor air temperatures between same exposed test cells, follow in a reliable class. In any case to carry out comparative evaluation between test cells, has other limitations in FACT, to be carefully evaluated during the first experimental activity, due to lateral wall effect. For instance if two test cells with same exposition are considered, the side walls of the test cells will present a different exposition i.e. test cell 5 has an east side wall and test cell 3 has a west side wall. Side walls will receive solar radiation during different time of the day, influencing the indoor surface temperature and consequently the mean radiant temperature as well as the heat and moisture transfer on the tested façade. But it is also important to underline that FACT was designed to verify in real scale the building envelope components under real conditions meaning that a guarded test cell configuration (i.e. test cell surrounded with a guarded zone, in order to reduce the energy flow of the lateral wall), suitable for comparative test, was avoided to have a test configuration closer to reality. For these reasons the experimental activity in FACT will be coupled with simulations to evaluate absolute performance of the building technologies in a calibrated test cells [13]. In any case, given the dimension of the facility, the possibility to build a box inside the box, in order to create a guarded zone, is still open for specific project.

The next steps of the research will be the validation of the preliminary simulation against experimental data. An experimental preliminary campaign will be carry out to evaluate the air tightness of the building as well as the thermal bridges by means of infrared camera measurement. Than the fixed sensors will be positioned in each test cells in order to measure the indoor environment data. At this point a characterization campaign is planned for summer - autumn season in order to evaluate the thermal properties of the different test cells. After these steps the first experimental activity will start in FACT to perform experimental measurements at different levels: the building envelope components themselves evaluating also building corner solution; the impact of these components on the energy behavior of the room and the building; the indoor environmental quality: thermal, visual comfort and indoor air quality.

Building envelope tests can be carried out measuring: heat and mass transfer in the tested envelope; light and solar transmission for transparent envelope: to avoid the influence of the structure on the transmitted radiation, it can be removed as schematically showed in Fig.8; the efficiency of PV or thermal collector integrated in façade.

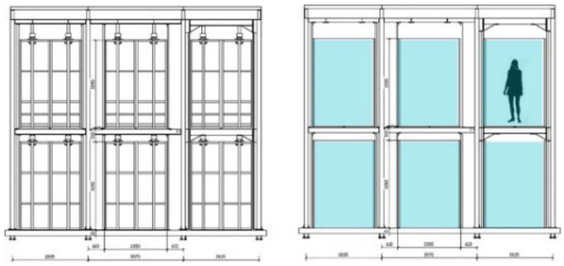


Fig. 8. FACT south façade with metallic structure (left), south façade without metallic structure, to perform test on lightweight façade and transparent components (right).

5. Conclusion

This paper has discussed the design and the preliminary simulation of a new versatile and full-scale facility for building envelope test, FACT (FACade Tool). This new tool is a two floors building composed of 10 different test cells (9 m^2 each), and it is now under construction in south – eastern France (CEA –INES Le Bourget du Lac). The layout definition and the conception of the facility are described in the paper. A preliminary simulation activity is carried out to support the design and the main outcomes are analyzed in order to build the protocol and the working principle of the new utility. Firstly the results of the preliminary simulations showed the importance to take into consideration an equal distribution of the thermal mass in the facility structure in order to have the same dynamic response at both ground and first floor. Secondly results showed a good degree of comparison for certain test cells, but as a measurement protocol, absolute tests coupled with simulation will be used, in order to avoid the influence of lateral walls. To conclude, the aim of the facility is both to perform energy and IEQ test as well as to evaluate technically innovative building envelope solution for façade application (corner solution, floor-wall and window-wall junction), exposed to real conditions. The facility is already involved in three different European projects which will occupy a large number of test cells. In the following months FACT will be used to do field experiments on: technological solutions for building envelope aerogel based components (HomeSkin and WALL IN ONE, H2020 projects) and the integration of innovative cladding unit for buildings deep renovation (Conipher Life).

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