NANO-HVAC: Nanotechnology based approaches to increase the performance of HVAC system

Deliverable D6.1:

Full scale NANO-HVAC demonstrator in a demo building

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Executive Summary

The present document constitute Deliverable 6.1 carried out by ACCIONA in the framework of the Nano-HVAC Project entitled “Nanotechnology based approaches to increase performances of HVAC system” (Contract No.: FP7-2012-NMP-ENV-ENERGY-ICT-EeB- 314212).

The document reflects the result of activities performed within the framework of WP6 “Full scale Demo and Validation” and more specifically in Task 6.1 “Full scale demonstration in demo building”. The task has been executed by ACCIONA with the support of AIDICO and VENTO related to the ducts of NanoHVAC and Reference system and NANOPHOS associated with covering filters with photocatalytic coatings and the LED system for activating the photocatalytic coating that was developed and provided by NTUA.

FARBE provided a prototype of injectable nano-enabled polymeric coating that will be tested for antibacterial efficiency in a real condition under the Task 6.3: Validation of Strategies for pathogens and allergenic removal.

Work carried out in this task gathered all technologies and equipment developed under previous works realised in WP1, WP2, WP3, WP4 and WP5 to test them in the full scale demo building.

List of Acronyms and Abbreviations

HVAC	Heating, Ventilation, and Air Conditioning
ACCIONA	Acciona Infraestructuras, S.A.
NANOPHOS	Nanophos Commercial Societe Anonyme of Services and Development
NTUA	National Technical University of Athens
VENTO	Vento NV

1 Introduction and Scope

The main objective of this report is to present a full scale demonstrator to validate the NanoHVAC system in the demo building.

According to the DoW, the developed system was to be installed by ACCIONA in a demo commercial building. Due to technical reasons and in order to gather more complete set of results, during the Technical Project Meeting that took place in Rome on the 20th of November 2012 the NanoHVAC Partners agreed on the ACCIONA's proposal to transfer scheduled studies to the ACCIONA´s Demo Park instead of a commercial building.

This solution allowed to make possible to carry out a comparative validation test of two systems: the new one NanoHVAC and Reference traditional system in the same indoor and outdoor conditions.

This document presents the design and installation process of the NanoHVAC system and its Reference realised in two demonstration buildings located in ACCIONA Demo Park close to Madrid.

2 Mock Up Installation

The NanoHVAC system and its Reference have been installed in ACCIONA´s experimental facility located about 30 km from the center of Madrid, **Figure 1**.

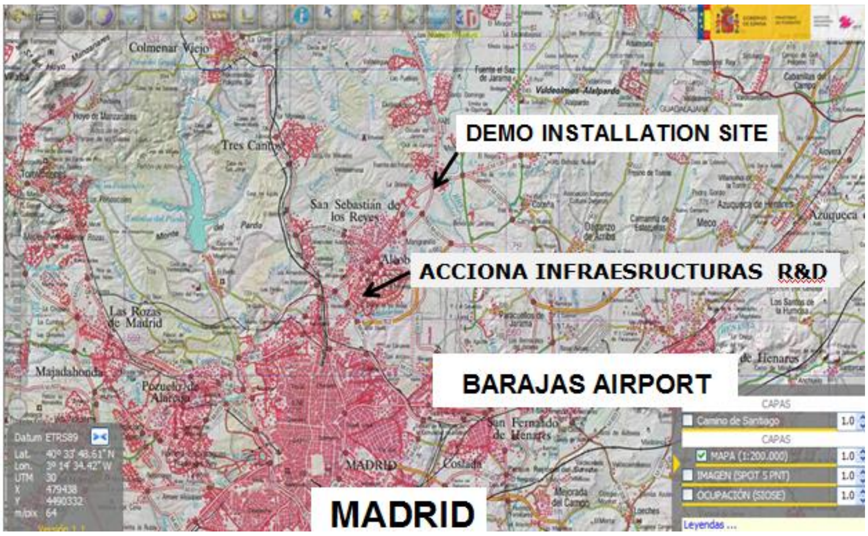

Figure 1: Location of the ACCIONA Demo Park

To carry out the goal of the task 6.1, two full-scale test-cells were installed in the ACCIONA Demo Park.

In order to avoid undesirable shadowing effects during the thermal monitoring and energy performance studies, a preliminary simulation of shadowing effects between the two demo buildings was carried out via DesignBuilder® software. In consequence it was necessary to move demo buildings and set them in a more suitable position that guarantee the same solar gains and thermal behavior in the free-floating regime before materials installation, **Figure 2**.

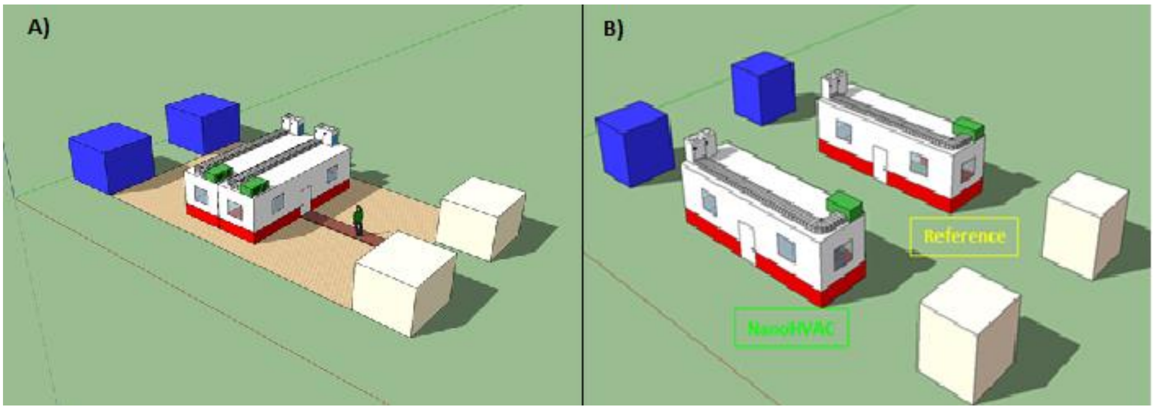

Figure 2: A) Demo buildings view before rotation B) Demo buildings view after rotation (software simulation assessment)

Dimensions of the demo buildings are presented in the **Table 1**.

Table 1: Dimensions of the demo buildings

	NanoHVAC building	REFERENCE building
Dimensions [LxWxh], [m]	7.71x2.28x2.28	7.82x2.28x2.27
Volume [m^3]	40.07	40.47

Since NanoHVAC project aims to validate NanoHVAC thermal performance through a full-scale comparative test, the two demonstrators were thermally analyzed before materials installation campaign, in order to confirm the same boundary conditions which are shared for both rooms (NanoHVAC and REFERENCE). Tests were carried out from 24.3.15 to 13.4.15 (26 days). Two Tinytag Data Loggers with a Pt100 RTD (error 0.1°C) were used for this test.

Thermal waves overlapped during the whole testing period, presenting slight differences when the statistical peak-to-peak comparison is carried out (absolute differences under 0,36°C for all relative maxima and minima). No time delays are observed, which indicates identical U-values and composition for both building envelopes (**Figure 3**).

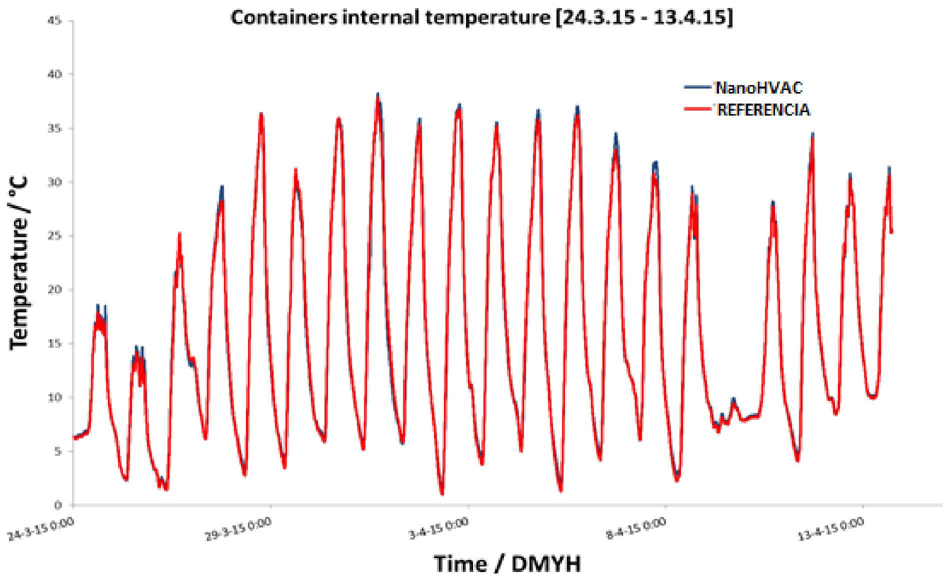

Figure 3: Thermal control of the demo buildings

Regarding calibration results, the two demo buildings can be considered identical from a thermal point of view and valid for a full scale comparative thermal analysis.

3 Installation of NanoHVAC and Reference systems

The two systems were installed according to a previously agreed scheme (Madrid Consortium Meeting 1-2.12.2014). The critical part (roof) is presented in **Figure 4**.

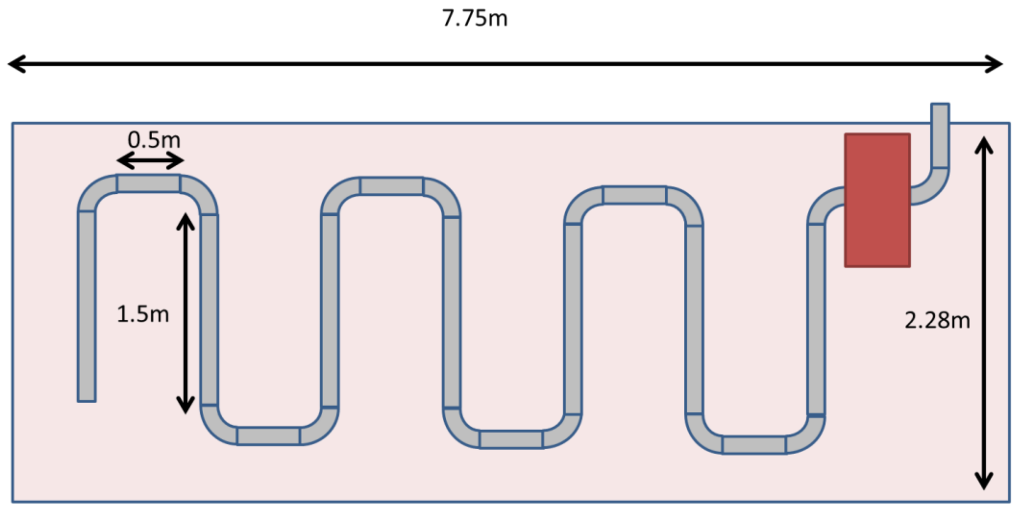

Figure 4: Geometry pipes for rooftop - "spaghetti form" for maximisation of bends

For each system, following number of items were used regarding insulated pipes and bends:

- 15 units of bends,
- 8 units of 0.5m-long tubes
- 8 units of 1.5m-long tubes

The only difference between NanoHVAC and Reference systems lies in tubes and bends insulation material. NanoHVAC pipe cross section is made - from inside to outside - of 125 mm. Aluminium tube have been covered by AIDICO insulation material (25 mm) and Air-Bur Thermic solution to protect ducts against damage related to corrosion and other external factors. Reference insulation material consists of 25mm of mineral wool covered by a metallic plate. Estimated weight on the roof is approximately 80 kg (3,5 kg/m^2 in average).

The list of equipment and assumptions for installation of two systems is presented in the following list:

- HVAC machine: DXS50F cooling unit (ducted, 1x1 system, Inverter, 5kW cooling capacity, around 1.8kWh power demand), **Figure 5**

Figure 5: Exterior HVAC machine

- Temperature range for climatization was set on 21°C. Thus, ΔT between IN and OUT is expected to be around 15°C in May/June and more than 20°C in July, when external temperature beats 40ºC (50ºC on the rooftop at midday).

In the case of the NanoHVAC system extra filter with photocatalytic coatings developed by NANOPHOS and NTUA reactor with the LED system for activating the photocatalytic coating were installed, **Figure 6** and **Figure 7**.

Figure 6: Filter covered by coating formulation developed by NANOPHOS

Figure 7: NTUA reactor

The considerable amount of elements presented in both systems, together with the small section of the tubes and the intricate geometry of the ducted system product of the maximization of bends gave rise to a system with a huge pressure drop comparing to standard HVAC systems:

- NanoPhos filter placed inside NTUA reactor (diam. 140mm) works at 180 Pa @ 150 m^3/h or 300 Pa @ 200 m^3/h
- 18 linear meters of ducts (d. 125 mm) increase the pressure drop in 18 Pa (1 Pa/m)
- 18 bends (d. 125 mm) increase the pressure drop in 72 Pa (4 Pa/bend according to datasheet)

- NTUA UVA-LED reactor (d. 135 mm, length 60 cm) increase the pressure drop in 0 Pa (aprox.)

Summary total system pressure drop added up to 270 Pa in just 20 linear meters. In order to beat such pressure drop both systems needed an extra 150W fan placed upstreams (340 Pa @200 m^3/h, 428 m^3/h MAX.) Mod. RVK + REE1 speed regulator, **Figure 8.**

Figure 8: Fan Mod. RVK with REE1 speed regulator

3.1 Reference system installation

The ducts with Rockwool insulation material were selected as a REFERENCE for further analysis.

Reference system installation was carried out according to the standards. The work is registered in the **Figures 9** - **11**.

Figure 9: Reference pipes & internal HVAC machine preparation

Figure 10: Works on rooftop (Reference bends & pipes)

Figure 11: Final scheme of ducts installation

3.2 NanoHVAC system installation

NanoHVAC system installation was carried out according to the scheme presented in the **Figure 12**.

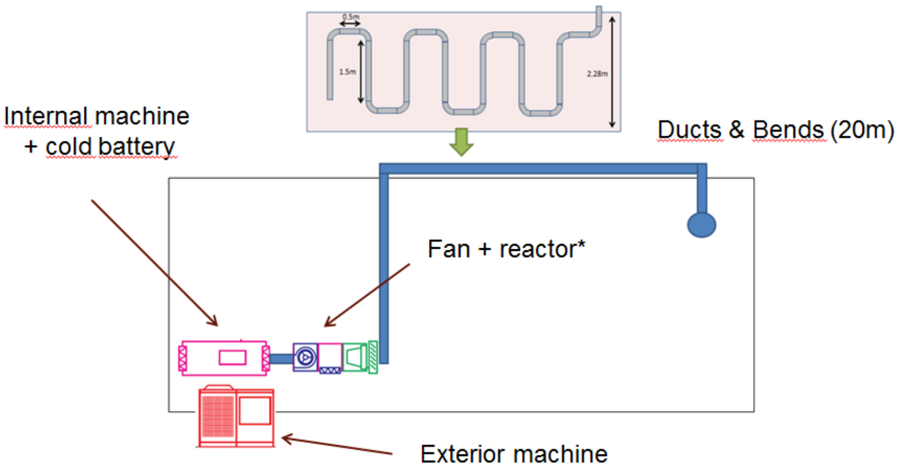

Figure 12: Scheme for installation of the NanoHVAC system

The NanoHVAC ducts arrived at ACCIONA´s demo facility in a damaged condition. Almost 40% of the NanoHVAC insulator was breakdown due to material poor mechanical properties even when it was handled with care. To fix this critical point, insulator was wrapped with Air-Bur foil.

The material covers the duct mitigating pressure effects, thus providing robustness during the installation process and protecting roof ducts and bends from environmental conditions (rain, air, radiation). The Aluminium foil counts on a reflectance of 98% (**Figure 13**).

Figure 13: 40% of the NANOHVAC insulator was damaged. Poor mechanical properties

Figure 14: Air-BUR provides enhanced robustness to the whole system

View of the NanoHVAC system installed on the roof is presented in the **Figure 15.**

Figure 15: Works on rooftop (NANOHVAC bends & pipes). Finishing touch

The overview of the NanoHVAC system installation is presented in **Figure 16**.

Figure 16: Overview of the NanoHVAC system installation

The NTUA reactor and fan devices installed in the NanoHVAC demo are shown in the **Figure 17**.

Figure 17: NanoHVAC interior machine + NTUA reactor + 180W fan

The view of the both systems inside of the demo building with the control system of the temperature is presented in **Figure 18**.

Figure 18: Interior view of both HVAC systems

In order to avoid thermal bridges and extra thermal load there was necessary to cover Western and Southern windows using aluminium foil laminate, **Figure 19**.

Figure 19: Western and Southern windows were blocked to diminish thermal load and solar gains (Northern window remained diaphanous)

In order to guarantee mirror behaviour of both installations required for further studies, it was necessary to calibrate airflow rate of both systems. When the systems reached desirable airflow rate (8.5 m/s, around 300 m^3/h), both installations were steady for the measurement of energy performance required in Task 6.2, **Figure 20**.

Figure 20: Airflow measurements

4 Fire Resistance Testing

The fire resistance test was carried out by AIDICO and is focused only on the NanoHVAC insulating material. Although this analysis doesn´t cover a fully expectation of this study without a doubt gives valuable information about the most relevant element of the whole system. Anyway it is recommended to perform this test after the end of the project.

The test of the NanoHVAC foam panels has been carried out in a smaller furnace of 3x3x3 m^3 with a normal curve of heating

$$T = 345 \log (8t + 1)$$

Where T is the temperature in Celsius degrees over the initial temperature, t is the time expressed in minutes. The temperature is measured in the not exposed face with thermocouples.

Criteria that was taken into account during the test:

- **Thermal insulation:** it is determined by the time that face not exposed to flame increase temperature until 140 ºC as average of all points measured, over the starting temperature.

Reference values
Following standard NCh 935/1 constructive elements, once exposed to fire test, are classified as a function of time duration:
- Class F0 minor than 15 minutes
- Class F15 higher or equal to 15 and lower than 30 minutes
- Class F30 higher or equal to 30 and lower than 60 minutes
- Class F60 higher or equal to 60 and lower than 90 minutes
- Class F90 higher or equal to 90 and lower than 120 minutes
- Class F120 higher or equal to 120 and lower than 150 minutes
- Class F150 higher or equal to 150 and lower than 180 minutes
- Class F180 higher or equal to 180 and lower than 240 minutes

- Class F240 higher or equal to 240 minutes

Equipment description

- The **cubic furnaces** from **Ineltec**, model HC1.5x1.5
- The mechanical construction is of modular type
- The furnace is expected to build steel exterior panels made of refractory linked together by screws
- The isolating system is done by low-density refractory bricks and ceramic fiber blanket
- It's formed by propane gas burners and low pressure modulating flame

Samples preparation

There were prepared 5 panels of formulation P15 with following thickness:

Table 2: Panels specifications

Samples	Thickness (cm)
Panel 1:	2,40
Panel 2:	2,47
Panel 3:	2,43
Panel 4:	3,13
Panel 5:	4,62
Reference panel:	4,99

NanoHVAC panels were dried at 50 ºC during 3 days.

Preconditioning of test specimens

The panels were placed at laboratory conditions over several days before be tested. There were casted 5 panels of nanoHVAC foam and one of Mineralwool in a wall of a cubic furnace of 3x3x3 m^3. The three fists were around the same thickness and the rest of a higher thickness, in order to have different values of Reference.
Each sample had two thermocouples stick in two points of not exposed face.

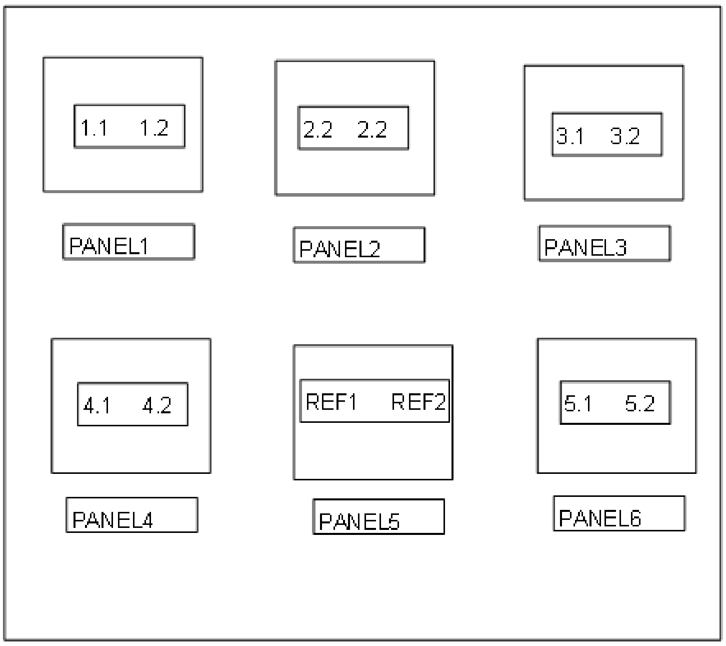

Figure 21: Panels disposal in furnace wall

Results

The test was carried out as it has been described before. The test was stopped when temperature in all the panels overcame 140 ºC.

Figure 22: Panels before test

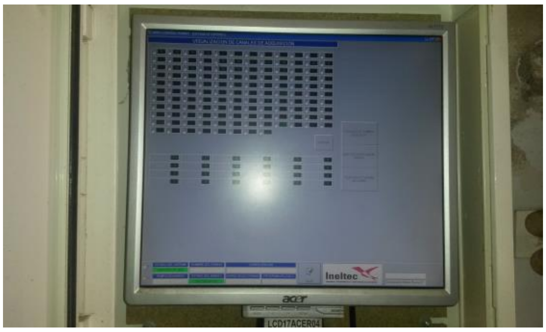

Figure 23: Data recorder

Figure 24: Panels at 15 min of test

Figure 25: Panels at 25 min of test

Figure 26: Detail of Reference panel and nanoHVAC panel with a similar thickness.

Figure 27: Panels at 30 min of test

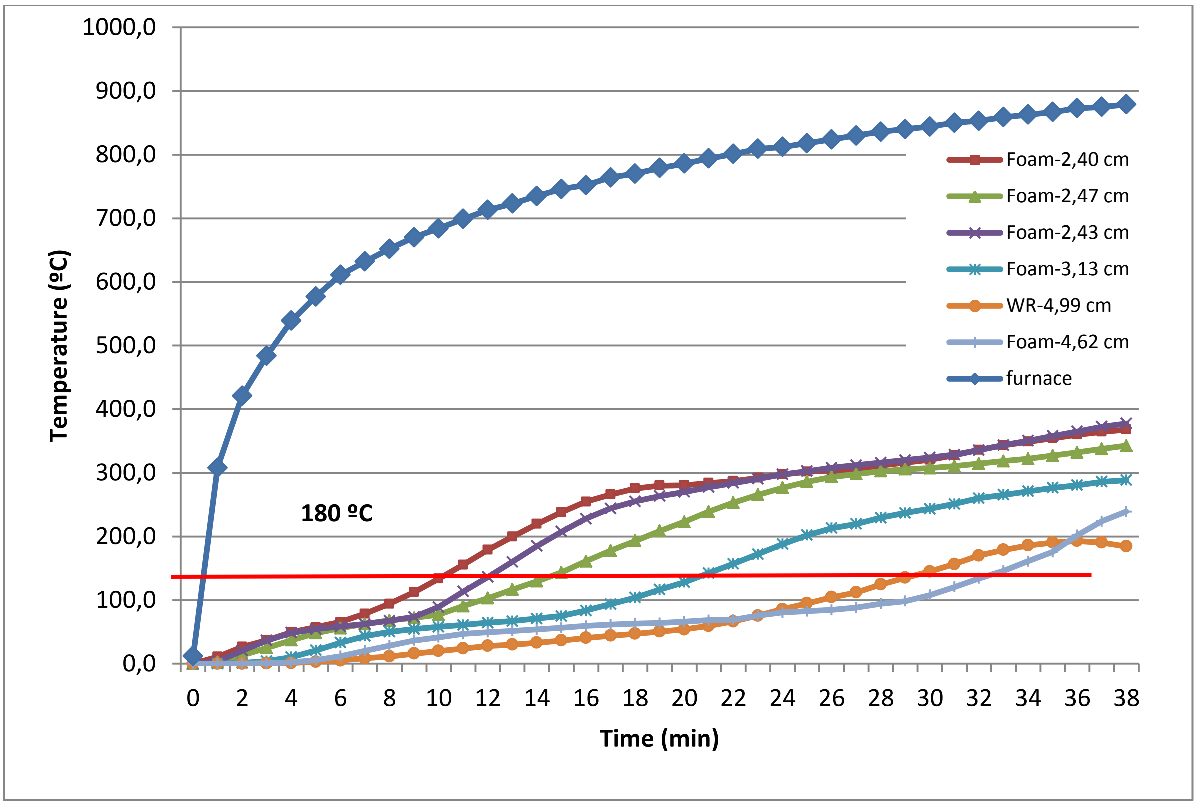

Figure 28: Temperatures curves of samples during the fire test

Table 3: Results of fire test. Time to achieve 140ºC as average of both thermocouples temperature.

Samples	Thickness (cm)	Time (140 ºC)	Class
Panel 1:	2,40	10	F0
Panel 2:	2,47	15	F15
Panel 3:	2,43	12	F15
Panel 4:	3,13	21	F15
Panel 5:	4,62	32	F30
Reference panel:	4,99	29	F15

5 Conclusions

The full scale demonstrators of the NanoHVAC and REFERENCE systems have been installed in the ACCIONA´s Demo Park close to Madrid.

Calibration of the indoor thermal conditions as well as airflow rate of both systems have been realised to prepare them for further analysis.

The fire test of the NanoHVAC insulation foam shows that similar thickness values of NanoHVAC panels present higher thermal insulation than mineral rock panels.

The FARBE's product will be sprayed inside the tubes together with foreseen testing phase of task 6.3, in order to coordinate the activities and to guarantee the operation phase to test the antibacterial properties of the system.