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D7.6. – Monitoring and evaluation of refurbishment results

Author(s):	Ignacio del Val	ACCIONA
	Araceli Gálvez	ACCIONA
	Mónica García	ACCIONA
	Jose Cubillo	ACCIONA

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Table of Contents

Summary	5
1 Abbreviations and Concepts	6
2 INTRODUCTION	7
3 works Carried out in both demo-parks (month26-month 36).....	8
3.1 Warsaw DEMOPARK Construction.....	8
3.2 Infrared scan	10
3.2.1 NANOPCM mock-up.....	10
3.2.2 REFERENCE mock-up.....	11
3.3 PUR panels installation	13
4 Monitoring System Installation	19
4.1 Measurement units and thermal sensors	19
4.1.1 Data acquisition unit Agilent 34972A	20
4.1.2 Measuring heat fluxes: Heat Flux Plates (HFP).....	21
4.1.3 Temperature: T-Type Thermocouples	24
4.1.4 Weather station and Pyranometer	27
4.2 Sensor distribution for NANOPCM and REFERENCE mock-ups at Madrid and Warsaw DEMOPARKS	28
5 Monitoring and acquisition system	33
6 Measurement Strategy	35
6.1 Stage One: from April 8 th to April 15 th	37
6.2 Stage Two: from April 26 th to April 30 th	38
6.3 Stage Three: from May 6 th to May 13 th	38
7 Results	39

7.1	Stage One: from April 8 th to April 15 th	39
7.1.1	Results for April 8th experience:	40
7.1.2	April 9 th - Apr 15 th experience:.....	41
7.2	Stage Two: April 26 th to April 30 th	44
7.3	Stage Three: from May 6 th to May 13 th	46
8	Conclusion.....	49
9	Acknowledgements	49
10	References.....	50

SUMMARY

This report is the antecessor of Deliverable 7.5 "*Refurbishment of a real apartment and office*" (M26), in which construction of Madrid DEMOPARK was detailed from the grasp, describing mock-ups and the whole infrastructure at that facility.

The Deliverable 7.6 "*Monitoring and evaluation of refurbishment results*" starts with the description of the construction of the second DEMOPARK down the line. This DEMOPARK is considered as a twin of the first, this time located in a colder zone, agreed to be in the southern Warsaw (Poland), at Mysiadlo demopark, facilities near the town of Piasezno.

The document continues with the description of the installation of the different PUR panels analysed and described in previous works for both DEMOPARKS during the last months.

Details of the monitoring system installation are also fully related: thermal sensors used, principles of work, installation procedure into the mock-ups and finally the coupling with the Data Logging system. Acquisition interfaces and efforts done to design a remote control access are detailed right after.

Last chapters are devoted to describe the measurement strategy carried out during the third weeks of April, in which temperature resembled a typical pre-summer week (peaks around 30°C in the morning).

Finally, thermal results from the comparative system are discussed, as well as some safety issues regarding the experience acquired in the installation of the PUR panels.

1 ABBREVIATIONS AND CONCEPTS

NANOPCM	New Advanced Insulation Phase Change Materials
PCM	Phase Change Materials
Mock-up	Demonstration building constructed for the project within the demo-park implemented by the Nano E2B Cluster. It is refurbished with NanoPCM panels
DEMOPARK	Park used for demonstration of developed advanced materials. It was constructed within the Nano E2B cluster. There are two demo-parks: one placed in Warsaw (Poland) and other one in Madrid (Spain)
NANOPCM PUR panels	Mock-up refurbished with NANOPCM PUR panels
PUR	Rigid polyurethane panels
NANOPCM PUR panels	PUR panels without PCMs
Standard PUR panels	PUR panels with PCMs
NANOPCM mock-up	Mock-up refurbished with NANOPCM PUR panels
REFERENCE mock-up	Mock-up refurbished with Standard PUR panels
COOLCOVERINGS	Project developed within the FP7 program involved in the NanoE2B Cluster
NanoInsulate	Project developed within the FP7 program involved in the NanoE2B Cluster
NanoFoam	Project developed within the FP7 program involved in the NanoE2B Cluster
Hipin	Project developed within the FP7 program involved in the NanoE2B Cluster
AeroCoins	Project developed within the FP7 program involved in the NanoE2B Cluster

2 INTRODUCTION

The demonstration activity is one of the most important works within the NanoPCM project because the solutions found at lab scale can be implemented at building level. That way, the results show the differences between the expected values and the real ones. Consequently, the performance of the NanoPCM products will be registered during the time.

Additionally, as mentioned in the deliverable 7.5 "Refurbishment of a real apartment and office", the products will be tested under two different climates with the purpose of covering the entire European weather profile.

The materials developed within the WP2 and WP3 have been implemented in WP6 by the construction of different prototypes. After extracting thermal conclusions in WP4, the selection was carried out and the panels were installed in both demonstration parks. The acquired experience is reported here.

Then, that report will contribute to different Workpackages, such as WP8 "Dissemination and exploitation plan" in terms of exploitation of the NanoPCM products and dissemination of project results; WP 5 "LCA, recycling, cost analysis and safety" in relation to the cost benchmarking as the energy saves will be registered and the saves in energy costs could be calculated automatically.

On the other hand, the demonstration phase has been developed in the context of the NanoE2B Cluster, implemented by 6 projects from the FP7 program (NanoPCM, CoolCoverings, AeroCoins, NanoInsulate, Hipin and NanoFoam). In relation to the demonstration activities, 4 projects are present in the Spanish demo-park (NanoPCM, CoolCoverings, NanoInsulate and AeroCoins) while 2 are currently working in the Polish one (NanoPCM and NanoInsulate). It is expected that other projects could join soon.

3 WORKS CARRIED OUT IN BOTH DEMO-PARKS (MONTH 26-MONTH 36)

This first point shows the works undertaken at Madrid and Warsaw DEMOPARKS since the presentation of the previous Deliverable "D7.5 Refurbishment of a real apartment and office" (M26), in which the construction of Madrid DEMOPARK was described thoroughly from the grasp.

From month 26, the consortium has continued working in the demonstration of the thermal performance of the NanoPCM products. The following pages report mainly the construction of the Warsaw DEMOPARK and the materials installation at Madrid and Warsaw DEMOPARKS.

Warsaw DEMOPARK Construction

The works were developed from Dec 12th to Dec 22th 2012 near Piaseczno town, around 15 km South from Warsaw centrum (coordinates 52° 4' 0" N, 21° 1' 0" E).

Two mock-ups were built: first one (called NANOPCM Mock-up) was refurbished with NANOPCM PUR panels, whereas the second one (called STANDARD Mock-up, mirror of the first) was refurbished with STANDARD PUR panels, following with the idea of comparing thermal data from a symmetric couple of real-scale buildings equipped to check out thermal differences between them in order to measure energy efficiency of developed materials.

The result is shown in **Figure 1**. As explained in the Deliverable 7.5, the structure, dimensions and characteristics of demo-buildings constructed in the Mysiadlo demo-park is totally similar to the mock-ups installed in the Spanish demo-park.

The electric and ventilation system installation was undertaken for both mock-ups following the guidelines described in D7.5. Regarding the electric

installation, each mock-up was equipped with one Electronic Differential of 25A and 2 Magneto-thermal switches (16 & 10A), that manage the 220V / 50 Hz current from the power source (see **Figure 2**). With this installation, each mock-up can hold up around 2000W, enough to cope with Data Acquisition System (sensors, multiplexer and Data logger), internal illumination and some punctual extra devices as for example a little heating machine (1000W), in case it is needed.

Regarding ventilation system, holes were done to install the fan in the right top corner of the North façade (external and internal) and the grilles (in the bottom left corner of the North façade), completing the output/input ventilation system. A speed regulator was added, so as to control the air flux of the fan.



Figure 1 Warsaw DEMOPARK at MOSTOSTAL facilities near Piaseczno (Warsaw), ended up by Dec. 15th. On the right, NANOPCM Mock-up; STANDARD Mock-up on the left.



Figure 2 Electrical fitting-out at NANOPCM Mock-up.

Up to the present day, because external temperatures are very low, fan system is switched off and grilles have been covered so as not to let the air come inside the mock-up.

Infrared scan

By November 7th 2012, an Infrared Analysis of Madrid NANOPCM and REFERENCE naked mock-ups (still uncoated with the PUR panels) was done so as to check if thermal bridges were present. Then, future problems can be avoided such as mistakes while monitoring.

A FLIR B425 visible/infrared camera was used to see in the IR spectrum. The camera has zoom limitations inside small rooms, so panoramic images of the inner walls were unviable. Nevertheless, after a scan of the whole surface, details of the critical points were registered in order to get information about optimal zones for sensor installation, avoiding hotspots. Zoom was fixed at its minimum and sensibility $\pm\Delta T$ adjusted at 0.1°C.

3.1.1 NANOPCM mock-up

Window/wall (**Figure 3**), door/wall (**Figure 4**) and fan/wall interfaces were clear and no hotspots were found. Temperature was homogeneous in every wall and on the rooftop, despite some hotspots that do not correspond with any screw or knock on the wall, so problem could be motivated by internal impacts. This situation was revealed not only on the SW corner but also on the SE corner. Despite this, the rest of the wall surface was homogeneous.

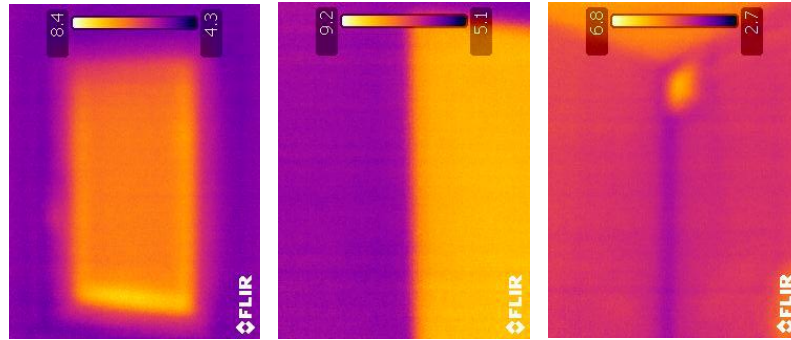


Figure 3 Thermal pictures from the mock-ups

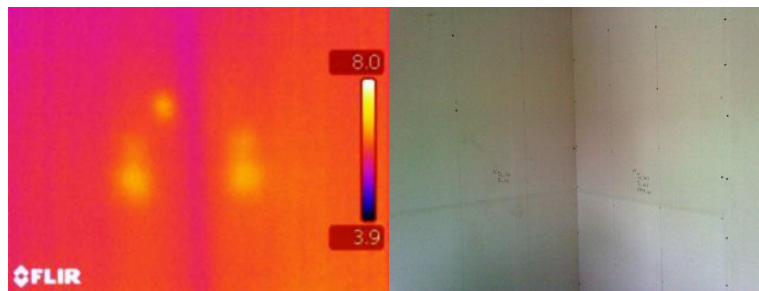
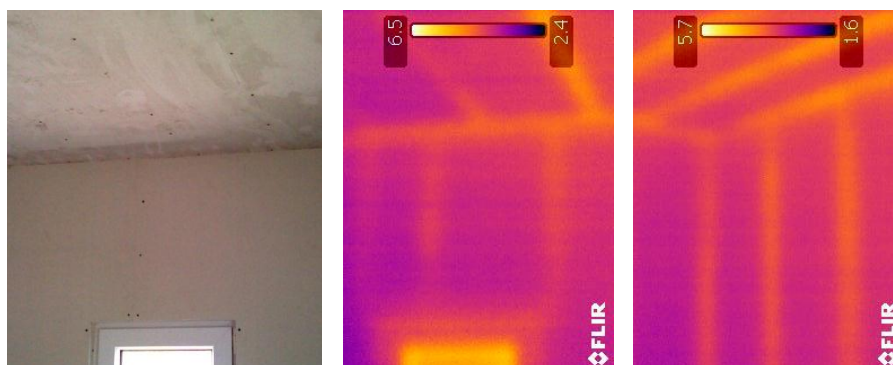


Figure 4 Hotspots on SW corner, at 0.75 m high.

Those thermal pictures were really useful in the installation of sensors. The monitoring system was allocated avoiding the thermal bridges.

3.1.2 REFERENCE mock-up

No thermal bridges were found on the window/wall and door/wall interfaces. In this case, joints between structural plasterboards were eye-catching (ΔT around 4°C), as it can be seen in **Figure 5**. This situation is the same for all of the joints.



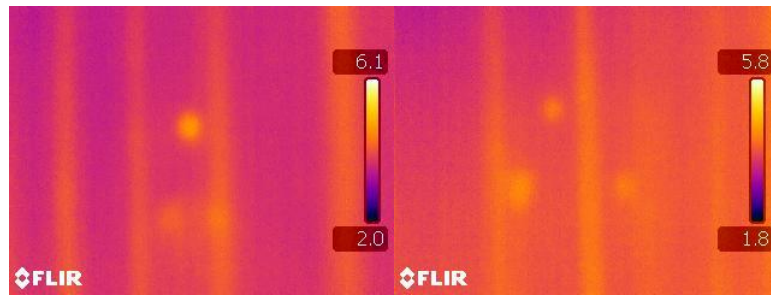


Figure 5 Thermal pictures from mock-ups

In this case, as it can be seen in the picture above, hotspots are spread at random on every wall, and once again do not correspond with any visible source.

As the other case above, the thermal bridges were avoided, so not influence is collected by sensors.

The next picture presents the aspect of Madrid DEMOPARK by Apr 22th 2013. As observed in the picture, other demo-buildings are testing different materials within the Cool-Coverings project.



Figure 6 Madrid DEMOPARK by Apr 20th 2013.

PUR panels installation

Full panels installation was undertaken for both DEMOPARKS. For that, encapsulated PCMs developed in WP2 and WP3 were used as well as the PU system optimized in WP6:

- NANOPCM Madrid mock-up was refurbished with PUR panels doped with LDPE-EVA micro-capsules confining RT27® on the walls ($T_m=27^\circ\text{C}$) and PUR panels doped with SiO₂ microcapsules containing Octadecane on the roof ($T_m=27.67^\circ\text{C}$). STANDARD mock-up was refurbished with Standard PUR panels.
- At Warsaw, NANOPCM mock-up was refurbished with PUR panels doped with LDPE-EVA micro-capsules confining RT27® on the walls ($T_m=27^\circ\text{C}$) and PUR panels doped with SiO₂ microcapsules containing a mix of fatty acids on the roof ($T_m=19^\circ\text{C}$). STANDARD mock-up was refurbished with Standard PUR panels.

All this data was previously explained in D.7.4 "*NanoPCM materials production and incorporation to insulation components*" (M30).

A visual summing up is shown in **Figure 7**.

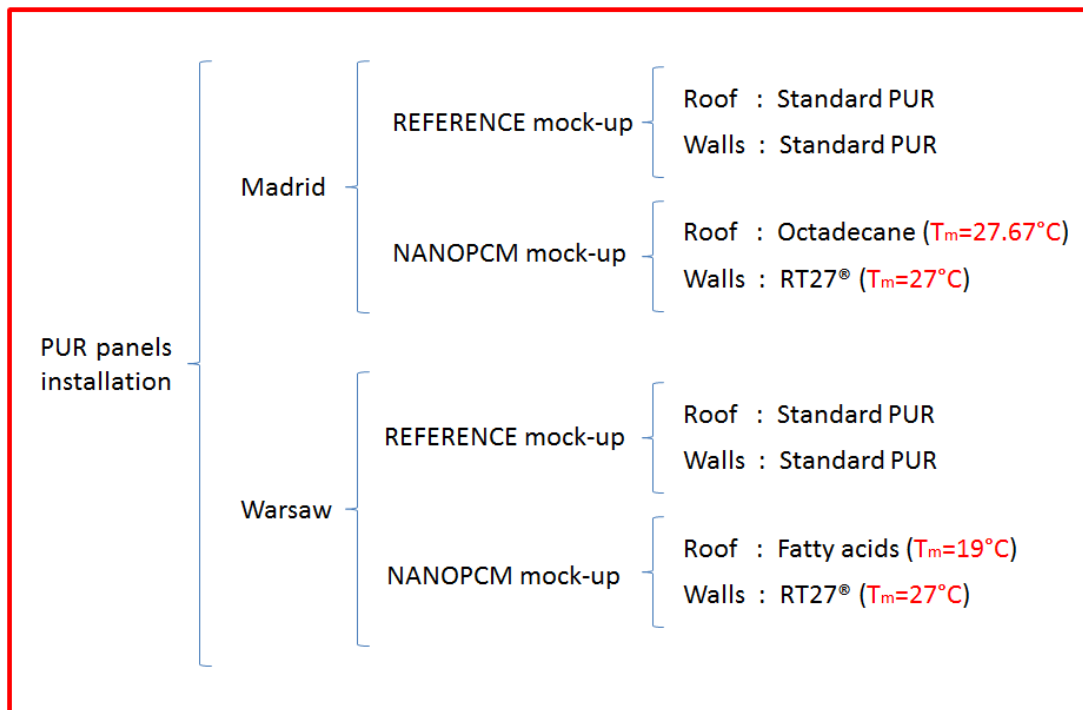


Figure 7 Panels installation overview.


All NANOPCM panels have a 10% of PMCs in their bosom. Additionally, some nanoparticles were added to improve their thermal properties such as nanoSiO_2 in the case of the panels installed on walls. Next pictures offer examples of the installation process.

Panels were stuck using silicone (silicon gun). Because extreme low temperatures at Warsaw, a tanned was done during the night, using a heating machine at 1000W regime.

Some difficulties arose mainly because of:

- Differences in size and thickness for NANOPCM mock-up panels.
- Safety issues: during the installation, a lot of dust came off the panel's surface. This dust is highly irritant for eye's conjunctiva and also for the throat, even wearing suitable protection equipment. Because of it, safety cloths were used during the installation such as gloves, glasses, mask

and overalls. Additionally, the safety sheets were taken into account such as silicone glue or common glue.


Technologies
 página 1 de 1

Nº SDB: 164824
 Revisión: 25.04.2008
 Fecha de impresión: 07.03.2007

5368 ADHESIVO SELLADOR N.310ML

1. Identificación de la sustancia o preparado y de la sociedad o empresa

Nombre comercial: 5368 ADHESIVO SELLADOR N.310ML.
 Uso previsto: sellador de silicona
 Designación de la empresa: Henkel AG&Co, Standort Henkelberg, 49113 Henkelberg, Teléfono: +49 (0)231 79010, Fax: +49 (0)231 792243, Alemania
 Información de emergencias: +353-1-490501/+353-87-202625/+33-1-494644

2. Composición / datos sobre los componentes

Descripción química general: Silicona de curado acetato
 Declaración de componentes según la Directiva 91/269/CEE:

Ingresos peligrosos	REACH	contenido	Clasificación
no tiene de sustancia 4212-54-3	229-221-9	1 - 5 %	R11 C - Corrosivo: 234 la "Nostr. R23"

3. Posibles peligros del producto

No clasificado como peligroso

4. Medidas de primeros auxilios

Inhalación: Sacar al aire libre. Si persisten los síntomas buscar asistencia médica
 Contacto de la piel: Lavar con agua corriente y jabón. Si la irritación persiste consultar a un médico
 Contacto con los ojos: Lavar bajo agua corriente (durante 10 min), acudir al médico.

página 2 de 2

Nº SDB: 164824 V001.0 5368 ADHESIVO SELLADOR N.310ML

Ingerción: No provocar vómitos. Consultar con un médico.

5. Medidas para la lucha contra incendios

Extintor apropiado: Espuma de carbono, espuma, polvo. Niebla de agua.
 Equipo de protección especial para el personal de lucha contra incendios: Llevar puesta protección respiratoria independiente del aire ambiente.
 Formación de productos de combustión o gases: óxidos de carbono, Emulsión de silice, Formaldehído.
 Indicaciones adicionales: En caso de incendio, extinguir con agua pulverizada.

6. Medidas en caso de liberación imprevista

Medidas de precaución personal: Evitar el contacto con los ojos y la piel. Proporcionar ventilación y extracción de aire suficientes.
 Medidas medio ambientales: No dejar que el producto entre en el sistema de alcantarillado.
 Procedo para la limpieza y la recogida: Poner la mayor cantidad de material posible. Proporcionar ventilación y extracción de aire suficientes. Conservarlo en un contenedor cerrado, parcialmente lleno, hasta su eliminación.

7. Manejo y almacenamiento

Manejo: Utilizarse solo en zonas bien ventiladas. Se debe evitar los vapores para evitar inhalación.
 Almacenamiento: Guardar el recipiente en un lugar fresco, bien ventilado. Se recomienda que el producto no tenga contacto con agua durante su almacenamiento.

8. Limitación de exposición y equipo de protección personal

Componentes con valores límite referidos al puesto de trabajo que tienen que superviarse: Vapores, España, Fundamento: Límites de Exposición Profesional para Agentes Químicos en España

Componente	límite	unidad	Tipo	Causas	Observación
ácido acetico, %	10	25	Máximo ponderado en el tiempo		
66-15-	10	10'	Límite a corto plazo		
	10	25	Máximo ponderado en el tiempo		EU-2000/39/EC

página 3 de 3

Nº SDB: 164824 V001.0 5368 ADHESIVO SELLADOR N.310ML

Protección respiratoria: Usar únicamente en lugares bien ventilados.
 Protección manual: Se recomienda el uso de guantes resistentes a los productos químicos, de nitrilo. Evitar el contacto con la piel. En la práctica, la vida útil de los guantes puestos a los productos químicos puede verse reducida considerablemente como resultado de la influencia de muchos factores (ej. la temperatura). Los riesgos que conlleva deberán ser evaluados por el usuario final. Reemplazar los guantes si se observan signos de desgaste o desgaste.
 Protección ocular: Lavar guías protectoras.
 Medidas de protección general e higiene: Deben observarse unas buenas prácticas higiénicas industriales.

9. Propiedades físicas y químicas

Aspecto	Pasta blanca
Olor	Air. Acético
Valor pH	No aplicable
Punto de ebullición	Indeterminado
Punto de inflamación	> 150 °C (-302 °F)
Peso de vapor	< 0,1 mmHg
Densidad	1,04 g/cm ³
Solubilidad cualitativa (Disolvente: Agua)	prácticamente soluble
Solubilidad cualitativa (Disolvente: Acetona)	insoluble
Tenue VOC (EC)	< 5,00 % (Tal y como tal e como se define en Directiva de Consejo 1999/13/EC se define en la Directiva de la Comisión 1999/13/EC)

10. Estabilidad y reactividad

Condiciones a evitar: Evitar en condiciones normales de almacenamiento y uso.
 Materiales a evitar: Agentes oxidantes orgánicos. Polímeros al contacto con agua.
 Productos de descomposición peligrosos: El ácido acético se libera lentamente al estar en contacto con la humedad. A altas temperaturas (>150°C) puede separarse formaldehído (líquido).

11. Información toxicológica

Toxicidad oral aguda: Este producto tiene baja toxicidad.
 Toxicidad inhalativa aguda: El ácido acético se libera lentamente al estar en contacto con la humedad. La inhalación de vapores en concentración elevada puede originar irritación del sistema respiratorio.
 Irritación de la piel: El contacto prolongado o repetido puede causar irritación en la piel.
 Irritación de los ojos: El ácido que se libera durante la polimerización de las siliconas RTV acéticas es irritante para los ojos.

página 4 de 4

Nº SDB: 164824 V001.0 5368 ADHESIVO SELLADOR N.310ML

12. Información ecológica

Efecto ecotoxicológico: No verse en el desajuste aguas de superficie aguas subterráneas.
 Biodegradabilidad: Los efectos cuando son inmediatos.
 Persistencia / Degradabilidad: El producto no es biodegradable.
 Potencial de bioacumulación: No hay datos.
 Detalles generales de ecología: Los productos curados de Loctite son polímeros normales y no suponen un peligro inmediato para el medio ambiente. En el estado curado, la contribución de este producto a los poliguanos/monoguanos es insignificante en comparación con los aplicados según se usa. Se deben considerar las precauciones con respecto a los poliguanos/monoguanos de los artículos en que se utilice este producto.

13. Notas para la eliminación

Producto: Evacuación: Eliminar según las disposiciones locales y nacionales que corresponden.
 Clase de desechos(WEC): 601-07 residuos de adhesivos y selladores que contienen disolventes orgánicos y otros sustancias peligrosas.
 Embalaje: Evacuación: Después de usar los tubos, cajas y envases conteniendo residuos de producto deberán eliminarse como desperdicios químicos/contaminados, en vertederos legal autorizados o incinerados. Destruir los envases de acuerdo con la normativa vigente.

14. Información de transporte

Información general: No es un producto peligroso según RID, ADR, ADN, IMDG, IATA-DGR.

15. Prescripciones - clasificación y caracterización

Frase R: No clasificado como peligroso.

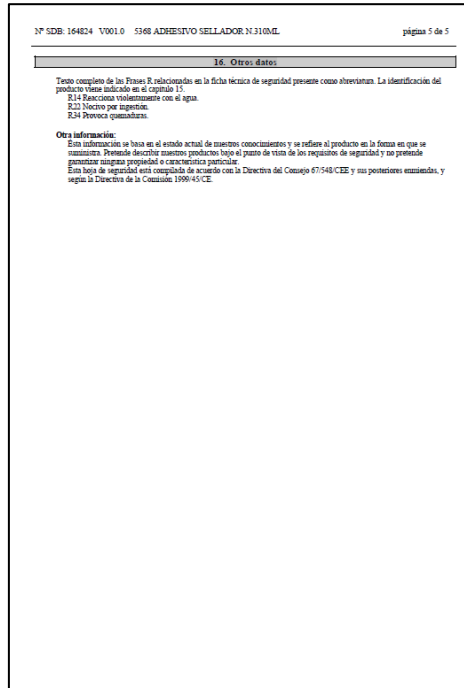


Figure 8 Pictures from the safety sheet of the silicone glue (Spanish supplier)

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Enriching lives through innovation

Advanced Materials
Araldite® AW 4856 Hardener HW 4856
 MACHINE APPLIED EPOXY ASSEMBLY ADHESIVE

Warm-curing toughened epoxy adhesive

Key properties

- Two component toughened epoxy adhesive
- Outstanding impact and fatigue resistance
- High resistance to crack formation after cure
- Non-slumping on vertical surfaces up to 50mm⁽¹⁾
- Low exotherm and shrinkage for thick bond lines
- Long working time
- Easy to pump and mix

Applications

- Assembly adhesive for large composite structures, particularly where thick bond lines may occur.
- Ideally suited for wind turbine blade assembly.
- The adhesive is designed for application by machine.
- High thixotropy enables application of heavy beads on a vertical surface without slumping.

Product data

	ARALDITE® AW 4856	HARDENER HW 4856	Mixed adhesive
Colour (visual)	Yellow	Blue	Green
Specific gravity (23°C)	1.31-1.4	1.10-1.15	1.35-1.35
Viscosity at 23°C (Pa.s)	Ca 30	Ca 3	Thixotropic
Pot Life (500g at 23°C, visual)	-	-	240-280 min

Processing

Pre-treatment
 The strength and durability of a bonded joint is dependant on proper treatment of the surfaces to be bonded.
 At the very least, joint surfaces should be cleaned with a good degreasing agent such as acetone, iso-propanol (for plastics) or other proprietary degreasing agents in order to remove all traces of oil, grease and dirt.
 It is recommended to mechanically abrade the substrate surface in order to ensure consistent adhesion. The surface should be degreased following abrasion (as above). For composite laminates, the surface may be conveniently prepared by use of a peel ply which is removed immediately prior to bonding. Low grade alcohol, gasoline (petrol) or paint thinners should never be used for degreasing.

(1) a maximum thickness of 20-25 mm is recommended to avoid exotherm effect as well as excessive induced stresses in thick joint.

November 2009 ARALDITE® AW 4856_HARDENER HW 4856 Page 1 of 4

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Mix ratio	Parts by weight	Parts by volume
ARALDITE® AW 4856	100	100
HARDENER HW 4856	42	50

Resin and hardener should be blended until they form a homogeneous green coloured mix. It is strongly recommend to apply the adhesive using a meter-mix machine.

Application of adhesive
 The resin/hardener mix is applied to the pretreated and dry joint surfaces.
 A layer of adhesive 0.05 to 0.10 mm thick will normally impart the greatest lap shear strength to the joint. The joint components should be assembled and clamped as soon as the adhesive has been applied. An even contact pressure throughout the joint area will ensure optimum cure.

Mechanical processing
 Specialist firms have developed metering, mixing and spreading equipment that enables the bulk processing of adhesive.
 We will be pleased to advise customers on the choice of equipment for their particular needs.

Equipment maintenance
 All tools should be cleaned with hot water and suitable detergent or solvent before adhesives residues have had time to cure. The removal of cured residues is a difficult and time-consuming operation. If solvents such as acetone are used for cleaning, operatives should take the appropriate precautions and, in addition, avoid skin and eye contact.

Typical cured properties

GEL TIME (HOT PLATE)	(°C)	(min)
	at 70	40-50
	at 90	25-35

LINEAR SHRINKAGE Cured at: 70°C 0.2 – 0.0%


GLASS TRANSITION TEMPERATURE Cure: T_g (°C)

(IEC 1030, DSC, 10 K/MIN)		
7 days 23 °C		61 – 67
6 hrs/ 50°C		64 – 60
24 hrs/ 50 °C		70 – 76
5 hrs/ 70 °C		73 – 79
4 hrs/ 70°C+ 3 hrs/ 100°C		79 – 85
4 hrs/ 90°C		80 – 85

FLEXURAL TEST (ISO 178) Cure: 5h 70 °C

	Flexural strength [MPa]	Ultimate elongation [%]	Flexural modulus [MPa]
	120 – 140	2.5 – 3.0	4600 – 5500

November 2009 ARALDITE® AW 4856_HARDENER HW 4856 Page 2 of 4



TENSILE TEST
(ISO 527) Cure: Sh 70 °C

Tensile strength [MPa]	80 – 85
Ultimate elongation [%]	1.3 – 2.0
Tensile modulus [MPa]	4900 – 5200

BEND NOTCH TEST
(ISO 13588) Cure: Sh 70 °C

Fracture toughness K_{IC} [MPa √m]	2.90 – 3.20
Fracture Energy G_{IC} [J/m ²]	1400–1700

SIMPLE LAP SHEAR TEST ON ALUMINIUM
(ISO 4587) Acid etched Cure: Sh 70 °C

Test at	Joint thickness	Lap Shear Strength [MPa]
23°C	0.5 mm	25 - 30
	3.0 mm	13 - 16
50°C	0.5 mm	22 - 29
	3.0 mm	13 - 16

SIMPLE LAP SHEAR TEST ON VARIOUS SUBSTRATES
(ISO 4587) Metals (sandblasted, degreased) Composites (abraded, degreased) Cure: Sh 70 °C

Steel (CR1)	13.0 – 16.0
EP-GRP	22.0 – 25.0 *
UP-GRP	9.0 – 10.0 *
SMC	7.0 – 8.0 *
CFRP	27.5 – 30.0 *

* substrate deformation or failure

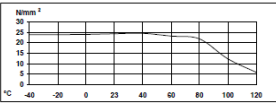
SHORE HARDNESS
(ISO 888) Cure: Sh 70 °C


Shore D	78 - 82
---------	---------

EXOTHERM MEASUREMENT
(ISO 888) 500 gr of mix, 50 mm thickness Cure: Sh 70 °C

Peak exotherm [°C]	80 - 90
Time to peak [min.]	330 - 345

SIMPLE LAP SHEAR TEST vs. TEMPERATURE ON ALUMINIUM
(ISO 4587) (typical average values) Acid etched Cure: Sh 70 °C





Storage ARALDITE AW 4556 and HARDENER HW 4556 may be stored for up to 2 years at room temperature provided the components are stored in sealed containers. The expiry date is indicated on the label.

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Huntsman Advanced Materials
(Overseas) Office
 45725th Street
 4077 East
 Salt Lake City, UT 84111
 Tel: +1 (801) 399 1111
 Fax: +1 (801) 399 1112
www.huntsman.com
 Email: araldite_sales@huntsman.com



November 2009

ARALDITE® AW 4556_HARDENER HW 4556

Page 3 of 4

November 2009

ARALDITE® AW 4556_HARDENER HW 4556

Page 4 of 4

Figure 9 Safety sheet of the two- components glue



Figure 10 Full panels installation at Warsaw STANDARD (left) and Madrid NANOPCM (right) mock-ups.



Figure 11 (left). Differences in size between NANOPCM panels. (right). Dust come-off the walls after installation.

Many attempts were done to seal the joints between panels, so as to avoid possible thermal bridges:

- Applying a mixture made of silicone and dust from the panels. It failed because of the huge ΔT suffered by the panels (mainly during the night, joints broke up).
- Applying PUR foam. It failed because despite PUR foam and PUR panels are "friendly" materials, the porosity of the panels let the foam came inside the porous cracking the surface after drying because of the volume increase (300%).
- Applying silicone. It failed because it did not get stuck onto the panels interface (low T).

Finally the problem was sorted out putting the panels under pressure, putting them so close together. After that, joints were sanded down with PUR pieces. Small holes and big joints were filled with PUR foam.

4 MONITORING SYSTEM INSTALLATION

In this point it can be found a description of the sensors, data acquisition units and data transferring protocols for storage used both for Warsaw and Madrid DEMOPARKS.

As the NanoPCM products have strong influence in thermal performance and energy efficiency in buildings, the main parameters to be measured are related to those characteristics. Then, the temperature at different points of the demo-building as well as the heat flux which is going through the walls is essential to extract proper conclusions about the behaviour of the NanoPCM products. The monitoring system was designed and optimized taking into account those parameters and considering the different materials installed in the mock-ups.

4.1 Measurement units and thermal sensors

All sensors of a given wall are located in the same panel and (x, y, z) point, following an imaginary axe.

This is shown in the following sketch:

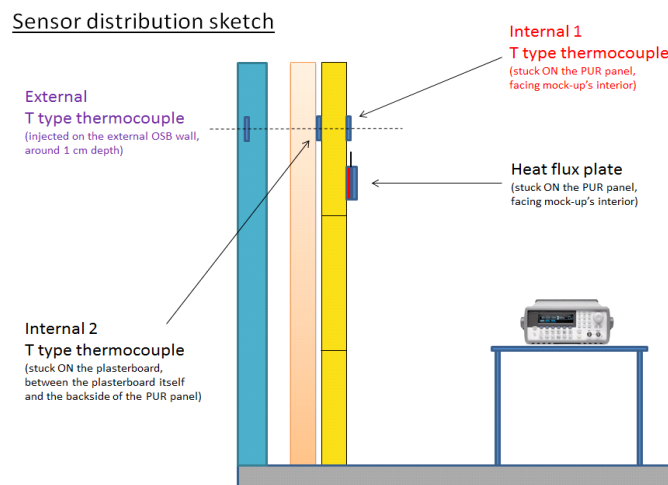


Figure 12 Geometrical distribution of the sensors on the panels.

Next pages show a detailed description of the sensors used in the Monitoring system.

4.1.1 Data acquisition unit Agilent 34972A

A Data acquisition unit (also known as Data logger) is a system that acquire analog data from a given set of external inputs and convert it into binary data. Data loggers are used to monitor multiple signals over extended periods of time.

Data acquisition unit chosen for NANOPCM demonstration purposes is the Agilent 34972A, a 22-bits of resolution multimeter with extra-high accuracy (about 0.004% basic 1-year DC accuracy) and ultra-low reading noise.

Every Agilent 34972A at DEMOPARK counts on an internal multiplexer module (model Agilent 34901A), with 20 channels independently configurable depending the input signal is going to be registered (temperature, VDC, etc.). The 34901A module is the most versatile multiplexer for general purpose scanning. It has low thermal offset characteristics and a built-in thermocouple reference on the terminal block, making it ideal for temperature measurements. The dense, multi-function switching, with 100 channel/second scan rates, addresses a broad spectrum of data acquisition applications.

Once every channel is properly digitally-labelled and memorized, the Data acquisition unit builds a scan list that includes all configured inputs in ascending order by channel number (from 101 to 120 in our one-multiplexer scenario). Scans can be configured by means of an internal timer for automatic scanning at a specific interval Δt , which was agreed to be 5 minutes for DEMOPARK purposes. The way data is managed after each five-minute logging will be deeply explained at point 3.3 "Monitoring System Overview", as well as transferring protocol used for both mock-ups.



Figure 13 Agilent 34972A Data Acquisition Unit.

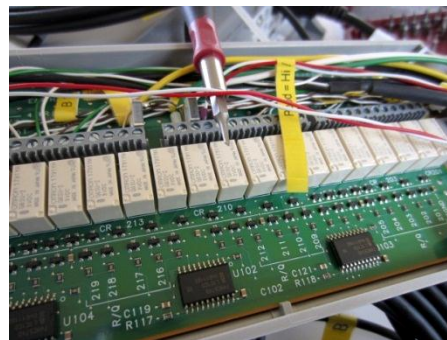


Figure 14 Agilent 34901A 20-Channel Multiplexer Module.

4.1.2 Measuring heat fluxes: Heat Flux Plates (HFP)

The sensors used for the heat flux measurements are Hukseflux HFP01 heat flux sensors, capable for in-situ measurement of building envelope thermal resistance (R-value) and thermal transmittance (H-value), according to ISO 9869, ASTM C1046 and ASTM 1155 standards. Traceability of calibration is to the "guaranteed hot plate" of National Physical Laboratory (NPL) of the UK, according to ISO 8302 and ASTM C117.

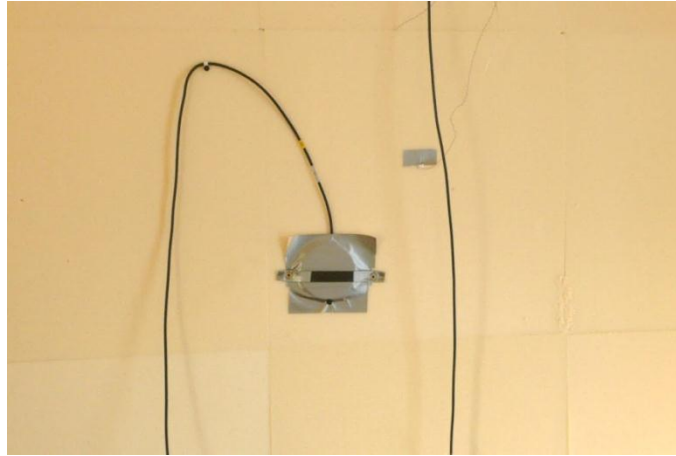


Figure 15 Heat flux plate mounted on the PUR panel

The working principle of the gadget is quite simple. When heat is flowing through the sensor, the filling material acts as a thermal resistance. Consequently, the heat flow will go together with a temperature gradient across the sensor ΔT , which will create a hot side and a cold side. The HFP is based on a thermopile, this is, a number of thermocouples connected in series. A single thermocouple will generate an output voltage V in the mV range that is proportional to the ΔT between the joints (copper-constant and constant-cooper, this is, a T-Type Thermocouple, as we will see in point 3.1.3). This ΔT is proportional to the heat flux (ϕ), depending only on the thickness and the average thermal conductivity of the sensors, following this linear law:

$$\phi = V/E$$

Where E is the sensitivity constant that is supplied with each individual sensor (in $\mu\text{V}/\text{Wm}^{-2}$). To turn the measured voltage V into an understandable heat flux ϕ in W/m^2 , it is enough to divide the output voltage by the sensitivity constant. The output information then is a scalar in W/m^2 with its sign, following the criterion shown in **Figure 19**.

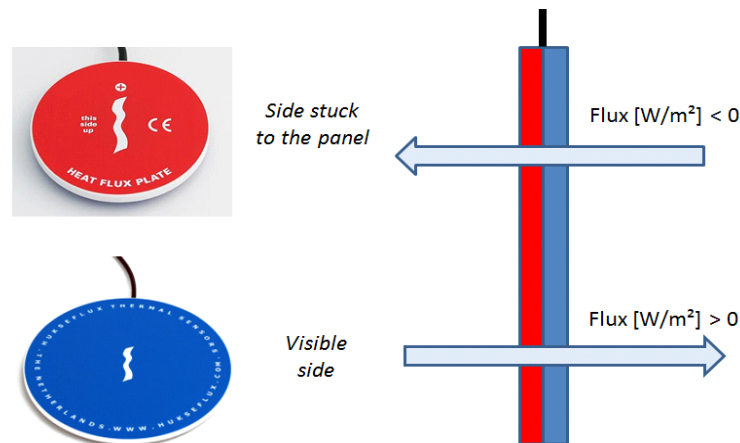


Figure 16 The sign criterion. When the heat evacuates the mock-up's walls from inside to outside, then a negative voltage is registered by the Data logger. On the other hand, when heat comes from the outside to the inside of the mock-up, then the voltage shown by the data logger is positive.

When studying the energy balance of buildings, heat is exchanged by various mechanisms. The total result is a certain heat flux. The dominant mechanisms are usually radiative transfer by solar radiation and convective transport by flow in air.

For this application, the sensor HFP01 is simply mounted on the object of interest, in this case the PUR panel (see **Figure 18**). At the sensor surface, the convective heat of the air and the radiation by the sun are transformed into conductive heat.

If direct beam solar radiation is present, the solar radiation is usually dominant. The maximum expected solar radiation level is about 1500 W/m^2 , but this is not the case, because all the sensors are installed indoor. In this case, convective transport of heat by the air is the main contribution, and the convective transport is roughly proportional to the difference in temperature between wall and air.

According Hukseflux technical support, in a perfect environment, the initial calibration accuracy of heat flux sensors is estimated to be $+3 \text{ /- } 3\%$. In case of use of HFP01 on walls (insulating as well as bricks and cements) the overall expected measurement accuracy for is $+5 \text{ /- } 5\%$.

4.1.3 Temperature: T-Type Thermocouples

A thermocouple is a commonly used type of sensor that is prepared to measure temperature. Thermocouples are popular in industrial control applications because of their relatively low cost and wide measurement ranges.

Thermocouples are fabricated from two different electrical conductors made of two different metal alloys. The conductors are typically covered into a cable having a heat-resistant sheath, often with an integral shield conductor. At one end of the cable, the two conductors are electrically shorted together (*hot junction*) and are attached to the object to be measured. The other end (called *cold junction* or *reference junction*) is attached to a multimeter, so as to register the output signal.

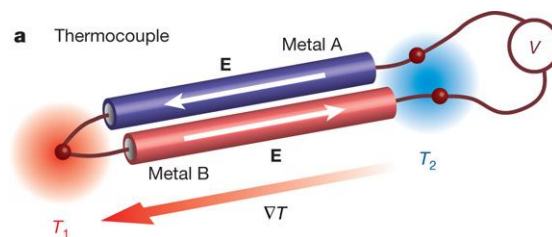


Figure 17 One Thermocouple at work.

Thermocouples generate a kind of open-circuit voltage, called *Seebeck voltage* (ΔV), that is proportional to the temperature difference (ΔT) between the hot and cold junctions. Upon heating, the Seebeck effect will initially drive a current. However, provided the junctions all reach a uniform internal temperature, and provided an ideal voltmeter is used, then the thermocouple will soon reach an equilibrium where no current will flow anywhere ($J=0$). As a result, the voltage gradient at any point in the circuit is proportional to the temperature gradient at this point and will be given simply by the linear equation:

$$\Delta V = -S \Delta T$$

where S factor is the Seebeck coefficient at the given point, and ΔT is the temperature gradient at that same point.

It is important to note that ΔV is generated in the wires leading between the hot and cold junctions (where $\Delta T \neq 0$), and not in the junctions themselves. Because of this, the chemical nature of the junctions does not influence the measured voltage. On the other hand, and because of this same reason, if variations in the composition of the wires occur in the thermal gradient region outside the junction (due to contamination, oxidation, etc.), this could lead to changes in the measured voltage.

The Type T thermocouple has a Copper positive leg and a Constantan negative leg. Type T thermocouples can be used in oxidizing, reducing or inert atmospheres. The typical temperature range for Type T is -300°C to 700°C , and its wire colour code is blue and red.



Figure 18 Two examples of thermocouples installation. On the left hand, thermocouple placed on the outside OSB walls at Warsaw NANOPCM mock-up. On the right, thermocouple placed over a PUR panel inside Madrid REFERENCE mock-up (slightly poked on the PUR surface, secured with a plastic flange and stuck with silicone gel).



Figure 19 Thermocouples arranged in the multiplexer module at Warsaw DEMOPARK.

Because of the special nature of the PUR material, tapes, glues and similar compounds do not work on their surface, aspect that supposes a critical problem for sensor anchorage.

Assorted mechanical support solutions were tested during the sensor installation to sort out this problem:

- Sticking was tried on the first attempt for thermocouples. They were insulated with special thermocouple attachment pads and a reflective tape secured with a plastic staple. Unfortunately, any tape solution sticks onto the PUR panels, because their dusty surface and its porosity. In the end, thermocouples were slightly "injected" on the PUR panels, the wire being secured with mechanical anchorage and a silicone gel dot. External thermocouples were passed through the ventilation grid (left bottom corner of the North façade) and distributed properly, then pocked on the OSB walls. The hole was filled with an extremely dense handmade mixture of OSB dust merged with neutral silicone.
- Heat flux plates were fixed to the panel using a plastic tape that was screwed to the plasterboard to fasten the sensor. At the bottom, an additional screw was put to hold part of the weight.

4.1.4 Weather station and Pyranometer

As it can be seen in **Figure 20**, Madrid DEMOPARK counts on an independent Weather station and a Pyranometer located on the top corner of the shelter, the building in which central PC is housed (see D7.5). Weather data in Warsaw is taken from a station close to the park.

The Weather station (model Davis Vantage Pro2) is synchronized with the central PC and logs meteorological data every 5 minutes using its own software, called *WeatherLink 6.0.0*. Among the different parameters measured, external temperature, RH and wind speed and direction can be obtained. Pyranometer (model Delta Ohm LP) acquire global irradiance data (in W/m^2) every 5 minutes, using an independent software (*PyraReader*), a homemade solution programmed in Visual Basic by Delta Ohm technicians for this particular case.



Figure 20 Weather station (on the left) and Pyranometer (on the right), located at the roof of Madrid DEMOPARK shelter.

4.2 Sensor distribution for NANOPCM and REFERENCE mock-ups at Madrid and Warsaw DEMOPARKS

The sensor distribution was designed and optimized taking into account the limited channels in the data logger and temperatures or conditions the consortium was interested to follow-up.

Next pictures show the sensor distribution for NANOPCM and REFERENCE mock-ups in both Madrid and Warsaw DEMOPARKS.

Sensor	Façade	N	S	E	W	Roof	Indoor	# Items	
Sensor position [cm]		(230,170)	(60,156)	(60,157)	(96,163)	(160,130)	(132,103,42)		
T-type thermocouple		3 -, B102 B113	3 B103, B104 B114	3 B109, B110 B115	3 B105, B106 B116	3 B107, B108 B117	1 B101	16	
Heat flux plate Calibration factor E [$\mu\text{V}/\text{Wm}^{-2}$]			1 B118 61.03		1 B119 62.57	1 B120 62.81		3	
# MUX Channels		3	4	3	4	4	1	19	19

Figure 21 Sensor distribution for Madrid NANOPCM mock-up.

As observed in the figure above, 19 channels of the data logger was used, having every wall and roof totally monitored.

Sensor	Façade	N	S	E	W	Roof	Indoor	# Items	
Sensor position [cm]		(240,170)	(70,162)	(54,173)	(103,170)	(190,116)	(132,103,42)		
T-type thermocouple	3 C101, C102 C103	3 C104, C105 C106	3 C107, C108 C109	3 C110, C111 C112	3 C113, C114 C115	1 C119		16	
Heat flux plate		1 C116		1 C117	1 C118			3	
Calibration factor E ($\mu\text{V}/\text{Wm}^{-2}$)		62.55		62.36	64.26				
# MUX Channels	3	4	3	4	4	1	19	19	

Figure 22 Sensor distribution for Madrid REFERENCE mock-up.

Sensor	Façade	N	S	E	W	Roof	Indoor	# Items	
Sensor position [cm]		(64, 78)	(74, 69)	(59, 76)	(113, 69)	(206, 121)	(157, 86, 42)		
T-type thermocouple	3 B101, B102 B103	3 B104, B105 B106	3 B107, B108 B109	3 B110, B111 B112	3 B113, B114 B115	1 B119		16	
Heat flux plate		1 B116		1 B117	1 B118			3	
Calibration factor [$\mu\text{V}/\text{Wm}^{-2}$]		62.6		63.4	62.8				
# MUX Channels	3	4	3	4	4	1	19	19	

Figure 23 Sensor distribution for Warsaw NANOPCM mock-up.

Sensor	Façade	N	S	E	W	Roof	Indoor	# Items	
Sensor position [cm]		(203,165)	(70, 166)	(60, 129)	(103, 161)	(170, 145)	(63, 81, 42)		
T-type thermocouple		3 A101, A102 A103	3 A104, A105 A106	3 A107, A108 A109	3 A110, A111 A112	3 A113, A114 A115	1 A119	16	
Heat flux plate			1 A116		1 A117	1 A118		3	
Calibration factor ($\mu\text{V}/\text{Wm}^{-2}$)			63.0		62.4	63.4			
# MUX Channels		3	4	3	4	4	1	19	19

Figure 24 Sensor distribution for Warsaw REFERENCE mock-up.

In order to follow a visual criteria to permit a quick check when sensors were been set, colour key shown in the tables was designed: in red, the thermocouples placed on the outside of the PUR panel (stuck to the visible face of the panel); in black, thermocouple on the backside of the PUR panels (stuck between the plasterboard and de PUR panels). Finally, maroon is reserved for thermocouples injected on the outside OSB walls (around 1 cm depth), facing the exterior.

Sensor position (x, y) for N, S, E, W façades and Roof are written down on the sensor position tables correspond with a coordinates system distributed as follows it can be seen in the tables, always looking from the inside of the mock up.

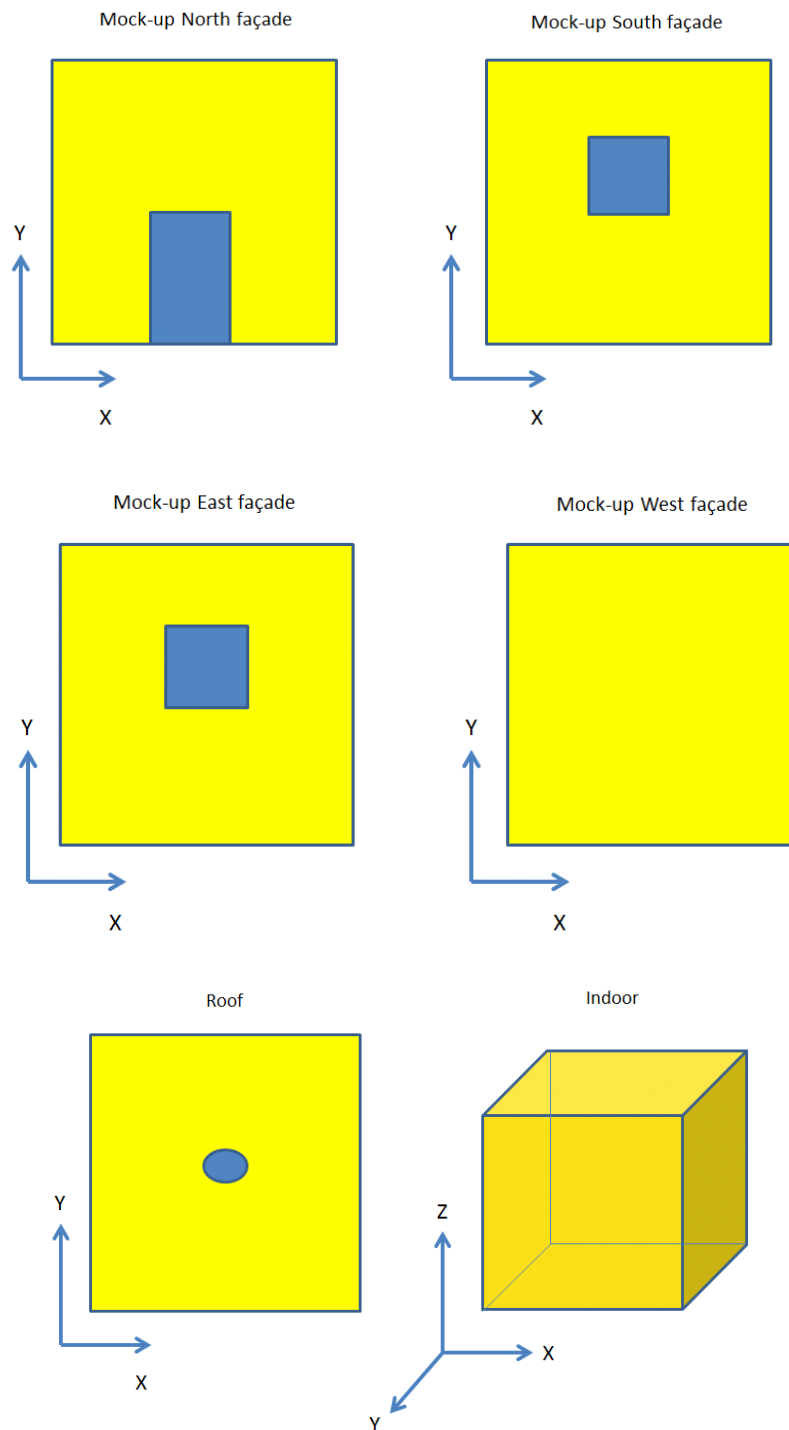


Figure 25 Coordinate system used to give sensor position.

After the panels installation, the internal dimensions of the mock-ups (internal free air volume) were:

- Madrid NANOPCM mock-up: 265cm x 207cm x 226cm

- Madrid REFERENCE mock-up: 265cm x 210cm x 226cm
- Warsaw NANOPCM mock-up: 270cm x 209cm x 228cm
- Warsaw REFERENCE mock-up: 269cm x 208cm x 228cm

5 MONITORING AND ACQUISITION SYSTEM

The Local Area Network design (LAN) that join data from each Data logger in the central PC at Madrid DEMOPARK is shown in the next picture. This LAN was first designed by TNO within the DEMOCLUSTER frame projects, and finished by ACCIONA so as to provide it with remote control access (WAN). Each Agilent Data logger multiplexes signals from 19 channels each $\Delta t=300s$ through its RJ45 own cable (its own IP address). Then data is registered in an Excel file and it is refreshed following the clock.

Data from Weather Station and Pyranometer are also synchronized with the PC. TNO designed an *ex profeso* software to act as a ruler of the acquisition procedure by the LAN (see figure below). Because it was designed to host just seven IP addresses, just Madrid NANOPCM mock-up runs with this system. The other mock-ups involved within the NANOPCM project (this is, the REFERENCE mock-up at Madrid DEMOPARK and the couple of mock-ups placed at Warsaw DEMOPARK) acquire information through an USB drive interface, that has to be manually removed from the Data logger.

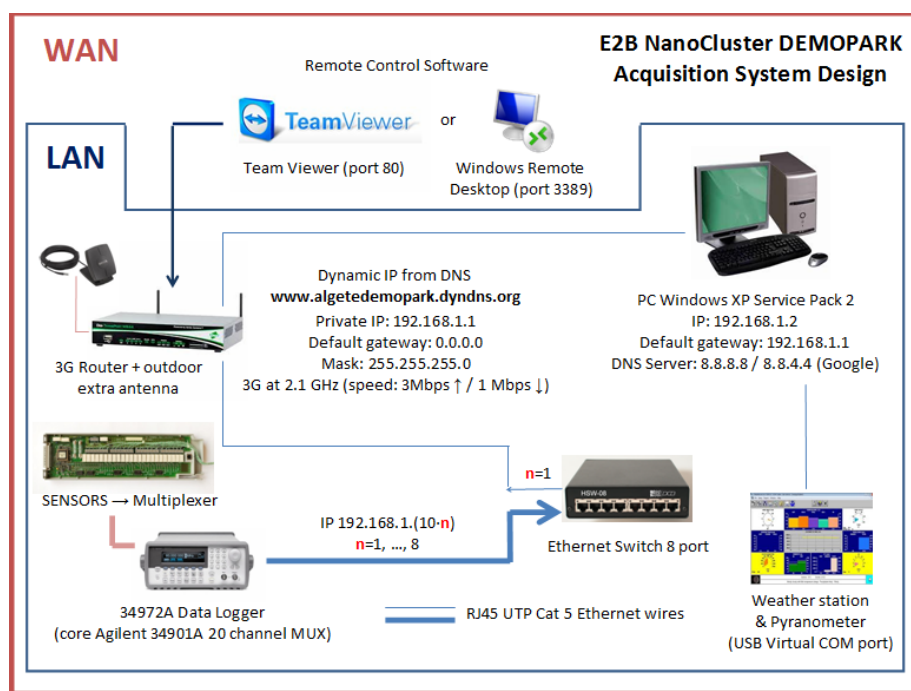


Figure 26 The LAN/WAN design for Madrid DEMOPARK

As it can be seen in the next picture, a protocol was designed to take over the PC data by means of remote control, just for Data loggers configured with LAN interface.

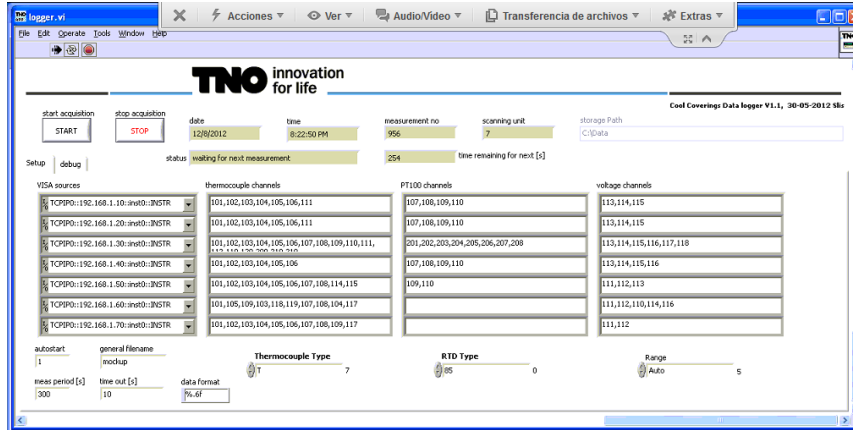


Figure 27 TNO Logger interface.

The remote control software chosen was Teamviewer. This software uses an UDP hole punching protocol, providing extra assets in the stability of the connection. Because static IPs do not exist for free in Spain, a stable access was created using the free dynamic DNS server DynDNS, registering the domain "algetedemopark.dyndns.org", which connects the dynamic IP to the DynDNS server, that always provide the user a secure and stable way to connect with the remote PC.

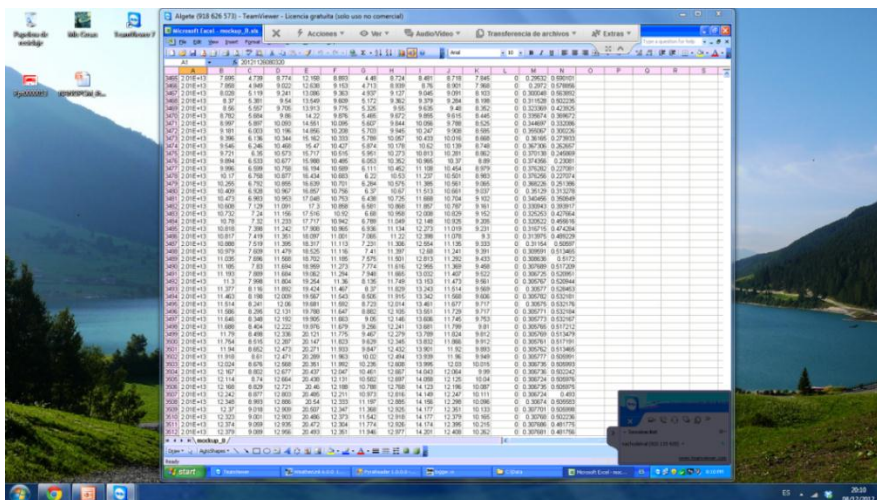


Figure 28 TNO Logger interface.

Then, data from Weather Station, Pyranometer and Madrid NANOPCM mock-up is available on-line.

For the rest mock-ups (Madrid REFERENCE, Warsaw NANOPCM and Warsaw REFERENCE), a manual removing of the USB Drive is a must to collect the data.

6 MEASUREMENT STRATEGY

In this chapter, measurement strategy undertaken during April and May measurement campaign at Madrid DEMOPARK is fully detailed, as previous and necessary part to understand Results shown in Chapter 6.

Measurements were carried out at Madrid DEMOPARK from Apr 8th to May 13th 2013. Because external temperatures did not fit with the melting point temperatures of the NANOPCM panels installed in Madrid (both roof and walls around 27°C), extra heater methods were used to overheat the mock-ups from the inside.

Two different heating devices were used. First one, a portable air-conditioning system model Elisse® HP, capable to work at a maximum power of around 1100-1200 W. Second device used was a Garza® space heater, a common resistance-based heating machine, capable of working in two different regimes (1000W and 2000W nominal power, respectively), with twenty different positions. Two models are depicted in the figure below.



Figure 29 The two heaters used in this experience: Elisse® HP portable air-conditioning system (left) and Garza® space heater (right)

In order to check devices energy consumption, a Velleman® digital energy meter connected in series with an analogic one, so as to double check it with two different gadgets. These mechanisms can measure average energy consumption per hour (in KWh), summing up individual contributions.

For both scenarios, thermal parameters logged using the sensor distribution system deeply explained in Chapter 3 were the following ones:

- Internal temperature.
- Heat fluxes for the Roof and the façades.
- Temperature on the back and the front of the panels for units on the roof and the façades.
- Weather conditions from the Weather Station and global irradiance using the Pyranometer.

Heat fluxes and temperatures on the back and the front of the panels give rise to the knowledge of the thermal resistance of the panels.

Extra set-up items for both mock-ups are described in next figure:

ELEMENT	NANOPCM Mock-up (items)	STANDARD Mock-up
1000W Heater	1	1
Energy Meter	1	1
Temperature sensors	16	16
Heat flux meters	3	3
Acquisition unit	1	1

Figure 30 Items per mock-up.

Fan systems were blocked and covered, as well as eastern windows. Southern windows remained uncovered.

Measurement campaign was divided in three different stages:

Stage One: from April 8th to April 15th.

In this first stage, measurement casuistry was divided in two different but complementary parts:

- **April 8th experience:** both mock-ups, NANOPCM and REFERENCE, were heated at max power using Elisse® HP portable air-conditioning system (27°C). System was turned on April 8th at 9:50 and it was switched off at 17:30, heating the rooms for eight hours (in order to let the mock-ups reach an homogeneous and stationary temperature (even into the panels volume) and then letting the panels chilling on their own. In this case, the intention was to force a cooling curve in both mock-ups to compare differences in the heating release of NANOPCM and REFERENCE panels, as well as significant differences in the room temperature.
- **April 9th - Apr 15th experience:** experience started on April 9th at 9:15 and finished on April 17th at 10:00 pm. In this case, air-conditioning systems were programmed at its maximum operative temperature

(27°C) for a complete week, with the purpose of finding differences in the cumulative energy consumption (kWh) of the machines. In this case, because of the nature of the PCM panels, NANOPCM mock-up was expected to be more energy-efficient than its REFERENCE twin.

Stage Two: from April 26th to April 30th.

In this second part, Elisse® HP systems were replaced by the Garza® space heaters. Heating machines were started on April 26th at 10:30 and turned off on April 30th at 10:30. Both NANOPCM and REFERENCE devices were programmed above PCM melting point temperature, at around 33°C. In this case, the intention was the same than in the April 9th to April 17th experience, trying to check differences in the energy consumption but with a more powerful machine.

Stage Three: from May 6th to May 13th.

In this last scenario, external weather conditions (sometimes around 20°C at midday) allowed to disconnect auxiliary heating devices and let the room heat up just by means of external solar irradiance.

For days in which external temperatures did not reach 20°C (May 9th and May 10th), heating/cooling cycles following the method described in Stage One scenario were prompted using Garza® space heaters.

7 RESULTS

In this chapter, measurement results are offered following the structure described in Chapter 5 "Measurement Strategy".

Due to the huge amount of collected data, 1 hour averages have been made from the 5-minute interval records programmed on the Data Loggers, avoiding transitory effects.

If needed, sensor data is backed up by meteorological data coming from the Weather Station described in 3.1.4, serving as a weather report for the period of time analyzed and helping to understand possible external contributions to the data output of the mock-ups monitoring system (3.1).

Stage One: from April 8th to April 15th.

The next figure shows air temperature profile from Apr 7th to Apr 30th. During this period, temperatures reached a typical pre-summer week scenario (midday between 15°C and 20°C, with an unusual break from Apr 13th to Apr 17th in which peaks around 26°C were registered).

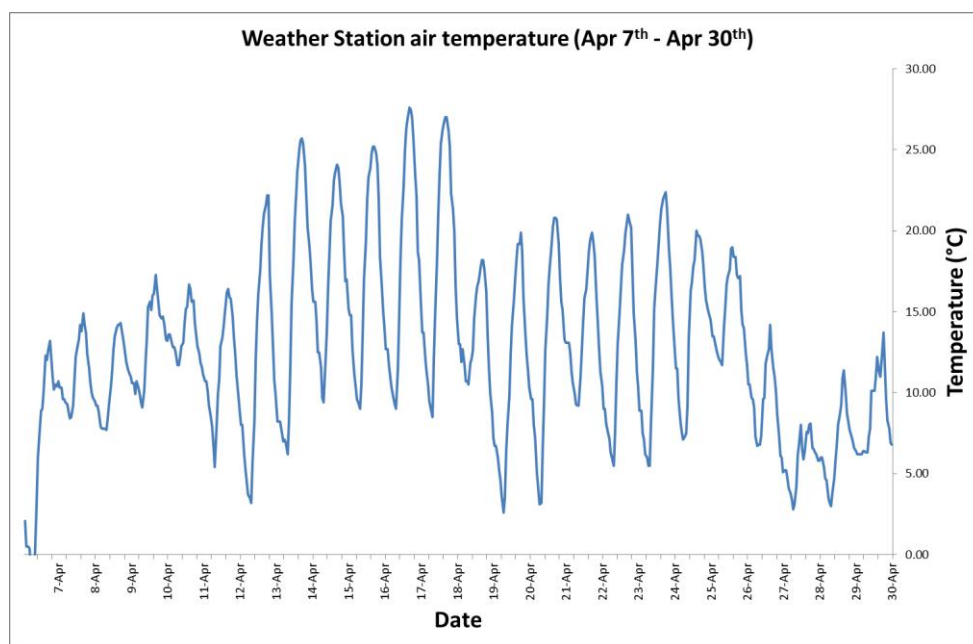


Figure 31 Weather Station air temperature per day from April 7th to April 30th

7.1.1 Results for April 8th experience:

The next figure presents the NANOPCM and REFERENCE cooling curve following the criteria described in 5.1.

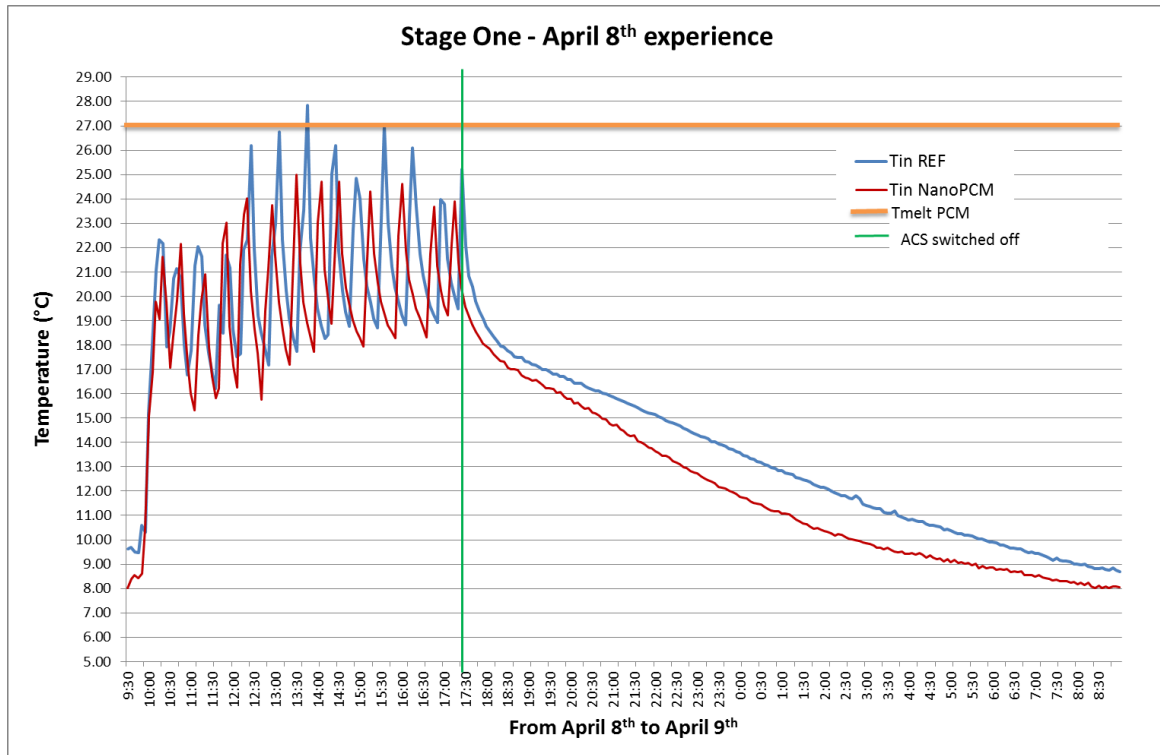


Figure 32 April 8th induced cooling curves.

Both mock-ups were heated for eight hours at air-conditioning maximum operative temperature (27°C). However, regarding the results, real temperature (the one measured by means of B101 and C119 thermocouples, see 3.2) never beat 25°C for NANOPCM mock-up, whereas REFERENCE mock-up sometimes reached peaks around 27°C.

The noise observed between 9:30 and 17:30 is due to the air-conditioning system behavior itself, that it is based on a thermostat that triggers off the heating process when an internal thermocouple notices the programmed temperature (27°C). It can be seen that from the very beginning devices start showing a behavior that it is quite different from each other. Specifically,

REFERENCE system make more cycles per hour than NANOPCM one for the same period of time.

Regarding cooling curve, no conclusions can be drawn since cooling curve starting point is much below melting point temperature.

7.1.2 April 9th - Apr 15th experience:

In this experience attention was focused on the analysis of the cumulative energy consumption of the air-conditioning systems, as an indirect way to understand PCM panels thermal behavior in terms of possible energy savings.

The next table shows a table with the cumulative energy consumption of four partial readings within the experience time. On April 11th, realizing that REFERENCE energy consumption was almost double than NANOPCM one, (a result suspicious to be too optimistic), both Elisse® air-conditioning apparatus were checked in terms of electric current demand using a current clamp, quarantining the two systems inside a third room by the DEMOPARK for two hours, one next to the other and fixed at the same power. As a result, a 2-factor was founded, finding out that REFERENCE device energy consumption was actually double than its pair. Devices were permuted and energy consumption was read after other four days (April 15th), in order to balance the experiment.

			Cumulative electric energy consumption E [kWh] (± 0.1 kWh)	
Date	Time start	Elisse® ACS regime	REFERENCE	NANOPCM
9/04/13	17:00	P=1kW, T=27°C	1.9	0.8
10/04/13	17:00	P=1kW, T=27°C	5.5	2.7
11/04/13	17:00	P=1kW, T=27°C	8.3	4.1
15/04/13	9:30	P=1kW, T=27°C	12.2	13.6

Figure 33 Cumulative electric energy consumption from April 9th to April 15th. After that period, energy readings did not show significant differences (12.2 kWh for REFERENCE mock-up versus 13.1 kWh for NANOPCM one).

The next figure depicts the whole thermocouple collection data for NANOPCM mock-up. The most significant channel related with temperature is the one recording temperature inside the room (see 3.2), also related with comfort perception. So from now on it will be depicted when temperature data is required.

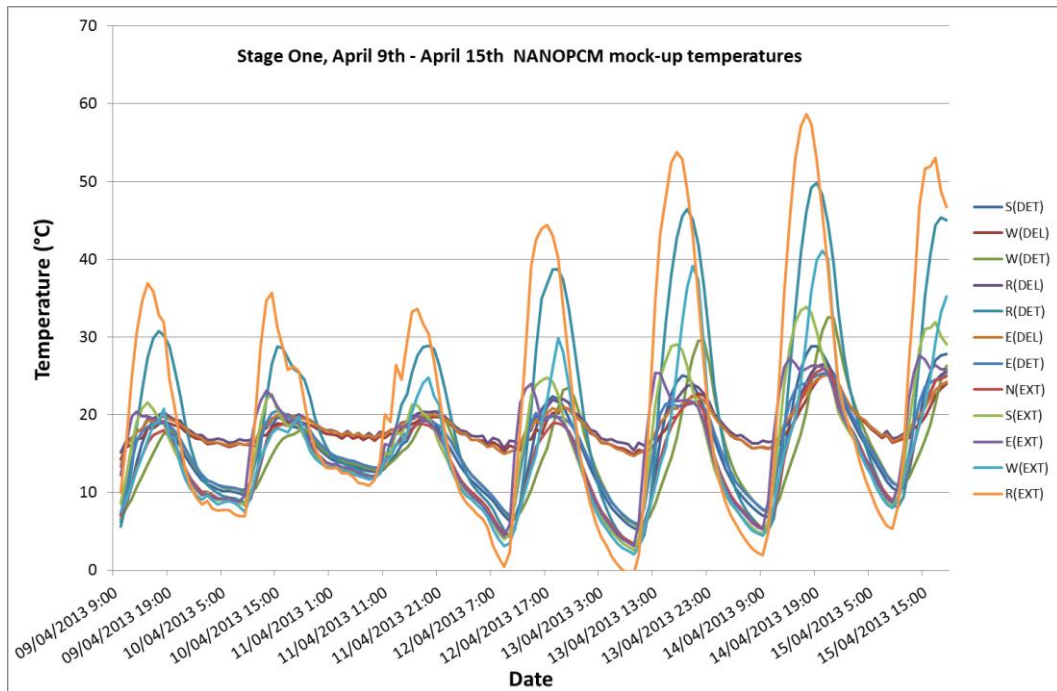


Figure 34 NANOPCM mock-up thermocouples data set from April 9th to April 15th.

Behavior shown in **Figure 31** can be partially understood going through **Figure 34** results. In average, internal temperature for both mock-ups does not beat 21°C barrier, standing far away from PCM melting point (27°C), barely taking advantage of phase transition energy shown in DSC enthalpy versus temperature curves analyzed in previous deliverables.

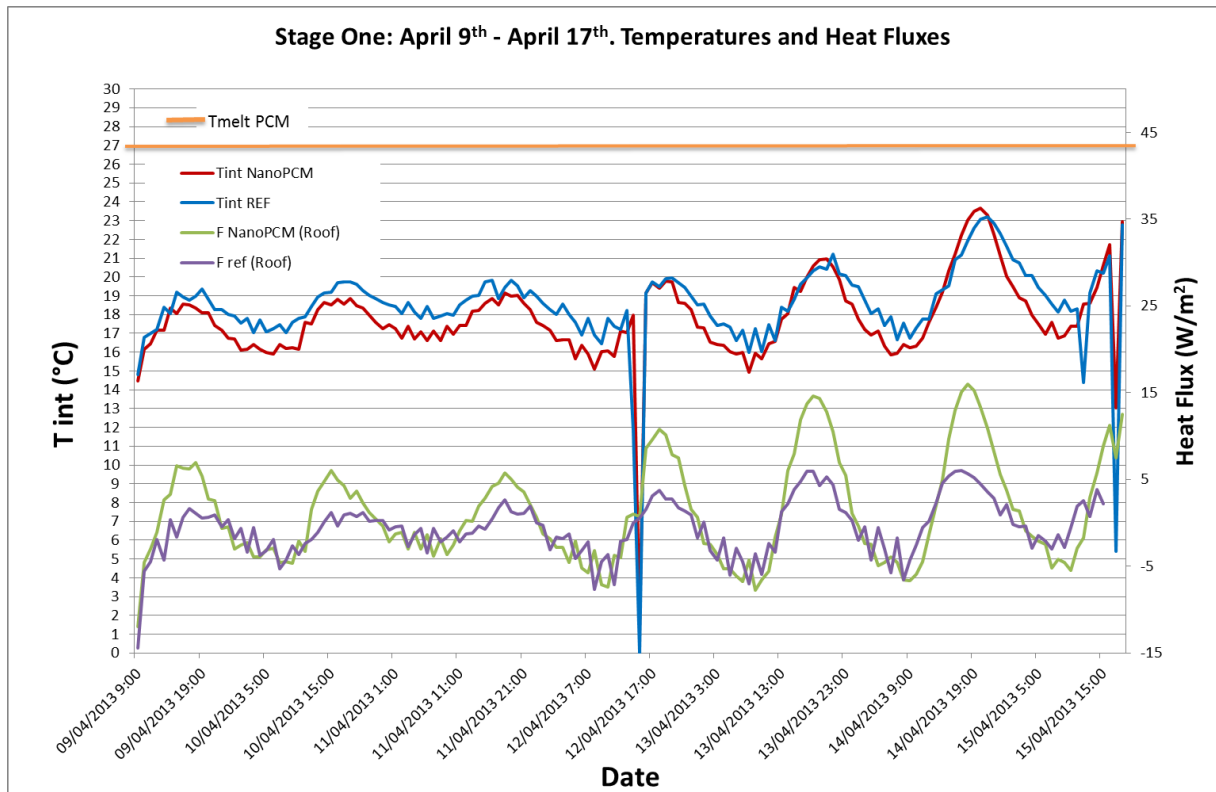


Figure 35 Internal temperatures and heat fluxes throughout the roof for NANOPCM and REFERENCE mock-ups (April 9th - April 17th period). The fall observed on April 12th at 17:00 was provoked by an overload in the electric system.

Stage Two: April 26th to April 30th.

Because Elisse® portable air-conditioning systems revealed not only differences in the energy consumption but also a lack of power to be able to beat and be above melting point temperature barrier, in this second stage Elisse® HP systems were replaced by the Garza® space heaters explained at the beginning of this chapter. A pre-test was done to check whether devices showed identical behavior in terms of energy consumption, and it was found out that for a same period of time and fixed at the same power, current intensity and energy demand was exactly the same, so they could be considered basically identical.

Figure 34 sums up the results of a test of the same nature as the one described for April 9th -April 15th period, just modifying the heater machine.

			Cumulative electric energy consumption E [kWh] (± 0.1 kWh)	
Date	Time start	Garza® Heater regime*	REFERENCE	NANOPCM
26/04/13	10:30	P=1kW, I=85%	0.0	0.0
27/04/13	10:30	P=1kW, I=85%	19.1	13.2
29/04/13	10:30	P=1kW, I=30%	52.3	20.0
29/04/13	17:30	P=1kW, I=60%	58.2	25.9
30/04/13	9:00	P=1kW, I=40%	72.2	39.4

*Machine power and heating intensity (%MAX intensity) at data reading time.

Figure 36 Cumulative electric energy consumption from April 26th to April 30th.

Results, complemented with the information depicted in **Figure 35**, show up such a disconcerting scenario. **Figure 34** can be understood taking into account that, once again, REFERENCE heater experiment more heating/cooling cycles than NANOPCM one. Moreover, even having been fixed at the same temperature and power, a shift between curves from April 27th to April 29th is observed ($\Delta T=5^{\circ}\text{C}$).

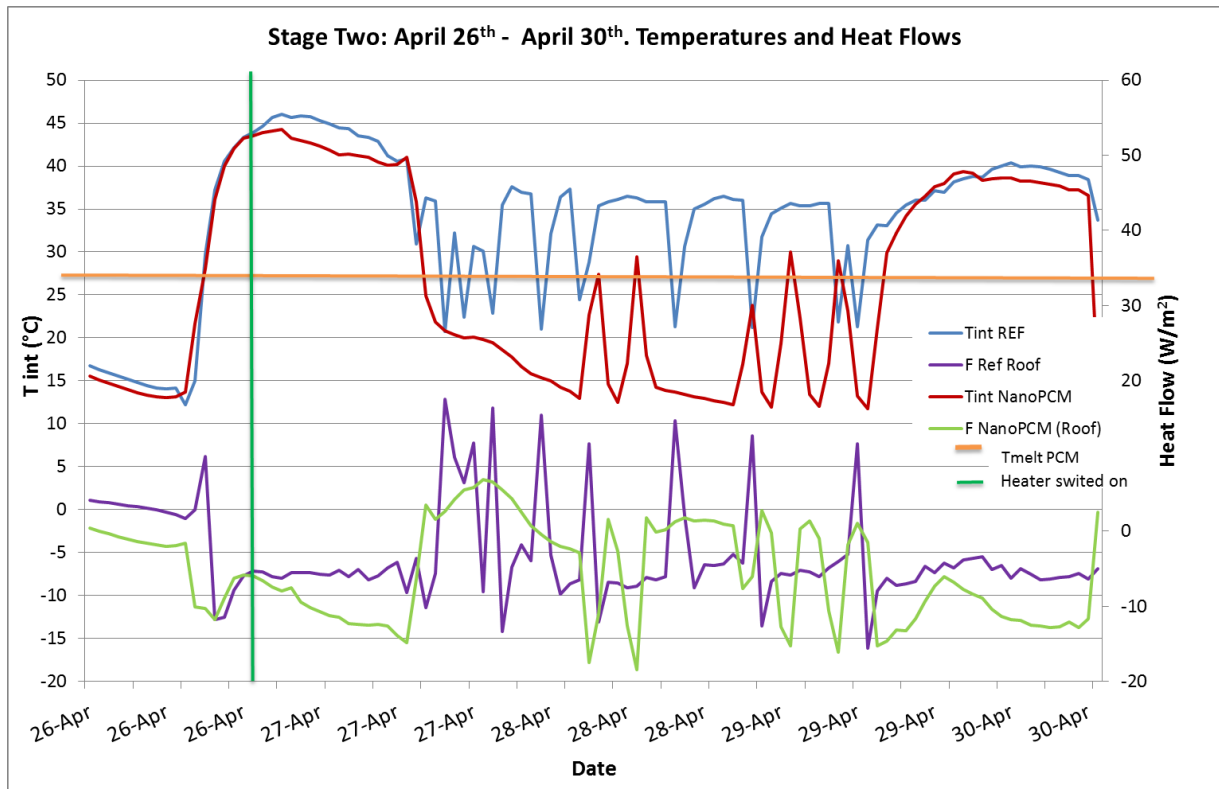


Figure 37 Internal temperatures and heat fluxes throughout the roof for NANOPCM and REFERENCE mock-ups (April 26th - April 30th period).

Stage Three: from May 6th to May 13th.

The heating devices are disconnected from May 6th to May 9th owing to the warm temperatures reached in Madrid. But after the analysis of the data and to find the temperatures do not get the melting temperatures of the PCM, the Garza® space heaters are switched on May 9th and May 10th during 3-4 hours to increase the internal temperature of the mock ups and logging the cooling process.

Figure 50 shows the temperature profile of the testing days of May and an increment of the average temperature is obvious comparing with figure 44 (April temperature profile)

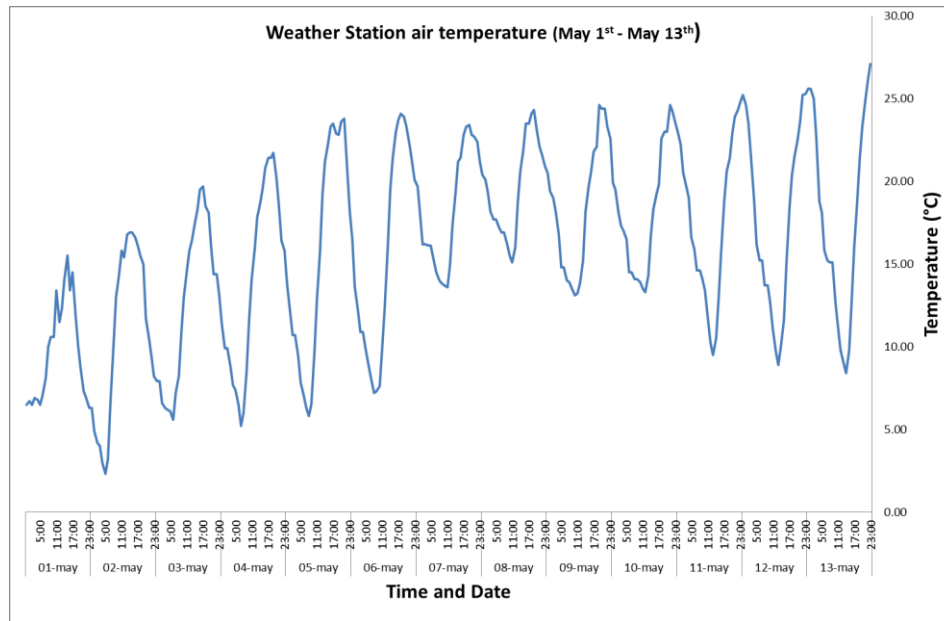


Figure 38 Weather Station average air temperature per day from May 1st to May 13th.

Figure 38 shows the internal temperature and the heat flow through the roof of both mock ups. The days included between 6th to 9th of May have a maximum temperature of 23 °C and the days between 11st to 13rd, it is around 25°C. These temperatures are below the melting point of the PCM but owing to the PCM melts during a temperature range, part of these should be working along these days.

In the figure any effect of heat storage is presented in the NanoPCM mock up. A light delay in the cooling (6th to 9th of May) and in the heating (11st to 13rd of May) is shown in the reference mock up compared with NanoPCM one.

In the analysis of the roof heat flux, this behaviour is reflected with the differences in the fluxes in both mock ups. NanoPCM one has higher fluxes in the beginning of the cycle, but reference one has wide and lower peaks along all the cycle.

This behaviour could show us that the thermal mass of both mock ups is different and the PCM added in one of them is not working to improve the foam functionality.

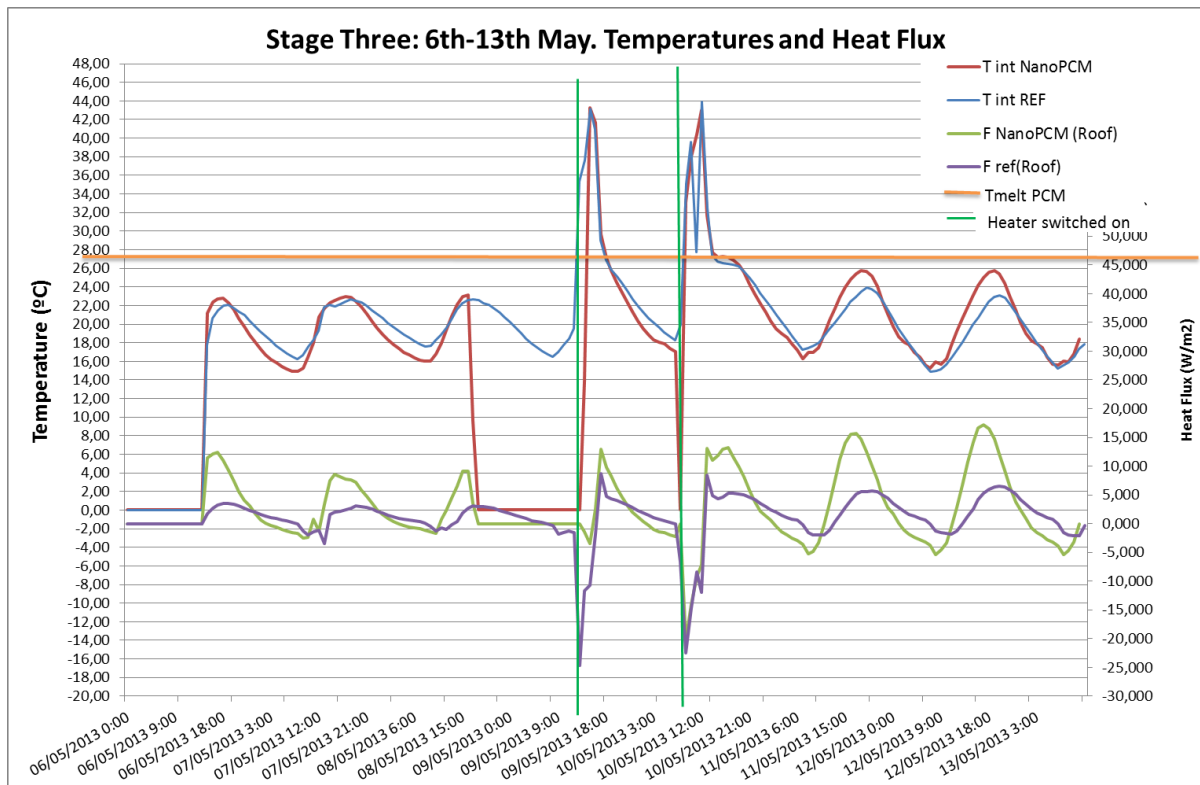


Figure 39 Internal temperatures and heat fluxes throughout the roof for NANOPCM and REFERENCE mock-ups (May 6th –May 13th period).

Trying to work in the temperature melting range, heaters were connected the days 9th and 10th some hours (1-2 hours) to study the cooling process. In figure 51, the heating is clearly presented and a quick cooling process is similar in both mock ups. Any effect of the different materials can be evidenced and, in this case, the reason can be there is not enough time during the heating step to heat all the walls of the mock ups.

8 CONCLUSION

Additional works have been carried out from month 26 to month 36. That way, the construction of both demo-parks (placed in Poland and Spain) finished and the installation of the developed innovative panels was done.

Following the pictures and comments above, the conclusion of the monitoring behaviour logged so far is that warmer temperature is needed to demonstrate the performance of the NanoPCM materials and to show the improved thermal properties reached at laboratory scale.

Despite of the official end date of the project, the data will be collected the coming months to finalize the demonstration task in the most favourable environment conditions.

Similar test will be carried out. One of them with an HVAC system to know the energy consumption needed to achieve the comfort temperature and other one studying the passive cooling.

Thanks to the demonstration in two different climates, the behaviour of the NanoPCM products under a proper range of weather conditions will be extracted.

9 ACKNOWLEDGEMENTS

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