ecoPhaser

Field Trial Report

Preliminary Evaluation of a Passive Drop-Ceiling Climatization System

Date: October 2024

In Collaboration with: Pluss Advanced Technologies B.V.

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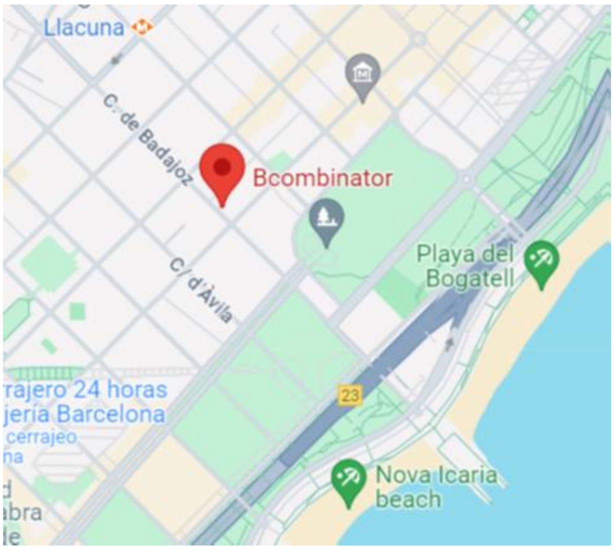
1. Purpose of the trial

The aim of the test is to demonstrate the effectiveness of the ecoPhaser passive suspended ceiling cooling system based on phase change technology in a real, occupied office building containing both open and cellular offices. The test site allows us to set up multiple control and mechanical concepts, thereby measuring their effectiveness and their impact on energy and/or cost savings. Another important aspect of the test is to support the results of our public survey on user experience, and in case of a long-term test, to assess the potential on reducing respiratory diseases.

2. Test location

2.1 The Location

The test site is the Barcelona headquarters of the Bcombinator startup center, located at C/ de Badajoz, 32, in the Sant Marti neighborhood.



Barcelona has a Mediterranean climate, bordered to the east, southeast and south by the Mediterranean Sea. Summers are dry, long and hot, although in July and August the maximum daily temperature rarely exceeds 30 °C, as the wind blows from the sea to the mainland.

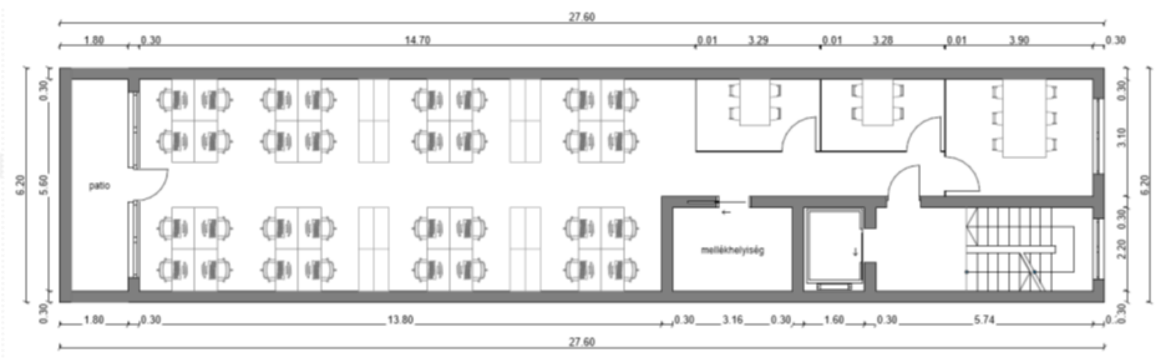
Climate data for Barcelona - Les Corts (1987-2010) [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean daily maximum °C (°F)	14.8 (58.6)	15.6 (60.1)	17.4 (63.3)	19.1 (66.4)	22.5 (72.5)	26.1 (79.0)	28.6 (83.5)	29.1 (84.4)	26.0 (78.8)	22.5 (72.5)	17.9 (64.2)	15.1 (59.2)	21.2 (70.2)
Daily mean °C (°F)	11.7 (53.1)	12.4 (54.3)	14.2 (57.6)	15.8 (60.4)	19.3 (66.7)	23.0 (73.4)	25.7 (78.3)	26.1 (79.0)	23.0 (73.4)	19.5 (67.1)	14.9 (58.8)	12.3 (54.1)	18.2 (64.8)
Mean daily minimum °C (°F)	8.8 (47.8)	9.3 (48.7)	10.9 (51.6)	12.5 (54.5)	16.1 (61.0)	19.8 (67.6)	22.7 (72.9)	23.1 (73.6)	20.0 (68.0)	16.5 (61.7)	11.9 (53.4)	9.5 (49.1)	15.1 (59.2)
Average precipitation mm (inches)	43.7 (1.72)	31.4 (1.24)	33.0 (1.30)	47.7 (1.88)	47.4 (1.87)	25.5 (1.00)	25.1 (0.99)	40.8 (1.61)	81.9 (3.22)	96.5 (3.80)	45.1 (1.78)	46.8 (1.84)	565.0 (22.24)
Average precipitation days (≥ 1 mm)	6.0	5.0	6.2	7.9	7.5	5.5	3.1	5.8	8.0	8.0	6.6	7.0	76.6
Source: Servei Meteorològic de Catalunya[30]													

2.2 Site description

The building serves as the Barcelona headquarters of the Bcombinator startup center. The ground floor features a bar, lecture hall and communal areas, while the upper floors house a mix of cellular and closed office spaces with coworking functions. The roof floor accomodates communal areas, terraces and mechanical spaces. It is crucial for the evaluation of the pilot measurements that the building has the same architectural design on the upper floors, so we have two reference floors available for the tests.

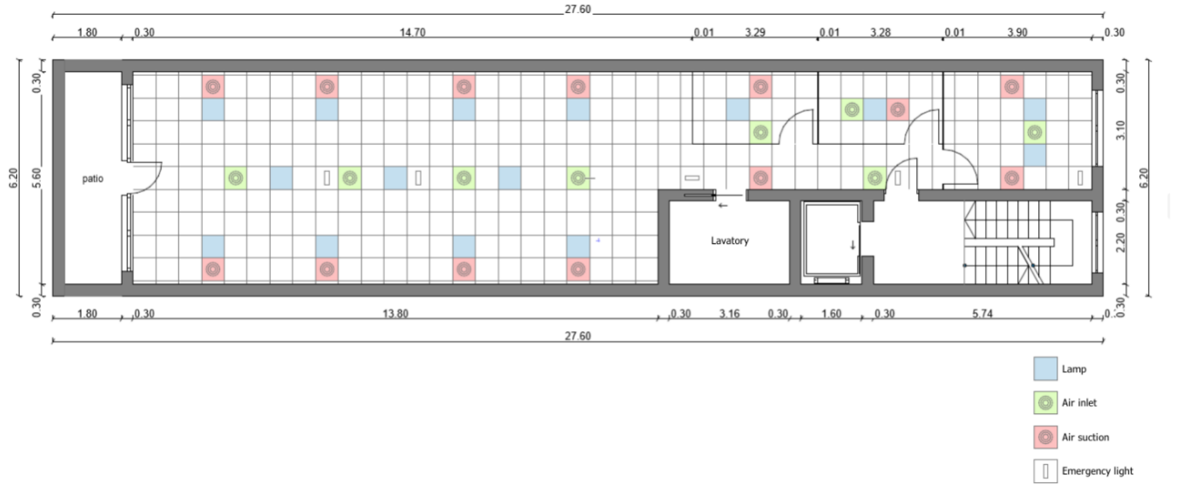
2.3 Architectural design

The building is a closed-row, NE-SW oriented, ground floor + 4-storey building without a basement, built in 1967. The vertical structural design of the building is a reinforced concrete pillar frame with 11 cm thick ceramic frame infill masonry, and the horizontal load-bearing is carried out by monolithic reinforced concrete slabs. The internal walls are 11 and 4 cm thick ceramic masonry, and the separation of the closed offices and meeting rooms is solved with a 2-layer laminated glass wall. There are plasterboard suspended ceiling elements (60x60cm) on the office floors of the building.



2.4 Mechanical design

The building is cooled and heated by DAIKIN Seasonal classic ducted air conditioning systems. It is crucial for the pilot concept, measurement and evaluation, that for each floor a separate outdoor unit of the same type provides the temperature control, so we have direct and comparable data sets for each floor separately.

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DAIKIN

3. Test Environment

3.1 Site Description

It is important to highlight the unique nature of the location for running the tests. The identical architectural design, orientation, and function, along with the same number of workstations on each level and, most importantly, the separate outdoor units for each level, enable precise measurement of consumption per level, allowing for an accurate demonstration of the system's efficiency.

3.2 Ceiling panels

For the efficiency of the system, it is important that the heat transfer coefficient between the phase change material and the office interior is maximized. To this end, the existing plasterboard ceiling panels in the office were replaced with 0.8 mm thick perforated aluminum ceiling tiles.

3.3 Phase Change Material (PCM)

During the test, we used PLUSS savE®HS22 Climate Ceiling Pouches, pouches containing phase change material, which provided us with an energy storage capacity of 1811.76 kJ/m2.

3.4 Mechanical Auxiliary Elements

The plenum space houses the ecoPhaser's mechanical components.

3.5 Sensor system

The ecoPhaser sensor system was installed in the drop-ceiling panels.

3.6 Control

The climate control is provided by the ecoPhaser's unique control system.

4. Measurement methodology

4.1 Methodology

During the discussions with potential customers and users, dual expectations emerged regarding the product. From the owner and operator side, electricity consumption savings and operating time reduction were the most important benchmarks, while from the user side, convenience and comfort requirements were the most important. Since the measurement site allows for measuring energy consumption savings through separate outdoor units per level, we could measure the electricity consumption of the outdoor units of the PCM level and the reference levels. The difference in consumption between the PCM and reference levels provides an accurate picture of the daily savings, which is one of the most important metrics of the system.

During the daytime measurement period (06:00 - 20:00), the indoor unit started cooling when the indoor temperature at the thermostat exceeded 24 degrees. During the nighttime measurement period (20:00 - 06:00), the air conditioning unit blew cold air (16°C), which was used to re-freeze the PCM pouches with the EcoPhaser air technology solution.

4.2 Measuring instruments

We measured the electric consumption of each outdoor unit with Orno single phase power meters (OR-WE-504), for data logging we used Arduino Nano to capture data from the power meter every minute to be saved on an SD-card.

5. Measurement results

5.1 Cooling demand

In order to get a more comprehensive picture of the system's operation when evaluating the measurement results, it is necessary to calculate the cooling demand of the different levels. Since we are not aware of the layer structure of the boundary structures, this value will be approximate, but it will accurately weight the differences in cooling power consumption resulting from differences in the number of people.

Cooling power requirement based on basic structures, heat load calculated from transmission heat flows and radiation gain is 15kW, which is the baseline for the overall cooling demand.

Source	Unit load	Total load	Calculated heat load
Baseline from structure	-	15kW	15kW
Illumination	10-15 W/m2	12.5x112	1.4 kW
Office machinery (32 persons)	100 W/PC	32*100	3.2 kW
Office machinery (18 persons)	100 W/PC	18*100	1.8 kW
Personnel (32)	100-175 W/person	175*32	5.6 kW
Personnel (18)	100-175 W/person	175*18	3.15 kW

Office level cooling demand at full occupancy: 25.2 kW

Office level cooling demand at average load: 21.35 kW

An important conclusion to be drawn from the above calculation is that the difference in cooling demand due to the number of people is approximately a 15% between the nominal maximum number of employees (32 people) and the average documented office load (18 people). This is important when analyzing the measurement results because the operator specified a nominal monthly number of employees during the measurements. The resulting difference in cooling demand provides an important basis for interpreting the measured data when evaluating consumption data.

5.2 System sizing

The aim of the measurement is basically to prove the effectiveness of the product to the end user. This is primarily reflected in operating cost savings, i.e. measurable and demonstrable electricity consumption savings. In Spain, the price of electricity varies hourly, the figure shows the data of a typical summer day with color codes.

The figure shows that the most efficient operating mode is to cool the PCM charges in the early morning hours (between 00:00 and 10:00) and then discharge them in the morning and early afternoon (10:00 and 14:00). The amount of PCM charges was sized according to this concept, and in the first step we proved that the charges could guarantee the targeted office temperature of 22-23 °C under full load without cooling assistance.

5.3 Comparison methodology

During the test, we monitored the consumption of three floors, which have the same floor plan and nominal load. However, the number of employees on the third floor of the office building is radically less than the number of employees on the first floor and the second floor, equipped with PCM charges, and the employees here were not constantly at their workstations. This is also clearly visible from the measurement results. Therefore, the consumption savings compared to the third floor are not relevant.

In the consumption comparison tables, we have separately shown the energy savings for the whole day, and for the PCM cooling down and targeted discharge (10:00-14:00) periods.

It is important to mention that in this test phase we could not eliminate unjustified user intervention in the operation of the air conditioning (PCM fillings can maintain the target office temperature until 2:00 PM in the afternoon on a sunny warm day, according to the test results), which is partly based on the different thermal perception of individuals, thus distorting the savings calculations.

5.4 Measurement results – Spring / Autumn / Mild summer

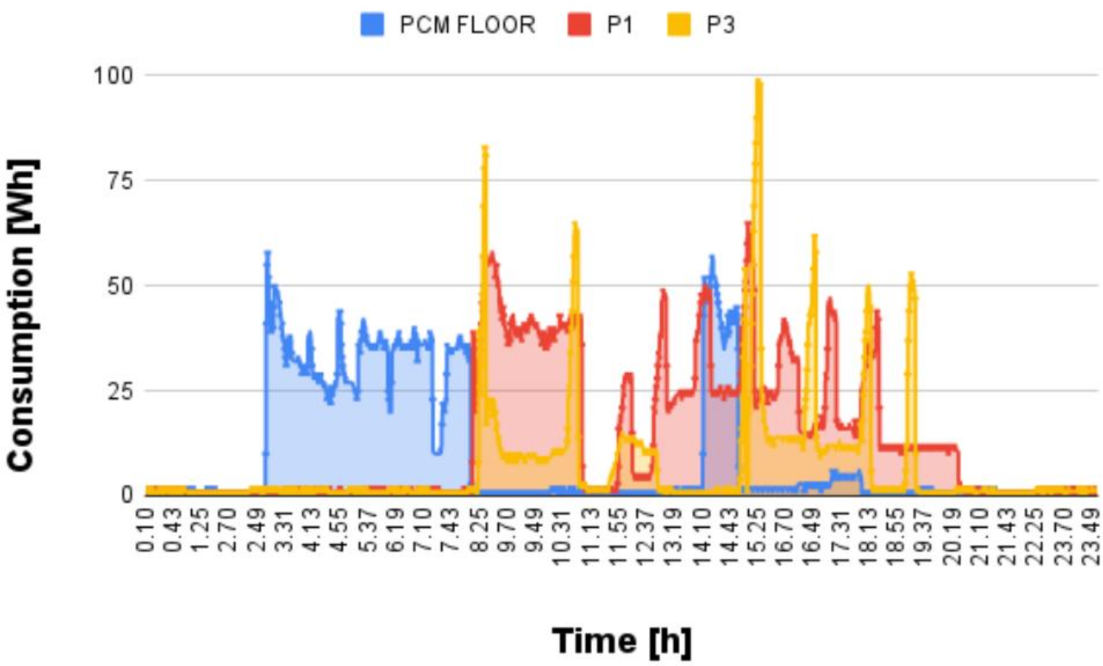
Date: 2024.10.01

Daytime temperature maximum: 25 °C

Nighttime temperature minimum: 15 °C

With these temperature and sunlight conditions, we see approximately the savings values that can be achieved under spring, mild summer and autumn weather conditions.

Measurement results:



Savings calculations:

	P1 - FIRST FLOOR	P3 - THIRD FLOOR	PCM FLOOR	$AVINGS	
DAILY				P1	P3
CONSUMPTION	19350	9556	13658	29.42%	-42.93%
ELECTRICITY COST	€3.29	€1.59	€1.93	41.34%	-21.02%
0:00-14:00 PERIOD					
CONSUMPTION	10068	4055	10539	-4.68%	-159.90%
ELECTRICITY COST	€1.82	€0.73	€1.49	18.57%	-103.10%

The development of the consumption curves under lower external load is interesting. The beneficial effect of the lower external temperature is visible during the night-time recooling, and the prolongation of the cooling effect of the PCM charges during daytime use.

The consumption peak around 3:00 p.m. may be due to the sudden increase in heat load and air conditioning demand of office workers returning from lunch, but after the office space was properly recooled, the PCM charges were able to maintain the internal temperature for longer. This is supported by the fact that we registered continuous consumption at the reference levels in the afternoon. The cost savings during the period until 2:00 p.m. are 18.57%, while the savings projected for the whole day are 41.34%.

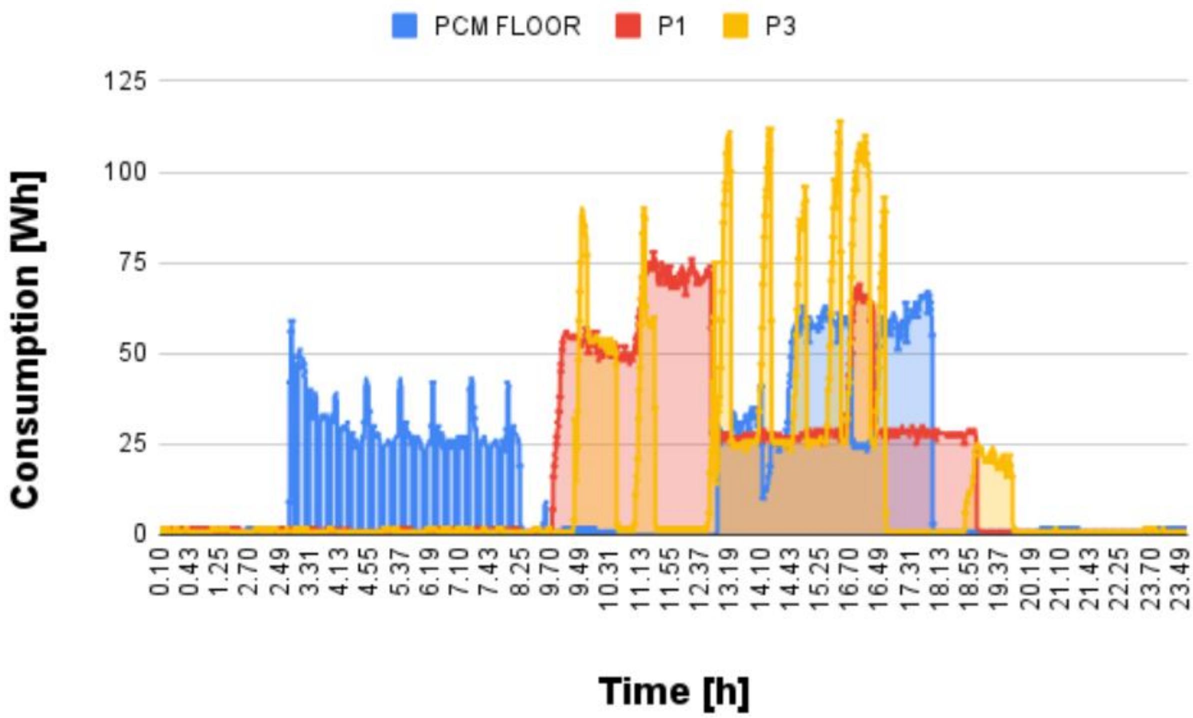
5.5 System potential – Sunny weather

The results of the measurements in the hot summer day scenario were influenced by several factors that could distort the results, which will be eliminated in the next development stage of the system. These efficiency-enhancing steps include increasing the recooling efficiency by intermittent air flow, monitoring the office space temperature, and partially limiting user intervention depending on the office space temperature (while avoiding a decrease in comfort). The application of these two concepts to the sunny (summer) measurement results would yield the following expected (based on existing measurement results):

Daytime temperature maximum: 32 °C

Nighttime temperature minimum: 17 °C

Measurements results:



Savings calculations:

	P1 - FIRST FLOOR	P3 - THIRD FLOOR	PCM FLOOR	$AVINGS	
DAILY				P1	P3
CONSUMPTION	25441	19750	20490	19.46%	-3.75%
ELECTRICITY COST	€4.35	€3.18	€2.94	32.44%	7.57%
0:00-14:00 PERIOD					
CONSUMPTION	15440	8306	8696	43.68%	-4.70%
ELECTRICITY COST	€2.84	€1.52	€1.31	53.91%	14.28%

The measurement results were modified in the 00:00-14:00 measurement period, so a saving of 53.91% can be forecasted in the same period and 32.44% on a daily basis.

6. Comparison of simulation and measurement results

Summarizing the measurement results, we measured a 41% cost saving and a 29% electricity consumption saving in spring/autumn/mild summer conditions, while on an expected warm (over 30°C) summer day, we obtained a 32% cost saving and a 19% electricity saving based on the measurement results. It is important to emphasize that a key aspect of the architecture developed by EcoPhaser is the simulation of the system design, which, among other things, predicts substantial savings. This measurement cycle has validated our simulation method, as the measurement results align closely with the simulation predictions.

7. User experiences

We gathered user feedback primarily regarding thermal comfort and acoustic performance. We received positive feedback from employees in both areas, the passive surface cooling provided them with a particularly pleasant thermal sensation. No acoustic problems were reported (they didn't even notice that the suspended ceiling had been replaced in the first week), despite the fact that the office basically lacks sound-absorbing coverings that could compensate for the increased reflection from the suspended ceiling.