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**Abstract**: This deliverable describes the aspects of the project related to the effectiveness of the project in motivating energy savings and in particular the savings that resulted from specific measures and interventions. For the purpose of the performance assessment the campaigns performed at three pilot sites were evaluated. The energy savings were calculated using baselines derived from Energy Performance Certificates, and where possible, detailed computer thermal models of the buildings under consideration were used. In addition to the evaluation of performance in terms of effectiveness of campaigns and reduction of energy use, this deliverable gives a comprehensive description of the lessons learnt in the project. This wealth of know-how comprises lessons learned about practical matters such as hardware deployment, feedback from the users, and the best practices identified after running all the campaigns.

**Keywords**: Performance; Energy savings; Behaviour change; Lessons learnt; IoT; Buildings; Intervention.
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Executive Summary

This document shows the performance of project ENTROPY in the aspect of energy savings and behavioural change. Project ENTROPY aims to investigating the potential energy savings that can be achieved in building via the incorporation of an IoT infrastructure that is capable of delivering personalised and timed feedback to users that move them towards more efficient behaviours.

This document shows how several facets of behaviour can be changes when adopting a solution as the one designed in entropy. It is particularly relevant how the experiments show that in all cases it has been possible to improve the so called energy saving competence, which represents the knowledge of a person to save energy or in different words the potential of a user to save energy by using things they know. This finding is highly positive as interventions of the kind carried out here aim mainly on improving energy literacy, so users know better what energy is, how it is used, and how they can reduce it. The literature has shown that this savings also last for longer when they are based on a better energy literacy.

Overall, it has been seen that these initiatives have great potential to decrease energy use in buildings. And that considering the low cost that they may represent in modern building in which the IoT infrastructure is already in place, they should proliferate rapidly.

This document shows the details about the performance that the project has had on tackling the issues of behavioural change and energy use reduction, but also it describes the lessons learnt that the consortium has gained during the time of the project. Making sure that future projects take into account these lessons, and use the know how created in this project will result in successful interventions in virtually any building of Europe.

Disclaimer

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1 INTRODUCTION

Buildings are responsible for around 40% of the energy demand in developed countries. However, society has a great opportunity on reducing the emissions coming from that demand, as the sector has been seen to have a great potential of energy savings. The scientific literature suggests that savings in energy of 20% can be achieved if interventions to change behaviour are carried out in buildings. The latest research has shown that when these behavioural-change interventions are based in feedback to users that is in real time and personalised the savings are higher than when providing general feedback.

The new paradigm of IoT in buildings opens the opportunity to use sensors that are already installed in buildings or which marginal cost is rather low, to create a framework capable of delivering personalised real time feedback aimed to tackle the behaviours that represent the largest energy waste.

This has been done in project ENTROPY, and the results is a framework that uses an IoT platform as the core to administer the data, create the logic that detects energy waste, elaborate messages that are personal and timed, and deliver the information via created-for-purpose mobile apps.

This deliverable shows the details about the project and evaluates the performance of the activities carried out within it. The main objective of this project as part of the umbrella goals of the European Society is the reduction of energy use in building to eventually reduce Carbon emissions. As this is done in this project via the change in habits and behaviours, the evaluation of performance has a second pillar on this project that it is the performance of behavioural change. The summation of these two objectives will provide the success of this endeavour.

This project has been, to the knowledge of the consortium, very successful, and not only has proven to be capable of saving energy via intelligent feedback to building users, it has also generated as a product of the project a functional platform and a set of mobile phone applications that alone could be a market product in the near future. These solutions have been seen to our perception to almost reach commercial maturity, and to provide added value to the European society because of the innovation they represent, and because of their effectiveness on saving energy.

The document has a section in which the performance of the interventions on changing behaviour is evaluated (Section 3). This is followed with a thorough explanation on how the framework to evaluate the savings was created in project ENTROPY. It should be noted that within this section, the detailed thermal model created for two of the buildings were the solution was tested are described. These are thermal models that allowed to calculate the maximum impact that our interventions could have, and created a great deal of knowledge to design our campaigns. Section 5 shows the savings that have been seen after deep analysis of the data from the sensors. This has been done with the data from these experiments, however, as mentioned before the solution here developed has a substantial level of maturity, and in the platform has already included visualisations of energy use for the non-experts; this has been shown in Section 6.

This project has allowed all partners to gain a great deal of knowledge about the topic at hand. An extensive section on Lessons learnt is provided in Section 7. Following this, we summarise the conclusions of the work here presented and we complement this with a discussion of the results in Section 8. The document is closed with a section of references in Section 9.
2 SUMMARY OF KEY PERFORMANCE INDICATORS

This section provides a brief description on a “glossary-way” of the indicators that were used for the evaluation of the different aspects of the project. Although the methodologies defining these indicators and their results will be explained in detail in further sections, this section provides an overview of them structured in the facet each one evaluates of the project.

| Indicators of sensing infrastructure | - Devices connected to the platform and communicating.  
|                                      | - Volume of data “sensed” in the project. |
| Indicators of platform performance   | - Number of users registered.  
|                                      | - Volume of data handled by unit of time.  
|                                      | - Campaigns defined and run. |
| Indicators of mobile apps performance| - Number of variables being represented by apps.  
|                                      | - Strategies defined for rewards.  
|                                      | - Strategies defined for gamification.  
|                                      | - Strategies defined for improving engagement. |
| Indicators of user engagement        | - Ratio of participants over recruitment.  
|                                      | - Length of campaigns.  
|                                      | - Number of drop-outs. |
| Indicators of users’ interactions    | - Communications from participants to pilot managers’.  
|                                      | - Reading tips, answering questions, complete quizzes and performing tasks.  
|                                      | - Opening and closing of the application and “clicks”. |
| Indicators of energy savings         | - Savings at users’ level.  
|                                      | - Savings at areas’ level.  
|                                      | - Savings at buildings’ level.  
|                                      | - Savings extrapolation. |
| Indicators of users’ interactions    | - Changes on behaviour based on data.  
|                                      | - Self-awareness of change.  
|                                      | - Changes on participants’ perceived norm.  
|                                      | - Changes on participants’ personal values. |
| Indicators of users’ behavioural change| - Indicators of users’ improvements on energy literacy  
|                                          | - Results from surveys.  
|                                          | - Results from games. |
3 PERFORMANCE EVALUATION OF BEHAVIOURAL CHANGE

Behavioural change is one of the key aspects of this project. We aimed to reduce energy consumption in buildings via the change in habits of building users. It is therefore an important part of the performance of this project the success that we found on changing these behaviours. For a detailed explanation about the methodology and the results obtained in this facet of the project the reader is referred to Deliverable 5.4; however, for a comprehensive understanding of the performance of this project the main indicators of performance in this aspect have been included in this section by pilot.

3.1 UMU Pilot

3.1.1 Initial campaigns at UMU

a. Sample Characteristics

The participants in the introductory ENTROPY energy-saving campaigns at UMU comprised of mostly male participants (6/7), without children (5/7). They were on average highly engaged with their work (avg. Vigor = 4.81/7) and felt competent in carrying out their duties at work (avg. 5.02/7), while at the same time experiencing a connection - relatedness to their colleagues (avg. 4.05/7) and the autonomy to enact their duties at work (avg. 4.90/7).

b. Motivation to Save Energy at Work

The participants at UMU were on average self-determined and autonomously motivated to conserve energy at their workplace before the ENTROPY campaigns (avg. SDI = 9.89 / positive). After participating in the ENTROPY campaigns, most of the participants (57.14%) reported an increase in their self-determination to save energy at work. Finally, the employees’ self-determination to conserve energy at work, increased by 11.93%, on average, during the initial ENTROPY campaigns at UMU.

c. Personal Norms

The employees’ personal pro-energy-conservation norms at UMU were on average reported as positive (avg. 5.49/7). This meant that they were generally positively inclined towards personally performing energy-saving at work and had inscribed the rules within them to do so regularly. Following the initial ENTROPY campaign, a decrease in the personal energy-saving at work norms was observed for more than half (57.14%) of the participants. However, the participants’ pro-energy-conservation norms at UMU remained high, with an average observed decrease of 6% (-0.33/7).

d. Subjective Norms

The employees at UMU, on average, reported moderately high subjective norms towards energy saving at work (4.86/7) before the initial campaigns. This belief that their fellow employees expect them to conserve energy at work decreased by 17.7% (-0.86/7 lower) after participating in the campaigns. Therefore, perceived social pressure to conserve energy at UMU was lower after the initial campaigns.

e. Behavioural Intention

The employees at UMU, on average, reported equally high intentions to conserve energy at work (6.0/7), both before and after the initial campaigns (6.0/7). Therefore, their strong intention to conserve energy at their workplace remained unaltered during the first ENTROPY campaigns.

f. Self-Reported Behaviour
The participants in the first campaigns at UMU admitted to enacting a set of energy-saving behaviours regularly at work with a very high rate of agreement on average (5.86/7). Following the initial ENTROPY campaigns, most of the employees at UMU (57.14%) believed that they were enacting the same energy-saving actions even more so (5.92/7). The average recorded increase in self-reported energy-saving behaviour at work was 1.02%.

g. Energy-Saving at Work as a Habit

The participants of the first campaigns at UMU believed that performing energy-saving at work was a strong habit for them (avg. 6.18/7). This belief remained high, but on average decreased by 6.14% (-0.43). However, for the majority of the participants it was increased (42.86%), or remained the same (28.57%).

h. Personal Impact

The participants at UMU on average highly believed that their own personal actions can have a real impact on energy saving at work (4.76/7). This belief remained high after the first ENTROPY campaigns (4.38/7), but for the majority of the participants (57.14%) it decreased and the average recorded decrease was 8%.

i. Collective Impact

The participants’ strong beliefs at UMU that, as a whole, employees can collectively have an impact on energy consumption at their workplace through their behaviour was recorded as very high (6.0/7). This belief remained, on average, unaltered and equally very high, as recorded after the campaign (6.0/7).

j. Energy-Saving Competence

The participants at UMU rated their competence in energy saving at work very highly (6.18/7) before the ENTROPY campaigns. Their confidence in their capability to personally conserve energy at work remained high (5.82/7) after the completion of the first campaigns. However, a relative decrease was recorded for 57.14% of the participants, while on average perceived energy-saving competence at UMU decreased by 5.82%.

k. Attitude Towards Energy-Saving at work

The participants on average rated their attitude towards conserving energy at work low (2.29/7) before the ENTROPY campaigns. This attitude remained almost unaltered on average (-1.7% decrease). However, for the majority of the participants it either increased (42.86%), or remained the same (28.57%).

3.1.2 Final campaign at UMU

a. Sample Characteristics

The participants in the final ENTROPY energy-saving campaigns at UMU were in their majority male (21/23), without children (17/23). Their average age was 33.17 years old and they worked in eight (8) different areas/rooms. They were on average highly engaged with their work (avg. Vigor = 4.33/7) and felt competent in carrying out their duties at work (avg. 5.07/7), while at the same time experiencing a moderately rated connection - relatedness to their colleagues (avg. 3.64/7) and high autonomy to enact their duties at work (avg. 4.61/7).

b. Motivation to Save Energy at Work
The participants at UMU were on average self-determined and autonomously motivated to conserve energy at their workplace before the final ENTROPY campaigns (avg. SDI = 7.86/positive). After participating in the ENTROPY campaign, the vast majority of the participants (82.61%) reported an increase in their self-determination to save energy at work. Finally, the employees’ self-determination to conserve energy at work, increased by 31.3%, on average, and reached 18.17 during the last ENTROPY campaign at UMU.

c. Personal Norms

The employees’ personal pro-energy-conservation norms at UMU were on average reported as positive (avg. 4.78/7). This meant that they were generally positively inclined towards personally performing energy-saving at work and had enscribed the rules within them to do so regularly. Following the final ENTROPY campaign, a significant average increase of 27.68% in the personal energy-saving at work norms (5.94/7) was observed. The vast majority (82.61%) of the participants also reported higher energy-saving at work norms.

e. Behavioural Intention

The employees at UMU, on average, reported high intentions to conserve energy at work before the final ENTROPY campaign (5.04/7). Their intentions to conserve energy at work were recorded as considerably higher (+25.79%), and very high (6.35/7), after the final ENTROPY campaign.

f. Self-Reported Behaviour

The participants in the final campaign at UMU admitted to enacting a set of energy-saving behaviours regularly at work with a very high rate of agreement on average (5.40/7) before the campaign. Following the ENTROPY campaign, the vast majority of the employees at UMU (73.91%) believed that they were enacting the same energy-saving actions even more so (6.28/7). The average recorded increase in self-reported energy-saving behaviour at work was 16.11%.

g. Energy-Saving at Work as a Habit

The participants of the last campaign at UMU believed that performing energy-saving at work was a strong habit for them (avg. 5.08/7). This belief was considerably increased by 20.43% (+1.04). At the same time, for the majority of the participants this habit was enhanced (69.57%), or remained the same (13.04%).

h. Personal Impact

The participants at UMU on average moderately believed that their own personal actions can have a real impact on energy saving at work (3.94/7). This belief was considerably reinforced (4.72/7) after the last ENTROPY campaigns (+19.8%), and for the majority of the participants (60.87%) it increased or remained the same (4.35%).

i. Collective Impact

The participants’ beliefs at UMU that, as a whole, employees can collectively have an impact on energy consumption at their workplace through their behaviour was recorded as high (5.0/7) before the last campaign. This belief was, on average, considerably reinforced (+25.2%), as recorded after the final campaign (6.26/7).

j. Energy-Saving Competence

The participants at UMU rated their competence in energy saving at work highly (5.11/7) before the last ENTROPY campaign. Their confidence in their capability to personally conserve energy at work was considerably reinforced (6.36/7) after the completion of the last campaign (+24.46%).
At the same time, a relative increase was recorded for the vast majority of employees (73.91%), while the strength of the beliefs of the 13.04% remained the same.

k. Attitude Towards Energy-Saving at work

The participants on average rated their attitude towards conserving energy at work low (3.10/7) both before (3.10/7) and after (2.75/7) the ENTROPY campaigns, with an average decrease of -29.36%. At the same time, the attitude of the majority of the participants was either decreased (69.57%), or remained the same (13.04%).

3.2 HESSO Pilot

3.2.1 Initial campaigns at HESSO

a. Sample Characteristics

The participants in the introductory ENTROPY energy-saving campaigns at HESSO comprised of mostly male participants (2/3), without children (2/3). They were on average moderately engaged with their work (avg. Vigor = 3.4/7) and felt competent in carrying out their duties at work (avg. 4.7/7), while at the same time experiencing a connection - relatedness to their colleagues (avg.3.9/7) and the autonomy to enact their duties at work (avg. 4.5/7).

b. Motivation to Save Energy at Work

The participants at HESSO were on average self-determined and autonomously motivated to conserve energy at their workplace before the ENTROPY campaigns (avg. SDI = 5.3 / positive). After participating in the ENTROPY campaigns, most of the participants (66.67%) reported an increase in their self-determination to save energy at work. Finally, the employees’ self-determination to conserve energy at work, increased by 30.19%, on average, during the initial ENTROPY campaigns at HESSO.

c. Personal Norms

The employees’ personal pro-energy-conservation norms at HESSO were on average reported as positive (avg. 4.6/7) before the campaigns. This meant that they were generally positively inclined towards personally performing energy-saving at work and had inscribed the rules within them to do so regularly. Following the initial ENTROPY campaigns, a slight increase in the personal energy-saving at work norms was observed for more than half (66.67%) of the participants. Therefore, the participants’ pro-energy-conservation norms at HESSO remained high, with an average observed increase of 2.17% (0.1/7).

d. Subjective Norms

The employees at HESSO, on average, reported moderate subjective norms towards energy saving at work (3.7/7) before the initial campaigns. This belief that their fellow employees expect them to conserve energy at work was increased by 8.11% (0.3/7 higher) after participating in the campaigns. Therefore, perceived social pressure to conserve energy at HESSO was higher after the initial campaigns.

e. Behavioural Intention

The employees at HESSO, on average, reported equally high intentions to conserve energy at work (5.0/7), both before and after the initial campaigns (5.0/7). Therefore, their moderately strong intention to conserve energy at their workplace remained unaltered during the first ENTROPY campaigns.
f. Self-Reported Behaviour

The participants in the first campaigns at HESSO admitted to enacting a set of energy-saving behaviours regularly at work with a high rate of agreement on average (4.5/7). Following the initial ENTROPY campaigns, most of the employees at HESSO (66.67%) believed that they were enacting the same energy-saving actions even more so (4.7/7). The average recorded increase in self-reported energy-saving behaviour at work was 4.2%.

g. Energy-Saving at Work as a Habit

The participants of the first campaigns at HESSO believed that performing energy-saving at work was a habit for them to an extent (avg. 4.9/7). This belief remained to a comparable extent, but on average decreased by 5.1% (-0.25). However, for the majority of the participants it was increased (33.33%), or remained the same (33.33%).

h. Personal Impact

The participants at HESSO on average moderately believed that their own personal actions can have a real impact on energy saving at work (4.1/7). This belief decreased after the first ENTROPY campaigns (3.7/7), and for the majority of the participants it was decreased with an average recorded decrease of 10.73%.

i. Collective Impact

The participants’ beliefs at HESSO that, as a whole, employees can collectively have an impact on energy consumption at their workplace through their behaviour was recorded as strong (4.7/7). This belief considerably increased in intensity (+14.25%), as recorded after the campaign (5.3/7).

j. Energy-Saving Competence

The participants at HESSO rated their competence in energy saving at work moderately highly (4.7/7) before the ENTROPY campaigns. Their confidence in their capability to personally conserve energy at work remained the same after the completion of the first campaigns.

k. Attitude Towards Energy-Saving at work

The participants on average rated their attitude towards conserving energy at work averagely (4.0/7) before the ENTROPY campaigns. This attitude decreased on average (-12.5% decrease). However, for the majority of the participants it either increased (33.33%), or remained the same (33.33%).

3.2.2 Final campaign at HESSO

a. Sample Characteristics

The participants in the final ENTROPY energy-saving campaigns at HESSO were in their majority male (18/22), without children (13/22). Their average age was 34.96 years old and they were allocated for the purpose of the analysis to one room/area, due to the restrictions in the sensing infrastructure. They were on average moderately engaged with their work (avg. Vigor = 3.68/7) and felt competent in carrying out their duties at work (avg. 4.92/7), while at the same time experiencing a moderately rated connection - relatedness to their colleagues (avg. 3.89/7) and autonomy to enact their duties at work (avg. 4.39/7).
b. Motivation to Save Energy at Work

The participants at HESSO were on average self-determined and autonomously motivated to conserve energy at their workplace before the final ENTROPY campaigns (avg. SDI = 7.17 / positive). After participating in the ENTROPY campaign, the vast majority of the participants (68.18%) reported an increase in their self-determination, or the same (31.82%) self-determination to save energy at work. Finally, the employees' self-determination to conserve energy at work, increased by 28.59%, on average, and reached 9.22 during the last ENTROPY campaign at HESSO.

c. Personal Norms

The employees' personal pro-energy-conservation norms at HESSO were on average reported as positive (avg. 4.61/7). This meant that they were generally positively inclined towards personally performing energy-saving at work before participating in the campaign and had inscribed the rules within them to do so regularly. Following the final ENTROPY campaign, a decrease of -9.76% in the personal energy-saving at work norms (4.16/7) was observed. Half (50.00%) of the participants also reported lower energy-saving at work norms.

d. Subjective Norms

The employees at HESSO, on average, reported moderate subjective norms towards energy saving at work (4.14/7) before the initial campaigns. This belief that their fellow employees expect them to conserve energy at work decreased by 2.17% (0.09/7 lower) after participating in the campaigns. Therefore, perceived social pressure to conserve energy at HESSO was slightly lower after the initial campaigns.

e. Behavioural Intention

The employees at HESSO, on average, reported moderately high intentions to conserve energy at work before the final ENTROPY campaign (4.86/7). Their intentions to conserve energy at work were recorded as slightly lower (-2.88%), and moderately high (4.73/7), after the final ENTROPY campaign.

f. Self-Reported Behaviour

The participants in the final campaign at HESSO admitted to enacting a set of energy-saving behaviours regularly at work with a high rate of agreement on average (5.13/7) before the campaign. Following the ENTROPY campaign, the employees at HESSO believed that they were enacting the same energy-saving actions even more so on average (5.19/7). The average recorded increase in self-reported energy-saving behaviour at work was 1.17%.

g. Energy-Saving at Work as a Habit

The participants of the last campaign at HESSO believed that performing energy-saving at work was a strong habit for them (avg. 5.11/7). This belief was further increased by 1.57% (+0.08). At the same time, for the majority of the participants this habit was enhanced (36.36%), or remained the same (22.73%).

h. Personal Impact

The participants at HESSO on average moderately believed that their own personal actions can have a real impact on energy saving at work (3.70/7). This belief was slightly lower after the last ENTROPY campaigns (-0.8%), and for the majority of the participants (45.45%) it decreased or remained the same (18.18%).
i. Collective Impact

The participants’ beliefs at HESSO that, as a whole, employees can collectively have an impact on energy consumption at their workplace through their behaviour was recorded as high (5.36/7) before the last campaign. This belief was, on average, lower (-8.4%), as recorded after the final campaign (4.91/7).

j. Energy-Saving Competence

The participants at HESSO rated their competence in energy saving at work highly (5.03/7) before the last ENTROPY campaign. Their confidence in their capability to personally conserve energy at work was reinforced (5.18/7) after the completion of the last campaign (+2.98%). At the same time, a relative increase was recorded for the vast majority of employees (63.64%), while the strength of the beliefs of the 22.73% remained the same.

k. Attitude Towards Energy-Saving at work

The participants on average rated their attitude towards conserving energy at work low both before (3.20/7) and after (2.99/7) the ENTROPY campaigns, with an average decrease of -6.88%. At the same time, the attitude of the majority of the participants was either decreased (50.0%), or remained the same (18.18%).

3.3 POLO Pilot

3.4 Initial campaigns at POLO

a. Sample Characteristics

The participants in the introductory ENTROPY energy-saving campaigns at POLO comprised of mostly female participants (5/7), with children (6/9). They on average recorded moderately low work engagement scores (avg. Vigor = 2.96/7) but felt competent in carrying out their duties at work (avg. 5.11/7), while at the same time experiencing a connection-relatedness to their colleagues (avg. 3.85/7) and the autonomy to enact their duties at work (avg. 4.26/7).

b. Motivation to Save Energy at Work

The participants at POLO were on average self-determined and autonomously motivated to conserve energy at their workplace before the ENTROPY campaigns (avg. SDI = 14.42 / positive). After participating in the ENTROPY campaigns, most of the participants (66.67%) reported a decrease in their self-determination to save energy at work. Finally, the employees’ self-determination to conserve energy at work, decreased by -13.45%, on average, during the initial ENTROPY campaigns at POLO.

c. Personal Norms

The employees’ personal pro-energy-conservation norms at POLO were on average reported as positive (avg. 5.43/7). This meant that they were generally positively inclined towards personally performing energy-saving at work and had inscribed the rules within them to do so regularly. Following the initial ENTROPY campaign, a decrease in the personal energy-saving at work norms was observed for more than half (55.56%) of the participants. However, the participants’ average pro-energy-conservation norms at POLO on average increased by 1.84% (0.10/7).

d. Subjective Norms

The employees at POLO, on average, reported moderately high subjective norms towards energy saving at work (4.86/7) before the initial campaigns. This belief that their fellow employees expect
them to conserve energy at work decreased by -12.28% (-0.86/7 lower) after participating in the campaigns. Therefore, perceived social pressure to conserve energy at POLO was lower after the initial campaigns.

e. Behavioural Intention

The employees at POLO, on average, reported high intentions to conserve energy at work (5.89/7), before the initial campaigns. Their intentions after participating in the ENTROPY campaigns was slightly less (5.67/7), a decrease by -3.75%. Therefore, their strong intention to conserve energy at their workplace decreased slightly but remained high during the first ENTROPY campaigns.

f. Self-Reported Behaviour

The participants in the first campaigns at POLO admitted to enacting a set of energy-saving behaviours regularly at work with a very high rate of agreement on average (5.42/7). Following the initial ENTROPY campaigns, most of the employees at POLO (55.56%) believed that they were enacting the same energy-saving actions even more so. However, there was an average recorded decrease in self-reported energy-saving behaviour at work by -2.95%.

g. Energy-Saving at Work as a Habit

The participants of the first campaigns at POLO believed that performing energy-saving at work was a habit for them (avg. 5.14/7). This belief remained high, and on average increased by 6.03% (0.31). Furthermore, for the majority of the participants it was increased (55.56%).

h. Personal Impact

The participants at POLO on average moderately believed that their own personal actions can have a real impact on energy saving at work (3.89/7). This belief decreased -4.88% further after the first ENTROPY campaigns (3.70/7), as well as for the majority of the participants (66.67%).

i. Collective Impact

The participants’ strong beliefs at POLO that, as a whole, employees can collectively have an impact on energy consumption at their workplace through their behaviour was recorded as very high (6.0/7). This belief remained, on average very high and increased by 7.33%, as recorded after the campaign (6.44/7).

j. Energy-Saving Competence

The participants at POLO rated their competence in energy saving at work highly (5.22/7) before the ENTROPY campaigns. Their confidence in their capability to personally conserve energy at work increased (5.39/7) after the completion of the first campaigns by 3.26%. At the same time, for the majority of the participants it increased (44.44%), or remained the same (22.22%).

k. Attitude Towards Energy-Saving at work

The participants on average rated their attitude towards conserving energy at work low (2.61/7) before the ENTROPY campaigns. This attitude further reduced during the campaigns (-21.46% decrease). At the same time, for the majority of the participants it either decreased (66.67%), or remained the same (11.11%).

3.4.1 Final campaign at POLO

a. Sample Characteristics
The participants in the final ENTROPY energy-saving campaigns at POLO were in their majority female (7/9), with children (6/9). Their average age was 48.33 years old and they worked in eight (3) different areas/rooms. They were on average moderately engaged with their work (avg. Vigor = 2.96/7) and felt competent in carrying out their duties at work (avg. 5.11/7), while at the same time experiencing a moderately rated connection-relatedness to their colleagues (avg. 3.85/7) and high autonomy to enact their duties at work (avg. 4.26/7).

b. Motivation to Save Energy at Work

The participants at POLO were on average self-determined and autonomously motivated to conserve energy at their workplace before the final ENTROPY campaigns (avg. SDI = 14.42/positive). After participating in the ENTROPY campaign, the vast majority of the participants (66.67%) reported an increase in their self-determination to save energy at work. Finally, the employees’ self-determination to conserve energy at work, increased by 3.47%, on average, and reached 14.92 during the last ENTROPY campaign at POLO.

c. Personal Norms

The employees’ personal pro-energy-conservation norms at POLO were on average reported as positive (avg. 5.43/7). This meant that they were generally positively inclined towards personally performing energy-saving at work and had enscribed the rules within them to do so regularly. Following the final ENTROPY campaign, a significant average increase of 17.5% in the personal energy-saving at work norms (6.38/7) was observed. The vast majority (77.78%) of the participants also reported higher energy-saving at work norms.

d. Subjective Norms

The employees at POLO, on average, reported moderately high subjective norms towards energy saving at work (4.56/7) before the initial campaigns. This belief that their fellow employees expect them to conserve energy at work decreased by -7.24% (-0.33/7 lower) after participating in the campaigns. Therefore, perceived social pressure to conserve energy at POLO was lower after the initial campaigns.

e. Behavioural Intention

The employees at POLO, on average, reported high intentions to conserve energy at work before the final ENTROPY campaign (5.89/7). Their intentions to conserve energy at work were recorded as even higher (+7.47%), and very high (6.33/7), after the final ENTROPY campaign.

f. Self-Reported Behaviour

The participants in the final campaign at POLO admitted to enacting a set of energy-saving behaviours regularly at work with a very high rate of agreement on average (5.42/7) before the campaign. Following the ENTROPY campaign, the majority of the employees at POLO (66.67%) believed that they were enacting the same energy-saving actions slightly less so (5.04/7). The average recorded decrease in self-reported energy-saving behaviour at work was -7.01%.

g. Energy-Saving at Work as a Habit

The participants of the last campaign at POLO believed that performing energy-saving at work was a strong habit for them (avg. 5.14/7). This belief was considerably increased by 25.49% (+1.31). At the same time, for the majority of the participants this habit was enhanced (77.78%), or remained the same (11.11%).

h. Personal Impact
The participants at POLO on average moderately believed that their own personal actions can have a real impact on energy saving at work (3.89/7). This belief remained unaltered on average for the participants after the last ENTROPY campaign.

i. Collective Impact

The participants' beliefs at POLO that, as a whole, employees can collectively have an impact on energy consumption at their workplace through their behaviour was recorded as high (6.0/7) before the last campaign. This belief was, on average, reinforced (+7.33%), as recorded after the final campaign (6.44/7).

j. Energy-Saving Competence

The participants at POLO rated their competence in energy saving at work highly (5.22/7) before the last ENTROPY campaign. Their confidence in their capability to personally conserve energy at work was considerably reinforced (6.06/7) after the completion of the last campaign (+15.9%). At the same time, a relative increase was recorded for the vast majority of employees (66.67%), while the strength of the beliefs of the 11.11% remained the same.

k. Attitude Towards Energy-Saving at work

The participants on average rated their attitude towards conserving energy at work low both before (2.61/7) and after (2.94/7) the ENTROPY campaigns, with an average increase of 12.64%.
4 ENERGY SAVING EVALUATION FRAMEWORK

4.1 Baseline calculations

4.1.1 General methodology for baseline energy performance evaluation

As it will be shown in further sections, project ENTROPY developed a comprehensive evaluation of the buildings and their savings. This was done via the exploration of the data, but also by the creation of computer thermal models that allow to evaluate the effect that the changes on behaviour will have in actual year demands.

Although these detailed analyses are of great value, it was believed that it is important to have savings analysis methodologies that can be implemented in the platform on an easy way. Only in that manner the users of a solution as the one developed in this project will be able to become popular and be adopted by a great deal of building managers.

This will require a way for the platform to “know” the building we are looking into. The construction of a detailed thermal model has to be ruled out for this purpose. Thermal models require the input of the whole geometry of the building (see below) and all building materials and properties of the envelope. This information is hard to get, and in most cases impossible to obtain in full.

For this, we took advantage of the European regulatory situation that under directive 2010/31/EU (now amended on 2010/31/EU) that encourages all member states to create national regulation that forces to create Building Performance Certificates (BPCs) for all public buildings and for building to be sold or rented. This performance certificates, that building managers know, and can understand, have been used to serve as the input that will “inform” the platform about the performance of the building at hand. This is a great advantage of the platform as it will give it the feature of being able to predict the expected energy use, what allows it to provide with real time savings (or waste) based the values fed by the streams. Figure 1 shows a BPC produced in Italy of one of the buildings of the pilot, the right hand part of the image shows how the data can be easily introduced in the platform.

![Energy Performance Certificate](image)

Figure 1. energy Performance Certificate and the relevant values introduced in the ENTROPY platform.
### Glossary of terms

**HTC**: Heat Transfer coefficient.

**SHTC**: Specific Heat Transfer coefficient.

**CDD**: Cooling Degree Days from previous year according to [https://www.wunderground.com](https://www.wunderground.com).

**HDD**: Heating Degree Days from previous year according to [https://www.wunderground.com](https://www.wunderground.com).

**cdd**: Cooling Degree Days for last hour as calculated by the platform.

**hdd**: Heating Degree Days for last hour as calculated by the platform.

**epc**: EPC value in kWh/m3 (Energy performance certificate) that comes from the energy certificates of the building.

### Input parameters to the platform:

<table>
<thead>
<tr>
<th>Floor Area in m2 (area_surface)</th>
<th>area_volume = area_surface * 3 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPC value in kWh/m3</td>
<td>Global Energy performance - Cooling</td>
</tr>
<tr>
<td></td>
<td>Performance - Heating Performance (epc)</td>
</tr>
<tr>
<td>Previous year HDD</td>
<td>(with base temperature 18.3 Celsius) from <a href="https://www.wunderground.com">https://www.wunderground.com</a></td>
</tr>
<tr>
<td>Previous year HDD Previous year CDD</td>
<td>(with base temperature 15 Celsius) from <a href="https://www.wunderground.com">https://www.wunderground.com</a></td>
</tr>
</tbody>
</table>

### Degree-days calculation

We consider two periods:

- 6/10 - 15/04 (cold period), base_temp = 24 C
- 16/04 - 15/10 (warm period), base_temp = 23 C
For the cold period (averages per hour), pseudo-code:

If avg_temp_out < base_temp AND avg_temp_in > base_temp then hdd = (base_temp - avg_temp_out) * 1/24. temp_diff = avg_temp_in - base_temp.

energy_waste = surface * temp_diff * SHTC (Kwatt)

If avg_temp_out < base_temp AND avg_temp_in < base_temp then
hdd = (base_temp - avg_temp_out) * 1/24  energy_waste=0

If avg_temp_out > base_temp then hdd = 0 energy_waste=0

For the warm period (averages per hour), pseudo-code:

If avg_temp_out > base_temp AND avg_temp_in < base_temp then
cdd = (avg_temp_out - base_temp) * 1/24 temp_diff = base_temp - avg_temp_in

If avg_temp_out > base_temp AND avg_temp_in > base_temp then
cdd = (avg_temp_out - base_temp) * 1/24  energy_waste=0

If avg_temp_out < base_temp then  cdd = 0 energy_waste=0

Energy waste calculation and baseline calculation pseudo-code:

HTC = (epc * surface * 3) / (24*HDD) (kW/K)

(CDD/HDD calculated by https://www.wunderground.com)

SHTC = HTC / area_surface  kW/K*m2

density_waste_indication = surface * temp_diff * SHTC (kW) OR temp_diff * HTC

(kW) baseline_consumption = SHTC * cdd * surface (kW)

(cdd is calculated for an hour time period) OR HTC * cdd

4.2 Detailed energy performance evaluation

To make sure that the potential of the energy interventions was understood adequately, we created two comprehensive models of the two buildings under study in the UMU pilot. The two models were created using EnergyPlus, the software commonly used for this purpose in building physics literature, and they were both calibrated with real data. As the two buildings are two very different buildings, the details are explained below for each one of them.
4.2.1 Pleiades

The objective of this work is to analyse an efficiency of public use, to which more than 200 IoT (Internet of Things) devices have been installed to capture data related to energy consumption and comfort. The real data taken from these devices is studied in front of a thermal model of the building with the computational tools for the advanced thermodynamic analysis of buildings; both of the thermal envelope and of the HVAC equipment that airs it. Using the data of the IoT devices, the aim is to calibrate the model, to make the evaluation of the scenarios in recent times. IoT has served as actuators for energy saving. The possibilities of having a large building with IoT sensors and actuators, allows us a real reference that serves to contrast the reliability of the designed models. This leads us to a related power in building modelling, which can then be used to evaluate the effect that the implementation of IoT devices can have on other buildings. With this, it is intended to make a detailed study of the building and identify rehabilitation strategies that result in energy savings. The use of simulated models helps the rapid distribution of heat flows in buildings and thus can be changed to other energy efficiency strategies in the building.

The software used is Energy Plus. EnergyPlus is a building energy simulation program that engineers, architects and technicians use to model both energy consumption and heating and cooling processes.

Building description

The plot area delimited for the construction of the building is practically a square of 10,982.77 m2. It consists of 5 floors of maximum height in addition to the ground floor, spread over 4 buildings. Building 1 has 5 floors, building 2 has 3 floors and building 3 has 3 floors. The fourth building will be a library (CRAI) with 2 floors. Horizontally the building is organized around a large corridor axis that separates the research areas of the Library area, whose extension would allow connecting in the future with extensions. The orientation of the building is 20º with respect to the North axis, having latitude of 38º. The laboratories to be simulated are located on the first level of building 2. The three laboratories of similar size will be referred to as laboratories 14, 15 and 16 and the largest as 17. The latter also has an attached server room Figure 3.

Figure 2. Photography of the building.
Description of the data

The data is obtained through sensors installed in rooms 14, 15, 16 and 17. In general, ten results were obtained per hour for several months but for a closer approximation only one data was collected every hour in order to be able to obtain the appropriate variations to adjust them with the model. The data was classified and ordered from the Odin project website where the data measured in these laboratories are located.

Room 14: CO₂ and temperature.

Room 15: CO₂ and temperature.

Room 16: CO₂, temperature, lighting and humidity.

Room 17: CO₂, temperature, lighting and humidity.

CO₂ data is used, together with information provided by the staff, to estimate occupancy levels. The lighting was used to create temporary lighting levels. Those of temperature, the most used, to make estimations and energy comparisons. These are sometimes elevated because the meter processor is heated because is continuously running. The variation is of several degrees and therefore this has been taken into account when comparing with the results of the model. The difference in °C of each sensor (measured with temperature probe) being:

Room 14: Probe: 22.8 Sensor: 25.5

Room 15: Probe: 23.2 Sensor: 23.3

Room 16: Probe: 23.5 Sensor: 25.5

Room 17: Left probe: 24 Left sensor: 24.3

Right probe: 23.3 Right sensor: 23

In addition, in each room it was measured if the machine was operating at that moment and if the temperature set. With this it is possible to deduce the demand that was necessary at each moment and observe how the measured data vary when the equipment is working.
**Energy plus model**

A representation of the laboratories and corridors is made in 3D to observe their situation and thus begin to make the appropriate considerations and estimates. For this, the SketchUp program is used, which allows a simple and intuitive representation Figure 4.

![3D model of the areas](image)

**Figure 4. 3D model of the areas.**

In order to comprehensively analyse the influential aspects that affect the comfort level in the building, we resort to the introduction of various parameters. For this Energy Plus is used.

- **Location**: latitude of 38.0245º, a length of -1.1732º. Time slot +1 GTM and with an altitude of 60m above sea level.

- **Holidays, working hours and occupation.**

- **Materials**: We proceed to define the composition of both walls and windows in order to obtain the real structure represented in the building. This composition will be defined by layers of different materials.

- **Equipment following the scheme of Figure 5. Central unit MMY-AP3014HT8 and units in rooms MMU-MAP0362H.**
Figure 5. HVAC equipment based on VRF. From the Input/Output manual of EnergyPlus documentation.

Sensor data and its preparation for validation

After the processing and calibration of the sensor data, the data obtained is represented. The temperature data of each room are highlighted, which are then compared to those provided by the model. Figure 6, Figure 7, Figure 8 and Figure 9.

Figure 6. Temperature in room 1.14, the x-axis represents hours of simulation.
Figure 7. Temperature in room 1.15, the x-axis represents hours of simulation.

Figure 8. Temperature in room 1.16, the x-axis represents hours of simulation.
Performance evaluation and lessons learnt

In the model it is known that the thermal load of the building is much lower than in reality since in the whole building a temperature is maintained and the laboratories do not receive the impact of the environment directly. To solve this problem a constant temperature is established in the corridors 12 and 13 (out of the intervention) in order to represent that thermal load of heat conservation of the building.

Simulation data

Once the real temperature values have been added, the set-point temperatures, the hours of operation of the equipment and the rest of the measured values. It is about checking if the real data are adjusted to the ones provided by the model. For this, three intermediate weeks in the simulation are analysed exactly in each room. The brown line being the simulated temperature and the lilac the actual temperature. It has been chosen for example from January 29 to February 18. Figure 10.

As it is observed the model adjusts quite well to the measured temperature. So it can be said that thanks to the data taken has been able to simulate with some accuracy a part of the building without the need to know it completely. In order for the simulation to have been perfect, that is, for the temperature to have been kept constant on the weekends, thermal mass data of the building at all times would be needed, which is almost impossible to measure considering that the
building is very big. Therefore, the model is accepted as valid when calculating consumption, energy and possible improvements.

Consumption data

A table with the most relevant consumption data of the laboratories to see its global operation is added as a corollary.

<table>
<thead>
<tr>
<th>Consumption</th>
<th>Electricity (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>1542.24</td>
</tr>
<tr>
<td>Cooling</td>
<td>0.00 (In winter)</td>
</tr>
<tr>
<td>Interior Equipment</td>
<td>6979.88</td>
</tr>
<tr>
<td>Fans</td>
<td>131.86</td>
</tr>
<tr>
<td>Total End Uses</td>
<td>8653.98</td>
</tr>
</tbody>
</table>

The heat provided by the air conditioning system is 1542.24 kWh and the internal equipment 6979.88 kWh. Within the interior equipment reference is made not only to computers and office equipment but also to other elements such as sensors and lighting, that is, any device within the volume that consumes electricity. Therefore, it can be assumed that laboratories do not have a high consumption of electricity in terms of air conditioning in these months. This is because the rooms are mainly computers and servers, they give off a lot of heat and being well insulated do not need an excessive supply of equipment. Also, keep in mind that the rooms are only working a few days so the rest of the time there is no need to maintain the temperature.

One-year prediction

The model described makes it possible to simulate the three months from which the data were obtained, but if the marked set-point values are considered to be approximately 24ºC for the maximum and 20ºC for the minimum. This prediction can be extended for the whole year if the defined patterns are respected. The work modules are established and it is assumed that the building works at its maximum occupancy (see Figure 12).

<table>
<thead>
<tr>
<th>Consumption</th>
<th>Electricity (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>2138.86</td>
</tr>
<tr>
<td>Cooling</td>
<td>3011.98</td>
</tr>
<tr>
<td>Interior Equipment</td>
<td>25623.49</td>
</tr>
<tr>
<td>Fans</td>
<td>1125.75</td>
</tr>
<tr>
<td>Total End Uses</td>
<td>31900.08</td>
</tr>
</tbody>
</table>

The heat and cold provided by the air conditioning equipment are 2138.86 and 3011.98 kWh respectively and the internal equipment is 25623.49 kWh. Therefore, it can be assumed that laboratories do not have a high consumption of electricity in terms of air conditioning in these months. This is because the rooms are mainly equipped with the computers and servers that give off a lot of heat and being well insulated do not need an excessive supply of equipment.
Potential theoretical savings

The procedure to be followed to see if it is improved with these proposals will be to simulate the models both real (3 months) and predictive (1 year) to observe if consumption is reduced, keeping in mind that certain comfort must be maintained in the building. Only the data proposed in the simulated models will be changed so that the results obtained in the previous analyses are respected. In addition, other interesting aspects will be analysed depending on the proposal. Main improvement proposals:

- Eliminating the control by set-point and introduce a thermostat. It is concluded that the workers of the Pleiades building made good use of the equipment, that is, they did not leave the equipment on, they did not put the equipment to work at its maximum capacity and they were only connected when necessary. Whenever a good use of the slogans is made and the worker tries to be aware of the efficiency of the building, it will be useful to give the consumer the option of regulating their thermostat.

<table>
<thead>
<tr>
<th>Demand with thermostat</th>
<th>Electricity [kWh]</th>
<th>Potential Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>1666.8</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand with fixed set point</th>
<th>Electricity [kWh]</th>
<th>Potential Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>1542.24</td>
<td>7.4 %</td>
</tr>
</tbody>
</table>
4.2.2 La nave

Geometry

For the creation of the model, first of all, the measures necessary for the geometrical definition of the spaces that belong to the two rectangular storeys, these were collected in situ.

Figure 12. Blue prints of La Nave.

In the same way, we have measured the heights, and the actions and positions of doors and windows, exterior and Interior.
Figure 13. Orthogonal views of the building.
The spaces have been designed in SketchUp, with a tilt to the North of 250 °. The design process has required several phases, as soon as the geometrical model has special features that have not been noticed immediately, and also at times when it was not possible to access all areas.

Figure 14. Isometric views of the building using Sketch Up.

For this model, it was possible to define the geometry of the model, defining the eleven different spaces that will be the true object of study of the simulation, as for each space will be a different thermal zone:

<table>
<thead>
<tr>
<th>- Nave</th>
<th>- Warehouse First Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Office 1</td>
<td>- Laboratory</td>
</tr>
<tr>
<td>- Office 2</td>
<td>- Suspended Ceiling</td>
</tr>
<tr>
<td>- Office 3</td>
<td>- External Space</td>
</tr>
<tr>
<td>- Office 4</td>
<td></td>
</tr>
<tr>
<td>- Toilet</td>
<td></td>
</tr>
<tr>
<td>- Warehouse Ground Floor</td>
<td></td>
</tr>
</tbody>
</table>

Spaces, created using extruded surfaces, joined by the operation 'Surface Matching', in order to define which areas belong to the interior of the building and which to the outside, exposed to direct sunlight and wind.

The definition of the spaces has been completed with the inclusion of doors and windows, defined in the program as subsurface. The windows have been divided in fixed window and operable window, according to the possibility of opening, and indoors and outdoors, according to their position on the envelope; the doors, against, have been divided into opaque normal doors (used for spaces as the toilet or the plant warehouse, overhead door (the door of entry into the main façade) and glassdoor (interior doors). A model composed of surface and subsurface, describing just the geometry of the building, without thermal considerations in this first phase was then obtained.
Materials and constructions

For the definition of the buildings, all the materials used have been defined, with its properties; composed as union of different technical elements of the different layers, and have attributed to relative surfaces in the model, depending on the position of each space. The choice of constructions and materials has been based on Visual considerations and continuity with the materials of the structure, having no real technical details available. For each material used on features is inserted into OpenStudio according to code, i.e. conductivity, density, specific heat, thermal absorption, solar absorption and visible absorption. In addition, materials considered directly as layers, each being specified thickness in meters. Created layers are used to mount different structures present in the building. Then, joined the sets of constructions, which attributed to the different constructions to the surfaces that define a space.
Thermal bridges

Thermal bridges refer to thermally weak points of the enclosure, which has a significantly less than the constructions of heat resistance. According to Spanish legislation, has sense talk about thermal bridges in the presence of a change in material or geometry in the envelope.

To describe this phenomenon, it introduces a new parameter which is the linear thermal transmittance $\Psi$, which depends on the heat transfer that occurs adjacent to the thermal bridge elements. The calculation of this parameter is one of the main problems when it comes to heat building analysis, calculation methods are very complex and, even for very simplified systems, are very imprecise.

The legislation tries to resolve this situation by introducing tables with linear transmittance values in most common cases. As the linear transmittance depends on the length of the thermal bridge, which both can be calculated using as a reference system the inside length as the outer length, for every case values are given two $\Psi_e$ and $\Psi_i$ referred to the outside and the Interior respectively. OpenStudio, in reference to the thermal bridges, supported only the methodology of calculation from the outside, so there is no doubt in reference to $\Psi_e$.

The regulation defines cases in which are presented the thermal bridges: pillars embedded in facade, hollows, slabs, flat roofs, front corners, soil in contact with the ground floor. In the case study, the steel pillars are not integrated into the facade and do not have information on the composition of the cover and sill, which only would have felt considering other cases. Of these

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Figure 17. Example of constructions and their materials (In Spanish).
cases, the technical code considers only options with continuous insulation or not continuous, while in our case the insulation is not present in any construction. However, by increasing the accuracy of the model has been thought of calculating thermal bridges using another program: Therm\(^1\). In Therm geometries that generate thermal bridges and have been attributed materials with different conductivities are manually designed. In addition, the boundary conditions, have been created to define the interior, with a temperature of 20° C and a transmittance of 7,692 [W/m²K], and abroad, with a temperature of 0° C and a transmittance of 25 [W/m²K]. The edges which have cross elements, not allowing the reality of transmit heat, have been considered adiabatic.

![Figure 18. Example of geometrical thermal bridge evaluated with THERM.](image)

![Figure 19. Thermal model with thermal bridges.](image)

---

\(^1\) Therm, Cálculo y simulación de Puentes Térmicos, Guía de Uso, Germán Campos, www.ecoeficiente.es
Data for validation

As mentioned above, several sensors that have allowed the realization of this project have been implemented. Without describing each of the sensors, it is important to consider that there are different kinds of devices based on the type of measure. In particular, for the temperature have been considered 213 devices (exterior), 242 (experimental probes, different interior rooms) and 323 (probe PT100, different interior rooms). Different files of these three classes compose the table of history, date of the historical and the corresponding temperature value.

It should be noted that two different kinds of sensors recorded the same piece of information, the temperature in different rooms. In the first type is measured with the experimental method, with a tube inserted in a metal box; the second typology (PT100) with a resistance thermometer of Platinum with nominal resistance of 100 Ω. The latter can be considered more accurate, which has been mostly account for differences between the two measures (differences that vary between 1 and 6 °C, depending on the case). Tea anyway, in previous work was experimental sensors values were above the actual temperature of 5 °C approximately.

With respect to consumption, devices 248, whose sensors can be further divided into three categories: consumption on air-conditioning, relative to lighting consumption and consumption relative to the plugs. Files report, between voltage, current, active power, reactive power and apparent the multistep power, although it has been taken into consideration first.

As regards moisture, corresponding device class is the 242, and the reported values are historical chart, the historical date and historical value.

Finally, to reveal the presence of 211 and 299 devices classes are used. Sensors show whenever someone enters or leaves a room, without specifying the number of contained people, for which data have been interpreted as presence or absence of all workers. Data collected by various devices have been processed, divided and sorted before used for the case study. Throughout the year the sensors reported a few anomalies, hence the process of transcription of data into several files have required time and patience.

Then the exemplar templates of the disposition of the sensors on the ground floor and on the first floor, used by UMU:

---

Figure 20. Sensors in the ground floor.
Infiltrations

In addition to the lack of insulation, one of the problems that the ship has a heat level are infiltrations. In fact, are in the building some enclosures that do not prevent the passage of air, and she is also quite long fissures which cross the whole wall.
By sealing data, when a test such as the Blower Door test is not possible, you can use a reference manual, as the GT Calener Reference Manual.

<table>
<thead>
<tr>
<th>Grado de exposición a los vientos</th>
<th>Nivel de estanqueidad del edificio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alto</td>
<td>Bajo, Medio, Alto</td>
</tr>
<tr>
<td>1.5</td>
<td>0.8, 0.5</td>
</tr>
<tr>
<td>Medio</td>
<td>1.1</td>
</tr>
<tr>
<td>1.1</td>
<td>0.6, 0.5</td>
</tr>
<tr>
<td>Bajo</td>
<td>0.7</td>
</tr>
<tr>
<td>0.7</td>
<td>0.5, 0.5</td>
</tr>
</tbody>
</table>

Figure 23. Infiltration values for Spain (In Spanish).

In the table above average exposures to winds high in the case of buildings in open field or very high buildings in town, half level of buildings in outfield with trees or other buildings around it, in the case of buildings with average height in inner cities and buildings in forest. In the case under review, which is normally exposed to the wind and with a normal density of building on his around, can be considered a value of 0.6 renewals for hours in the spaces that is considered more protected from infiltration, a value of 0.8 renewals per hour in the false ceiling and, finally, a value of 1.1 renewals per hour in the spaces that are considered to be most affected by the infiltrations, i.e. warehouse.

**Equipment**

The facilities of air conditioners present on the ship are of the same type, i.e. simple Split system, which provides both heating in winter and cooling in summer. There are two types of equipment: four-way equal in each of dispatches from the ground floor and a different computer in the laboratory of the first floor.

---

**HEAT PUMP (R407C)**

<table>
<thead>
<tr>
<th>MODEL</th>
<th>RCM 20DR</th>
<th>RCM 25DR</th>
<th>RCM 30DR</th>
<th>RCM 40DR</th>
<th>RCM 50DR</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>5325</td>
<td>5975</td>
<td>7125</td>
<td>9520</td>
<td>12190</td>
</tr>
</tbody>
</table>

Figure 24. HVAC of the Laboratory.
Performance evaluation and lessons learnt

Simulation results

In order to refine the model, set different parameters were set, based on the differences between the results of the simulation and the data.

Figure 25. Characteristics of the HVAC in the offices.

Figure 26. Power obtained for Office 1.
The last values used in the model were the result of different tests and many attempts, whose description is not fully include for the sake of brievity. As an example, reported some of the different variations that the model has raised in a typical day of summer in the Office 2 is shown in Figure 27.

Figure 27. Fitting of the internal temperature. red is the real data and blue is the result of the simulation.

Extrapolation to year temperatures.

The results can be considered acceptable. It should be noted that only a certain level of accuracy can be achieved. Many parameters are uncertain and the models can only reach a certain degree of precision. Not having real data on wind and infiltrations, in particular, can affect the results, so a reasonable level of accuracy has to be stablished as the limit of the search of parameters.
Figure 28. Representation of the fitting of the model using the whole year for The warehouse.
Figure 29. Representation of the fitting of the model using the whole year for The open space.
Figure 30. Representation of the fitting of the model using the whole year for The Lab.
Office 1

Figure 31. Representation of the fitting of the model using the whole year for Office 1.

The results on the Warehouse show that the waves overlap perfectly both throughout the year as in the analyzed seasons. Also in the analysis of the typical days, the oscillations of the waves are perfectly comparable, and also at the points where they do not match, the difference is almost irrelevant.

In the Nave, some problems remain relating to temperature differences. However, it can be noticed a relevant improvement which is concerned with the daily swings. These improvements are confirmed in the analysis of the typical days of summer and winter, in which, the difference in temperature is negligible.
In the laboratory model and data waves overlap for the sensor PT100 throughout the year, presenting the hottest peaks and more obvious oscillations in intermediate seasons of spring and autumn. However, if we analyse the graph of summer and winter, the waves coincide almost in all cases.

Office 1, does overlap completely as in the other cases. The most satisfactory results concerning the typical days of summer and winter, where you can see the accuracy of temperature set point and a good approximation in the hours in which the air conditioning equipment is off, especially on the day of winter, in which the curve nearly coincide.

**Office 2**

![Graph of temperature over the year for Office 2.](image)

*Figure 32. Representation of the fitting of the model using the whole year for Office 2.*
Figure 33. Representation of the fitting of the model using the whole year for Office 3.
Office 4

Figure 34. Representation of the fitting of the model using the whole year for Office 3.

In Office 2, we obtained waves which in any case were acceptable. In the summer and winter simulations, curves coincide almost in all points, excluding the peaks recorded by the sensor, as discussed above. In the graph of the typical summer day, can be seen that the model fairly follows the evolution of the actual temperature throughout the day. However, it is on the graph of the typical winter day that the results almost coincide, especially in the free hours in swing.

For Office 2, in the summer and winter graphics, curves coincide almost in all points, excluding the peaks recorded by the sensor, as discussed above. In the graph of the typical summer day, can be seen as model fairly accurately follows the evolution of the actual temperature throughout the day. However, it is on the graph of the typical winter day, that the results almost coincide, especially in the free hours of temperature swing.
In Office 4, the values of the model temperature are satisfactorily when compared with the recorded by sensors. As regards to the typical summer day, an attempt to reproduce the temperature peaks reached the goal partly. It was seen not to be worth perfecting this case in particular, as there are variations depending on the day, thus increasing the peaks increases the difference in other cases. The same considerations apply to the day of winter.

In summary, in almost all cases, the expected result is obtained. However, there are two spaces (Office 1 and especially the open space or Nave) which accuracy is slightly smaller yet acceptable.

**Power demands**

A comparison between the registered power by sensors and the powers used in the final configuration of model was done to validate the model. The powers were in agreement, and an example has been shown in Figure 35.

![Figure 35. Power in Office 1. Real data (orange) and modeled (blue).](image)

Final result of electricity consumption throughout the year, the program provides the table reported in Figure 36.
Potential energy savings

Today the concept of 'thermal comfort', mentioned in Chapter 2, is always used, despite the difficulty of defining it precisely. In fact, the evaluation of thermal comfort, presupposes that the subjective feeling of each user can be quantified. You have to reach the thermal environment, as is set of all its factors (temperature, humidity, speed of air, etc.) may be nice, say that it is not experience the sensation of cold or heat. To get to this subjective feeling, the balance of profit and loss of heat must be null, reached thermal equilibrium.\(^2\)

The subjectivity of this parameter is expressed well by the standard ISO 7730, which even refers to 'a mental condition in which is expressed the satisfaction with the thermal environment'. For confirmation, in this case study, you look at how the concept of thermal comfort change extremely depends on the workers, through temperature and air conditioning preferences. It is possible to propose a change of habit to user groups so that, always staying on the fringes of the thermal comfort, energy savings can be reached.

It was proposed a minimum set-point temperature variation, so that thermal comfort is not in any way altered. There is a temperature of 22 °C heating and a temperature of 26 °C for cooling.

As regarding lighting, it was proposed a use more intelligent, based on the use of sunlight. In fact, it has been noted that in some cases (especially in the laboratory), the electricity consumption for lighting was reduced in summer. This reduction in consumption is approximately half of the wattage, so it follows that the lighting system provides differentiated power in the different spaces, which makes it possible to turn a group of luminaires on and off without necessarily use of all.

What is being proposed then is a systematic reduction of the use electric light in the summer season, how much in labor hours of each day (up to 2.00 p.m. or 3 p.m. depending on the case.

It can be seen as in the current configuration, that lights consumption throughout the year is 0,30 kW at any business day, both in summer and in winter. This fact seems even more serious when one considers that the office 1 has a window to take advantage of sunlight. What is proposed in

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\(^2\) Construmática. Metaportal de Arquitectura, Ingeniería y construcción.
this case is to use a single group of luminaires (0.15 kW) until 3 p.m., to then turn on all the lights in the rest of the workday.

In summer, it remains only a group of luminaires on throughout the day. On summer mornings could even turn off all the lights, but left this margin of consumption extra to compensate for cloudy days in which should be all lights. Applying such changes, the new electricity consumption was obtained with the program.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>1.76</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cooling</td>
<td>4.19</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Interior Lighting</td>
<td>18.42</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Exterior Lighting</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Interior Equipment</td>
<td>36.10</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Exterior Equipment</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Fans</td>
<td>0.48</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Pumps</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Heat Rejection</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Humidification</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Heat Recovery</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Water Systems</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Generators</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total End Uses</td>
<td>60.95</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Figure 37. Savings with 100% effective behavioral change interventions.

Finally, an average of € 0.15/kWh cost, you get a summary of both energy and economic savings disaggregated by type of consumption. Then the maximum energy savings of the interventions in la nave can be seen in the following table.

<table>
<thead>
<tr>
<th>Model demand [GJ]</th>
<th>Potential after intervention [GJ]</th>
<th>Potential Savings</th>
<th>Energy Saving (kWh)</th>
<th>Monetary Saving (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>2.51</td>
<td>1.76</td>
<td>30%</td>
<td>208,33</td>
</tr>
<tr>
<td>Cooling</td>
<td>5.11</td>
<td>4.19</td>
<td>18%</td>
<td>255,55</td>
</tr>
<tr>
<td>Lighting</td>
<td>26.24</td>
<td>18.42</td>
<td>30%</td>
<td>2172,24</td>
</tr>
</tbody>
</table>
5 PERFORMANCE ON ENERGY SAVINGS OF THE PILOTS

The campaigns used a series of automatic triggers that allowed to identify specific behaviours that were not optimal in terms of energy use. Based on these triggers, the platform was able to tackle behaviours that resulted on energy waste. Also and in parallel with this more focused actions, energy literacy was improved in the participants as means of background-permanent improvement of the behaviour in terms of energy use.

As the sensors continued providing information during and after the campaigns, it was possible to identify how effective the campaigns were. In addition to that, data form the interaction of the users was captured. This was of great use, as one can consider that engagement and effectiveness of energy behaviour advice can only work together, and engagement is driven by a variety of factors, some of which scape from the scope of this project.

5.1 UMU Pilot

Within the UMU pilot, two buildings were used to evaluate the ENTROPY solution at hand. The first one, Pleiades had 5 campaigns, whereas La Nave only had one campaign. The reason to do an extra campaign in La Nave was to evaluate the system when it comes to a cohort anew. The results of both interventions are shown in the following sub-sections.

Participation

Within the platform developed in ENTROPY, it is possible to identify the number of participants that have interacted with the app. This is in the form of answering a quiz, performing a task, filling a questionnaire or reading a tip. This was of great use to monitor the engagement of the users with the tools that interfaced between the platform and the participants.

This also allows to truly evaluate the performance of the campaign itself, as the motivation for engagement is only one aspect of the success of the messages sent by the platform.

![Figure 38. Representation of the engagement via interaction to the events. Campaign 6 represents the results in fresh campaign in La Nave.](image)
5.1.1 Pleiades

Heating

Heating accounts for a large proportion of the energy use in office buildings, as it is the case of the building at hand. Within the intervention, several of the tips and tasks were related to use the heating in an efficient manner. Two examples of these are the encouragement to lower the set-point temperature in winter and to rise the set-point temperature in summer.

To evaluate if this intervention was effective, the set-point temperatures in the four rooms of the pilot under study were analysed. It was important for this case to see if the cases in which the users were choosing high temperatures were reduced. Four images are provided in # that show the evolution of high temperatures in this building during winter.

The visual observation of the results in Figure 39. Shows that the intervention was successful in most cases in this aspect. A more quantitative analysis is done in the following, whoever it should be noted that in campaign 1 and two and in the period after campaign 2 the one can already see that the behaviour representing the set-point preferences was changed.

Although the graphs below represent a valuable preliminary result of this important behaviour on the energy use, the calculation of the savings based on this was also performed. For our case in particular and considering the building at hand we considered a saving of 8% per degree on energy use for heating. We took this educated guess based on the thermal model (Section 4.2) and because no exact power consumption of the conditioning machines was available.

To translate the change on set-point preferences into actual savings of heating, means of the set points were chosen before and during the campaigns. With this we want to obtain an accurate quantitative indicator of the energy demanded for conditioning. The results of this translation are shown in

---

3 The heating/cooling consoles provide the conditioning from four VRF machines on the roof that serve the refrigerant to the whole building. Disaggregating the power use for the specific rooms was virtually impossible.
Figure 39. Boxplots of the Set-point temperatures in winter. The heating in Campaigns 3, 4 and 5 was very reduced so should not be considered in this plots.
Table 1. Savings on energy for heating by tackling the behaviour of set point preferences.

<table>
<thead>
<tr>
<th>UMU Pleiades Heating</th>
<th>Campaign</th>
<th>Pre1</th>
<th>1</th>
<th>Pre2</th>
<th>2</th>
<th>Pre3</th>
<th>3</th>
<th>Pre4</th>
<th>4</th>
<th>Pre5</th>
<th>5</th>
<th>post 5</th>
<th>Tendency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.14</td>
<td>SetPoint</td>
<td>22.24</td>
<td>23.97</td>
<td>22.97</td>
<td>23.23</td>
<td>23</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>0.04K/campaign</td>
</tr>
<tr>
<td>Savings %</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.15</td>
<td>SetPoint</td>
<td>24</td>
<td>21.42</td>
<td>22.57</td>
<td>22.44</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>-0.42K/campaign</td>
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<tr>
<td>Savings %</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1.16</td>
<td>SetPoint</td>
<td>25</td>
<td>22</td>
<td>21.7</td>
<td>22.37</td>
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<td>Savings %</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>1.17a</td>
<td>SetPoint</td>
<td>25</td>
<td>22.92</td>
<td>22.27</td>
<td>22.46</td>
<td>21</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>-1.68K/campaign</td>
</tr>
<tr>
<td>Savings %</td>
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<td></td>
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<tr>
<td>1.17a</td>
<td>SetPoint</td>
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<td>21.82</td>
<td>22.36</td>
<td>22.21</td>
<td>21</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>-1.52K/campaign</td>
</tr>
<tr>
<td>Savings %</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average savings: 6.62 %

Cooling

Conditioning is the result of heating and cooling, and in a warm climate as the one of South Spain where the UMU pilot was done, it is crucial to see if the behaviour of the participants can also be modified to make them rise the set-point temperatures in summer and we do not have a rebound effect as the temperatures were decreased for the winter.

As in the previous case, temperatures have been plotted in the fashion of boxplots to visually analyse if the low temperatures were changed to higher one after the campaigns in the four rooms. This can be seen in Figure 40. The plots are less clear in this case, and although rooms 1.14, 1.16 and 1.17 show certain tendency of using higher set-point temperatures, one requires of a quantitative method to see the results. These were shown in Table 2.

As it can be seen in the table, the results are very positive. Despite the fact that set point temperatures for winter were decreased to be in most cases bellow or in the 22C, the cooling seems to be being delivered at a temperature that is above or in the 24 in most cases, what is an excellent result for the cooling. This results on average savings for cooling of 4.90%.

Table 2. Savings on energy for cooling by tackling the behaviour of set point preferences

<table>
<thead>
<tr>
<th>UMU Pleiades Cooling</th>
<th>Campaign</th>
<th>Pre1</th>
<th>1</th>
<th>Pre2</th>
<th>2</th>
<th>Pre3</th>
<th>3</th>
<th>Pre4</th>
<th>4</th>
<th>Pre5</th>
<th>5</th>
<th>post 5</th>
<th>Tendency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.14</td>
<td>SetPoint</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>23.87</td>
<td>24.15</td>
<td>24.41</td>
<td>28.98</td>
<td>na</td>
<td>3.12K/campaign</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.15</td>
<td>SetPoint</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>24.94</td>
<td>24.99</td>
<td>24.97</td>
<td>25</td>
<td>na</td>
<td>0.032K/campaign</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.16</td>
<td>SetPoint</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>25</td>
<td>24.24</td>
<td>24.82</td>
<td>25.88</td>
<td>na</td>
<td>0.64K/campaign</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.17a</td>
<td>SetPoint</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>23.76</td>
<td>22.74</td>
<td>23.98</td>
<td>25</td>
<td>na</td>
<td>1.0K/campaign</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.17a</td>
<td>SetPoint</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>23</td>
<td>22.85</td>
<td>23.96</td>
<td>25</td>
<td>na</td>
<td>1.42K/campaign</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average savings: 4.90 %

© ENTROPY Consortium
Figure 40. Boxplots of the Set-point temperatures in winter. The cooling in Campaigns 1, 2 and 3 was very reduced so should not be considered in this plots.
Illumination

The third energy related behaviour that corresponds to a substantial share of the energy consumption was the use of lighting in the rooms. Two of the rooms were studied in detail and then the overall savings were evaluated.

Figure 41. Data for power used in illumination in rooms 1.14 and 1.16. The blue bars represent the campaigns.

The rooms of this building that were studied require of artificial light in all working hours and across the year. It was for this that we did not consider realistic to evaluate the performance of the intervention on the total savings based on 24/7 calculations. Instead we aimed to tackle the energy waste that may occur when lights are left on during the night and could represent a substantial waste of energy.

The energy use for lighting was used (as it is one of the streams of the platform) and taken only in the periods where the building was closed (from 8am to 8 pm) the energy use on lighting was then evaluated for savings. A graphical representation of this analysis can be seen in Figure 42

Figure 42. Power use in lighting in Room 1.14 shows a very low value (y-axis is average power).
As one can see in this figure, it seems like no substantial saving was achieved after the interventions. However, looking at the scale (and later more clearly with the other study) one can see that no much energy was being wasted in this room in out of hour-periods anyway. The quantification of this will be shown in the following table. The second room, which energy consumption in lighting in out of hours periods is shown in Figure 43 clearly shows how the intervention had its effect. Figure 44 shows the overall savings for both rooms.

Figure 43. Power use in lighting in Room 1.16 that showed high value at the beginning is seen to decrease substantially (y-axis is average power).

Figure 44. Power use in all rooms in out of hours' periods during campaigns.
Table 3. Energy use and savings in Lighting in out of hours’ periods of pilot UMU Pleiades.

<table>
<thead>
<tr>
<th>UMU Pleiades Light (only out of hours periods)</th>
<th>Cam.</th>
<th>Pre1</th>
<th>1</th>
<th>Pre2</th>
<th>2</th>
<th>Pre3</th>
<th>3</th>
<th>Pre4</th>
<th>4</th>
<th>Pre5</th>
<th>5</th>
<th>post 5</th>
<th>Tendency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.14</td>
<td>Power</td>
<td>2.35</td>
<td>2.07</td>
<td>5.56</td>
<td>6.29</td>
<td>6.21</td>
<td>14.56</td>
<td>7.47</td>
<td>10.66</td>
<td>8.05</td>
<td>2.49</td>
<td>8.12</td>
</tr>
<tr>
<td></td>
<td>1.14</td>
<td>Savings</td>
<td>11.8%</td>
<td>-13.0%</td>
<td>-</td>
<td>134%</td>
<td>-42.7%</td>
<td>69%</td>
<td>0.86 W/campaign</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.16</td>
<td>Power</td>
<td>68.74</td>
<td>87.68</td>
<td>63.47</td>
<td>59.07</td>
<td>59.80</td>
<td>50.66</td>
<td>58.45</td>
<td>36.96</td>
<td>53.1</td>
<td>2.08</td>
<td>47.6</td>
</tr>
<tr>
<td></td>
<td>1.16</td>
<td>Savings</td>
<td>-27.5%</td>
<td>6.92%</td>
<td>15.2%</td>
<td>36.7%</td>
<td>96%</td>
<td>9.52 W/campaign</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>Power</td>
<td>71.10</td>
<td>89.76</td>
<td>69.03</td>
<td>65.36</td>
<td>66.01</td>
<td>65.23</td>
<td>65.92</td>
<td>47.63</td>
<td>61.1</td>
<td>4.58</td>
<td>55.8</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>Savings</td>
<td>-26.2%</td>
<td>5.31%</td>
<td>1.19%</td>
<td>27.75%</td>
<td>92.5%</td>
<td>8.66 W/campaign</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.1.2 La Nave

The intervention in La Nave added great value to the UMU pilot. This is for two reasons: the participants encountered the first version of the platform and the game from the start; and two, other variables that were not being monitored in Pleiades were available in this intervention. In the following we give details about the evaluation of performance of the intervention in La Nave.

To evaluate the performance of the intervention that encouraged participants to decrease their energy use by turning devices off when they leave the premises. The evaluation of the out-of-hours consumptions was again evaluated. This is shown in Figure 45 and Figure 46, and can be evaluated graphically. Also the quantification of these savings can be seen in Table 4.

Table 4. Energy consumptions and savings in out of hours’ periods in La Nave before and at the end of the campaign.

<table>
<thead>
<tr>
<th>UMU La Nave main power (Out of hours)</th>
<th>Campaign</th>
<th>Pre1</th>
<th>End camp.</th>
<th>Tendency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office 1</td>
<td>Power</td>
<td>309.4</td>
<td>173.83</td>
<td>43.82%</td>
</tr>
<tr>
<td>Office 2</td>
<td>38.17</td>
<td>33.77</td>
<td>11.53%</td>
<td>-4.4</td>
</tr>
<tr>
<td>Office 3</td>
<td>22.98</td>
<td>28.1</td>
<td>-22.28%</td>
<td>5.12</td>
</tr>
<tr>
<td>Office 4</td>
<td>6.56</td>
<td>7</td>
<td>-6.71%</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>377.11</strong></td>
<td><strong>235.77</strong></td>
<td><strong>35.64%</strong></td>
<td><strong>-141.34 W/campaign</strong></td>
</tr>
</tbody>
</table>
Figure 45. Representation of the power consumption being measured before and during the intervention in La Nave in rooms 1 (left) and 2 (right). The top graphs represent the power use in the whole period and the two graphs in the bottom represent the power consumption in out of hours’ periods.
Figure 46. Representation of the power consumption being measured before and during the intervention in La Nave in rooms 3 (left) and 4 (right). The top graphs represent the power use in the whole period and the two graphs in the bottom represent the power consumption in out of hours’ periods.
5.2 HESSO Pilot

HESSO pilot building

Techno-Pôle has seven buildings named TP1, TP2, TP3, TP4, TP5, TP6, and TP10. It includes several companies active in different fields. It gathers about 500 people. The building dates from the 1980s to the 2000s for the latest facilities. Techno-Pôle is equipped with a solar photovoltaic (PV) 203.5kWc. The technology of the heating and air conditioning are provided by panel radiant

![Technopole building.](image)

In 2011, the consumption of the entire site was 1183MWh. The solar power plant installed in 2012, produced 307MWh in 2013. The global electricity consumption during the year 2013 for the firms located at Technopole is shown in Figure 21.

The Institute of Information Systems (IIG) is a distinct environment comprised of a set of offices, other rooms, coffer rooms, meeting rooms and corridors.

![HES-SO Building overview](image)

Data collected for energy savings evaluation

The building area covered by sensors is 16.m². Electricity is used for devices consumption and lighting. Heating is provided by radian panels and a high efficiency gas boiler. Cooling is provided by the same radian panels that and a pump that uses the cool water from the Rhone river located close
to the Techno-Pôle to refresh the building in summer. In order to calculate energy consumption and provide recommendation to the users, the following sensors have been installed and used to assess energy performance of the campaigns:

- Thermal energy consumption
- Electricity consumption
- Inside and outside temperature
- Open/Closed doors and windows
- Person counters

Energy savings observations

2nd Campaign

The campaign was run in rooms SAP and Cyberlearn. The energy performance indicators were not defined yet but thermal energy data had been analysed for rooms SAP and cyberlearn. Below is the thermal consumption analysis two weeks before the campaign and 2 weeks during the campaign.
The graph above show that the thermal consumption actually increase during the campaign as the outside temperature was decreasing.
Theoretically, the energy signature should decrease when the temperature increase which is not the case in both graphs above. This analysis enables us to show and identify potential for savings for the next campaigns.

### 3rd Campaign

The campaign was run in rooms SAP and Cyberlearn. The tables below assess Electricity and thermal consumptions values 2 weeks before the campaign and two weeks during the campaign.

As the number of people and the outside temperature were quite similar before and during the campaign, the electricity and thermal consumption values have been compared. During this campaign no savings were recorded, the consumption actually increased. But this campaign enables us to identify potential for savings thanks to the energy load curve analysis and also to identify appropriate event-based rules for the next campaigns to save energy. Let’s also note that the Energy performance indicators were being defined.
Electricity

<table>
<thead>
<tr>
<th>Electricity</th>
<th>Cyber</th>
<th>SAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Campaign</td>
<td>During Campaign</td>
</tr>
<tr>
<td>Consumption (kW)</td>
<td>35.32</td>
<td>36.77</td>
</tr>
<tr>
<td>Consumption/# persons</td>
<td>17.39</td>
<td>21.40</td>
</tr>
<tr>
<td>Consumption when 0 person</td>
<td>27.37</td>
<td>36.46</td>
</tr>
</tbody>
</table>

Figure 53: Electricity before and during campaign

Thermal

<table>
<thead>
<tr>
<th>Thermal</th>
<th>Cyber</th>
<th>SAP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Campaign</td>
<td>During Campaign</td>
</tr>
<tr>
<td>Delta consumption (Wh)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Temp ext moyenne °C</td>
<td>Min (-9) Mean(0) Max (10)</td>
<td>Min (-13) Mean(-2) Max (8)</td>
</tr>
<tr>
<td>Nbr pers moyen</td>
<td>1.7</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Figure 54: Thermal Energy before and during campaign

4th campaign

The campaign was run in rooms SAP and Cyberlearn. The tables below asses Electricity and thermal consumptions values 2 weeks before the campaign and two weeks during the campaign.

As the number of people and the outside temperature were quite similar before and during the campaign, the electricity and thermal consumption values have been compared. The most decrease in thermal consumption was performed by Cyberlearn. More details are given in the table below.

<table>
<thead>
<tr>
<th>metric</th>
<th>Savings electricity</th>
<th>Savings cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy consumption before the campaign (kWh)</td>
<td>19.3</td>
<td>35.2</td>
</tr>
<tr>
<td>Total consumption during the campaign (kWh)</td>
<td>15.6</td>
<td>34</td>
</tr>
<tr>
<td>Savings (kWh)</td>
<td>-3.7</td>
<td>-1.23</td>
</tr>
<tr>
<td>%</td>
<td>-19%</td>
<td>-3.4%</td>
</tr>
</tbody>
</table>

Figure 55: Savings SAP
The campaign was run for the whole building that has around 80 people. The campaign duration was 17 days from November 5th to November 21st. The streams for this campaign are

- The total energy consumption for heating
- The total electricity consumption
- The internal temperature
- The outside temperature

The thermal and electricity consumption have been calculated two weeks before the campaign and two weeks during the campaign. The results described in the table below show a decrease of 16% of the thermal energy and an increase of 4% of the electricity consumption. As electricity is used for light and devices consumption, it depends on the number of people in the building. Sensors for the whole building cannot measure the number of people but we have noticed many people have vacation during end of October and beginning of September because of November 1st which is a free day. That might cause a decrease of the electricity consumption before the campaign.

<table>
<thead>
<tr>
<th>metric</th>
<th>Savings electricity</th>
<th>Savings cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy consumption before the campaign (kWh)</td>
<td>155</td>
<td>229</td>
</tr>
<tr>
<td>Total consumption during the campaign (kWh)</td>
<td>138</td>
<td>89</td>
</tr>
<tr>
<td>Savings (kWh)</td>
<td>-17.1</td>
<td>-140</td>
</tr>
<tr>
<td>%</td>
<td>-11%</td>
<td>-61%</td>
</tr>
</tbody>
</table>
Energy savings in the last two campaign

Sensor based energy savings calculations are summarized in the table below. For comparison the data have been analysed two weeks before the campaign and two weeks during the campaign.

<table>
<thead>
<tr>
<th>metric</th>
<th>Before the campaign</th>
<th>During the campaign</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption (kWh)</td>
<td>328</td>
<td>275</td>
<td>-53</td>
</tr>
<tr>
<td>Electricity consumption (kWh)</td>
<td>1349</td>
<td>1409</td>
<td>+60</td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>9.7 °C</td>
<td>9.2 °C</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 58: Savings Iig**

Thermal energy savings of 32% resp. 16% have been achieved during the 4th resp. 5th campaign. 15% of electricity consumption have been saved during the 4th campaign whereas the sensors indicate an increase 4% in the last campaign. The number of people affects electricity consumption and the week before the campaign included a free day at the end of the week so that people took a long week...

**Figure 59: sensor based energy savings calculations**

**Figure 60: Example of electricity savings for SAP room during the 4th campaign**
holiday, which could lead to a decrease of the baseline for electricity performance evaluation. Actually, the last campaign targeted the whole building and people presence couldn’t be count for the whole building. Therefore, the analytical savings from the platform could provide further results later in this deliverable.

5.3 POLO Pilot

The third pilot was that done in Polo at Pisa. This pilot has a substantial number of participants, but due to the installation of the conditioning machines and lighting was slightly more difficult at the time of calculating the energy savings.

For calculating the effect of the campaigns in this case, we took the overall energy consumption of three different buildings i.e. Lotto 1, Lotto 2 and Lotto 3. As the consumptions were aggregated we used heating degree days (see Section 4.1) for eliminating the effect of the weather in the energy consumption, and with that investigate the net effect of the campaigns in the pilot.

Each one of the campaigns was evaluated independently considering the situation before the campaign and the situation reached at the end of the campaign and calculating the savings (or lack of) in this period.

The data shows how the savings were in general positive, and although we have seen a great deal of variability on them depending on the campaign and on the specific area. The overall effect is advantageous. The quantification of the savings are shown in Table 5. One can see in this table that although the last campaign was somehow not ideal, the general savings are very similar to those anticipated by the literature that puts them around the 20%.

Table 5. Summary of savings per area and per campaign in POLO pilot.

<table>
<thead>
<tr>
<th>Campaign</th>
<th>POLO (Positive numbers represent saving)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Lotto1</td>
<td>26.70%</td>
</tr>
<tr>
<td>Lotto2</td>
<td>26.20%</td>
</tr>
<tr>
<td>Lotto3</td>
<td>6%</td>
</tr>
</tbody>
</table>
Figure 61. Evaluation of energy use and savings in Lotto 1. The four graphs represent the four campaigns, and the red line is the normalized energy consumption once the effect of the weather has been eliminated. The grey box represents the campaign; the green line represents the effect of the weather.

Figure 62. Evaluation of energy use and savings in Lotto 2. The four graphs represent the four campaigns, and the red line is the normalized energy consumption once the effect of the weather has been eliminated. The grey box represents the campaign; the green line represents the effect of the weather.
Figure 63. Evaluation of energy use and savings in Lotto 3. The four graphs represent the four campaigns, and the red line is the normalized energy consumption once the effect of the weather has been eliminated. The grey box represents the campaign; the green line represents the effect of the weather.
6 ENERGY SAVING CALCULATIONS FROM PLATFORM

During the last year of the project, an extra analytic module has been added to the platform, related to the calculation of the heating/cooling degree days/hours and any associated energy waste based on the current heating/cooling needs of each room. The overall calculation for the energy performance is based on the methodology provided in section 4.1.1 “General methodology for baseline energy performance evaluation”. Calculation of heating and cooling degree hours is based on the real-time sensor data streams for the outdoor and indoor temperature and the consideration of specific basis temperature values for the winter and summer period. Following, based on the provided heating or cooling degree hours and the heat transfer (HTC) of the building, estimation of the required power for heating/cooling of the rooms is provided. It should be noted that this approach is mostly applicable to small offices and houses environments, where the provided HTC can be considered stable per room. Under this perspective, such analysis for energy saving or potential energy waste has been realised in all the pilots, however with focus given on the small in size buildings and mainly in the La Nave building.

Based on the provided analysis process, outcome graphics are generated automatically and include information about the real energy consumption, the baseline energy consumption, indications about when the combination of building characteristics and the external weather conditions present a possible energy waste and how cooling and heating degree days affect the energy consumption of the building.

Following, part of the produced diagrams is presented for two of the subareas of the La Nave Building, mainly the Office2 and the Lab. As shown in the graphs, both during as well as after the campaign, the time slots where some energy waste can be claimed are following a reduction trend, that can be associated to the following up of the suggested actions as well as the increase in the energy awareness levels of the participants.

What is important to note is that the provided analytic process can constitute a very valuable reporting tool for the campaign manager for evaluating in a daily fashion the efficiency in terms of usage of heating/cooling infrastructure and, thus, lead to immediate corrective actions that can have as outcome significant energy saving in small offices and houses.

During Last Campaign at Laboratory of La Nave Building

![Graph 1: Real Power vs Baseline (degree days)](image)

![Graph 2: Indication for Energy Waste (degree days)](image)

After Last Campaign at Laboratory of La Nave Building

![Graph 3: Real Power vs Baseline (degree days)](image)

![Graph 4: Indication for Energy Waste (degree days)](image)
During Last Campaign at Office 2 of La Nave Building

After Last Campaign at Office 2 of La Nave Building
7 LESSONS LEARNT

7.1 Lessons learnt - UMU

We were mainly involved with the technical parts of the project regarding deployment of sensors, collection and storage the data they produce, and administer the UMU Pilot as campaign manager.

7.1.1 Sensors

In order to control the main aspect of a room regarding energy consumption and personal comfort, a specific set of sensors is required. As a lesson learnt in this area we can say that there is an indispensable set of sensors that must be present if we want to achieve our goal of save energy and improve the quality of the air and comfort:

- Outdoor temperature sensor
- Indoor temperature sensor
- Energy meter measuring the electric sockets consumption
- Energy meter measuring the lights consumption
- Energy meter measuring the HVAC consumption
- CO2 sensor

The following type of sensors may help but resulted optional:

- Humidity
- Illumination
- Presence

Also, a very important thing regarding sensors is their calibration. We have found a lot of calibration problem, mainly in temperature and CO2 sensors, that we had to mitigate establishing a skew or offset to obtain the real value. In the campaign setup steps should appear the calibration step, visiting the rooms measuring the real values with reliable portable sensors where available. This offset should be added as part of the configuration of a sensor or stream in the platform. Those offsets have been actually enforced manipulating the data in the gathering process.

7.1.2 Gathering and storing data

All collected sensors data have been retrieved from a central postgres relational SQL database, storing it in an intermediate point between UMU database and Entropy platform. Orion Contact Broker and Short-Time Historic COMET FIWARE entities are in charge of implement this part of the system. As lessons learnt we can mention some points:

- The Short-Time Historic COMET open implementation resulted a bit buggy after some month of a correct behaviour. We were forced to implement an alternative COMET software to implement its same functionality. It was call familiarly TIAMAT, developed in python and MySQL. Two big improvements were reached here: one, the required storage space for the data was reduced to 10% than before, and two, the speed of requests became higher.

- FIWARE entities do not implement security measurements in order to avoid undesired people or devices accessing the data.

- Entropy platform also stores the gathered data in its own database. So there is a duplicity of data that should be avoided in future implementations.
7.1.3 **Administrating Entropy campaigns**

Campaign managers are the responsible people that participants can find and notify about the correctness and reliability of the platform and apps during the campaigns. They have a good point of view of the system in order to detect malfunctions and issues. After this experience of managing several campaigns, some lessons learnt have appeared:

- Campaign manager should have a step-by-step manual in order to setup the campaign, including recommendations of streaming and sensors naming, areas structuring, recommendation engine optimization, etc. As our point of view, these are the main steps to setup a campaign that should be covered by this manual:
  1. Select a building.
  2. Look for available sensors.
  3. Test if sensors are measuring correctly and set offsets.
  4. Decide which rooms are going to be in the focus of the campaign.
  5. Participant recruitment. Take note in which rooms they are.
  6. Installation of the platform in a server.
  7. Link the platform to the FIWARE servers to gather sensor definition and data.
  8. Definition of the campaign manager accounts
  9. Creation of Areas and Subareas in the platform
  10. Contact participants with a user manual, by mail first and physically second, and notify them the start date of the campaign, apps installation steps, and platform registration process.
  11. Get an overview of the sensor values in order to define recommendation thresholds.
  12. Create recommendation templates.
  13. Create recommendation rules associated to the templates using the previous thresholds, and recommended values to ensure balance between energy saving and comfort.
  14. Define the campaign period.
  15. Monitor the campaign during its realization, taking corrective actions if needed.
  16. Request participants periodically to be more participative. People tend to forget their participation in Entropy campaign. Remind them to fill the post-questionnaire.
  17. Collect data when campaign ends.

- Setting the room where participants will be present should be in the initial questionnaire, when the user is requested its age, genre, etc. Most of the user forgot to set the room because it implies to enter in the platform again and set it.

- Campaign managers should have a clear view of the user registration steps and the status of each user. For example: be able to reset the credentials to the users, resend the questionnaire email, delete a user, etc.

- The apps should be extremely tested in order to avoid problems during campaign. Participants are easily get stuck with the more insignificant error appears. Permissions should be requested by the apps at the first launch, not asking the user to do it manually. This is only for advanced smartphone users.

- The apps should be fast and responsive. TH game needed too much time to login the first time, more than a minute waiting. This is considered as an error by participants and which up waiting and exited the app.

- Industry participants are harder to enroll to the campaigns than academia participants. In both cases the usage of real awards to motivate them are crucial.

- Setting up a campaign is a time-consuming and repetitive task that would be improved with some kind of tools that help campaign managers to accelerate this. Some ideas:
  1. Create a new recommendation rule from an existing one (cloning)
2. Import/export facility to save and restore the work made

7.2 Lessons learnt – UBITECH

Within the project, the ENTROPY platform has been deployed for supporting the pilots’ needs, namely the set of campaigns realised at UMU, HESSO and POLO pilot sites. In each of the cases, the main stakeholder interacting with the platform is the campaign manager assigned per pilot. In parallel, support in terms of technical aspects has been continuously provided by the technical partners of the project, based on the continuous feedback provided by campaign managers and end users.

Given the realisation of several rounds of campaigns per pilot, the feedback collected in each campaign was very helpful towards the realisation of various improvements, as well as the introduction of new functionalities in the platform (e.g. statistics regarding triggering of rules, production of analytics related to degree days and potential energy saving). The main improvements were realised targeting on one hand the improved experience and the provision of the required functionalities to the campaign manager and, on the other hand, on the improvement of the overall user experience and efficiency of recommendations provided to end users. Following a continuous development and integration approach, it could be claimed that the final version of the platform is close enough to a solution that can be promoted for market introduction, given its extensive usage in operational conditions.

The main lessons learnt and suggestions for following adopters could be summarized as follows:

- **Setup and configuration of the platform is straightforward.** The main attention has to be given on the sensors’ configuration and registration to FIWARE components. Following, the overall interaction and navigation through the platform is realised in an intuitive way.

- **Setup of streams per area/subarea has to be carefully selected,** leading to the collection of time series data for the required parameters, avoiding unnecessary data collection and transmission. Power consumption and indoor/outdoor temperature streams are of high importance, since they can lead to direct insights with regards to the energy efficiency achieved per area.

- **Pay attention during content and rules definition.** Content definition in terms of templates (tip, quiz, question, task) along with appropriate design of the rules triggering the sending of recommendations has to be carefully considered by campaign managers, leading to providing targeted and not too often messages to end users. The objective is to provide recommendations that can lead to increased awareness or motivation for energy saving, without in parallel adding too much overhead in the recipients.

- **Provide guidance and communication channels to end users.** Interaction with end users in terms of guidance in the initial campaign steps is required. Introduction of gamification concepts is also very important for keeping up the engagement level and leading to significant results in terms of saving. Keeping up an interaction channel -if considered helpful- during the campaign may be also beneficial.

- **Keep an eye on the daily campaign evolution.** Daily monitoring of the status of the streams, the proper triggering of recommendations, the proper extraction of analysis results as well as the responsiveness level of end users is strongly suggested to campaign managers in order to identify problems arisen in the infrastructure, misbehaviour in the platform or very limited responsiveness levels and proceed to corrective actions.

- **Let the event-based recommendations work for you.** Upon proper setup of recommendations and triggering rules (considering realistic threshold levels and inertia time slots), the platform should send recommendations following real conditions in the considered areas/subareas. In case, upon some days of the campaign, a rule seems to be triggered very of the with low responsiveness levels, the inertia time period could be increased.
• **Take advantage of the daily analysis reports**, identifying potential energy waste and proceeding to corrective actions.

### 7.3 Lessons learnt - INTELEN

We were mainly involved with the development of the Personalized App and various data analytics tasks.

#### 7.3.1 Apps (INTELEN)

One of our major tasks was the creation, analysis and development of the Personalized App. ENTROPY’s Personalized App follows the behavioural subliminal educational approach. Behavioural-based learning adopts the idea that the instruction is centralized around individualization. Understanding each individual characteristics and personality, it provides an effective way of meeting the educational objectives of each course or behavioural objective.

Behavioural-based Learning Systems combine both motivation and task/tips-based learning techniques to make people learn without effort. In every organization or firm each individual must stay focused on his job’s tasks in order to achieve the main objective of the strategy.

While people should not be side-tracked from their everyday activities, raising a strong culture and driving energy-saving commitment among them, appears more than crucial.

Furthermore, people tend to resist to change, especially when it comes to their work and their daily routine. Thus, a subliminal learning model is needed. Subliminal Learning is acquiring knowledge and processing information on a subconscious level or by some means other than consciously, for later recall. Subliminal learning can be facilitated through audio and visual cues and metaphorical experience.

The core functional components of the ENTROPY Personalized App are shown below:

1. Android mobile app
2. Educational Content in the form or Tips
3. Educational content in the form of Quizzes
4. Questions in the form of Surveys
5. Visual representation of buildings
6. Visual representation of various sensor streams (energy, Temperature, building KPIs, etc.)
7. Profile settings

A digital user experience from the Personalized App includes:

- The user can select and solve educational quizzes, receive notifications and educational tips, can check in real time energy indicators and energy consumption graphs and push thermal comfort and various building faults/conditions to the Entropy (crowd-feeding). All content is personalized and adapted to users’ behavioural profile;

- The Personal app has an objective to create various interactive behavioural KPIs without any gaming element in order to test users’ ability to shift profile due to personalized educational content.
Lessons learned from these tasks were the structured methodology for developing a mobile app for behavioural change. We had to study well behavioural science theory, together with subliminal learning, in order to create an app to influence people.

Furthermore, the lean methodology was used to create various iterations for optimizing the mobile app, according to the user’s experience and feedback. This is crucial, in order to achieve the optimal UIX, for user engagement.

Last but not least, we were able to correlate digital interactions with behavioural change KPIs, so that to track efficiently the behavioural change, due to the digital technology. This is called Captology (introduced by BJ Fogg from Stanford).

- The Development of the personal app took place on Android SDK, using Android Development Tools - Android studio 3.0.

Development life cycle was the following:
- Requirements
- Analysis & Design
- Development & Testing
- Deployment
- Support & Upgrades.

Testing procedures:
- Test Case Preparation: Designing test cases.
- Manual testing
- Usability testing
- Performance testing: using Android tools
- Device Testing: Execute test cases in other devices of the lab, install the app in different emulators of different versions of Android.

7.4 Lessons learnt from ELTRUN

Too much of a good thing is not the best option for energy-behaviour change at the workplace through the ENTROPY solution.

The smallest average behaviour change between the users was recorded in HESSO, where at the same time there was the least interaction with the ENTROPY apps. However, this proportionate connection between interaction with the apps & behavioural change was not observed in the other two sites (UMU and POLO). The maximum positive energy-behaviour change was recorded in UMU,
where the users' interaction with the apps was mid-level. There, the users received and interacted with a fair amount of messages – not too few, but not too many either. In POLO, on the other hand, where the average interaction with the apps was by far the highest (compared to UMU and HESSO), the strength of behaviour change was not the highest. It was higher than in HESSO, where minimum interaction took place, but lower than in UMU, where the interaction was a fair amount but not as much as in POLO.

This leads us to believe that the amount of user interaction in the three pilot sites was not proportionately connected to the users' mean behaviour change results, across all the behavioural parameters that we inspected. A fair amount of interaction with the apps was the optimum remedy to effect behaviour change. Too little led to lower behavioural change, whereas too much interaction from a point on was in lines with “bombarding” the users with content from the apps, and overall led to less behaviour change. Therefore, a reasonable amount of interaction with the ENTROPY apps is the optimum remedy, in order to effect the maximum behavioural change with regards to energy-saving at work.

The strongest behavioural change across pilot sites was observed during the last campaign.

Across all sites the behaviour was improved much more in the last ENTROPY campaign. We believe that this is the result of many parameters. First of all, the ENTROPY solution was more mature by the time we organized the final campaign. In the previous campaigns, the users had to bear with the evolving nature of the solution, as technical issues were discovered and reported and the solution was constantly fine-tuned. Furthermore, the content provided to them was improved during the first campaigns, towards reaching its final form for the final campaign. Moreover, the rules surrounding the distribution of the content to its end-users were tested against real-life situations during the first campaigns and delivered in a much more effective form for the final campaign. In addition, during the first campaigns, the technical infrastructure, including the IoT that were used during the first ENTROPY campaigns, was used in different configurations and continuously calibrated to optimally pair with the ENTROPY platform, in order to provide the content to the users in the timeliest and engaging manner. Last, but not least, having heard the comments from our end-users with regards to the ENTROPY solutions during the first campaigns, we took them into account for the materialization of the final campaign. This included the personalization of the content that was delivered to the users, based on their behavioural profile. All in all, these changes that were effected to the ENTROPY solution, and its optimum deployment scenario, led to a final ENTROPY campaign that was perceived of by the users as considerably more engaging and led to significantly amplified behavioural change results.

An improvement on behavioural results does not automatically translate to energy savings.

The energy savings we observed during the two ENTROPY campaigns were somewhat contradictory in their comparison to the fluctuation of the behavioural parameters we observed from the end-users. Although we did observe significant positive change in the behavioural parameters surrounding the users' energy behaviour between the initial campaigns and the final campaign, this improvement was not necessary translated into proportionate energy behaviour change results. In UMU, the improved behavioural parameters were indeed in line with an improvement in energy savings: +11.78% more energy savings were recorded in the final ENTROPY campaign, compared to the previous campaigns (4.54% savings in the first campaign and 16.32% in the last campaign). However, contra-intuitively, in POLO and HESSO, where the behavioural parameters observed were also enhance in the last campaign, compared to the first campaigns, the picture regarding their connection to the energy saved during the campaigns was quite different. In HESSO, the total savings observed during the first campaigns, where the users' behavioural parameters (Norms, Intention, Self-determination to conserve energy, etc.) were not significantly improved, were quite high (31.28%). Similarly, in POLO they were 19.7%. However, in the last campaign, in HESSO there were -30.86% less savings (31.28% savings in the first campaign and 0.42% in the last campaign), and in POLO there were -28.74% less savings (19.70% savings in the first campaign and -9.04% in the last campaign). Therefore, in HESSO and POLO, although the users' behavioural parameters were improved in the last campaign compared to the first campaigns, the actual savings were not improved. These results might be possibly
attributable to the overall use of much less heating/cooling in these two pilots, which is by far the most energy consuming factor in buildings, due to seasonal conditions, and/or the common disconnect between behavioural intentions and actual behaviour reported in the literature. This gap between the users’ intention to conserve energy and their actual observed energy saving in POLO and HESSO, may also be possibly connected to the characteristics of the final campaign in the three pilot sites (engagement with the apps, content delivered, etc., as discussed in Lesson 1 above). It is an issue that deserves further investigation in future pilot applications for energy saving through IoT-enabled behavioural interventions.

7.5 Lessons learnt from HES-SO

7.5.1 Hardware and sensors, infrastructure

<table>
<thead>
<tr>
<th>Category</th>
<th>Lesson Learned</th>
<th>Context/Problem</th>
<th>Raised by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pay attention to the impact on people comfort (noise,..) Use medium/high quality sensors</td>
<td>- No more data sent by the sensors</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>The sensors quality need to be high in order to keep a high stability</td>
<td>- Connectivity issues</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>The connectivity between sensors and database have to be defined at the beginning of the project</td>
<td>- Connectivity issues</td>
<td>HES-SO</td>
</tr>
</tbody>
</table>

7.5.2 Pilot aspect

<table>
<thead>
<tr>
<th>Category</th>
<th>Lesson Learned</th>
<th>Context/Problem</th>
<th>Raised by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A &quot;How to use&quot; should be done before providing the tool to the campaign manager.</td>
<td>- Useability of the platform</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>The definition of the rules to use should be clearly defined in order to have a well defined campaign plan</td>
<td>- The rules are not defined</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>A well developed platform should be available in order to optimise the campaign manager work</td>
<td>- Underdeveloped UX</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Simplify the platform in order to let the campaign manager using only the working part of the platform</td>
<td>- Rules definition parameters too complicated</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Start working with campaign manager at the beginning of the project in order to understand potential issues and adress them earlier than just the first day of the campaign</td>
<td>- Issues with the platform</td>
<td>HES-SO</td>
</tr>
</tbody>
</table>

7.5.3 Team building of participants

<table>
<thead>
<tr>
<th>Category 1</th>
<th>Lesson Learned</th>
<th>Context/Problem</th>
<th>Raised by</th>
</tr>
</thead>
<tbody>
<tr>
<td>USER ENGAGEMENT</td>
<td>Limit the amount of time requested for the user to participate in the project (10 min max per day)</td>
<td>20 min to complete a questionnaire more than once, 10 tips to read per day</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Have a feedback or activity or prize to engage the user</td>
<td>- Lack of motivation to interact with the applications</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Use competition among users to increase motivation</td>
<td>-</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Tips of energy consumption related to the pilot site are interesting and bring knowledge to the user</td>
<td>-</td>
<td>HES-SO</td>
</tr>
</tbody>
</table>
### 7.5.4 Apps

<table>
<thead>
<tr>
<th>Category</th>
<th>Lesson Learned</th>
<th>Context/Problem</th>
<th>Raised by</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERACTION</td>
<td>Stabilisation of the platform before providing it to campaign managers and/or users -&gt; Internal testing</td>
<td>- Authentication failed on the platform</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Platform is extremely slow</td>
<td></td>
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<tr>
<td></td>
<td>For a PoC platform, the development should be more advanced to interest people. When the application needs specific access, it should be defined and asked to the final user</td>
<td>- Platform stability</td>
<td></td>
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<td></td>
<td></td>
<td>- UX development</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- No notification on the mobile app</td>
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<tr>
<td></td>
<td></td>
<td>- No iOS version</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Unfinished iOS version</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Regular crashes of the app</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- TH black screen</td>
<td></td>
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<tr>
<td></td>
<td>The migration of the platform or any server/application update need to be planned. Any modification during the campaign is painful and frustrate everybody (users and campaign manager). As well, the data lost is not possible</td>
<td>- Migration of the platform</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Server update</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Personal data lost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stream within the application (if number limited) should be well defined. If the number is limited because of stability, the details need to be well presented</td>
<td>- No more data within the streams</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Streams not updated</td>
<td></td>
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<td></td>
<td></td>
<td>- Rules not triggered</td>
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### 7.5.5 Project Management

<table>
<thead>
<tr>
<th>Category</th>
<th>Lesson Learned</th>
<th>Context/Problem</th>
<th>Raised by</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERNAL COMMUNICATION</td>
<td>When an update is made somewhere, the project team needs to be aware in order to keep a high product quality</td>
<td>- Update of the platform</td>
<td>HES-SO</td>
</tr>
<tr>
<td>EXTERNAL COMMUNICATION</td>
<td>In order to have a lot of users, the communication with them is an important point. To motivate and make them participate to the campaign</td>
<td>- Project not understood</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Importance of the project</td>
<td></td>
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### 7.5.6 Other

<table>
<thead>
<tr>
<th>Category</th>
<th>Lesson Learned</th>
<th>Context/Problem</th>
<th>Raised by</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTHER</td>
<td>Have only one application instead of two. has to be simple for the user</td>
<td></td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Motivate the management first</td>
<td>If management is not motivated the employees will feel the same</td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Find interesting reward for the user so that participating also bring personal satisfaction</td>
<td></td>
<td>HES-SO</td>
</tr>
<tr>
<td></td>
<td>Keep focusing on user interest and needs while developing the app and delete any aspect that will disturb the user</td>
<td></td>
<td>HES-SO</td>
</tr>
</tbody>
</table>
7.6 ARVR - Augmented Reality Treasure Hunt Application

The Augmented Reality Treasure Hunt serious game was iteratively developed and modified based on number of criteria:

- Technical issues/bugs reporting
- User feedback reporting
- Data analytics collected through pilot campaigns

All issues can be broadly divided into

- Technical issues related to the software
  - Software related issues due to different mobile platforms and versions of operating system
  - Software related issues due to interaction with the ENTROPY platform
  - Software functionality issues
- UX/UI issues
- Game mechanisms

Technical issues related to the software were tracked, reported by the pilot managers and corrected through ENTROPY’s bug reporting and tracking mechanism via Github. UX/UI issues are related to the look of the screens, and user experience reflected by the ease of usage of the application. Different game mechanism was implemented to motivate user to use the application and modify their behaviour.

The following issues were identified:

1. Lack of user responsiveness to the real-time Actions that directly lead to energy savings
2. When Actions were opened, users did not press “DONE” button to confirm that action was completed
3. All questions available throughout the whole campaign (All Pilots)
4. Very few questions being answered (at POLO site)
5. Knowledge could be higher, and that players did not use Hints to get to the correct answer

Lessons were learnt from all the issues that were identified, and lead to the following changes for the final campaign:

1. A real-time notification was implemented for active Actions, even when the applications is off
2. Look of Action screen was changed, and size of the DONE button more visible displayed and enlarged
3. A total number of 50 different questions were split across 2 weeks of campaign, 5 questions per day.

Figure 64: Active Notifications for Actions

Figure 65: Done button for completed Actions
Introduction screens were introduced explaining in more details (see figures below):

- Game play
- Augmented Reality clues scanning
- Actions to be completed

Badges that are awarded

Figure 66: AR Treasure Hunt gameplay

Figure 67: AR scanning explained
1. The ultimate badge was added. It can be won if all types of Actions are done 3 times
2. The scoreboard for SOLO play available in real-time
3. The scoreboard for TEAM play was introduced with total number of points and badges from all pilot sites (Italy, Spain and Switzerland)
4. Help extended
In summary, the lesson learned from the usage of Augmented Reality Treasure Hunt serious game as follows:

1. Adjust the format of the game to suit the end users. We believe that the application is better suited to be played as a game on, for example, Friday afternoon where co-workers can play in more relaxed atmosphere without being interrupted at work

2. Motivation using different gamification elements as well as visualisation of real data and concrete energy savings will be fully exploited in such scenarios

3. Series of games need to be organised over a period of time in order for energy saving habits to be adopted on more permanent bases

4. The testing of application when changes are introduced has to be over longer period of time, due to issues that can arise from the interactions with the platform, different versions of the games for 3 pilot sites, different platforms (iOS and Android) and usage of great range of mobile phones having different versions of operating systems

5. The marketing campaign has to be organized before the application is used.
7.7 Lessons learnt - UIBK

We were mainly involved with the technical parts of the project, mainly the behavioural modelling, conceptualization of the recommender system. Additionally, we coordinated the Work-package 3. Below you can find our lessons learnt in terms of the relevant aspects of our involvement.

7.7.1 Platform

- One of our major tasks was to define a semantic model to behavioural aspects of the ENTROPY users. This was more challenging than we expected, since there were not too many existing ontologies or any other data models towards this direction. ENTROPY project adopted different intervention channel such as games, gamified and personalized applications. We had to come up with a model compact but yet expressive enough to represent different behavioural aspects each of these intervention channels uses the create recommendations. For instance, we created Task model for the games, Quiz and Tip model for the personalized applications.
- On the other hand, the ontologies to represent Internet of Things, sensor- and building- related parts have been largely available, and have been reused. The standardisation efforts and developments are however still ongoing in this area. For example, we expect that the semantic models describing the physical characteristics of the buildings will be appearing, enabling to represent, compare and benchmark the specifics of the energy consumption in each of the buildings, as well as the degree of success of the energy saving measures. Thus, in the future, the ontology models would also need updates, and the quality of the information representation in the platform can be increased in the future as well.
- The conceptualized recommender system was mostly implemented in the platform, although the implementation details have diverged from the initial plan. At the beginning we aimed to use a RDF triple store to benefit from the full semantic web technology stack. However, after some tests and discussion with technical and implementation partners, we decided to go with in-house rule engine development of our partner UBITECH, which is based on Drools, enriched with some OWL constructs and stores the data in a scalable document database. This way the Java based platform was kept homogenous and easier to deploy. We still stored the data as JSON-LD in the document store, which gave us an easier path for opening the data later, as we utilized the developed semantic models as metadata.

7.7.2 Data Management

The main lesson we learned for data management is that it is challenging to keep up with the regulations and recommendations from EU in terms of data protection and privacy, as well as best practices suggested by standardization bodies like W3C for data publication. We had to carefully study the data and identify the points anonymization needs and privacy concerns with the help of our partners. The regulations and recommendations like GDPR and FAIR principles had to be adopted rapidly. Since the production of actual data takes place at the end of the project, this process is still ongoing.

- With respect to the publishing of the research data generated in the experiments (sensor readings data, etc.), the project would have benefited from an availability of guidelines / common practices on how to anonymise and publish such data in compliance with the state of the art regulations and principles.

7.7.3 Project management

For a relatively large project like Entropy, some difficulties in terms of project management are inevitable. Although we had some minor delays mostly due to technical issues, the overall coordination of our work package was not very problematic, thanks to the commitment of partners involved. We learned that being proactive and responsive is important to collect necessary output from various aspects of the work package.
8 DISCUSSION AND CONCLUSIONS

The large magnitude and comprehensive approach of project ENTROPY has allowed us to gain a great deal of understanding about the issue of changing behaviour to promote energy efficiency in buildings. The learnings related to performance have been shown in this deliverable.

The reduction of energy in buildings in this initiative is done via the change on behaviour, so it is worth committing our first discussion to the performance of this behavioural change.

The pilot in UMU had five interventions that were preceded by a survey that helped characterising social and psychological indicators. Another survey was carried on between the campaigns (after fourth) and a final survey was provided at the end of all campaigns.

We have seen from the study that the personal norms to save energy was found high even before the campaigns. This comes with no surprise as the personnel of the university have in almost all cases high level degrees and are aware of the environmental issues of society. Nevertheless, an increase on the motivation to save energy has been seen in the results of the surveys after the campaigns of ENTROPY. This comes as a success, as some of the games outlined the necessity to save energy to mitigate climate change. More importantly, the attitude towards saving energy was one of the indicators that appeared to be low at the beginning of the campaign. This is the final step to do or do not an action to save energy. It was interesting to see, that although for some participants the intention stayed the same, for the majority of the participants this attribute increased. This is an interesting finding as it is expected that the behavioural change interventions have no effect on some people due to factors that scape from the scope of this project (engagement, personal situation, understanding of English etc.) but we have seen that on those that had an effect, this effect was considerably positive.

The changes seen in behaviour in UMU between the interim survey and the final survey that bounds the final campaign, shows results that are even more promising. We should take into consideration, that although the development of the work packages of this project was smooth, improvements were done along the way, and the final campaign enjoyed the optimal components. Also, an extra campaign in UMU took place with "fresh" participants that only saw the final version of the framework. In this final intervention, we saw the motivation increase substantially, increasing by 31.3%. Although smaller, we also saw certain increase on personal norm for energy saving; this implies that the participants were aware of being saving more energy after the campaign. This is also seen in the behavioural intention and in the self-reported behaviour. Also, we considered very important the increase we saw on energy-saving competence (I know how to save energy) that increased substantially in UMU after the last campaign, this is highly relevant as a great deal of literature in the topic explains that permanent savings are the result of an increase in energy literacy.

The HES-SO Pilot was in general highly successful in terms of behavioural change. The first campaigns gave results that point towards an improvement on the factors that motivate behavioural change in this case. Only the personal norms, the behavioural intentions and the energy-saving competence that were high at the beginning of the study remained the same after the first interventions. The personal impact average shows a subtle decrease, but due to the small of the change (0.4/7) and the size of the sample one cannot consider this to be highly significant. The attitude towards saving energy at work seems to decrease on average by -12%, but as in UMU we see that in the majority of participants it either increased or remained the same, only in a small part of the participants this was seen to be reduced. Again we can justify this different in participants, with engagement.

For the HES-SO Pilot it was also seen that the final campaign had positive impact in a great number of attributes of behaviour. The motivation to save energy at work, self-reported behaviour, Energy Saving at work as a habit and Energy Saving competence was seen to increase; and although some other intentions such as personal norms, subjective norms, behavioural intention, impact and attitude was decreased after the last campaign in this pilot, this was also by less than 10% which can be in contrast with the improvement on the motivation to save energy at work that reached the 28.6%. This,
and the fact that as in the previous case, the competence towards saving energy has increased substantially represents a good result for the campaign.

With respect to the POLO pilot, we have seen as in the previous cases different effects in the different facets of behaviour, but most clearly a different result between the first campaigns and the last campaign. In the first campaigns, it was seen how only the energy saving at work as a habit, the collective impact and the energy saving competence increased, whereas the others decreased. This contrasts highly with the results of the last campaign. In this case, only the subjective norm and the self-report behaviour were seen to decrease, what is considerably interesting as these are both self-reported perceptions. Following with the argument said before, we see again that the competence to save energy (the main facet to attack in this project) has been seen to increase, in the first campaigns and in the last by as much as 15.9%.

Observing these indicators on behavioural change, one can see that although there are aspects, that can be more affected for exterior factors (such as norms or attitudes) in some cases were not raised by our interventions, in all cases we improved the competence to save energy, in all cases, in all pilots, in all sites. As the apps were equipped with tips and messages that will inform occupants how to save energy, we consider this a definite success. Knowing how to save energy empowers the occupant to do so and produce savings based on the improvements on energy literacy that last after the interventions.

The project developed an integrated solution that would help building managers and users to save energy without the need of being computer scientists or building physicist. This was the design philosophy in all the steps of the development, as failing of developing a “one-fits-all” solution would result on difficulties when trying to perform large scale roll-outs of these kind of solutions.

We faced an interesting challenge when confronting the need of introducing in the platform enough information about the energy performance of the building so the messages sent can be personalised and smart (necessary condition to reach the full potential of the solution). Although for the project we were able to performed detailed thermal models of the buildings, we needed something rather simple but yet informative and available to all building managers. Taking advantage of the Energy Performance on Buildings Directive, we adapted a part of the platform to be capable of integrating data from Building Performance Certificates. We found this solution considerably successful and they were included in the POLO pilot giving the results expected and performing adequately.

In the pilots of UMU we performed building detailed thermal models, although no all building managers will have the resources to create these detailed analysis of the buildings, they showed to be highly useful. The site called Pleiades was modelled in detail, and the unknown parameters were estimated used the great wealth of data coming from the IoT infrastructure. The result was a model that was providing variables highly accurate with those seen in reality. This model was used to evaluate “what if” scenarios, that among others allowed to design strategies for the interventions that would attack the most energy wasteful behaviours, as it was used to evaluate the effect that the intervention could have if applied with a 100% effectiveness. It should also be noted that this model helped also with the calculation of variables that were not being measured in the real world. For example, the real time power of each conditioning machine was not available for this site, but thanks to the model a correlation between the external and the set-point temperature was found that allowed to calculate this powers in a rather accurate way.

On the same way, a model for La Nave site was created with detailed representation of the thermal envelope, the services and the occupants. As in the previous case this model was used to evaluate the effect of the interventions and how the behavioural change was going to have an impact in the energy use.

The interventions had a substantial effect on the savings of the building under consideration. The UMU pilot had two buildings. Pleiades and La Nave. In Pleiades building, the behaviours related to conditioning and light use were tackled to motivate energy use reduction. In terms of heating, campaign one and two were used (no heating available in the others). In campaign one we saw a
substantial amount of energy reduction. This was the effect of changing the thermostat value, mainly by decreasing the high temperatures. These savings were around the 20%, as one can expect form the literature. The second campaign showed less savings, and in cases even an slight increase. However, this correlates rather well with a decrease in interactions of users with the solution (loss of interest). This can be seen in more detail on Deliverable 5.4.

With respect to cooling in Pleiades, we were able to use campaign 4 and 5, as no cooling was used in the other campaigns. It was interesting to see how in this case, campaign 5 was the one with the higher savings, again correlated with higher participation on quizzes, questions and tasks being also higher at that campaign. These results can be considered rather positive, as an evaluation on the thermal model placed the potential savings in this building near the 7% when adjusting the thermostat to an ideal value.

With respect to light in Pleiades. This pilot had a particularity that had to be taken into consideration: after preliminary tests, we saw that lights had to be turned on to reach adequate levels of illumination in the rooms. This implied that interventions trying to decrease energy use for lighting in this building was not adequate. For this reason, the interventions focused on turning the lights off when the rooms were left empty and the building was unoccupied. After the evaluation we saw that the interventions were highly successful. Particularly we saw substantial energy reduction in a room in which energy use for lighting was unreasonably high during the night. The repeated campaigns reduced that energy used in lighting during out-of-hour periods.

La Nave was a site in which the participants received an intervention anew. In this test, we aimed at reducing energy in out of our periods, but unlike the Pleiades example of the lighting, we aimed for an integral saving of energy. We evaluated the result of this fresh campaign and the findings were very positive finding results of 35.6% savings in average. This is partly explained by the fact that these participants did have the optimal version of the solution, and that they were not wear by multiple campaigns.

The HES-SO campaign were performed in two different buildings. As it has been shown in the document, this campaigns were also considerable. In this case the fourth and fifth campaign were the ones with the largest savings that reached the 32% in the fourth for heating. It should be noted that due to the weather on that specific site a saving in heating of 32% is rather significant. To ensure that these savings were calculated on a correct manner, normalisation with the previous two weeks and with the outside temperature (weather) were done in all cases.

POLO had four different campaigns in three different spaces for which the electricity used was measured in intervals of 12 hours during the campaigns and two weeks prior to them for normalisation. The energy used in this cases was representing heating, cooling, lighting and devices. Because of this, the seasonality of the data had to be extracted to ensure that the comparisons between before and after campaigns were true comparisons. The results of this comparisons were rather positive. As in the precious cases the highest savings were seen in the first campaigns when savings of 29.6% were reached. Savings on the fourth campaign were not seen to be that evident. However, it should be said that the data available for this campaign was partly lost and the campaign was not complete.

The savings obtained in all the pilots are indeed rather positive. We have seen correlations between the values obtained with the published scientific literature and with the preliminary calculations that we had perform prior the interventions (as with the thermal models). It should be noted that we in all case see a strong correlation between savings and interactions with the apps, so again, and as in the case of behavioural change, we see that these solutions are effective if we are able to maintain the attention of the users, which is on its own a substantial challenge.

The solution worked beyond expectations. Other deliverables have shown how the messages tips, questions and other actions were send to the participants successfully. But also, we have seen that the platform capabilities to calculate and to show the energy savings are rather powerful. One cannot expect that a building manager could perform data analysis as complex as the one shown in this
deliverable, so the fact that the project has been able to create the feature of a saving calculator within it, it is to our believe, of great value.

In general, a great deal of knowledge has been gained in this project. Above the performance of the different aspects have been summarised, but also, independent lessons on the functioning of the project have been learnt.

The sensitisation of the building can be rather challenging endeavour if it has not been done in the construction of the building. If this work had to be done once the building is in place, then a few sensors may be enough to capture the energy behaviour, and this should be considered. Large amounts of sensors mean large amounts of data. Efficient ways of storing and accessing this data should be considered.

Buildings have in many cases rooms and spaces that serve the same purpose and that have similar uses. When designing a solution as the own shown here, this has to be taken into account. Entering the same characteristics many times can render the task dull and make the building manager frustrated and eventually not to use the solutions. This should be taken into consideration.

Also, it seems like interaction with users have to be controlled. Too many messages can be overwhelming and have been seen to have a negative effect on the effectiveness of the interventions. Too few can cause the same effect, and decrease the effectiveness of the campaigns. We have seen that a few (2 or 3) messages a day could be the optimal rate.

Energy can be saved if you know how. And so is reflected in the scientific literature. An increase in energy literacy helps on energy saving, we have seen that our interventions were effective in this regard and we have seen a reflection on energy savings. Interventions with the aim of reducing energy use should have this into consideration.

Also, an important lesson was that the users can feel very reluctant to use an app if the steps are not perfectly clear and the use is not intuitive. No proficiency on technological aspects should be assumed in this type of interventions, or the frustration of users may make them ignore any recommendation.

Overall, the two pillars of ENTROPY that were represented by behavioural change and energy savings have been evaluated and shown in this document. Although more work has to be done to identify potential improvements of interventions, it has been shown that the savings are substantial and that the behavioural change can be considered to be achieved. This is definitely true in the improvement of the capabilities to save energy of the occupants i.e. it was possible to educate the users to empower them to save energy. This is of great value, as knowing how to save energy will allow them to do it in a more efficient way and with a motivation that comes from an educated will.
9 BIBLIOGRAPHY


