# Consumption performance, of a multi agent system used to achieve comfort preferences

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**Abstract.** In this work, a multi-agent system was developed to manage comfort preferences, in an autonomous and completely automatic and non-invasive way for the user. This system was based on the use of an architecture supported by low cost hardware, namely Raspberrys, to support the different actuators present in the different spaces. To carry out its validation, a methodology was created to analyze consumption performance, and the results obtained in two scenarios are demonstrated here, a domestic housing scenario, and a professional environment scenario. The results obtained were quite positive for the prototype developed, and validate the option of using low cost hardware.

**Keywords:** multi-agent · consumption · preferences.

## 1 Introduction

Currently, users are increasingly looking for automatism's that make their daily lives easier. And thus allow them to have more free time for themselves, not having to worry about routine tasks.

In which most of the time they are not able to optimize them in the same way, as is done by any automatic system. Still achieving autonomy, which is perhaps the characteristic most sought after by users of this type of system.

With this work, it has been validated a multi agent system to achieve the best comfort preferences using low cost hardware like Raspberry's, and at the same time improve consumption performance. This work aims to give continuity and finalize the doctoral work presented in previous editions [1][2][3][4][5][6][7].

This project demonstrates the complete development of a multi-agent system, and its effective performance related to energy consumption.

## 2 Materials and Methods

In this section, the different used actuators are detailed, as well the multi-agent system developed.

### 2.1 System Actuators

For the different actuators operation, in the different scenarios, different valences were used, and are following detailed:

**Temperature/Relative Humidity**

Namely in terms of heating, this was achieved through a hydraulic underfloor heating that is divided into different circuits to cover the different house areas, as well for its control, six thermostats from the *Tado* brand were used that allow in real time to send, using an API, the desired temperature. The thermostat and its operation mode, can be seen at Figures 1 and 2.

Fig. 1: Actuator desired temperature.

Fig. 2: Thermostat current temperature.

For cooling and relative humidity control, also six fan coils were used, one for each area, and controlled by individual thermostats, which also allow the desired temperature definition through an API.

**Luminance/Brightness**

For luminance and brightness, *Shelly* bulbs that have WIFI connection are used, that allow to control different luminance and brightness present at each individual environment, in the same way they have an API to integrate with other smart home systems, and that allow its direct control. This device can be seen at Figure 3.

**Sound**

For sound, were used *Echo* speakers from the brand *Amazon* which have WIFI connection, and allow to control the sound volume and also the played music (sound source, playlist or gender) present at each individual environment, in the same way they have an API to integrate with other smart home systems, and that allow its direct control. This device can be seen at Figure 4.


Fig. 3: Smart bulb.


Fig. 4: Smart speaker.

**Security Systems**

Also, was tested the possibility to use some security systems, and enable/disable this according to the user detection at the environment. The used device is from the brand *Ring* and it can be seen at Figure 5.

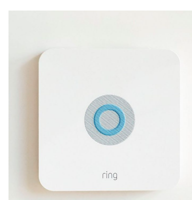


Fig. 5: Smart security system.

### 2.2 Multi-agent system architecture

The multi agent system was developed using JASON and ARGO, and the Figure 6 represent the different layers architecture separation, to easily identify the purpose of each, and agents containing it.

There will be one principal agent who will represent local system, namely each individual environment, where it was a need to ensure individualized comfort conditions, such as a room in a house, or a office in a building. This agent will take into account any directives that may exist for this environment, such as lower or upper limits to different comfort conditions, or also safety parameters that may be critical for a given space. This agent will have a obviously prevalence relative to others, since it will be the dominant for a given environment.

With users respect, each one in the space, will also be represented by an agent, this will receive user preferences from main system, for the place where it is, as well for the time in which it is. Also in this situation there will be a

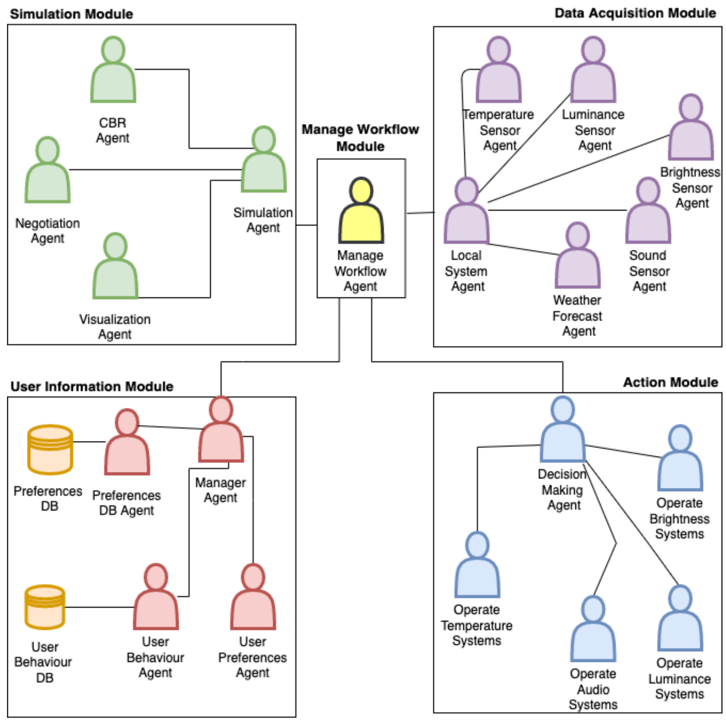


Fig. 6: Multi-agent system architecture

prioritization that identifies which user will have environment supremacy, so it also has an increase in the negotiation process.

In decision-making process, all users agents and agents representing the environment will be taken into account. With the different priorities that each of them has, and with this information will begin the negotiation process.

### 2.3 Evaluation scenarios

For the proposed framework analysis and evaluation, different scenarios were formulated. Initially it was applied in a two floors house.

In this way, it was possible to validate the domestic space concept, with a family composed of two adult users and a child, characterized before.

Their individual preferences were defined, and the MAS system analysis was carried out during a six months period.

The workspace concept was also defined, with different local systems being installed in the partner company's offices.

It was also planned to install some local systems, in partnership with the partner higher education institution, as well in a local health unit. But due to budget constraints, and costs associated with acquiring the high number of equipment's (*Raspberry's*) necessary for data acquisition, this was not possible.

This fact was also aggravated, due to the constraints introduced by the pandemic, having been completely impossible to access the health unit at that period, as well the higher education institution.

In section 3 the two defined scenarios results, are detailed, and explained for each of the aspects analyzed.

**Home Scenario**

Table 1 characterizes the different users that compose the home scenario.

Table 1: Home Scenario - Users characterization.

| **Username** | **Type** | **Proportion** |
|---|---|---|
| User1 | Adult | 1 |
| User2 | Adult | 1 |
| User3 | Child | 0,75 |

Table 2 was developed, where all the entry records (samples) considered for analysis are represented, and they are divided by the six months under analysis (October 2021, November 2021, December 2021, January 2022, February 2022 and March 2022).

Totalizing *15420* log records for the six months in question. Each of these samples represents one user entrance/presence, recorded by the local system. We can see an average of *84,45* samples registered for each day.

Table 2: Home Scenario - Total registered samples.

| | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Total/ Average** |
|---|---|---|---|---|---|---|---|
| Nr. of Days | 31 | 30 | 31 | 31 | 28 | 31 | 182 |
| Nr. of Periods | 992 | 960 | 992 | 992 | 896 | 992 | 5824 |
| **Total samples** | 3219 | 3033 | 1548 | 2988 | 1737 | 2895 | 15420 |
| **Average/Day** | 103,84 | 101,1 | 49,94 | 96,39 | 62,04 | 93,39 | 84,45 |

**Work Scenario**

Table 3 characterizes the six users that compose the work scenario.

Table 3: Work Scenario - Users characterization.

| Username | Type | Proportion |
|---|---|---|
| User10 | Hierarchy_1 | (100-1) |
| User20 | Hierarchy_2 | (100-2) |
| User30 | Hierarchy_2 | (100-2) |
| User40 | Hierarchy_2 | (100-2) |
| User50 | Hierarchy_2 | (100-2) |
| User60 | Hierarchy_3 | (100-3) |

Table 4 was developed, where all the entry records (samples) considered for analysis are represented, and they are divided by the six months under analysis (October 2021, November 2021, December 2021, January 2022, February 2022 and March 2022).

Totalizing *36578* log records for the six months in question. Each of these samples represents one user entrance/presence, recorded by the local system. We can see an average of *200,98* samples registered for each day.

Table 4: Work Scenario - Total registered samples.

| | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Total/ Average** |
|---|---|---|---|---|---|---|---|
| Nr. of Days | 31 | 30 | 31 | 31 | 28 | 31 | 182 |
| Nr. of Periods | 682 | 660 | 682 | 682 | 616 | 682 | 4004 |
| **Total samples** | 6024 | 8170 | 3676 | 6420 | 4968 | 7320 | 36578 |
| **Average/Day** | 194,32 | 272,33 | 118,58 | 207,1 | 177,43 | 236,13 | 200,98 |

## 3 Results

To assess the results, the scenarios identified in section 2.3 were defined, and implemented. Thus, a six-month period was defined for the identified scenarios analysis, as well the users present.

For the spaces characterized in section 2.3, information was then collected over a six months period. Thus, it was possible to carry out all the statistical analysis, in order to execute the results compilation presented below at section 3.1 and 3.2 and at Tables 6 and 8.

As previously mentioned, the results presented are preliminary and subject to industrial secrecy by the partner company. Therefore, all possible information is presented, considering the company's intention to commercialize the developed product, there are thus several restrictions on more data availability.

### 3.1 Home Scenario

Thus, all manual changes made during the testing phase were analyzed, and the satisfaction metric was calculated, by period of time/place.

The average satisfaction was also measured, for the different periods: morning (8am-1pm), afternoon (1pm-7pm) and night (7pm-12pm).

Also regarding energy savings, and knowing that it is currently a factor that isn't and cannot be neglected by any individual user or any business entity.

Considering the costs increase with different energy types, as well the ecological footprint that its production represents, the savings metric was also calculated, always considering that the purpose of this solution would not have this as prime factor, but indeed the maximum user comfort.

But knowing from the start that with all the introduced automatism's (detection of users present at the space, adjustment to minimum reference values in empty spaces, etc.) by the proposed solution, a decrease in consumption would be expected by itself.

Compared to solutions that only implement pre-programmed fixed adjustments and which most of the time don't include any automatism, such as simply allowing to detect absence periods, for example in the workspace, such as vacations, holidays or others, in this scenario, savings are expected to be even more significant.

To check exact values, the month global consumption was been verified for each analyzed space, and compared with the same month global consumption, after applying the solution.

At Table 5 we can see the mean value for the baseline day consumption, and the day consumption for the analyzed period, and also the difference in kWh, and the savings in percentage value.

Table 5: Home Scenario - Day Energy consumption (mean value).

| Scenario | Baseline (kWh) | Period analyzed (kWh) | Difference (kWh) | Savings (%) |
|---|---|---|---|---|
| Home | 35,2 | 32,05 | 3,15 | 9,84 |

At Table 6 we can see the total consumption value for the baseline, and for the 6 months period analyzed for the home scenario, and also the difference in kWh, and the savings in percentage value. At Figure 7 we can see the plot of this information.

Table 6: Home Scenario - Energy consumption - 6 Months.

| | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Total** |
|---|---|---|---|---|---|---|---|
| Nr. of Days | 31 | 30 | 31 | 31 | 28 | 31 | 182 |
| **Baseline** (kWh) | 806 | 960 | 1240 | 1426 | 952 | 930 | 6314 |
| **Period analyzed** (kWh) | 682 | 870 | 1209 | 1209 | 868 | 868 | 5706 |
| **Difference** (kWh) | 124 | 90 | 31 | 217 | 84 | 62 | 608 |
| **Savings** (%) | 18,18 | 10,34 | 2,56 | 17,95 | 9,68 | 7,14 | 10,66 |

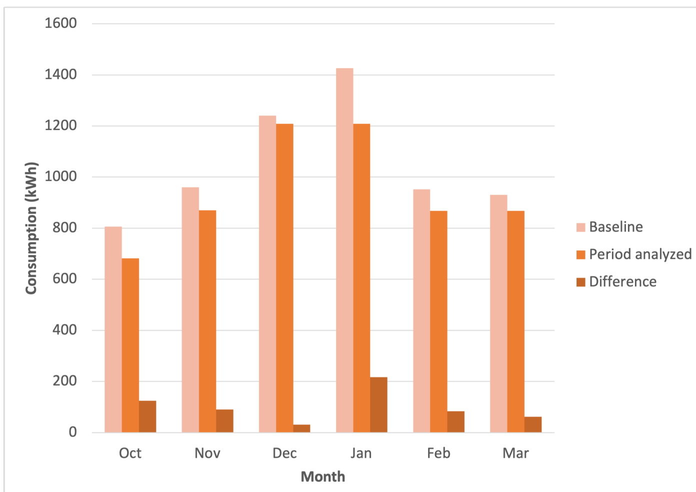


Fig. 7: Home Scenario - Energy consumption - 6 Months.

### 3.2 Work Scenario

At Table 7 we can see the mean value for the baseline day consumption, the day consumption for the analyzed period, and also the difference in kWh, and the savings in percentage value.

At Table 8 we can see the total consumption value for the baseline, and for the 6 months period analyzed for the work scenario, and also the difference in kWh, and the savings in percentage value. At Figure 8 we can see the plot of this information.

Table 7: Work Scenario - Day Energy consumption (mean value).

| **Scenario** | **Baseline** (kWh) | **Period analyzed** (kWh) | **Difference** (kWh) | **Savings** (%) |
|---|---|---|---|---|
| Work | 42,5 | 36,4 | 6,1 | 16,76 |

Table 8: Work Scenario - Energy consumption - 6 Months.

| | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Total** |
|---|---|---|---|---|---|---|---|
| Nr. of Days | 31 | 30 | 31 | 31 | 28 | 31 | 182 |
| **Baseline** (kWh) | 992 | 1050 | 1519 | 1643 | 1036 | 992 | 7232 |
| **Period analyzed** (kWh) | 899 | 840 | 1364 | 1612 | 868 | 868 | 6451 |
| **Difference** (kWh) | 93 | 210 | 155 | 31 | 168 | 124 | 781 |
| **Savings** (%) | 10,34 | 25 | 11,36 | 1,92 | 19,35 | 14,29 | 12,11 |

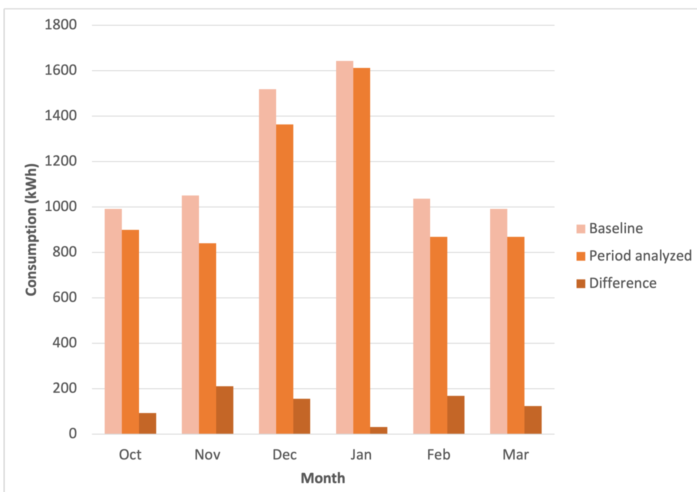


Fig. 8: Work Scenario - Energy consumption - 6 Months.

## 4 Conclusions

With this project, was achieved the complete development of a multi-agent system, an effective reduction in consumption.

The possibility of using low cost hardware (40€) to control this type of system was also validated. Therefore, it is effectively possible to use this type of equipment for the development of this type of project.

The 6 months analyzed period is not very extensive, but it can be seen as sufficient for this kind of spaces (domestic, small company) analysis,because users remain in some way very constant, and where there is thus no significant variance in their preferences.

For future work, some more scenarios have to be tested, to reinforce the full effectiveness of this system, and the values of his overall performance.

buted to the achievement of the main objective of the investigation was presented.

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