Distributed Lighting Control System

André Garção
Universidade de Lisboa - Instituto Superior Técnico,
Av. Rovisco Pais, 1 - 1049-001 - Lisbon, Portugal
andre.garcao@tecnico.ulisboa.pt

ABSTRACT

With the increasing concern for environmental protection, society begins to consider new ways to fight this problem which can negatively transform the world we live in. One of the ways to reduce our impact on the environment is by improving the energy efficiency of our products and processes. One of the areas where any reduction in power consumption has a major global impact is the lighting area. There are an increasingly number of solutions that aim to control the lighting of buildings. In this paper, we present one of these lighting control systems which is based on a wireless sensors and actuators network (WSAN). By adopting this type of network, we can take advantage of its features such as wireless communication. This way is easier to deploy this solution in buildings with a lighting system already installed. It is intended that the solution is distributed and decentralized, i.e., there is no central entity to control the communication between the nodes or to decide what the solution should do. Decisions on what to do will be taken by each of the network nodes. The algorithm installed on each node exploits the idea of using motion sensors to detect occupants creating a light area where they are. Furthermore, the algorithm should also be able to, if the occupant is in motion, predict the direction of their movement, illuminating this space in anticipation. All the goals described above have been achieved. The solution developed allows a significant reduction of energy consumption of these lighting systems, thus making up a serious alternative to traditional lighting control systems.

1. INTRODUCTION

Today, energy efficiency is one of the biggest issues of our society. The ability to reduce energy consumption and still be able to provide the same services and products without decreasing their quality, is an increasingly concern for both ordinary citizens and public entities. To enforce this concern, in 2012, the European Commission, launch the Energy Efficiency Directive, a set of measures to help the European Union to increase their energy efficiency by 20% until 2020[1]. With that in mind, this work is focused on finding a smart solution to control lighting systems. And why lighting systems? These systems are one of the largest energy consumers in buildings, with a consumption between 30% and 40%[2], and therefore a reduction on the energy consumption of these systems have a big impact in the global consumption of buildings.

There are already many lighting control systems schemes with the aim to reduce their energy consumption. Light level tuning is one of these schemes. This scheme, tries to adjust the intensity of the light emitted to the occupants preferences. This scheme generates energy savings because often the occupants don't need the standard level of luminosity and that level can be decrease. According to G.R. Newsham and J. A. Veitch, this type of system can offer savings of 15% to 25%[3]. Time switching strategy is another good scheme. This scheme is more efficient in buildings with well-defined working schedules because it consist in reduce the brightness of the lamps when there are no occupants. The occupancy sensing control system is the most usual to address lighting systems energy consumption problem. With this scheme, the lamp only turns on when it detects an occupant with it motion sensor, and turns off a few seconds later if the sensor don't detect more movement. Energy savings of 20% to 60% are common with this control system.[4]

Despite their advantages, many buildings don't adopt these solutions for theirs lighting systems. This occurs because these systems can be very complicated to install in building where the lighting system is already installed, causing large initial costs. Also, these solutions often fail to accomplish the occupant's requirements (for example: we see this when we go to a bathroom and the light don't turn on because the motion sensor is broken). To fight these disadvantages, we propose a lighting control system based on a wireless sensor/actuator network.

2. RELATED WORD

The WSAN have already being used by some authors to address the problem of energy consumption by lighting systems. The capacity of these networks to have some kind of intelligence and their ability to adapt their surroundings and interact with it make them the obvious choice to be the base of a new lighting control system. Next, we present different approaches we found in the literature.

2.1. DUST Networks Solution

DUST Networks[5] claims to be the pioneer in the use of wireless sensor networks for lighting control systems, and presents us, in conjunction with the Lawrence Berkeley National Laboratory (LBNL) and SVA Lighting, a centralized solution that promises to reduce installation costs significantly in relation to a wired solution. This solution presented by DUST Networks has several components that are all integrated inside DUST nodes, nicknamed SmartMesh motes. These SmartMesh motes transmit the data received by its sensors, to a central computer via wireless network. The central computer then uses an algorithm to decide which action should do. This algorithm uses mainly two lighting control techniques: the daylight harvesting and occupancy sensing. The DUST Networks states that this system installation costs are 30% lower when compared to a wired solution. It further states that this system covers its cost after three years, as it leads to a considerable increase in energy savings.

2.2. XPoint Wireless

Adura Technologies give us the XPoint Wireless[6], their solution for a lighting control system. Although there is not much information about this system we perceive by the sales brochure that it is a system that can be hybrid: the system can be combined with traditional wired systems or acted alone. We are also told that it is a decentralized system but nevertheless it requires the presence of components that form the bridge between the various nodes of the network, called Xpoint Wireless Bridges. Finally, this system also provides the customer with a web application that allows him to control, monitor and configure the network.

2.3. O'Reilly and Buckley Solution

Fergus O'Reilly and Joe Buckley[7] examine and explores the idea of daylight harvesting. To accomplish this idea they use a wireless sensor network to measure the amount of light that reaches a closed space and control the lighting system of that space based on that. For the control of lighting system they are using DALI technology. DALI[8] or Digital Addressable Lighting Interface is a type of dimmable ballast that utilizes a stand-alone communication protocol. This solution is designed but was not be implemented and therefore there aren't any practical results if this is a good solution to reduce the energy consumed by lighting systems or not.

2.4. Granderson, et al Solution

When trying to solve the problem between the light preferences of building occupants and energetic efficiency desired by buildings managers, Granderson et al[9] develop an algorithm that achieves an ideal balance between this two ideologies. Still, this lighting control system assumed that lights in the same region are identically controlled, and the resulting decision is a single optimal light setting for the entire region. Results from both simulation and physical implementation and user testing indicate that the intelligent controller can increase occupant satisfaction, efficiency, cost savings, and management satisfaction, with respect to existing commercial daylighting systems. They validate the work by using a sensor test bed consisting of 3 WSAN light sensor nodes and 4 WSAN nodes for lighting ballast actuation. This solution although also use a WSAN, is intended for small spaces such as offices or open-spaces, not as an alternative to the proposed solution.

2.5. Li Solution

The solution proposed by Li[10] is different from all others so far presented: he proposes solution where sensors and actuators are two separate networks. And how this works? Although both networks are separate from each other in terms of communications protocols it have a point of contact: a central server. This server bridges the gap between what the sensor system detects and tells the actuators system you have to do. This separation enables the provision of delay and service guarantees for time sensitive actuation commands. It is not presented in the paper any reference how the system behaves about energy issues.

2.6. Singhvi, et al Solution

Singhvi et al[11] solution is quite ambitious: they proposed to integrate the occupants preferences, the state of indoor and outdoor environment and the operation goals to reduce energy use. To reduce the complexity of its control algorithm of the lighting system and keep it efficient, the authors of this article optimize the problem assuming that a lamp illuminates only a small space around them. They tested their system using a testbed of 12 WSAN nodes and 10 desk lamps. They system behaved well in this condition but the control algorithm has not been tested under the combination of indoor light and daylight so this type of operation has not been proven. This solution does not foresee any movement by the occupants, assuming that these are static and so despite ambitious, this solution have quite different characteristics of the proposed solution.

2.7. Sandhu, et al Solution

A MAS system (multi-agent systems) is presented to us by Sandhu et al[12]. This work presents, although in theoretically form, a system where the various sensors work cooperatively to accomplish complex tasks which in this case is the management of the lighting system. They make a division of physical space for various static subnets where each one is characterized by having a MAC to control it dimmable lighting ballast. Each subnet may have several sensors and such sensors may be associated with more than one subnet. The advantage of such a system is it scalability, self-configuration and adaptation but interaction between agents is much more complicated than in centralized systems. The advantage of this system is it scalability, it capacity for self-configuration and it adaptation to the environment but the interaction between these agents proves to be much more complicated than that the one found in centralized systems. Moreover, this type of system is different from the proposed solution because we only want a movement detector to an actuator, not many.

2.8. Wen and Agogino Solution

This paper written by Y. Wen and A. M. Agogino[13] focuses on the control of the lighting system in a room with several occupants and therefore many lighting preferences. The proposed algorithm uses a centralized strategy to control the lighting system where it algorithm calculates the optimal linear combination of individual models and lighting luminance levels which minimizes energy usage. Tests have been made in a large workspace and energy savings with that system are between 68-70% depending on the number of occupants present.

2.9. Pan, et al Solution

Pan et al solution[14] is typical centralized solution. First you have light sensors to collect environmental information. This information is then passed to a central server that will decide, based on an algorithm. The decision algorithm seeks to maximize the user's satisfaction level while the constraints are the satisfaction threshold for various users present. Once you have a decision, centralized server passes commands to the lighting devices in order to them behave as is proper. The scheme was verified by a real implementation in an indoor environment. This solution is completely different from the proposed solution. The aim is, contrary to this, develop a distributed solution and adopting the lighting control technique of occupancy sensing.

2.10. Miki, et al Solution

An autonomous system and distributed control of the lighting system is presented by Miki et al[15]. In this case through movable luminance sensors, the system can provide the desired lighting at a desired location. Kaku's[16] work is based on Miki et al paper details the implementation of this system in 240 square meter workspace with 26 lighting fixtures and 22 luminance sensors. Despite being a solution that presents some aspects that can be adapted to the proposed solution, this one will use of static sensors because its lighting fixtures will be fixed on the ceiling

2.10. Park, et al Solution

Park et al[17] presents us the Illuminator, an intelligent lighting control system developed for entertainment and media production. In this system, Park et al also show us the Illumimote that it is a high fidelity light sensor module designed to meet the extreme requirements of production and media entertainment applications. Using a generic algorithm, the system computes optimal light settings at run-time to achieve the user-specified actuation profile. The results of tests, performed by the authors, reveal that the Illuminator, given the light setup and user constraints, finds the best light actuation profiles.

3. PROPOSED SOLUTION

We aim to create a distributed lighting control system for large areas inside buildings. This solution is alternative to traditional lighting control systems as a way to improve the energy efficiency of these spaces, helping owners to reduce their spending on energy bills without ever jeopardizing the comfort of occupants of these spaces. How we said before, this solution is based on a WSAN. The idea is to place a collection of devices (motion sensor, processing unit and lamp) linked together (we’re go call it node) on the ceiling of the space where we want to deploy this solution. This collection of devices linked together is a node of our WSAN. Then, when a node’s motion sensor detects an occupant’s movement, the lamp associated with the node must be turn on to illuminate the area where the occupant is.

Despite being a WSAN, the network will not have the power supply problem that normally these networks have. This is because the nodes of this solution will be arranged in buildings that have electricity so its energy power supply will come of it.

Moreover, this control system is intended to be distributed, i. e., there is any sort of central entity to which the data collected by motion sensors is sent. Instead, the goal is that the data collected are processed in each of the network nodes. For that, they have to know how to behave when they receive information from its motion sensor and when they receive network messages. This will allow reducing the disadvantages that introduces a centralized system, in particular the problem of the critical point of failure.

This feature will also require that the network can cooperate for the solution to be truly intelligent. Therefore, communication between nodes is a key point for this solution to be successful. Typically these distributed and decentralized systems generate many messages and it's important to try to reduce as much as possible the number of these. The solution for this problem is to limit the spread of messages only to the neighboring nodes. We know that in this type of network, there is no point to point communication but a broadcast message. Nevertheless, the creation of a list of target nodes in the messages we're able to simulate this point to point communication with the nodes that are present in this list accepting this message and the other to discard it.

The messages circulating on the network will also have other essential fields to ensure good communication between the nodes. Two of these fields are the node ID where the message originates from the node that sends the message. With this simple update of message fields, we guarantee that these nodes will not perform any actions due to a message initially generated by them. This ensures the correct operation of the system.

Another field, widely used in networks of this kind, is the number of hops in the network message. With the inclusion of this field in the message structure, we ensure that the message will not go indefinitely on the network. Giving to the nodes a parameter which tells them the maximum jumps on the network that a message can do to be accepted and processed, we ensure that all the messages that don't comply with this requirement are discarded and there is no propagation of them.

In the following figure is represented all fields present in the messages transmitted in the wireless network by sensor/actuator node. These messages have a fixed length of 24 bytes because they have to contain all the essential fields for the correct operation of the solution presented. The use of short as data type for these fields is explained by the need to reduce as much as possible the size of messages that traverse the network. The 8 shorts length array is required to indicate the destination of each message. The array length is fixed because a node can only have a maximum of 8 neighboring nodes and the message can be directed to more than one of these so we're forcing to predict the worst case scenario (when the message is directed to all its neighboring nodes).

WsnLogicMessage
+ type: unsigned short
+ originNodeID: unsigned short
+ senderNodeID: unsigned short
+ destinationNodesID: unsigned short[8]
+ hop: unsigned short

Figure 1 - Solution's message structure

Besides these features inherent in the creation of a distributed solution, this solution also had to take into account basic features that a system that deals with people has to offer. The first feature that this solution propose is to implement the creation of a lighting area, allowing the neighboring nodes of the node that detects movement to have its lamps also turn on.

The second desired feature is the ability of the nodes to have their lights always on when they are close to obstacles such as walls, stairs, doors, etc. This will enable the occupant to see, in advance, the obstacles and navigate safely in the space where this solution is implemented.

Finally, the last feature and perhaps the most interesting of this solution, is the ability to predict where the occupant is going and illuminate his path in anticipation. This will allow even more comfort to the occupant, as he is now able to see in advance the way that he are taking

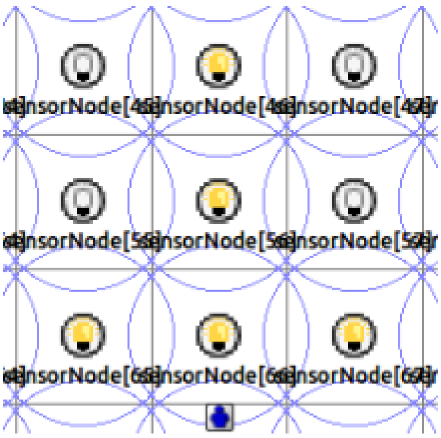


Figure 2 - The two solution's features: lighting area and lighting occupant's direction of movement

4. RESULTS

To prove the concept of this solution, we use the Omnet++[18] simulator. The use of a simulator to test these applications is normal because it is an inexpensive and simple way to test solution and check if it is viable in a real environment.

To obtain results in respect to energy saving, some assumptions have to be made. Although configurable, the light source present in the node has only three operating states: off, medium intensity and high intensity. To calculate the consumption of a node, we assume that the lamp on medium intensity refers to 800 lumens[1] spending 10 watts, while on a high intensity, the lamp reach 1600 lumens and spend 19 watts.[18]

In what concerns the node and its components, we use the example of the imote2 node. This node has a consumption of 0.1 watts when it's waiting to get a message from the network and when it want to transmit to the network[20]. In addition, we opt for a PIR motion sensor (passive infrared sensor) has an approximate consumption 0.005 watts [21] which can be neglected.

In the first simulation we wanted to see how much energy savings, the proposed solution can offer, when compare with a traditional solution where all the space has its lamps turned on. The results are presented in graph 1 (in the annex) and we can see that the savings are substantial. As the reader can see, the difference between the two solutions, begins to be small but, as time progresses, the difference increases and reach to savings near 30%.

Next we wanted to see how the presence of occupants influenced the energy savings. For that we run a simulation with 10 occupants in a space that was 10x10 nodes. As we can see in the graph 2 the energetic consumption of the proposed solution increased with the number of persons present in the simulation field. But we can also notice that as time progresses the savings between the proposed solution and the traditional solution increase what means that exist a saving of electric energy that is larger as time passes.

Finally, we wanted to approach the simulation of what happens in a real environment. For this we include obstacles in our simulation in order to see the influence of these on the energetic consumption of the solution. As expected, the consumption of the solution increases but not as significantly as expected. This is because even though we now have more lamps turn on because the presence of obstacles, we have also less lamps that are

[1] Luminous Flux Metric

turned on because when an individual is detected by a neighboring node is more likely to be an obstacle between these two nodes and the message does not reach the node. Results of this simulation can be seen in graph 3.

5. CONCLUSION

In this paper, we presented a solution to a lighting control system based on wireless network of sensors and actuators.

The main focus of this work was the development of an intelligent algorithm that aggregates different features to be installed on any node in the network, thus the solution could be distributed and decentralized.

Reviewing the results obtained in the simulations, we conclude that the objectives have been achieved. They confirm that this solution can significantly reduce the energy consumption of a lighting system installed in a large area with no natural light when compared to a traditional solution. Moreover, we note that in more real environment (simulation with obstacles), the solution behaves exemplary, achieving energy reductions that increase in percentage as time progresses when compared to a traditional solution.

6. REFERENCES

[1] European Commission. Retrieved 2016-04-25. https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive

[2] C. DiLouie, Advanced Lighting Controls: Energy Savings, Productivity, Technology and Applications, 1st ed. Fairmont Press, 2005.

[3] G. R. Newsham and J. A. Veitch, ”Individual Control over Office Lighting:Perceptions, Choices and Energy Savings,” in Construction Technology Updates, 1998

[4] A. D. Galasiu, G. R. Newsham, C. Suvagau, D. M. Sander ”Energy saving lighting control systems for open-plan offices: a field study” 2007

[5] D. Teasdale, F. Rubinstein, D. S. Watson, and S. Purdy, ”Adapting Wireless Technology to Lighting Control and Environmental Sensing” July 2006

[6] XPoint Wireless Sales Brochure. Retrieve 01-04-2016 http://www.acuitybrands.com/-/media/CF3E3DDB5E854A97BA98A92817284C92.pdf

[7] F. O'Reilly and J. Buckley, "Use of Wireless Sensor Networks for Fluorescent Lighting Control with Daylight Substitution," in Proceedings of the Workshop on Real-World Wireless Sensor Networks, Stockholm, Sweden, 2005

[8] Digital Addressable Lighting Interface, Retrieve 01-04-2016 http://www.dali-ag.org

[9] J. Granderson, "Human-Centered Sensor-Based Bayesian Control: Increased Energy Eficiency and User Satisfaction in Commercial Lighting," PhD Dissertation, University of California, Berkeley, 2007

[10] S. F. Li, "Wireless Sensor Actuator Network for Lighting Monitoring and Control Application," in Proceedings of the IEEE Consumer Communications and Networking Conference, Las Vegas, Nevada, 2006

[11] V. Singhvi, A. Krause, C. Guestrin, James H. Garrett, Jr., and H. S. Matthews, "Intelligent light control using sensor networks" in Proceedings of the 3rd international conference on Embedded networked sensor systems, San Diego, California, USA, 2005

[12] J. S. Sandhu, Wireless Sensor Networks for Commercial Lighting Control: Decision
Making with Multi-agent Systems AAAI Wopp., 2004

[13] Y. Wen and A. M. Agogino, Wireless networked lighting systems for optimizing energy savings and user satisfaction in 2008 IEEE Wireless Hive Networks Conference, 2008

[14] M. Pan, L. Yeh, Y. Chen, Y. Lin, and Y. Tseng, A WSN-Based Intelligent Light Control System Considering User Activities and Profiles, Sensors Journal, IEEE vol. 8, no. 10, pp. 1710-1721, 2008

[15] M. Miki, T. Hiroyasu, and K. Imazato, Proposal for an intelligent lighting system, and verication of control method efectiveness, in Cybernetics and Intelligent Systems, 2004 IEEE Conference on, vol. 1,, 2004

[16] F. Kaku et al., Construction of Intelligent Lighting System Providing Desired Illuminance Distributions in Actual Once Environment, in Artificial Intelligence and
Soft Computing, Berlin / Heidelberg, 2010

[17] H. Park, J. Burke, and M. Srivastava, Design and Implementation of a Wireless Sensor Network for Intelligent Light Control in Information Processing in Sensor Networks, 2007.

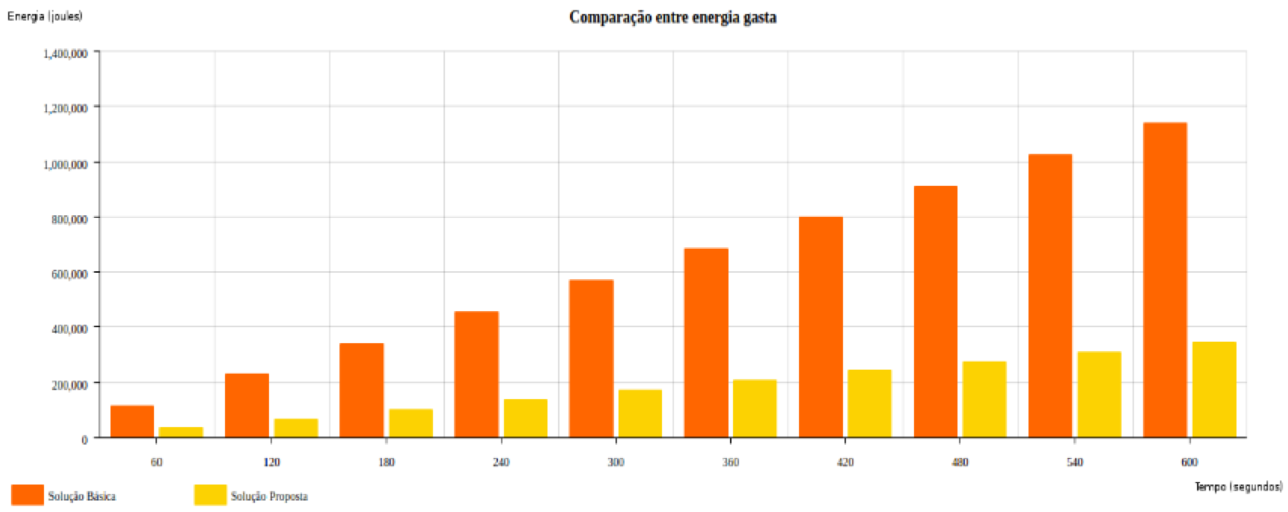
[18] Omnet++ Website. Retrieved 2016-04-30. https://omnetpp.org/

[19] Off Grid World. Retrieved 2016-04-30. https://www.offgridworld.com/the-future-of-lighting-save-money-energy-with-led-bulbs/

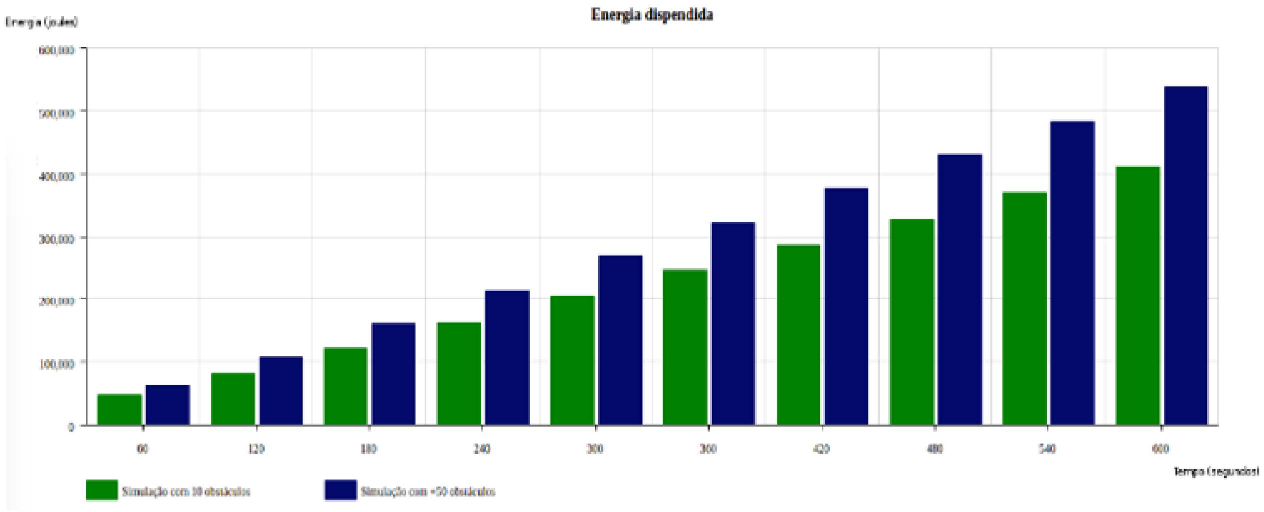
[20] iMote2 Specs. Retrieved 2016-04-30. http://wsn.cse.wustl.edu/images/e/e3/Imote2_Datasheet.pdf

[21] PIR Motion Sensor Specs. Retrieved 2016-04-30. https://www.sparkfun.com/products/13285

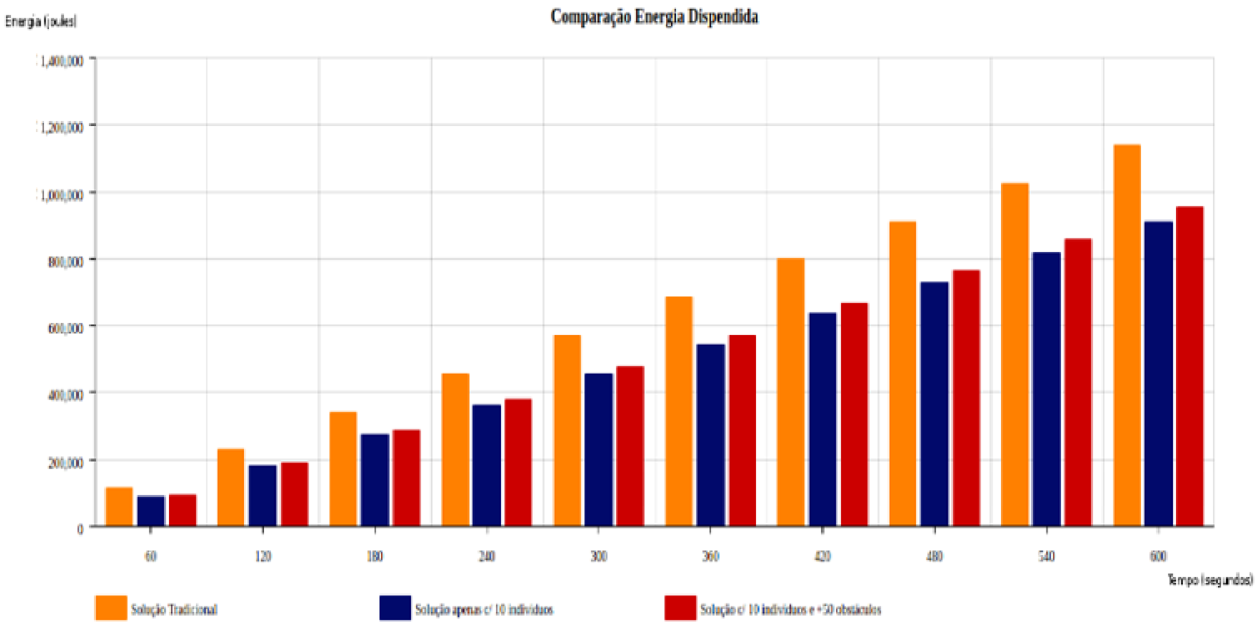
7. ANNEX



Graph 1 - Energy consumption of traditional solution vs proposed solution



Graph 2 - Energy consumption of proposed solution w/ 1 occupant VS proposed Solution w/ 10 occupants



Graph 3 - Energy consumption of tradional solution vs proposed Solution w/ 10 occupant vs proposed solution w/ 10 occupant and +50 obstacles