

# A Maker-Community-Friendly Implementation of a Smart and Green Office Environment: Lessons Learned

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**Abstract:** To support economic growth, it is generally agreed that the supply of electrical energy has to meet, or exceed, the demand for electrical energy. Assuming the above statement holds true, at least two options exist when one considers how the supply side can be matched to the demand side as far as electrical energy is concerned. One option is, albeit at the detriment of economic growth, to maintain the existing supply-side capacity in the provision of electrical energy. The second option is to reduce the demand-side need for electrical energy. Our research aim is to support efforts in reducing demand-side electrical energy needs. Minimising electrical energy needs in the office environment, whilst maintaining a comfortable working environment for the occupants, is a problem currently receiving significant attention. The Internet of Things is one technological approach that holds the promise of assisting engineers and architects in moving closer to a solution to this problem. In this paper we report on lessons learned as we instrumented an office that forms part of an Internet of Things research project that aims to reduce demand-side electrical energy consumption.

**Keywords:** Internet of Things, design science research, maker community, smart and green.

## 1. Introduction

The provision of sufficient electrical energy to meet the growing demand has become a limiting factor in economies. In an attempt to address the problem of mismatched supply and demand, significant research is being conducted worldwide in the development of so-called smart and green environments. Smart and green environments aim to alleviate the imbalance in electrical energy by providing a technology-based mechanism by which the demand for electrical energy may be reduced. An alternative approach to address the problem is through sociological mechanisms, but these will not be discussed here.

Smart and green environments refer to human habitable environments in which energy is conserved through the application of “intelligent” technologies. Here, intelligence refers to algorithms that execute as software processes on computers.

The research reported on here forms part of a larger research project which includes the development of middleware and applications that will derive their inputs from the technologies discussed. Inputs received will be processed and the results will determine what actuation instructions are to be sent to the technologies discussed here.

We acknowledge that the so-called maker community can contribute to the realisation of smart and green office environments, and it is in keeping this contribution in mind that we developed a sensing and actuation technology platform that integrates with our middleware.

This paper is structured as follows: section 2 discusses our research objectives, while section 3 provides an extensive motivation and overview of the Design Science Research

methodology we followed. In section 4 we discuss the technology we developed and how we overcame certain limitations in the sensors. Section 5 elaborates on our results, reiterating the importance of some of our design decisions in order to support the maker community. Section 6 discusses the potential benefit that the involvement of the maker community can have on businesses. Section 7 concludes.

## 2. Objectives

Our research objectives were twofold. First, we were interested to determine whether commercial off-the-shelf technology can be successfully combined to serve as a sensing and actuation platform in a smart and green office environment. Second, we wanted to determine whether low cost (as compared to more expensive professional options) ambient temperature and electrical current sensors can successfully be incorporated in a closed loop smart and green office environment.

## 3. Methodology

With this being a research project, it is worth considering the characteristics of what Cross[1] calls ‘good research’.

According to Cross, the problem being researched should be worthwhile to investigate and to report on (Cross calls these characteristics “purposive” and “communicable” respectively). Our research is worthwhile as it addresses the problem of limited electrical energy provision in an economy that relies on the continued, and increasing, supply of electrical energy. In contrast to classified projects such as those conducted for military purposes, this research is conducted with the interest of the general population in mind and with the basic assumption that making research results publically available will only serve to encourage further research by other entities, hopefully improving the current research and thereby bringing us closer to a viable solution to the problem of the increasing supply-demand disparity.

Another indicator of good research identified by Cross is that the purpose of the research is to gain new knowledge (that is, the research should be “inquisitive”). Our research breaks new ground in that it integrates new technological developments (with these being low-cost embedded systems and the concept called the Internet of Things) with existing infrastructure (this being the internet).

Yet another characteristic of good research (according to Cross) is that it is “informed”, that is, prior research that is related to the current research should be considered whilst the research is being conducted. In this research, we make use of previously published research results to guide our sensor and actuator designs.

Finally, Cross states that good research is methodical, that is, the research is conducted according to a plan. A project plan which incorporates start, ending, and various milestones (including testing) dates guided the successful completion of the project. Our funding source limited our choices in selecting the start date and end date for the study because funding is usually available for one financial year (commencing in March in the current year till February the following year). The various milestones had to be completed within this 12 month timeframe.

The research methodology we followed in this study (described later) allowed us to adapt the time and scope of the milestones according to our achievements, thereby contributing to the successful completion of the research study.

When conducting research, a researcher chooses from a variety of research paradigms , with the chosen paradigm implying the philosophy and assumptions that the researchers make. De Villiers [4] states that the philosophical stance of the researcher and assumptions the researcher makes often influence the approach and the methodology which the

researcher applies when conducting the research. De Villier's statement is supported by those of Burrell and Morgan [2] who put it that research results and the interpretation of the results can influence the results of the study because of the individualised views of the researchers.

Regarding the ontological nature of reality, in conducting this research, the researchers held a realism view of reality. This view of reality argues that the researcher is separate from the research and that the structures that are being researched are "discovered" by the researchers [3].

Regarding the epistemological assumption made during this study, the researchers took a positivist standpoint which assumes that the results produced are unbiased. This standpoint is in contrast to the views held by those following the interpretivistic epistemological standpoint which assumes that the results are mediated by the researchers and can therefore not be reproduced by other scientists [4].

In addition to the philosophical stance of the researcher and assumptions the researcher makes, De Villiers [4] also states that the research is guided and operationalised by the research approach (the research approach is sometimes also referred to as the research model). For this research study, the Design Science research methodology was chosen, and for the reasons as stated next.

Simon [5] states that the aim of design is to produce something in the future, with the design (composition) of music and the design of water containment dams being examples. These are examples of what is also referred to as state-of-the-art design [6] and routine design [7]. However, our research study considered the design of a smart and green office environment which is enabled by newly developed technologies (low cost embedded systems and the Internet of Things). The existing knowledge base that guides the implementation of a smart and green office environment (which includes low cost embedded systems and the Internet of Things) is limited when compared to the knowledge base that guides state-of-the-art designs and routine designs. A research methodology that makes explicit provision for limitations in the supporting knowledge base is the Design Science Research Methodology. Vaishnavi and Kuechler [8] use the terminology "exploring by building", whereas Jarvinen [9] uses the terminology "improvement research", both of which can loosely be equated to Design Science Research. Multiple Design Science Research process models exist, and we chose to use the process model developed by Vaishnavi and Kuechler. The Design Science Research process as developed by Vaishnavi is illustrated in Figure 1.

The first step in the execution of this study was the awareness of the problem. This problem was stated in the introduction section of this paper. To recap, the problem to be addressed is the imbalance between the supply of electrical energy and the demand for electrical energy. The output of this step was a proposal to gain first-hand research results by means of the implementation of a smart and green office environment that is geared towards relieving the problem.

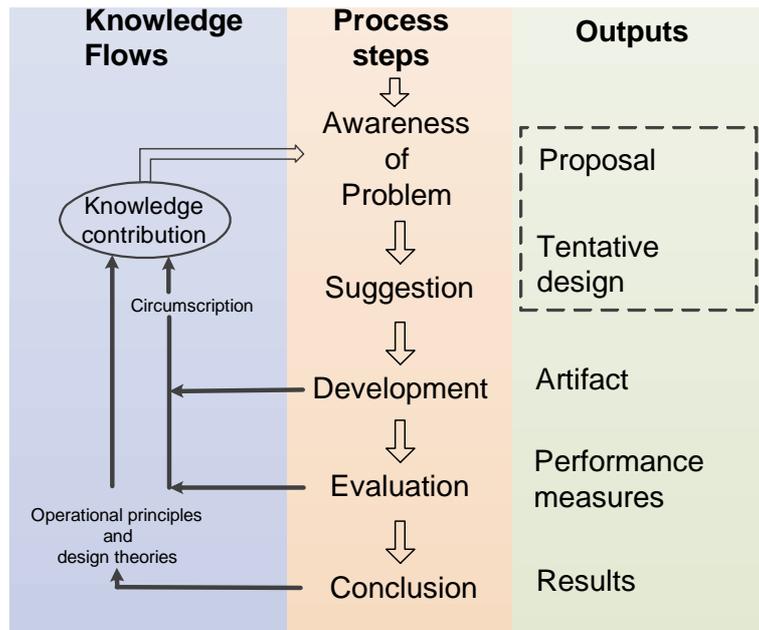


Figure 1: The Design Science Research Process Used in this Research Study

The second step in the execution of the research study was to consider the modalities that would be suitable for a smart and green office environment. The second step is referred to as the “suggestion step” in Vaishnavi and Kuechler’s Design Science Research process as illustrated in Figure 1. The output of this suggestion step was a tentative design. Here, the modalities of concern are switching and sensing. To inform our decision regarding the modalities to implement in this study, we considered existing publications, both in the academic domain and the hobbyist domain.

The hobbyist domain was considered because we anticipate that the long term success of smart and green environments will in part rely on the uptake of the maker movement [10] (in a nutshell, the maker movement is a term that describes individuals that collaborate on a project to the benefit of society and without direct financial compensation).

The third step in the execution of the research study was to develop an initial design of a system. This initial design, as well as a subsequent design, is described in section 4.

The fourth step in the execution of the research study concerned the evaluation of the initial design to determine the extent to which the design supports the requirements of a smart and green office environment. The subsequent design was also evaluated. The evaluation results for the two design iterations are discussed in section 5.

#### 4. Technology Description

Following the Design Science Research methodology, and specifically the process as depicted in Figure 1, we concluded two design iterations. The first design iteration was the most challenging as it incorporates a significant number of previously untested (by us) concepts and technologies. Although the second design iteration also involves previously untested (again, by ourselves) concepts and technologies, our learning from the first design iteration proved to be of significant value. Both design iterations incorporate a combination of an Arduino Uno [11] and a Raspberry Pi [12]. The following paragraphs describe the two design iterations.

The first design iteration implements various sensing modalities and one actuation modality. The office air temperature, the state of the office door, the state of an office window, and the presence of a person are sensed. Actuation includes turning the air conditioner on or off, and increasing or decreasing the temperature of the air emitted by the

air conditioner into the office. Sensing the state of the office door, the office window, and the presence of a person within the office is simple: By wiring three sensors that each sends one of two signals levels to an Arduino Uno circuit, we can independently detect whether the office door is open, the office window is open, and whether a person is present. However, sensing the office temperature is not as simple as the other three sensing modalities described here, and for reasons described later.

Since one of our objectives is to engage the maker community in the development of smart and green office environments, we set the objective of incorporating low cost sensors wherever possible. Two sensors for determining room temperature were considered in the design, and these are a low cost analogue temperature sensor, and a more costly digital sensor. Although the analogue temperature sensor is more affordable and therefore probably better suited to the maker community, this sensor requires calibration which the digital variety of sensors does not require. Nevertheless, we implemented both the first and second design iterations using the lower costing analogue temperature sensor, with the accompanying calibration which we describe next.

The physical properties of the analogue temperature sensor are such that the electrical resistance of the sensor varies uniformly (but not linearly) as the ambient temperature varies. In order to map the sensor readings to the ambient temperature, we connected the sensor in a voltage divider configuration in which the 5 Volt supply from the Arduino Uno circuit is divided across the temperature sensor and used as input to the analogue sensing pin of the Arduino Uno. We then proceeded to manually adjust the ambient temperature between 16 degrees Celsius and 26 degrees Celsius. An alcohol thermometer provided sufficiently accurate ambient temperature readings which we correlated with the readings obtained from our software executing on the Arduino Uno. We deem this calibration mechanism to be sufficiently accurate for the purpose of this research project.

Actuation of the air conditioner inside the office is accomplished by means of a two-step procedure. First, we “eavesdropped” the codes sent to the air conditioner when a person operated the accompanying handheld remote controller. From these codes we were able to successfully isolate the “turn on” and the “turn off” sequences. Second, we embedded these two sequences in the software that executed on the Arduino Uno and wired an infrared light emitting diode to lead from the Arduino Uno to a position close to the infrared detector of the air conditioner. Using this arrangement, the air conditioner can be turned on or off, and the temperature increased or decreased, under software control.

The second design iteration added a sensing modality that enables our system to determine the amount of electrical current consumed by the air conditioner. To this end, we added a current coil in line with the “live” wire that powers the air conditioner. A resistor of low Ohmic value is installed in parallel to the coil resulting in a measureable voltage across the coil. This voltage is in direct proportion to the current flowing in the conductor being monitored. As this measuring circuit can only deal with voltages between 0V and 5V DC, we implemented precautionary measures.

First, we ensured that the voltage produced by the measurement circuit (being the combination of the current coil and the parallel resistor) does not exceed the 5V amplitude restriction of the measuring circuit. We heuristically determined, with the aid of a voltmeter (and simultaneously setting the air conditioner to its maximum airflow output level), that the output of the measurement circuit would not exceed the capabilities of the measuring circuit.

Second, we implemented a half wave rectifier to ensure that the measuring circuit is not exposed to negative voltage levels. Here, the half wave rectifier consists of a single 1 Ampere, 500 Volt silicon diode placed in series with one of the two wires that connect the current transformer to the measuring circuit.

As is the case for the first design iteration, we heuristically determined what the mapping is between the actual current flow and the values as detected by our measuring circuit. This we did by comparing the maximum measured value to the maximum current as indicated on the manufacturer's specification plate attached to the air conditioner. Ignoring the power factor of the air conditioner (the power factor is a technical term that describes the phase relationship between the voltage and the current that flows), we calculated the consumed electrical power to be the scalar product of the measured current and the applied voltage (which we assumed to be 220 Volt). Although our "calibration" method for mapping the measurements to power consumed is crude, we deem it sufficient for the purpose of this research project.

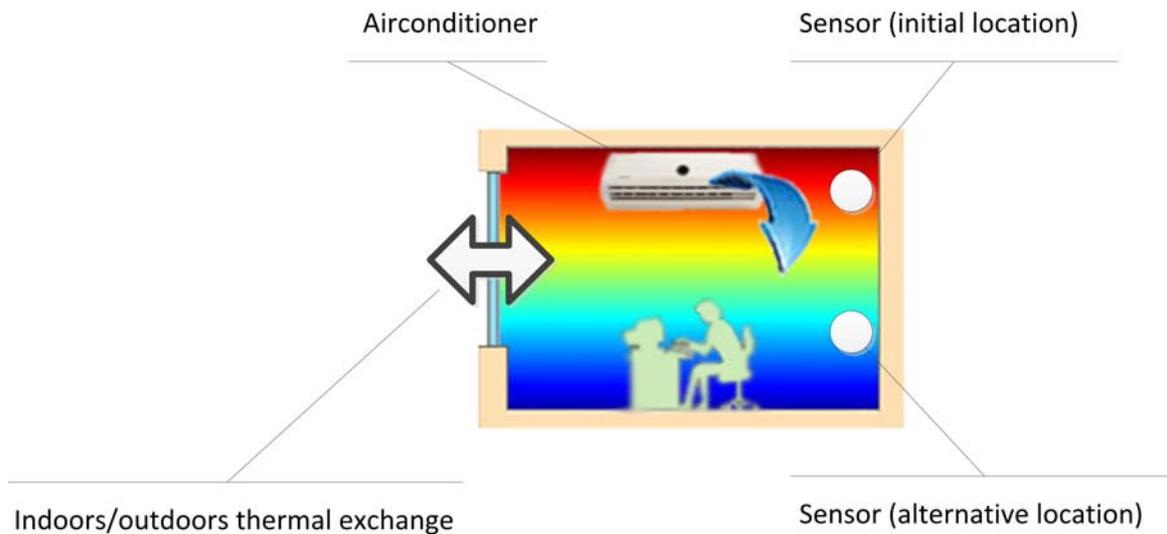
## 5. Results

Our research objective was to determine the viability of incorporating off-the-shelf technology in the design and implementation of a smart and green office environment. The two design iterations confirmed the following: First, it is feasible to combine an Arduino Uno with a Raspberry Pi in the creation of a functional and usable sensing and actuation platform. Second, low cost, non-calibrated sensors can successfully be used for sensing ambient temperature and electrical current consumption in a closed loop system with the proviso that an initial sensor calibration exercise be conducted.

The most significant problem experienced involved the closed-loop control of the room temperature. Here, the problem is due to the dynamic properties of chilled air, as explained next. The room temperature sensor was initially placed at the same height as the wall-mounted split-unit air conditioner, being approximately two meters above floor level. As designed, our closed-loop system monitors the air temperature inside the room. If the measured temperature is above a set threshold, a command is sent to the air-conditioner to increase the flow of cold air. However, we noticed that the measured temperature never reached the target temperature even though we could sense with our bodies that the temperature had plummeted below the target temperature. Analysis of the situation suggested that the air temperature at human body level had indeed crossed the set threshold and that the problem lay with the positioning of the temperature sensor together with the cooling capacity of the air-conditioner.

In an office environment, the capacity of an air conditioner is based on the volume of the room to be chilled or heated, and the assumption is that not all the air needs to be chilled, but only the air which the occupants get into contact with. The result is that air at ground level is cooler than the air at the ceiling. Compounding the situation is that one office wall in our experimental setup mostly comprises windows fitted with single glass panes. It is through these glass panes that heat exchange takes place, placing additional load on the air conditioner in its attempt at lowering the office temperature. Figure 2 illustrates the envisaged temperature variation within the experimental office space. Here, the colour blue indicates cold air and the colour red indicates hot air.

Considering the limited capacity of the air conditioner, the height above floor level at which the desired temperature is required, and the poor thermal isolation of the office as described above, we concluded that the temperature sensor should ideally be positioned at desk height. Repositioning the temperature sensor confirmed our prediction. Figure 2 illustrates the initial and alternative locations of the sensor within the experimental office space.



*Figure 2: The Experimental Setup Showing the Temperature Sensor Position*

## 6. Business Benefits

The primary objective of our research project is to determine how a smart and green office environment can be created in which monitoring and control is done using the Internet of Things. A secondary objective of the research is to determine to what extent the maker community can be empowered to participate in the advancement of smart and green office environments. The research reported on here is therefore aimed at both formal businesses and the informal maker community. It cannot be overstated that businesses will benefit from smart and green office environments due to the monetary saving when the electrical energy consumption is reduced. In addition, and perhaps more important, is that a reduced demand for electrical energy will help maintain reliable electrical energy supply to businesses because it becomes less likely that supply will be interrupted due to either planned or unplanned interruptions of electrical energy as supplied by the local utility.

In our experimental setup, the air conditioner's rate of energy consumption is approximately 5kW. This energy can potentially be saved by switching the air conditioner off when either the window or door has been left open for an extended period, or when no person has been detected in the office for an extended period.

## 7. Conclusions

Our objective was to determine whether it is possible to incorporate commercial off-the-shelf technological components, and at the same time incorporate low cost sensors in a smart and green office environment which is connected and controlled as part of an Internet of Things system. To this end, we successfully instrumented a single office to sense a variety of modalities and also actuate two air condition modalities within this office environment. Sensed data included the temperature within the room, the presence of a person within the room, and the status of the office door, and the status of one office window.

Through two design iterations, we concluded that it is indeed possible to implement a functional smart and green office environment by only using commercially off-the-shelf technologies for sensing and actuation.

Having successfully implemented a smart and green office environment, we next aim to do the same using wireless communication technologies to replace the current wired internet connection.

Finally, the preferred outcome of our research would be a framework that is simple enough to be understood by the maker community, for the framework to be made available at little or no cost, and for the framework to support implementation using readily-available technologies. We hope to publish such a framework in due course.

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