Executive Summary

**Key features:** computer-based control of the heating system of buildings that have still manual control of radiators. The solution optimizes the heating of rooms based on fusion of information regarding users' presence, external weather conditions, weather forecast, and university/user calendars. The goal is to control the room heating automatically and heat only when users are present, thus, optimizing the temperature given the weather exposition and the actual number of occupants present in the room.

**Benefits:** energy savings, economic saving, improved comfort and well-being for students/university personnel.

**Savings:** 15% of energy for heating.

**Target building for implementation:** Heymansgebouw, RuG

**Budget:** 100.000 euro.

**Return on investment in 10 years:** 165.000 euro.

**Payback period:** 6 years.
Project idea in a nutshell

The aim of SESEOS is to control the heating system of individual offices/lecture rooms in order to minimize the waste of energy due to unnecessary heating. The idea is to dynamically adapt the heating system of a room based on the fusion of several information coming from the environment (e.g., room occupancy, outside temperature, weather forecast), the room geometry and basic architectural aspects (e.g., size, number of windows, number of doors, radiator capacity), and coming from the room reservation system of the University of Groningen.

Our solution is first of all based on the ability to control individual heating systems at the room level. For this purpose, we use heating controllers that allow to remotely control the valve of a radiator to which the heating controller is attached with the provided software suite. With minimal software development effort such solution can allow the automatic regulation of the room temperature based on other external factors that can help optimizing the room temperature and energy use. Our project will enable to have a fine-grained control of room and ambient temperature. Our solution will interface with the room schedule application of the University of Groningen therefore knowing exactly when the rooms are free or empty, enabling the cut of unnecessary heating when no lectures are scheduled. In addition, having the information of the room gives a precise idea of the space that needs to be heated, the maximal amount of students expected in the room and the position of the room in a building, therefore having higher or smaller exposition to outside atmospheric conditions. In fact, given the volume of the room we can compute the amount of energy required to rise the temperature of the room and we can also exactly enable the duration of a pre-heating phase before the beginning of a lecture. Our solution does not only take care of eliminating unnecessary heating of unused spaces, but it also take care of the well-being of the users of the room by providing the optimal temperature based on the real-time occupancy of the room. We plan to monitor in real time the amount of persons present in a lecture or meeting, for instance, and adjust the temperature based on the actual occupancy. This will be done with no additional costs, just by fetching the information of the persons connected to the internet hot-spot closest to the room. In this way it is possible to avoid situations of overheating in a crowded room or cold rooms during less populated lectures. Our system also takes into the picture the meteorological conditions in order to optimize the heating given the external conditions of temperature, cloud coverage, wind and humidity. External atmospherical conditions together with position of the room and construction material of the building are essential pieces of information to take into the picture to realize a fine-grained control of the room temperature to save energy and improve the well-being of students and university personnel.

Problem background and motivation section

**Motivation**

We see great potential in reducing the energy use of the buildings of the University of Groningen in terms of heating. As students of the University of Groningen, we have experienced, especially in older buildings of the University, uncomfortable situations of warmth in rooms sometimes overcrowded with students and with full heating on, and other times
uncomfortably cold rooms. We have seen also warm rooms that were empty, both for single offices and classrooms. We therefore came with the idea that some smartness is necessary to improve the situation in terms of energy that is wasted for unnecessary space heating and as a side effect improve the well-being of the occupants of the rooms.

Background and state of the art

Heating Ventilation and Cooling (HVAC) is the biggest source of energy consumption in residential and office environments. Figure 1, for instance, shows the fraction of energy that is used for specific purposes inside an average American house [13]. Heating and cooling amount to more than 50% when combined.

![Figure 1: Average use of energy by activities in US households.](image)

Other studies show that in cold climate regions (e.g., U.K. and Canada) HVAC account to more than 60% of the overall energy consumption [1,2]. In the last years, academic and industrial efforts have been underway in order to improve the efficiency of HVAC solutions to save energy without interfering with the well-being of the inhabitants of the buildings. Smart thermostats, consisting of taking into account user daily patterns, and inhabitants presence sensing have proved to contribute to savings almost 30% of energy [3]. Weather information represents another precious source of information that influences the climate conditions inside a building, therefore adjusting the HVAC having information on the forecast weather is another essential piece of a smart HVAC solution. A study in the USA in the cooling season that took into account inhabitants presence sensing and weather forecast information was able to save on operating cost about 18% [4]. Sensing is an essential part of a smart heating system: understanding the amount of people in a room, understanding patterns of people use of spaces in building can drive the controller of an HVAC system. In this manner an HVAC can become intelligent and flexible to modulate its output given the rooms where it is needed, achieving 30% of savings without compromising comfort [5,10]. The use of real-time information obtained from wireless sensor technology has shown to be able to create models of presence and occupancy of inhabitants and drive the decisions of the working time of the HVAC in order to achieve energy savings of 42% [8].

The more fine-grained the approach in controlling the HVAC is (for instance at single room
level), the more possibilities are available to tune the system to save energy. Detecting presence in buildings with wireless and non invasive technologies has provided good results in the abilities of locally controlling HVAC in order to save energy. Scientific experiments in real environment with this fine-grained approach show savings around 15% [11,12]. Distributed sensing and sensing capabilities fusion is nowadays something achievable also in extensive environments with reliable and affordable technology [6,9]. Some of the authors of this proposal have also practical experience in distributed sensing environment implementation [7].

The team

The team is composed by three colleagues belonging to the Distributed Systems Group of the Computer Science Department. The team is also supported by a member of the Internal Services and Maintenance Department of the University of Groningen. The team has matured in the last years a deep knowledge of smart systems by working on the European Project GreenerBuildings whose focus was the energy savings in office environment; the team has realized a living lab where a distributed sensor network has been built based on Plugwise devices where the power consumption of several office appliances is measured and they are turned on and off in order to minimize the consumption of energy without compromising the well-being of the office personnel [7]. In addition, two member of the team have successfully participated in the first edition of the Green Mind Award winning the first prize and are now successfully implementing the proposed project solution in practice. The team therefore has also the experience and competence of realizing such type of project. Moreover, the team has started to implement a proof of concept software solution to control a radiator based on the external weather conditions, occupancy schedule constraints, and interaction with sensors to set temperature setpoints of the room. The proof of concepts is part of the team current research interests on the topic of smart solutions for reducing energy consumption in buildings. A more thorough description of the realized proof of concept is presented next.

Proof of concept

The realized proof of concept shows how heating can be controlled to adapt to user count, external weather conditions and take advantage of information about people’s agendas. The proof of concept realized aims at controlling the unnecessary waste energy in the heating system in order to adapt the use of heating in a building to the external temperature conditions and with the schedule of working hours. In other words, in a warm day the heating system can be turned off (in the morning or afternoon, when the outside temperature reaches a predetermined high value), or turned on later when it is necessary (e.g., in late afternoon when outside temperature decreases), and shut down when no lectures are scheduled in a room. The logic of the proof of concept realized is represented in Figure 2.

1 The proof of concept was done as a part of the internship of Tuan Luu, refer to http://www.cs.rug.nl/~faris/students/TuanLuu_report.pdf for more information.
The solution we have realized as a proof of concept for the automated heating control is divided into 3 main components: input data collector, central manager, and actuator on the HVAC. The input data collector will be responsible for collecting data from the sensors (temperature sensor and movement sensor which are placed inside the room) and other sources (weather forecast and agendas). The central manager, which contains all the logic code of the application, is responsible for performing the computation and it also acts as a data reporter to users. The last component (actuator) contains the commands to interact with the HVAC system. The information on the rooms contains the longitude and latitude, size, heater capacity, ventilatory capacity, and insulation values. All these data are needed when applying physical formulas to calculate the heat transfer of the room. The central manager will estimate the schedule to turn on the heating system for each room. In the current state, the actuator component periodically connects to the central manager to get the updated schedule.
The implementation of the proof of concept has been realized in a small garden shed, shown in Figure 3, where the equipment for the simulation has been placed consisting of a temperature sensor, a PC with the running software solution connected to the internet and an electrical heater controlled by a plugwise device (see red ovals in Figure 4). A plugwise device is a plug that has the ability to measure the consumption of electricity used by the appliance it is connected to and to share the values wirelessly. The plugwise device acts also as a switch, turning on and off the attached device through issuing commands via a computer with appropriate software and communication devices; that is the way the heater is controlled. In addition to the feasibility of the solution that we have tested in the experiment, an interesting result was achieved: the system optimally heats the room and the duration time of the pre-heating phase (thus the energy used) closely depends on the outside sensed temperature. Our goal was to have a temperature of 10 °C at 14.00 during the week of test. Table 1 shows that our solution is pretty accurate of achieving the predefined set-point temperature of 10 °C and that the heating system starts his operations taking into account the starting temperature perceived by the sensors.

Figure 3: Location and characteristics of the test.
Practical implementation

After surveying several potential building of the University of Groningen and after consulting with our implementation partner of the Internal Services and Maintenance Department of the University of Groningen, we identified as the candidate for the implementation of the SENSEOS project the Heymansgebouw. This building hosts the Faculty of Behavioural and Social Sciences. The building is located in Grote Kruisstraat 2/1 in Groningen; a picture of the building is represented in Figure 5. The choice of this building lies on several reasons. First of all, the heating and lighting systems are fully manual, this aspect gives a substantial possibility for improvement and savings by implementing non intrusive automation of these systems [14]; of course SENSEOS will focus only on the heating part of the system. In a manual system, users are fully in charge of dealing with the system and they have to modulate the heating system and the effort of turning it on and off. The manual system in use in the offices at the
Heymansgebouw is represented in Figures 6 and 7. In a busy and vibrant working environment such as the university, users should not be bothered by dealing with the manual management of their energy systems. A second reason to chose the Heymansgebouw is the modularity of the building that hosts several almost identical rooms (about 35 office rooms per floor) in each of the 5 floors composing the building. Such a modularity of the building allows us to test a solution initially in few offices and, once fully functional, easily extend it to the whole building. In addition, the building hosts a library (Figure 8) which is a perfect candidate to test the features of SENSEOS that take into account users presence and work schedules.

Looking at the building from an financial perspective, the Heymansgebouw is an interesting case since we can save substantially on heating. Our partner of the Internal Services and Maintenance Department of the University of Groningen provided us with the information of this building concerning the amount of energy used for heating. The heating system is fueled by gas and annually it consumes about 205,000 m³ to heat the whole 8,000 m² building. This consumption leads to an energy bill of about 111,000 euros per year.
General Architecture and Desired Functionalities

The idea is to control the heating system of individual offices/lecture room in order to minimize the waste of energy due to unnecessary heating. We will dynamically adapt the heating system of a room based on the fusion of several information coming from the environment and coming from the room reservation system of the University of Groningen. The following functionalities are desired:

1. **Room level occupancy prediction**: The system provides precise and accurate information about the room occupancy both in real-time manner as well as the occupancy prediction, such as the time users usually come to their room every working
day, or the time they usually go out for lunch and come back after that.

2. **Weather forecast and outside conditions**: The weather forecast information is taken into account as an input for our control solution. Also, outside conditions such as temperature, wind speed is considered.

3. **Room level environmental conditions**: The condition inside every occupancy area is very important to regulate the heating/cooling system inside each room. Our system monitors not only inside temperature, CO₂ but also the room's size, room's material as well as specific condition of each room. In this way the control strategy will be customized for each room individually.

4. **GUI for user interaction**: Our solution should also be able to provide a friendly graphical-user- interface (GUI) to the users in order to receive their direct goals and desires. Thus, the control strategy will be better customized to each user inside each room.

5. **Room level heating elements control**: All in all, our solution will be able to control individual heating system inside each room. The control strategy is customized in order to best fit the user's desires, occupancy patterns, room conditions, outside conditions, weather conditions. Therefore, the energy spent for the heating system will be minimized while the user comfort and productivity will be preserved.

In order to do so, our system should have an input as rich as possible. With this rich input, our solution will be able to optimally control the heating system at room level. A general architecture is depicted in Figure 6, in which:

1. The occupancy prediction component uses the following inputs
   1. Building/room/user calendar
   2. The activity of user’s workstation
   3. Sensor for presence detection (passive-infrared or Wi-Fi based using user’s mobile devices)
2. The room condition such as material, size, etc. will be provided as room parameters in advance.
3. The indoor environment is monitored by using ambient sensors (CO₂, temperature, etc.)
4. The outdoor condition is monitored by using not only ambient sensors, but also by using weather forecast services
5. The user goals and desires can be received through direct interactions with mobile web-based application.
6. The smart valve for radiators provides ability to control heating systems at room level.
Budget, Planning and Return on investment

Project Plan
The plan of the project is presented in Table 2. We envision nine main tasks to be realized in a year. The three key activities of the project are the development of the software solution and the related test in an experimental environment. The third key task is to set to professional scale the robustness of the software developed to sustain real world conditions. We also allot some time for the expansion of the solution to more complex environments and test and dissemination of the solution with facility managers involved.

<table>
<thead>
<tr>
<th>Project Plan</th>
<th>2014</th>
<th>2015</th>
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<tbody>
<tr>
<td>Activity</td>
<td>Nov</td>
<td>Dec</td>
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<tr>
<td>Project kick-off meeting</td>
<td></td>
<td></td>
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<tr>
<td>Ordering sensors and actuators</td>
<td></td>
<td></td>
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<tr>
<td>Testing sensors and actuators</td>
<td></td>
<td></td>
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<tr>
<td>Developing supporting software</td>
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</tbody>
</table>
**Budget**

The budget of SENSEOS is compliant to the budget requirement for the Green Mind Award competition (i.e., 100,000 euro). We allocate about 40% of the budget to the expenses related to sensors and actuators. This amount allows us to equip each of the 170 office rooms of the Heymans building with a control and actuation kit (estimation based on the Kieback&Peter radiator valve controller). The development of the software account for 20% of the budget; we will make use of temporary programmers to develop the modules of the architecture that are missing since the SENSEOS team can reuse software modules developed in the context of other projects and pilots solution realized at the Distributed System group. The supporting activities of project management for the correct implementation of SENSEOS and the deployment activities of installing the equipment on the field both account for less than 40,000 euro combined. The numbers are also reported in Table 3.

<table>
<thead>
<tr>
<th>Item</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project management</td>
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<tr>
<td>Sensors and actuators</td>
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</tr>
<tr>
<td>Software development</td>
<td>€ 20,000</td>
</tr>
<tr>
<td>Deployment of sensors and actuators</td>
<td>€ 10,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>€ 100,000</strong></td>
</tr>
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*Table 3: SENSEOS budget*

*Payback Period and Return on Investment*
We assume a prudential approach in the savings that we can obtain with SENSEO. We basically consider a potential saving in the energy used for heating the Heymans building of 15%; this amount can be basically considered a lower bound of the savings mentioned in the literature (see Section Problem background and motivation section). Such a prudential approach, however, enables to achieve the target of the Green Mind Award of returning on the invested amount within 10 years. Each year of savings of the Heymans buildings amounts for 16,500 euro. Table 4 represents a simplified (e.g., no discount rate of the invested capital) return on investment solution which shows that the payback period is achieved after little more than 6 years. In the total project time of 10 years allowed by the Green Mind Award rules, SENSEOS will allow a saving to the University of Groningen of 165,000 euro. In addition to this monetary saving, there are other very important improvements that SENSEOS will bring to the University of Groningen and its workforce. The increase in comfort of a heating solution that automatically adapts to the user and its calendar, that avoid overheating in the common crowded areas, overall a solution that enables the achievement of a better well-being at work. An increase in well-being in the workplace promotes a better productivity at work as showed in [15]. Thus the SENSEOS project is a win-win solution for the University of Groningen that will see improvement in the balance sheet by having less heating costs and more productive personnel, and a better public relation image by reducing its energy footprint.

<table>
<thead>
<tr>
<th>Time</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
<th>Year 10</th>
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<tbody>
<tr>
<td>Savings</td>
<td>€16,500</td>
<td>€33,000</td>
<td>€49,500</td>
<td>€66,000</td>
<td>€82,500</td>
<td>€99,000</td>
<td>€115,500</td>
<td>€132,000</td>
<td>€148,500</td>
<td>€165,000</td>
</tr>
</tbody>
</table>

Table 4: Yearly savings of the SENSEOS solution at Heymansgebouw.

**SENSEO Extensibility at University of Groningen**

At the University of Groningen there are many other candidate buildings that could reduce their energy consumption given the current manual operation of radiators. For example, the SENSEOS solution can be easily extended to several buildings such as the Harmoniegebouw in the city center or the Duisenberggebouw in the Zernike complex. These could be other projects to be evaluated after the experience of SENSEOS at the Heymansgebouw.

**Acknowledgment**

The SENSEOS team would like to thank Kor Smit Energiemanager Energie-en Watermanagement Facilitair Bedrijf RUG and Marko Milovanovic PhD student at Department Social Psychology, Environmental Psychology Faculty of Behavioural and Social Sciences RUG occupant of Heymans Building for the precious information sharing over the buildings.
References