# AMERICAN UNIVERSITY OF BEIRUT

# Project 89 - Spring Semester: Schedule-Based Automatic HVAC System Control

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# Executive Summary

This paper presents the details of the installation of an intelligent HVAC system that is controlled based on room reservation schedule in the buildings of a typical university campus in Lebanon, which we chose to be the Bechtel building in the American University of Beirut. The paper also includes the huge savings that this system will impose on the university due to a significantly lower electricity bill.
The electrical load demand in this university has been increasing lately due to the surge in the number of students as well as the increase in the average yearly temperature in Lebanon due to climate change. This in turn will force HVAC systems to work more than usual to maintain the desired temperature and thus consume more energy. One thing to note is that the majority of the electrical energy consumption in this university is for air-conditioning and lighting purposes. The installed building management system (BMS) called EnteliWEB remotely sets the desired temperature (usually 22 C° or 23 C°) by controlling the components in the installed chillers such as fan speed, chiller water temperature, etc.
Our aim is to continuously monitor the electrical load demand of the air handling units (AHUs) and room lightening and reduce the load demand by automatically controlling the appropriate settings of the AHUs depending on the daily schedule of each room in the building independently. This is achieved through building a smart API that is capable of analyzing the schedule provided by a scheduling software called Infosilem and sending appropriate commands to EnteliWEB for the AHUs to act accordingly. The preliminary investigation has shown that the load demand can be significantly reduced by the implementation of this API with a promising 7 figure savings on the university per year.
If Lebanese universities applied this to their campuses, not only will they save significant amounts of money, but they'll also help in reducing the oil crisis that Lebanon is currently facing with the skyrocketing prices of diesel used to power almost all electrical generators. The paper also highlights the potential to add countless building blocks on top of this basic API such as smart weather prediction to determine the best-desired temperature based on multiple climate parameters.

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# Introduction

## 1.1 Project Needs and Motivation

Lebanon is one of the top countries in the world suffering from hyperinflation and deep recession. In tune with this recession, the need for energy savings has a huge demand in the current local market. One of the leading concerns of energy-saving proposals revolves around heating, ventilation, and air conditioning (HVAC) systems. HVAC systems are an essential component in the building and maintenance of any institution. Although its presence and functionality are taken well care of in most cases, the cost of keeping them running at all times when there is no need to is often overlooked. With the current financial crisis that Lebanon is going through, the American University of Beirut is in desperate need now more than ever to minimize wasted costs and improve their spending efficiency in the hopes of providing more opportunities to students to pursue their diplomas with the help of increasing their financial aid. It is estimated that roughly 55% of energy consumption in a typical university is related to HVAC systems. Moreover, diesel prices have been increasing by roughly 30% in the past 3 months. This trend is most likely to continue in the upcoming future due to OPEC organization increasing its oil prices worldwide in congruence with the current Russian-Ukrainian war that has majorly affected the oil markets for Russia being the second biggest exporter of oil in the world. In addition to the economical and financial crisis in Lebanon, the average income of a household has majorly declined after the banks locked all the citizen's money and forcefully changed all accounts from Dollar to "Lollar" (aka the Lebanese bank dollar value). This has rendered Lebanese class families incapable of keeping their children in private universities for their lack of sufficient funds. Consequently, AUB has been searching through various proposals to help minimize its operational costs in the hopes of providing as much financial aid to students as possible. In this situation, proper usage of scarce oil and gas resources is critical for restoring the country's financial stability. The initial action that can generate a quick response is the deployment of demand-side management and energy conservation measures, which can reduce system losses and waste of electric energy consumption. This can also serve as a cushion for future energy diversification and other long-term objectives. This paper presents the results of the preliminary investigations of demand-side management through the implementation of a smart API that connects the energy management system to scheduling software in one of the buildings on the campus of the American University of Beirut.

Energy efficiency is a crucial concern for campus buildings since it is linked to student comfort and indoor air quality. AUB now enrolls 6,511 students. Electric use is always on the rise during the summer months. As a result, the university spends a considerable amount annually on electricity consumption. Hence it is imperative that AUB implements energy management policies to promote energy conservation on campus. Building an API on top of the existent web-based energy management and control system and scheduling program is built as a starter demo for a reduction in load demand of Bechtel building, and this paper explains the system specifications and the pilot study performed in this building. The paper also discusses the future trend in the implementation of smart API interconnection between BMS and schedule programs in universities, where demand response can be effectively used in the university by having a campus area network that takes advantage of recent developments in information and communication technologies.

The world and Lebanon, now, more than ever need to cut and reduce their energy consumption due to the scarcity of energy sources and the continuously increasing prices. So our project will focus on achieving full utilization of available and already installed Building Management System technologies in order to help the American University of Beirut cut its energy expenses, and use the savings to create more opportunities for students in need of financial support.

## 1.2 Requirements Specifications

- The system should update the command sent to the BMS every 5 minutes.
- The system should ensure the satisfaction and comfort of the building occupants.
- The system should help in maintaining optimum indoor air quality and thermal comfort.
- The system should help reduce energy and manpower cost by automating the state of the HVAC system.
- The system will be operational 24 hours a day, 365 days a year.

- The system should receive an XML file from the Infosilem software containing the current room schedule.
- The system needs admin credentials to communicate and get data from Infosilem and send requests to EnteliWeb.

## 1.3 Deliverables

Our product consists of an application that connects two independent software, and analyzes the collected data and information from "Infosilem", to then send requests to "EnteliWeb" to regulate the temperature according to the weather and the room schedule of Bechtel Building.

## 1.4 Related Work

## 1.5 Lighting Control and Monitoring for Energy Efficiency: A Case Study Focused on the Interoperability of Building Management Systems

This paper focuses on the energy aspects, which have been obtained by applying the designed system to monitor and control the electric lighting fixtures of different office spaces [1]. The outcomes obtained from the monitored data show a difference between the expected and actual saved energy and the paper offers possible explanations for this result. And finally, the paper talks about some of the criticalities that are in part related to the off-the-shelf used devices and in part related to the difficulty encountered in monitoring and analyzing the huge amount of data collected. It's been proven that buildings consume nearly one-third of the total global energy and contribute to one-third of the total $CO_2$ emissions, so it is a good idea to try reducing these numbers by using a designed Building Management System. To test the efficiency of this system in terms of energy savings, the comparison was made between pairs of rooms in different places: one with the BMS technology installed and the other without it.
The collected data have been saved to a centralized Data Base, for future analysis and interpretation.

The paper proposes a three layered architecture to solve the connection and interaction problem between the management system and the field devices in each room/building.

Table 1.1: Saving rates based on lighting control strategy

| Criteria | Saving Percentage |
|---|---|
| Time Scheduling | 12% |
| Occupancy Control | 20% - 93% |
| Daylight Harvesting | 10% - 93% |
| Daylight Harvesting and Occupancy | 26% |

The architecture consists of:

1. Integration Proxy Layer: which acts as a middle point between the devices and the management system

2. Service Layer: which provides secure communication and message encryption

3. Application Layer: at this level, it is possible for various devices to communicate with one another

### 1.5.1 Discussions

The study looked more into the lighting aspect and relied on different factors to manage the lighting in the test rooms for energy saving and these factors include: time scheduling, daylight harvesting, occupancy control, or a combination of the previous three.
First, Time Scheduling is to create a lighting schedule that takes care of turning lights On and Off. Second, Daylight harvesting is a technique that relies on determining the level of light in the room and it regulated the lighting power based on that, so by this they'll be profiting from day light to save energy. And finally, occupancy control is achieved through the use of motion sensors in each room, which could help indicate of the room is currently occupied or not, and based on that the necessary action would be taken.

The study has reported the following saving results depending on the different possible lighting-control strategies:

Table 1.1 presents a comparison between the efficiency of each lighting-control strategy

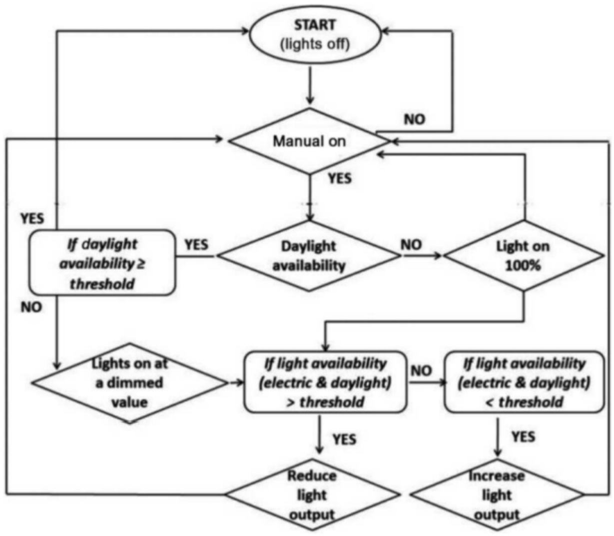



Figure 1.1: Control logics corresponding to the strategy of ADMIN and DITER offices.

## 1.6 Modeling user acceptance of building management systems

This paper examines user acceptance of BMS using a questionnaire survey [2]. The research reported in this paper concerns the computer-based building management systems (BMS) now commonly installed in commercial and industrial buildings and says that despite the failure of exploiting these systems, this doesn't directly affect workers' productivity but affects the efficiency and cost of the management of the building. Some of the reasons behind the failure of fully utilizing BMS are: Over-sophisticated control strategies [3], users' lack of knowledge and self-confidence in using BMS, deficiencies in the user interface [4].
Models to explain the process through which users do or do not accept new technologies have been developed like Technology Acceptance Model (TAM). In the TAM, the attitudes, and therefore the intentions, are influenced by external variables via the perceived usefulness, and perceived ease of use. An important finding is that while both ease of use and usefulness influence the intention to use, usefulness mediates the effect of ease of use. Ease of use and usefulness were especially important in explaining variations in users' satisfaction with information technology. Usefulness was found to be the more important factor while ease of use and simplicity of the solution plays a huge role.

**Research Method**

The first test employed multiple regression to determine how much current usage was connected to user perceptions. To ascertain if the user perceptions might categorize future usage intentions, the second test employed discriminant analysis. This was also taken into account in the model for the second test because the degree of present use is probably going to have an impact on future intentions as well.

### 1.6.1 Discussions

For BMS, this leads to the conclusion that, while success should be increased through improved perceptions of ease of use, compatibility, and relative advantage. Clearly, designers of BMS need to consider the ease of use. Commonly in BMS, the user interface is graphics-based in a Windows environment. When implementing BMS in a particular building project, attempts to maximize compatibility will require a consideration of how BMS use could fit with the potential user's values, experience, and needs. For future information systems, it can be expected that users will be increasingly mandated as the systems become integrated into routine work activities. However, as with BMS, the user may still exercise some discretion in whether to take full advantage of the system's facilities. In BMS, the facilities that may be left unexploited are those that call for significant user intervention to achieve full benefit and are likely to be those with the potential for optimizing building system performance.

## 1.7 Intelligent Housing Development Building Management System for Optimized Electricity Bills

This paper [5] explains how a Building Energy Management System (BEMS) implemented in Singapore has helped to control, monitor, and optimize energy utilization and cost. It aims to achieve this by integrating Demand Side Management and Supply Side Management.
Supply Side Management tackles the problem of how electricity should be distributed by developing optimal algorithms to use electricity efficiently.
The Demand Side Management would involve demand response and peak load scheduling which will encourage people to use electricity at night since it is cheaper in Singapore.
A Multi-Agent System (MAS) was built on top of the system to solve issues and complex problems and give the best solution available. This system is an AI that compromises two or more intelligent agents to achieve its goal. It was developed using Java Agent DEvelopment Framework (JADE) which is a Java extension software framework for MAS.


Figure 1.2: Overall Design of Multi-Agent System for HDBMS

HDBMS AGENTS

| Name | Descriptions | Agent Representative |
|---|---|---|
| **Management System** | | |
| House Development Building Management System | HDBMS | HDBMSAgent |
| Demand Side Management | DSM | DSMAgent |
| Supply Side Management | SSM | SSMAgent |
| **Electrical Supply System** | | |
| Solar Panel | PV | PVSystemAgent |
| Main Grid | MG | MGAgent |
| Electric Vehicle | EV | EVAgent |
| **HDB Building demands** | | |
| HDB Unit | HDBU | HDBUAgent |
| HDB Facilities | HDBF | HDBFAgent |

Figure 1.3: HDBMS Agents

The SSMS calculates the total supply from the electricity supplies and storage data.
The DSMS calculates the total demand through the collection of data from the end users.
The HDBMS then determines the type of algorithm which is suitable for optimization through the SSMS and DSMS calculations. The overall system would then optimize the best cost price for the same usage of electricity.

Fig. 1.3 and 1.4 show what kind of message will be created to facilitate communications between agents. The messages set are REQUEST, SUBSCRIBE,

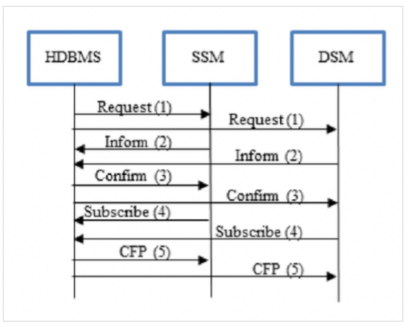



Figure 1.4: Agents Communication

SIMULATION RESULTS FOR DIFFERENT METHODS

| No. | HDB non-contestable price | HDB contestable price | Using Average as a set point | Using Cheap as a set point |
|---|---|---|---|---|
| **Year** | | | | |
| 1 | $88,330.19 | $28,555.82 | $27,665.90 | $25,135.81 |
| **Months** | | | | |
| 1 | $7,360.85 | $2,379.65 | $2,364.64 | $2,142.51 |
| 2 | $7,360.85 | $2,379.65 | $2,300.11 | $2,101.92 |
| 3-12 | $7,360.85 | $2,379.65 | $2,300.11 | $2,089.14 |
| **Days** | | | | |
| 1 | $245.36 | $79.32 | $140.79 | $92.08 |
| 2 | $245.36 | $79.32 | $77.07 | $70.70 |
| 3-30 | $245.36 | $79.32 | $76.67 | $70.70 |

Figure 1.5: Simulation Results for different methods

CONFIRM, INFORM, and CFP. Each message sent would provide different kinds of message or data when it is required during the process of algorithm calculations.

Fig. 1.5 shows the result from the simulation done. We notice a significant difference in cost compared to when no system is implemented (HDB non-contestable price and HDB contestable price)

### 1.7.1 Discussions

The advantages of this approach are that they used the supply-demand method to minimize cost and the set point has an option to be set as 'Cheap' or 'Average'.

## 1.8 Energy Consumption Optimization through Dynamic Simulations for an Intelligent Energy Management of a BIPV Building

This paper [6] presents the scientific context of the ADREAM project, which is a prototype smart building of France (French acronym for Embedded Reconfigurable Dynamic Autonomous and Mobile Architectures) which is a research program focused on the optimization of energy by deploying intelligent sensors and regulators without compromising user comfort.

The paper provides an overview of three different modeling and simulation methods – Dynamic Thermal Simulation, Black Box Modeling with Artificial Neural Networks, and Physical Modeling in Simulink - whose aim is to explore applicable solutions for energy consumption optimization through intelligent management of energy.

ADREAM had the potential of reducing the total electrical energy consumption by 20 percent.

The complete physical model of the ADREAM building, along with all the HVAC

TABLE 2: Comparison of the building's electrical consumption between 2014 and 2017 + 2018 following the implementation of optimization strategies

| | **HVAC Consumption 2014 [MWh]** | **HVAC Consumption 2017 [MWh]** |
|---|---|---|
| Jan.-Mai + Sep.-Dec. | 83,61 | 70,57 |
| | ***Energy Gain*** | ***16%*** |
| | **HVAC Consumption 2014 [MWh]** | **HVAC Consumption 2018 [MWh]** |
| Jan. - June | 44,87 | 34,669 |
| | ***Energy Gain*** | ***23%*** |

Figure 1.6: Comparison of building's electrical consumption

systems installed is developed using MATLAB and the Simulink interface.

### 1.8.1 Discussions

The advantage of the work presented is the use of an Artificial Neural Network for the calculation of the temperature.

## 1.9 Optimal HVAC Control in Shared Office Spaces Based on Deep Reinforcement Learning

[7] Only 38 percent of occupants are satisfied with their thermal environment in office buildings, and this is because temperature set points cannot be adjusted according to their thermal comfort. Therefore, adjusting the temperature dynamically is very necessary.
This paper states that with Deep Reinforcement Learning, an HVAC energy optimization problem with the consideration of uncertain parameters can be formulated to increase the comfort of the occupants. The advantage is that the algorithm can work without any system knowledge and with unknown parameters.

The proposed algorithm is divided into 2 parts:

The first algorithm is the training algorithm and the second is the testing algorithm
For simulation, they considered the cooling mode of an HVAC system. The total number of occupants N is 10. The data were registered from June 1, 2018, to September 30, 2018, for model training and testing. Specifically, the data in June and July are adopted for training and the remainder of the data are used for performance testing.

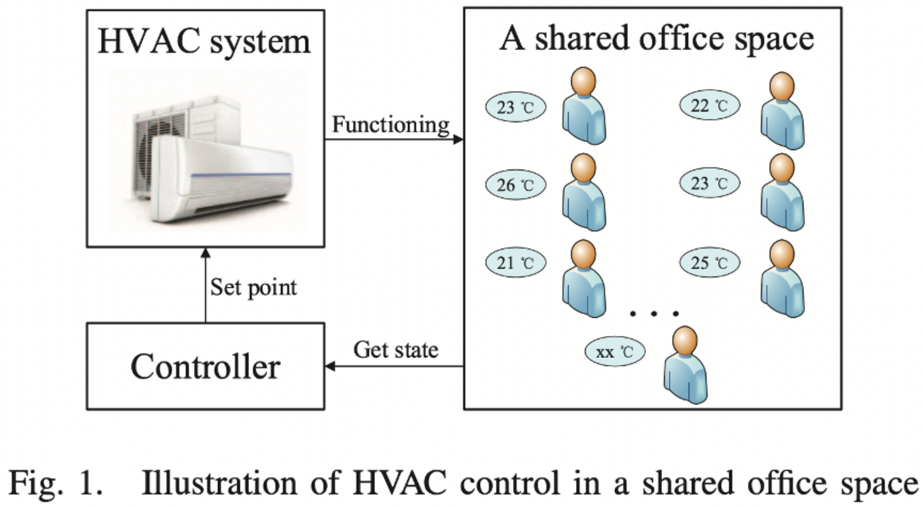



Figure 1.7: HVAC in shared office space

To compare results, we have 2 benchmarks:

The first baseline is a fixed temperature selected and the second baseline is the average temperature preferred by the occupants of the office. In both cases, the HVAC turns off when the office is empty.

In Fig. 1.3, we notice that the proposed algorithm can reduce the mean value of total energy consumption by 8.22-19.48 percent without sacrificing TCSR(Temperature-Compensated Self-Refresh) performance when compared with the baseline.

### 1.9.1 Discussions

The advantage here is that we can know the optimal and the preferred temperature of the room occupants without taking feedback from them and this temperature will be calculated by an algorithm that will ensure a decrease in electricity cost.

## 1.10 “Building Management System to Support Building Renovation

In his paper [8], Yin talks about how buildings are estimated to consume about 40 percent of global energy and that technical renovations have played a big role in improving BMS and contributing to decreasing energy consumption and costs while improving building performance and user experience.

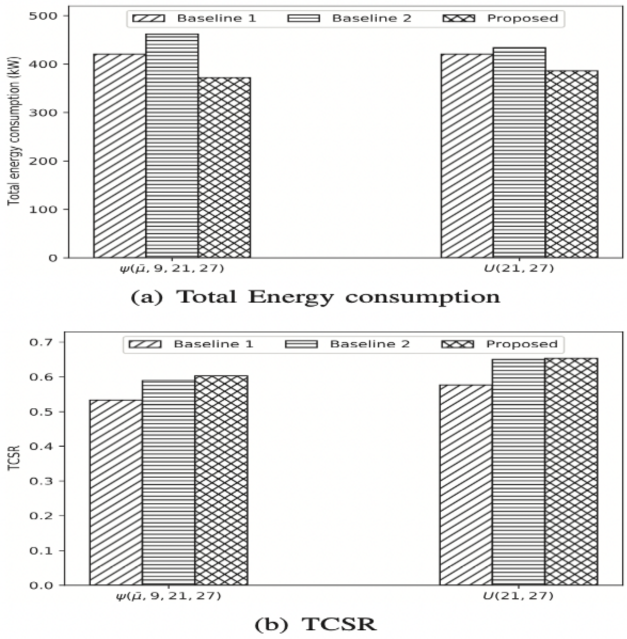



**Fig. 7. The impact of preferred temperature distributions**

Figure 1.8: Impact of preferred temperature distribution

BMS provides monitoring and control of services such as lighting, plumbing, fire services, heating, cooling, and ventilation, but also supports comfort and energy efficiency. Investing in BMS can save 14% of cost due to lost productivity and 15-20% due to energy saving. The primary motivation of this paper is to use a BMS to monitor a building's operation and energy performance. This system can collect real-time data (e.g. temperature, CO2 and humidity, etc.) from wired and wireless sensors. Real-time data collection not only provides a clear road map about how a building is performing but also delivers data for evaluation and ratification of a three-dimensional (3D) model in BIM.

### Building Information Modeling (BIM)

BIM is the process of generation and modeling building data during its life cycle.

<u>Define sensor requirements:</u>

BIM is a database of building data, which helps to define the sensor requirements of each task in the BMS process. A performance hierarchy that defines

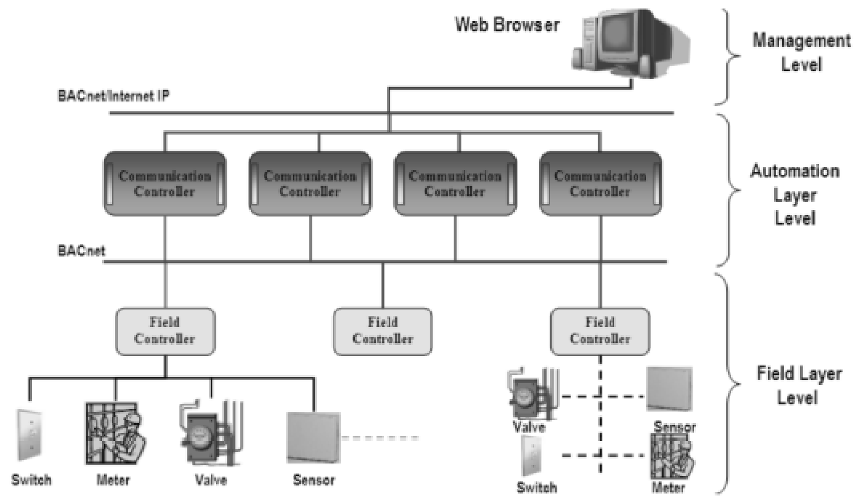



Figure 1: The basic structure of Building Management System

Figure 1.9: The basic structure of Building Management System

sensor requirements must also be done and then stored in the BIM.

<u>Energy simulation model:</u>

BIM provides useful information about the building to be analyzed and then used to manage the building using BMS. The simulation model greatly contributes to the understanding of energy utilization profiles in buildings and after simulation, a report is produced giving details about the heating and cooling loads for each room. In this research, they have developed a simulation model of the ERI building. And by comparing energy consumption from data given in energy simulation and data collected from the BMS they found that they are almost equal.

**Energy Cost Analysis**

BMS control building system operations automatically and in the most efficient way possible in order to improve energy efficiency and reduce fuel use and costs.

### 1.10.1 Discussions

There are various smart technologies available nowadays that can help reduce energy consumption and the cost of existing buildings. Occupants can install a BMS to automate building functions such as lighting and HVAC system and to allow the facility managers to prevent customer complaints moreover can reduce the cost of operating the building by 15The Energy Cost Analysis illustrates that

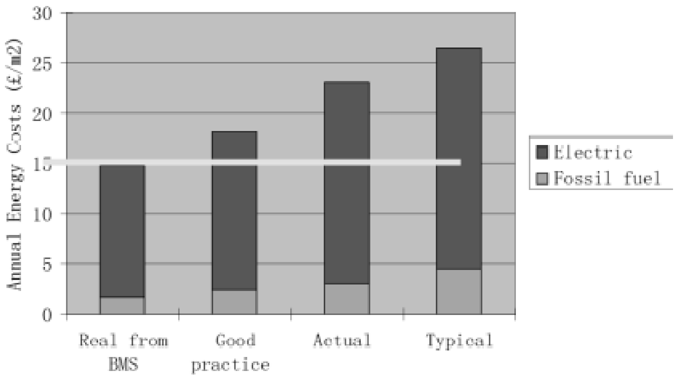



Figure 1.10: Cost Analysis

the total cost per annum is 14.8 £/m2 which is lower than annual costs for good practice, therefore, indicating the excellent influence of BMS

## 1.11 Influence of forecast control of heat supply on energy savings

Based on a field study executed in Poland, this report [9] illustrates how forecasting the management of the heat supply for heating affects the degree of energy consumption. The adoption of forecast control resulted in energy savings of more than 5The forecast control gives the building's current weather control specially tailored exterior temperatures many hours in ahead. The changes in user behavior profiles and weather information are taken into consideration while calculating the outside temperature. By using the heat consumption and outside temperature correlation formulae, the energy savings attributable to forecast control were determined. The experiment was performed during an 8 weeks-slot where the first four weeks had the forecast system not linked to compare results.

### 1.11.1 Discussions

The impact of forecast and model predictive control on HVAC systems is a subject of considerable investigation nowadays. The operational findings of such a system, which might be simply implemented in many existing structures, are scarce. The preliminary field findings of the novel forecast control approach that was developed were presented in this publication. When the heating system is operated in forecast mode, the building may see energy savings of more than 5.

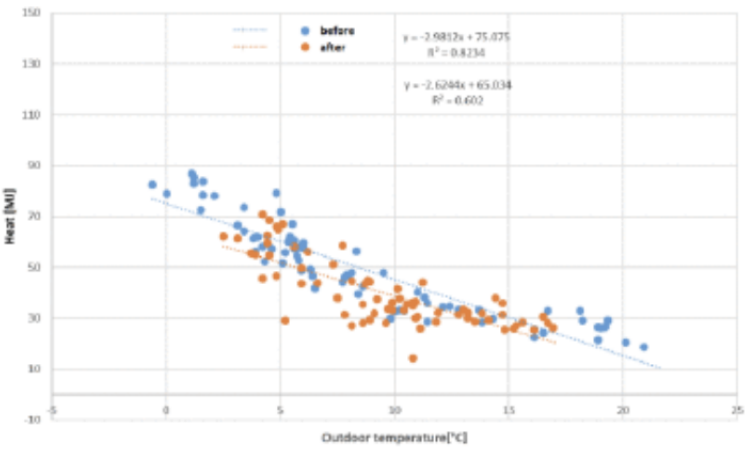



Figure 1.11: Heat consumption before and after the installation of forecast control of the heating system for the day hours

## 1.12 Trade-off decisions in a novel deep reinforcement learning for energy savings in HVAC systems

One of the major users of energy worldwide is building. They produce 30 % of all CO2 emissions while absorbing 40 % of all energy use. HVAC systems (heating, ventilation, and air conditioning) use around half of a building's energy. The HVAC systems in building sections have received a lot of attention in terms of energy management, either through scheduling or control. The HVAC systems are controlled using certain traditional techniques, such as feedback and rule-based control strategies, however, they are ineffective. In this study [10], the optimal HVAC control to utilize is chosen using machine learning algorithms.

### 1.12.1 Discussions

In order to reduce electrical energy consumption and keep passenger comfort levels within acceptable ranges, novel control techniques employing model-based reinforcement learning (RL) were proposed in this work. The occupants' thermal comfort levels were determined by the room temperature and CO2 levels. The conventional building model was updated in order to regulate the CO2 concentration level. A trade-off was established between maintaining interior comfort levels and reducing the electrical energy consumption of the HVAC system by choosing the right components for reward functions. Two case studies were simulated in the MATLAB environment to assess the performance of the controllers. According to the findings, DP-NARX-RL saves 38 % more energy than the benchmark controller.

## 1.13 HVAC energy savings, thermal comfort and air quality for occupant-centric control through a side-by-side experimental study

In the last two decades, building sensor devices have advanced quickly to help monitor the atmosphere of buildings and the efficiency of their energy systems. In this paper [11] and for the purpose of monitoring occupant activity in an interior environment, several occupancy sensor systems have been created. A smart building control technique that can increase both building energy efficiency and occupant comfort is occupancy-based building system control.

### 1.13.1 Discussions

The results of this study's side-by-side experimental comparison demonstrate the occupancy-based HVAC control's potential for real-time and practical energy savings. The findings show when these energy savings take place as well as how much energy may be saved by using occupancy-based regulation. Additionally, it was shown how the accuracy of the occupancy sensor affected energy savings. This information may be utilized to direct the implementation of occupancy sensing technologies in occupancy-based HVAC management, i.e., how precise the sensor has to be for substantial energy savings.

## 1.14 Trade-off decisions in a novel deep reinforcement learning for energy savings in HVAC systems

Intelligent buildings may give a fast response, great efficiency, and a strong support force environment. Users in intelligent buildings, in particular, can easily fulfill their business goals. This study suggests an intelligent building engineering information management system and then constructing it. Intelligent buildings' architecture is constituted of three parts:

1. Resources
2. Construction process
3. Building products

Climate control, light management, safety and security, traffic condition, energy consumption control, communication support, and other services are among the seven major categories of services in intelligent building construction. To build a powerful intelligent building, several digital devices such as Gateway, External subsystems, Audio and paging subsystem, Access control subsystem, Fire management system, Digital systems, and Energy controlling system should be installed, because an intelligent building refers to an entity that can create an environment to maximize the efficiency of building services and resource management with limited resources. Nonetheless, the transportation subsystem, security subsystem, fire prevention subsystem, lighting subsystem, communications subsystem, and so on are all part of an intelligent building.

## 1.15 Design of a Web-based Building Management System using Ajax and Web Services:

The purpose of this research is to offer a web-based building management system (BMS) based on Ajax and Web Services enabling real-time monitoring and control of BAS via the Internet. The user must send a request to the server, wait for the server to process the request and return a response, and then wait for the browser to refresh the interface with the results in traditional web-based applications. This sequence of request-wait-response-wait is tremendously disruptive and reduces productivity.

The primary goal of Web Services is to create a technical layer that is independent of platforms and programming languages in existing heterogeneous configuration platforms; depending on the technical layer, the applications of these different platforms can implement interlinkage and integration with one another.

Ajax-based Web applications improve the responsiveness of web pages by exchanging little bits of data with the server behind the scenes so that the complete web page does not have to be reloaded each time the user makes a change.

With the introduction of different worldwide standardized protocols, there are issues with BAS internal integration and interaction between BASs and current business applications, which will impede the expansion of the BAS market. Using Web Services in the BAS industry will not only enable seamless and just-in-time integration between BASs and enterprise applications, among BAS subsystems that use different standardized protocols or have different functions, but it will also help users save money and increase the utility of their BASs.

Shortly, this research encompasses a general architecture that was presented for implementing a new generation of web-based BMS that can monitor and manage BASs over the Internet in real-time utilizing Ajax and Web Services.

# Chapter 2

# Design Process

This section will discuss the design process that we have adopted for our project. The project is about creating an application that automates the functioning of the HVAC system inside the Engineering Bechtel Building at the American University of Beirut, based on the daily room schedule. The aim behind this application is to reduce the electrical load and generate significant savings to help reducing the electrical bill of the university. The design process that we adopted involves identifying the constraints, examining the various design alternative, deciding on the design that we will adopt and iterating over different design iterations in order to debug and fix any errors to achieve the final fully functional product.
We will discuss all of the above in detail, the constraints that we identified, either technical or non-technical, the design alternatives that we examined as well as the decision that we have made and the design that we have picked and the design iterations that we went through to finalize our application. We will also discuss how we incorporated engineering standards into our design to make sure the applications meets the conventional safety and performance requirements.

## 2.1 Engineering Constraints

### 2.1.1 Technical

1. Scalability: We are currently working on making our project functional only for the classrooms in Bechtel Building. But the system should be scalable in case our solution will be used for multiple buildings on campus.

2. Automation: our system should be fully automated and should not require any form of human intervention. Our code should automatically interact with both applications, the BMS and the room scheduling system without any manual request.

3. Security: Since we will be using admin credentials to be able to make

requests to the software mentioned before, it will be good practice if we encrypt these credentials to avoid accidental disclosure or malicious attacks.

### 2.1.2 Non-Technical

1. Sustainability: The main difference our solution will make is the energy and cost savings, so the task should be fulfilled but we should not make the mistake to compromise the comfort of the attendees.

2. Satisfaction: The system should ensure a satisfaction rate of at least 85 percent with the use of survey sent to instructors after every session.

3. Approval: Our system should have enough efficiency evidence and proof that it can make promising results to get approval from AUB to use it and deploy it on campus.

## 2.2 Design Alternatives

### 2.2.1 Design Alternative 1

A design alternative would be using NodeJS for establishing the connection between both software, analyze the retrieved information and taking the necessary action that will then be communicated to the Building Management System through the REST API. Additionally, in order to control temperature setting, we will be creating a static table that stores the optimal HVAC set temperature according to different weather variables such a Temperature, Humidity, etc. which are going to be collected through a third party weather forecast API.

NodeJS choice was due to its high scalability, since Node uses an event driven architecture which is capable of handling multiple requests especially if the software is used for multiple building in the university. Thus, NodeJS is practically faster than other languages due to its asynchronous nature.

### 2.2.2 Design Alternative 2

In the second alternative, a different solution to a static table is intended. Implementation of a machine learning model would be used in order to fill the HVAC set points based on weather forecast data and user satisfaction. We tend to collect users satisfaction data through Professors input on each session given. The communication would still persist on NodeJS due to the reasons listed above, Nevertheless the machine learning model will be built on Python. The wide community, libraries and platform independence makes Python the right choice for such implementation.

### 2.2.3 Design Alternative 3

In the third alternative, we gave the user full control to manipulate the state of the HVAC system and freedom to set the temperature through a web based user interface created using React. The user is, in this case, able to input any desired temperature and decide whether we are in cooling or heating mode. We added to this design an option to use smart weather prediction that uses a third party API 'Open-Meteo'.

## 2.3 Design Decisions

We decided to follow the third design alternative. By providing the user with a web-based user interface, we are addressing the scalability constraint since anyone can access the interface if connected to the local network, and it can be easily scalable for multiple buildings on campus with minimal effort. In addition, this design satisfies the automation constraint with the option to use the smart weather prediction feature that updates the temperature according to a third party API. And finally for the technical constraints, the design will be secure since we are encrypting the admin credentials that we are using to make all the modifications on the HVAC system.

## 2.4 Design Iterations

We went through several design iterations throughout the software development life-cycle to hone our approach and make sure it satisfied the project's needs.

### 2.4.1 Design Iteration 1

We concentrated on gathering requirements and establishing the project's scope in the first iteration. In this iteration, we created a code that uses a sample XML file fetched from "InfoSilem" that contains the room schedule of the Bechtel Building. We parsed this file and looped over all the information provided in it to decide if the room is occupied, then we used this information to decide in what mode the HVAC should be operating in each room, and we communicated with the Building Management System using the REST API to set each room to the correct state.

### 2.4.2 Design Iteration 2

In the second iteration, the application was now able to regularly and autonomously communicate with both the "InfoSilem" software and the Building Management System. The application at this stage can automatically fetch the required room data, analyse it and set the HVAC system of each room to the correct state based on the retrieved information.

### 2.4.3 Design Iteration 3

In the third and last iteration, We moved on to prototyping and designing the user interface. The designed User Interface is a web-based interface, that provides the administrator with the ability to control the behavior of the system, by setting the desired temperature, choosing between cooling and heating mode. The user interface also provides useful information about the financial benefits and savings of the application.

## 2.5 Standards

- IEEE 12207-1996 - ISO/IEC International Standard - Information Technology - Software Life Cycle Processes: Provides a common framework for developing and managing software. Our entire application should be built on a single framework.

- IEEE 1008-1987 - IEEE Standard for Software Unit Testing: It provides an integrated approach to systematic and documented unit testing. It uses unit design and unit implementation information, in addition to unit requirements, to determine the completeness of the testing. All of our software components will be unit-tested before deployment.

- IEEE 1233-1998 - Guide for Developing System Requirements Specifications: It is a guidance for the development of the set of requirements, System Requirements Specification (SyRS). The application should meet the requirements specified prior to implementation based on this standard.

- IEEE/ISO/IEC 26511-2012 - ISO/IEC/IEEE International Standard - Systems and software engineering – Requirements for managers of user documentation: It covers management activities in starting a project, including setting up procedures and specifications: Our application should have clear documentation.

- IEEE 1484.11.2-2020 - IEEE Standard for Learning Technology–ECMAScript Application - Programming Interface for Content to Runtime Services Communication: This standard describes an ECMAScript application programming interface (API) for content-to-runtime-services communication. This could be applied since our application will be a back-end API running on a server on campus.

- IEEE/ISO/IEC 23026-2006 - ISO/IEC 23026:2006, Software Engineering—Recommended Practice for the Internet—Web Site Engineering, Web Site Management, and Web Site Life Cycle: This document defines recommended practices for World Wide Web page engineering; this could be applied in the front-end possible part of our product.

- IEEE P7002 - IEEE Draft Standard for Data Privacy Process: This standard defines requirements for a systems engineering process for privacy-oriented considerations regarding data: This standard is applicable since the application discussed will handle information from 'Infosilem' system which should stay private.

# Chapter 3

# Implementation

The code implementation starts with requesting access to the INFOSILEM API by providing the credentials of the user. The user credentials are stored in the server environment which is not included in the repository for security reasons. These credentials are provided by the AUB IT department and are used to request an access token from the INFOSILEM API. The access token is in the form of code which is used to request the schedule of the rooms from the INFOSILEM API. This request/response is done using Axios library. The schedule is then parsed from XML to JSON format and stored in a JSON file called ”schedule.json”. The parsing is done using the ”xml2js” library. The code then cleans up the JSON file by removing all unnecessary data.

The remaining data includes all reservations for all rooms for the time period set in the Axios request. These reservations are looped through and in each iteration, a reservation is inspected after carefully and temporarily storing its start time, end time, room number, day of the week, reservation start date, and reservation end date. Any date received as a string is converted to a date object using the Date() function. The day of the week which is received as a string containing letters of the day of the week (ex: ”MWF”) is converted to a number after looping through each letter in this string.

A numDay array is populated with the resulting numbers where each letter resembles a number as follows:

- U = 0 (Sunday)
- M = 1 (Monday)
- T = 2 (Tuesday)
- W = 3 (Wednesday)
- R = 4 (Thursday)
- F = 5 (Friday)

- S = 6 (Saturday)

Then, the current date is compared to the reservation's start and end dates. If the current date is between the reservation start date and end date, the current day of the week is compared with the reservation's array of days of the week. If matched, populate an object called "lastReservationOfTheDay" holding the room numbers as keys, and each key's value is set to the last reservation of the day for that room. This is done to turn off the HVAC system after all reservations for the day are over. Then, check if the current time is between the reservation start time and end time with an offset of 15 min before and after room reservation. If matched, the HVAC system for the room is turned ON. After 15 min of reservation end, the HVAC system is put into STANDBY MODE. After fully populating the "lastReservationOfTheDay" object, loop through it and turn OFF the HVAC system for the rooms that have their last reservation of the day passed by 15 minutes. The room is put into standby mode everyday at 7 am to have enough time for the room temperature to reach the desired set temperature by the beginning of the first lecture. All the previous logic is handled by populating three objects (roomOn, roomStandby, roomOff) each with all classes as keys and each with a boolean value indicating whether it's set to the respective mode or not (ie. if room 212 is on and room 214 is off, their value in object roomOn is True and false respectively). At the end of this logic, these objects are looped through, and any class with a value true calls multiple functions where each handles updateRoomOccupancy, updateSetPointTemperature, updateHvacMode, updateDeltaTemperature, getActualTemperature, getSetPointTemperature, getHvacMode, and getDeltaTemperature.

The front-end is implemented using NextJS framework which uses React library. The layout starts with the "OptiSchedule" logo on the left and a navigation menu on the right. Below it, a hero section is show with a comparison between the power consumed by the HVAC system when our system is implemented and when it is not implemented (in kWh). Below it, we have a control settings form where you can set the desired room temperature, and smart weather prediction (it automatically fills the desired room temperature with the most comfortable temperature based on many parameters such as external temperature, humidity, etc. We can also control the mode (cooling or heating) and the standby delta temperature which is added or subtracted from the desired room temperature depending on whether cooling or heating mode is chosen, respectively. Once all values are set, a submit button is pressed that send all these values to a serverless api file that contains the logic discussed previously which takes these form values as parameters inside its req, and returns the temperature, mode, standbyDeltaTemperature, roomsActualTemperature, and runCount. RoomsActualTemperature contains an object with the rooms as keys and each of these rooms' temperatures as values. This object will be represented in a table at the end of the page with rooms as the first column and their actual temperature as the second column. As for runCount, it is used to calculate the power consumption mentioned before.

The component defines several state variables using the useState hook:

- temperature: the current temperature
- mode: the current mode of the system (cooling or heating)
- standbyTemperature: the temperature to set the system to when it is in standby mode
- smartWeatherPrediction: a boolean value indicating whether or not to use smart weather prediction
- isRunning: a boolean value indicating whether or not the system is currently running
- consumptionWithSystem: the power consumption of the system when it is running
- consumptionWithoutSystem: the power consumption of the system when it is not running
- roomsActualTemperature: an array of objects representing the current temperature in each room of the system

The component defines two functions:

- getSmartWeatherPrediction: an asynchronous function that fetches weather data from an API and uses it to calculate an optimal set temperature for the system
- optiScheduleCaller: an asynchronous function that makes a POST request to an API, retrieves data from the response, and updates state variables accordingly

The useEffect hooks:

- The useEffect hook is used to call getSmartWeatherPrediction when the smartWeatherPrediction state variable changes.
- The second useEffect hook is used to call optiScheduleCaller when the component mounts, and then set up an interval to call optiScheduleCaller every 5 minutes (if isRunning is true). The interval is cleaned up when the component unmounts.

- The component also defines a function called handleSubmit which is used as an event handler for a form submission.

All code concerned with scheduling the time to control the HVAC system mentioned before is called controlHVAC() which is called every 5 minutes using the setInterval() function.

As for testing, separation of concerns has been implemented in its methodology. Consequently, three main concerns emerged:

- InfoSilem: tested using SoapUI to well ensure that a proper connection with the right credentials and format is exchanged.
- Dummy XML Object: testing the core scheduling logic portrayed in the controlHVAC() function has been performed using a XML object with the correct InfoSilem response format but requested previously on SoapUI.
- EnteliWEB: tested using Postman to well insure that control variables are changed after receiving a corresponding request.

# Chapter 4

# Experimental Setup and Results

## 4.1 Experimental Setup

In order to thoroughly evaluate the effectiveness of our product, we designed a comprehensive experimental setup that involved several key components. The testing phase was divided to several parts, where each component of the application was tested alone before moving to test the whole project. As previously mentioned, our application establishes connections with two different application used by the university. The connection with each application was tested alone and separately, we managed to establish successful connections with "InfoSilem" which allowed us to retrieve the full reservation schedule of the rooms in the form of an XML file, using the SOAP API. The second connections we tested was the one with "EnteliWeb" using REST API, and through which we could set variables to the value or the mode we want, and retrieve the values of the needed measurements.

After making sure that the application could successfully communicate with the needed tools, we moved to ensure the accuracy of the retrieved information. As mentioned, we used SOAP API to get the reservations of the rooms of Bechtel Building, we went through the XML file and checked its content and try to compare it with what is happening in real life by checking if the reservations are really taking place in the specified rooms and at the specified times. Another test we had to do was to actually modifying variables in the Building Management System and checking if changes are taking effect. For instance, we set the mode to "Cooling—On" and we verify if that's really taking effect. All the different combinations where tested, "Cooling" and "Heating", "On" "Standby" and "Off" and we have also checked how the set temperature and standby temperature are getting modifying with each mode.

Then we moved to test the application as a whole. The code was put up together, it can now communicate with all the needed software automatically and independently without any need for human intervention. So the application was run, it started by retrieving the reservation schedule of the rooms of Bechtel, then the reservations were analysed carefully and based on this analysis the right decision was taken for each room based on its occupancy or in case any unpredictable reservations or changes of the schedule has happened. This part was carefully tested by creating and cancelling fake reservations and observing the behavior of the application, since one of the main interests of our project is to have a dynamic application that takes accurate decision in real time.

As the title of our project implies, "Schedule-Based Automatic HVAC System Control", the goal is to make the HVAC system behave automatically, based on real time data retrieved from the room reservations. Originally, the HVAC system in the American University of Beirut generally, and Bechtel Building specifically operated based on a fixed static schedule that is set inside the Building Management System, the issue with that is the huge and unnecessary incurred energy cost, because the system would be unnecessarily functioning at many times when the rooms are not occupied or when there are no more reservations made for the room. So to understand and the amount of energy we will be saving by running our project, we went to check the energy consumption of the Air Conditioning elements in Bechtel rooms, to get a rough estimate of how much energy is consumed and how much energy and cost we will be saving if we managed to reduce the operation time of the HVAC system.

## 4.2 Results

After finishing all the needed experiments, our application was run and tested during a normal university day at AUB. The behavior of the HVAC system was observed and analysed thoroughly. A copy of the retrieved and parsed room schedule was saved, which we started to compare to real life and the results where accurate and all the reservations happened exactly as our system is expecting. When a room is occupied and there is a reservation for it, the program automatically set this room to mode "On" with the specified set temperature, which is the correct behavior in that case. Another case that we observed was how the system behaves when there is no reservations in a certain room, but there are others to come during that day. In this case, the room was put into "standby" mode and the set temperature was elevated by a certain margin that we could manually control (though the administrator) based on certain parameters that aren't in the scope of the project. The third case, that we observed was the case where the room is not reserved and no upcoming reservations are expected for this room during that day, so the system turns off completely. The results where accurate and the system behaved exactly the way expected.

As for the savings, which are the goal of the project, we have done measurements to deduce the power consumption of each Air Conditioning elements in Bechtel rooms, and each machine turned out to use 0.4 Amperes, and having 2 of them in each room making it a total of 0.4 Amperes per room.

First, let's calculate the energy consumption per room in kilowatt-hours (kWh):

- Power = Voltage x Current = 220V x 0.4A x 2 = 176 Watts

Second, let's calculate the energy saved by turning off the system for an average of 14 hours per room per day:

- Energy Saved = Power x Time = 176 watts x 14 hours = 2.464 (kWh)
- Energy Saved taking into account the cost of chilled water = 2.464 x 1.3 = 3.21 kWh

Third, let' calculate the energy saved for the 13 class rooms in Bechtel:

- Energy Saved per day = 3.21 kWh x 13 rooms = 41.73 kWh
- Energy Saved per month = 1252 kWh

These numbers are for one day in Bechtel Building only. As we are aiming to expand our project to cover more buildings of the American University of Beirut campus, these numbers would grow quickly and the savings would become greater leading to fewer energy cost and less environmental .

## 4.3 Discussions and Future Work

The obtained results show how potentially high, the saved energy could be especially if the application could be successfully deployed in all AUB buildings, knowing that the campus has more than 60 buildings. The AUB power plant is the centralized and only source of energy that provides electricity for campus buildings, and it mainly uses diesel fuel for its generators, which has catastrophic environmental effects. On average the production of 1 kWh of electricity using diesel generators releases 1.27 kg of $CO2/kWh$. Knowing that in Bechtel alone we could save 1.27 kg x 1252 kWh = 1590 kg of CO2 emissions per month, this numbers can reach no less than 18 tons per year. This reduction in CO2 emissions could save a lot on the environment, since according to a study conducted in the United States and published in "nature.com", the damage per ton of CO2 can reach $185. [12]

As discussed earlier, the implementation of "OptiSchedule" will save almost 1252 kWh of energy per month compared to 2142 kWh of monthly consumption originally for the HVAC system in the classrooms. We can notice here that our application will help saving 58% of energy used by the "HVAC" system in Bechtel classes.

As for our future plans to improve our application, we are looking forward to implement a well trained machine learning model that takes multiple inputs such as outside temperature, humidity, size of the room, number of persons inside the classroom and user satisfaction in order to decide on the optimal set temperature inside each room and fully automate the process of setting the temperature, knowing that each degree of difference in temperature leads to a 3% of change in energy consumption. Additionally, we are aiming to expand this project outside Bechtel building, so it covers all of the 64 buildings on campus. This would increase the amount of energy saved, as well as lowering the $CO_2$ emissions which have detrimental environmental effects and finally save energy cost which could be used to subsidize the education of students through financial aid donations.

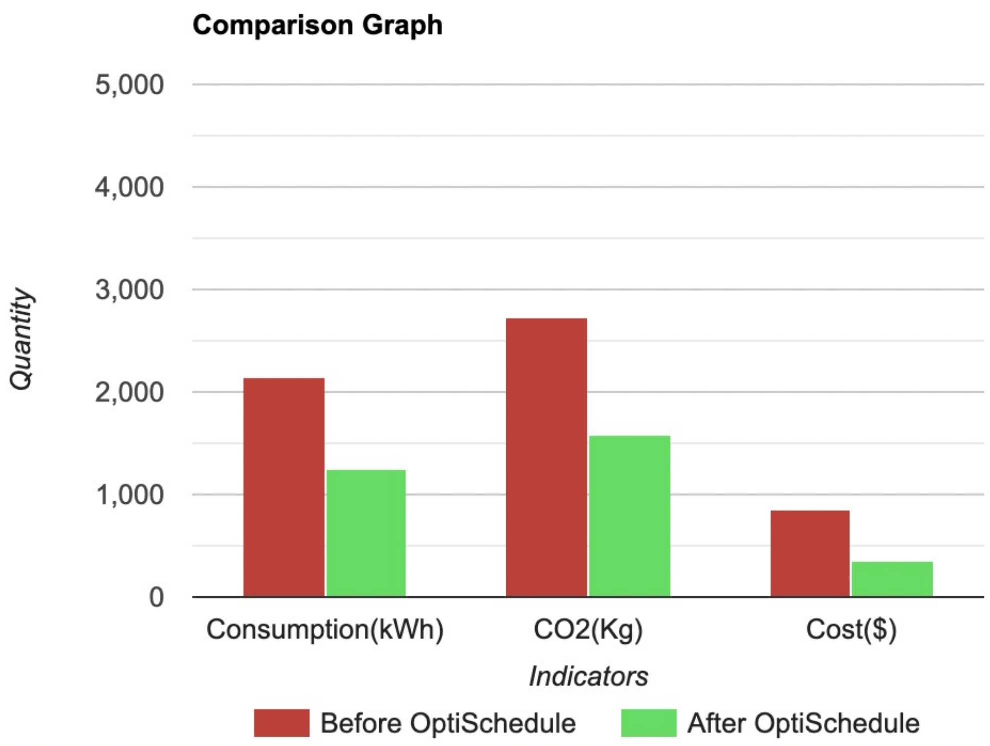



Figure 4.1: Comparison showing the difference between HVAC system consumptions with and without OptiSchedule

# Chapter 5

# Broad Impact: United Nations SDGs

The software program created to maximize HVAC system performance is an innovative technique with an extensive amount of promise to help achieve a number of UN Sustainable Development Goals (SDGs). The environmental impact of energy use is an increasing source of worry in Lebanon, since diesel is the primary fossil fuel utilized to produce electricity. This approach can help lessen the effects of climate change and build more sustainable and resilient communities by consuming less energy and operating HVAC systems optimally.

It is important to note that the BECHTEL building's initial condition was notable by unnecessary energy consumption and related costs. As a result of the software solution's adoption, the HVAC system's operating hours have been drastically cut, which has decreased energy usage and related expenses. This is a good illustration of how creative solutions like these can make buildings operate more sustainably and affordably, helping to achieve the Sustainable Development Goal for Access to Affordable and Clean Energy (SDG 7).

Additionally, the software solution supports other SDGs like Sustainable Cities and Communities (SDG 11), which aims to build more livable, resilient, and sustainable urban environments, and Industry, Innovation, and Infrastructure (SDG 9), which emphasizes the need for sustainable infrastructure and industrialization. The software solution can support the SDG of Quality Education (SDG 4) by improving the functioning of the HVAC system to assist provide a more pleasant and sustainable learning environment for students.

In conclusion, the software program created to enhance the performance of the HVAC system in BECHTEL building has the potential to support a number of SDGs. This novel approach supports the objectives of SDGs 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) by lowering energy consumption, lowering costs, and building more resilient and sustainable communities. Its use in Lebanon, where the environmental effects of energy consumption are a major source of worry, emphasizes how crucial it is to discover and implement novel solutions in order to build a more sustainable future.

# Chapter 6

# List of Resources and Engineering Tools

The list of resources used so far for our project:

1. ”EnteliWeb” Building Management System: We studied the REST API documentation to be able to start a session and send requests to the HVAC system.

2. Room Scheduling System ”Infosilem”: The SOAP API used for this software should be analyzed to get the data and room schedules.

3. NodeJS: NodeJS is a JavaScript run time environment that will be used to establish the connection between the two software cited above.

4. Postman: Postman is an application that allows API testing for the BMS.

5. SOAP UI: An application for SOAP API testing for the Infolisem software side.

# Appendix A

# Weekly Meeting Minutes

**American University of Beirut**
**EECE 502 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| 0 | | pm | 0 | ◉ Advisor ○ Students | Elie Mina |

**Attendees:**

**Briefly summarize the main discussions during the meeting:**

No meeting held

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

No meeting held

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

**American University of Beirut**
**EECE 502 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| 0 | | pm | 0 | ◉ Advisor ○ Students | Elie Mina |

**Attendees:**

**Briefly summarize the main discussions during the meeting:**

No meeting held

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

No meeting held

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Elie Mina | | |
| Karl Skaff | | |
| Abed Karim Nasreddine | | |
| Fadi Abdallah | | |

**American University of Beirut**
**EECE 501 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| 2 | 4/3/2023 | 2:00 pm | 1h | ◉ Advisor ○ Students | Karl Al Skaff |

**Attendees:**

Karl Al Skaff - Elie Mina - Abed Karim Nasredine - Fadi Abdallah

**Briefly summarize the main discussions during the meeting:**

In this meeting we have discussed the needed resources to be able to deploy our code on a VM on campus

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

We have submitted a request for the IT department after agreeing on the needed resources and specs of the VM, and we have filled the needed forms.

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Think of extra features to be implemented | Karl Al Skaff | 9/3/2023 |
| Think of extra features to be implemented | Elie Mina | 9/3/2023 |
| Think of extra features to be implemented | Abed Karim Nasredine | 9/3/2023 |
| Following up with the IT department concerning the VM | Fadi Abdallah | 9/3/2023 |

**American University of Beirut**
**EECE 502 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| 0 | | pm | 0 | (•) Advisor ( ) Students | Elie Mina |

**Attendees:**

| |
|---|
| |

**Briefly summarize the main discussions during the meeting:**

No meeting held

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

No meeting held

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Think of extra features to be implemented | Elie Mina | 20/3/2023 |
| Think of extra features to be implemented | Karl Skaff | 20/3/2023 |
| Think of extra features to be implemented | Abed Karim Nasreddine | 20/3/2023 |
| Following up with the IT department concerning the VM | Fadi Abdallah | 20/3/2023 |

**American University of Beirut**
**EECE 501 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| | 18/3/2023 | pm | | ◉ Advisor ○ Students | Karl Al Skaff |

**Attendees:**

Karl Al Skaff - Elie Mina - Abed Karim Nasredine - Fadi Abdallah

**Briefly summarize the main discussions during the meeting:**

We had no meeting for this week

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

We agreed as team members about some improvements for the project.

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Think of extra features to be implemented | Karl Al Skaff | 25/3/2023 |
| Think of extra features to be implemented | Elie Mina | 25/3/2023 |
| Think of extra features to be implemented | Abed Karim Nasredine | 25/3/2023 |
| Following up with the IT department concerning the VM | Fadi Abdallah | 25/3/2023 |

**American University of Beirut**
**EECE 502 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| 4 | 23/03/2023 | 2 pm | 1 | (●) Advisor ( ) Students | Elie Mina |

**Attendees:**

Khaled Joujou, Elie Mina, Karl Skaff, Karim Nasredin, Fadi Abdallah

**Briefly summarize the main discussions during the meeting:**

Meeting to have access to server

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

start testing phase

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Start testing | Elie Mina | 1/4/2023 |
| Start testing | Karl Skaff | 1/4/2023 |
| Start testing | Abed Karim Nasreddine | 1/4/2023 |
| Start testing | Fadi Abdallah | 1/4/2023 |

**American University of Beirut**
**EECE 501 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| | 1/4/2023 | pm | | (●) Advisor ( ) Students | Karl Al Skaff |

**Attendees:**

Karl Al Skaff - Elie Mina - Abed Karim Nasredine - Fadi Abdallah

**Briefly summarize the main discussions during the meeting:**

We were able to get access to the Virtual Machine and started to deploy our porject,in order to run it and test it

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

The deployment process will continue with the assistance of the IT department at AUB

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Work on the deployment | Karl Al Skaff | 7/4/2023 |
| Work on the deployment | Elie Mina | 7/4/2023 |
| Work on the deployment | Abed Karim Nasredine | 7/4/2023 |
| Work on the deployment | Fadi Abdallah | 7/4/2023 |

**American University of Beirut**
**EECE 501 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| Meeting # | Date: | Time: | Duration: | Meeting called by: | Minutes Taker: |
|---|---|---|---|---|---|
| | 4/4/2023 | pm | | ◉ Advisor ○ Students | Karl Al Skaff |

**Attendees:**

Karl Al Skaff - Elie Mina - Abed Karim Nasredine - Fadi Abdallah

**Briefly summarize the main discussions during the meeting:**

We were able to get access to the Virtual Machine and started to deploy our porject,in order to run it and test it

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

We will start testing the project

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Test the project | Karl Al Skaff | 12/4/2023 |
| Test the project | Elie Mina | 12/4/2023 |
| Test the project | Abed Karim Nasredine | 12/4/2023 |
| Test the project | Fadi Abdallah | 12/4/2023 |

**American University of Beirut**
**EECE 501 – Final Year Project**
**Course Coordinator – Dr. Youssef Tawk**
**Minutes for the Weekly Group Meeting – Submitted per Group**

| **Meeting #** | **Date:** | **Time:** | **Duration:** | **Meeting called by:** | **Minutes Taker:** |
|---|---|---|---|---|---|
| | 18/4/2023 | pm | | ◉ Advisor ◯ Students | Karl Al Skaff |

**Attendees:**

Karl Al Skaff - Elie Mina - Abed Karim Nasredine - Fadi Abdallah

**Briefly summarize the main discussions during the meeting:**

Discussed the deployment and testing issues, and how we are going to do the study of the financial benefits of the project and the needed calculations.

**Briefly summarize the conclusions drawn regarding the above-mentioned discussions:**

Deployment issues and needed access were resolved, and a meeting was set to do the financial study

**Enumerate the assigned tasks by the FYP advisor for each student + the deadline for delivery:**

| Assigned Task / Per Student | Name of the Student | Deadline |
|---|---|---|
| Test the project | Karl Al Skaff | 12/4/2023 |
| Test the project | Elie Mina | 12/4/2023 |
| Test the project | Abed Karim Nasredine | 12/4/2023 |
| Test the project | Fadi Abdallah | 12/4/2023 |

# Appendix B

# FYP Poster

## OUR SOLUTION

SMART MIDDLEWARE APPLICATION THAT ENSURES COORDINATION BETWEEN ROOMSCHEDULING AND HVAC CONTROL

DEPLOYED ON BECHTEL BULDING

# OPTISCHEDULE

THE KEY TO SUSTAINABLE BUILDING MANAGEMENT

## IMPACT

### Revolutionizing HVAC Control

OptiSchedule is a game-changer in the field of HVAC control. It utilizes precise technology to optimize the use of heating and cooling systems in university buildings. By turning off the HVAC system when it's not needed, OptiSchedule can help universities reduce their carbon footprint and contribute to a greener future in addition to significant energy savings.

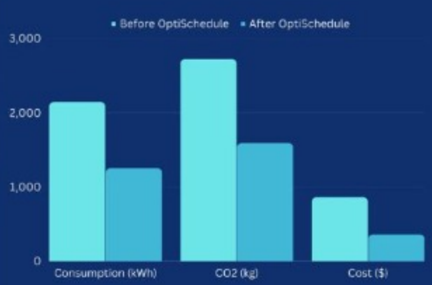
### Smarter Heating and Cooling with OptiSchedule

OptiSchedule employs intelligent algorithms to determine the optimal times to turn on and off HVAC systems based on class schedules and weather forecasts. This ensures that the building is only heated or cooled when necessary, and that the temperature is always comfortable for the occupants.

## FEATURES

- DASHBOARD CONTROL
- CUMULATIVE SAVINGS GRAPH
- STANDBYMODE IN BETWEEN RESERVATIONS
- TABLE VIEW OF ROOMS TEMPERATURE

## MEASURED SAVINGS



# Bibliography

[1] A. Pellegrino, V. R. M. Lo Verso, L. Blaso, A. Acquaviva, E. Patti, and A. Osello, "Lighting control and monitoring for energy efficiency: A case study focused on the interoperability of building management systems," *IEEE Transactions on Industry Applications*, vol. 52, no. 3, pp. 2627–2637, 2016.

[2] G. Lowry, "Modelling user acceptance of building management systems," *Automation in Construction*, vol. 11, no. 6, pp. 695–705, 2002.

[3] T. Brendel, A. Schneider, and E. McKay, *User Experiences in BEMS Applications: Energy Conservation in Buildings and Community Systems Programma Annex XVI Building and Energy Management Systems User Guidance.* IDB, 1991.

[4] R. John, R. Fargus, and G. Smith, "Building management systems: user experiences," 1989.

[5] W. Li, T. Logenthiran, V.-T. Phan, and W. L. Woo, "Intelligent housing development building management system (hdbms) for optimized electricity bills," in *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / ICPS Europe)*, pp. 1–6, 2017.

[6] I. Papas, B. Estibals, C. Ecrepont, and C. Alonso, "Energy consumption optimization through dynamic simulations for an intelligent energy management of a bipv building," in *2018 7th International Conference on Renewable Energy Research and Applications (ICRERA)*, pp. 853–857, 2018.

[7] S. Qin, L. Yu, D. Yue, and C. Shen, "Optimal hvac control in shared office spaces based on deep reinforcement learning," in *2021 China Automation Congress (CAC)*, pp. 1599–1604, 2021.

[8] H. Yin, "Building management system to support building renovation," *Department of Civil and Environmental Engineering, UCC, Snapshots of Doctoral Research, University College Cork*, 2010.

[9] A. S. P. M. P. W. T. Cholewa, A. Siuta-Olcha and Guz, “Influence of forecast control of heat supply on energy savings,” 2022.

[10] “Trade-off decisions in a novel deep reinforcement learning for energy savings in hvac systems, author=Suroor M. Dawood, Alireza Hatami Raad Z. Homod , year=2022,”

[11] R. Z. Z. O. Meng Kong, Bing Dong, “Hvac energy savings, thermal comfort and air quality for occupant-centric control through a side-by-side experimental study,” 2022.

[12] K. Rennert, F. Errickson, B. C. Prest, L. Rennels, R. G. Newell, W. Pizer, C. Kingdon, J. Wingenroth, R. Cooke, B. Parthum, *et al.*, “Comprehensive evidence implies a higher social cost of co2,” *Nature*, vol. 610, no. 7933, pp. 687–692, 2022.