Smart Energy Conservation System for High School Buildings

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***Abstract*—This paper is written based on the design of a smart energy conservation system used for high school building by applying machine learning into the feedback control system. It is further applied in the author's institution and the process and designs of the project are delivered.**

Keywords—energy conservation, system designed, machine learning, deep learning

I. BACKGROUND

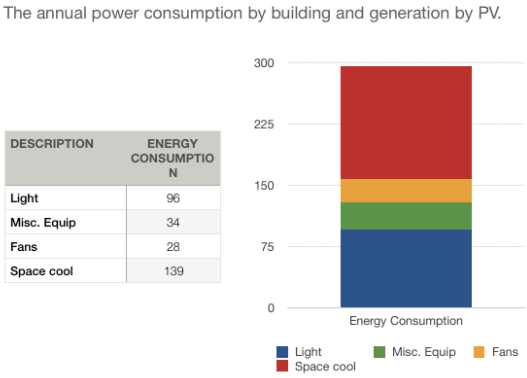
My journey of interested in this topic began with the MIT Energy Hackathon, where I started to know the idea of applying smart sensors to reduce greenhouse gas emissions. After I went back to my high school in China, I started realizing that we should not only apply these methods to university buildings, but we can make it simpler to apply it in high schools. "There are tons of high schools all over the world, if I can make it to my high school, I can make it to all." I think, which is why I chose this particular topic.

The problem we try to solve in this paper is how can we reduce the energy-waste in high-school, before doing specific researches, I predicted that we can use machine-learning and simple sensors underly with the basic feedback control system. During testing, I built up the prototype of the whole system. Overviewing my research, the heating & cooling part is more focuses on data analysis and computer science, while lighting is more complicated with how to apply it in real life situations.

Last time when I planned to leave the laboratory, I came upstairs and downstairs for about five times, closing the cooling system, experimental devices, computers, and lightnings. After I closed all these devices, the energy use of our lab would be 0. However, if I left the computer hosts behind, it will cost nearly 45 kilowatt-hours simply due to the 10 computers in our lab.

Students and teachers in high-school can only adjust the temperature manually because of the lack of human labors and technologies. While in MIT, probably the smartest campus among the world, there is only a computer-based control system that monitors energy using equipment rely on static set-points, simple feedback loops, pre-set occupancy schedules, and human operators. High schools tend to be a places with high energy consumption and lack solutions and available technologies that could help improving the situation.

This figure below gives an annual energy consumption for a school building.



——space cooling and lighting made up the main part of energy consumption.

My high-school, 179,334.3 m2 large, contains 12 teaching-buildings and 6 dormitory buildings, energy waste then becomes a serious problem. The energy-control system is commonly just relying on human labors, while students also didn't have the sense to save energy. So, how can we achieve the energy conservation in high-school by setting up smart sensors and control system seems to be an very important question.

In this paper, solution will be divided into two categories under the basic feedback control system:

1. cooling
2. lighting

All the needed input of the system will be identified in this paper, and sensors with a computer model were built for it.

Finally, I will achieve one aspect of my project's idea in the school robotics laboratory.

Since scientists have already explored the method of energy conservation for a long time, the project described in this

paper is a new try toward a different testing object than what scientists focus on.

The prototype came out finally is an efficient and reliable way of saving energy according to my calculation. However, because of the lack of resources, it's hard to apply them all now, but the project is still developing and applying.

II. Introduction

Several researches and papers were published about using machine learning ideas on calculating energy consumption and case studies were presented [1,2,3,4,5]. However, few real world application projects were designed to use the tools of machine learning on reducing energy consumption.

To further proving the likability for using machine learning in real world situation to reduce $C0_2$ footprint and energy consumption, I researched and found six academic articles providing first-hand information about using AI and machine-learning to smartly control the building, here are what I got:

-Google just gave control over data center cooling to an AI.

-Machine learning is the future of HVAC and building management.

-Machine learning is a good tool to build the Smart Building.

-Machine learning is the next step in building a smart model control system.

It's clear to see from all those articles and proposals (links in the reference section) that companies are right now focusing on reducing the GHG emissions and greenhouse effect, and all of those use machine-learning as a tool to better achieve the goal. This shows that my project is worth doing and energy-waste is a big problem in society. Besides, I also found that all these projects are more focusing on heating and cooling instead of lighting. And these projects are common focuses on big companies and universities. However, high schools are also facing this serious problem, and it needs to be solved in a different way.

By doing the research, the project proposed in this paper is narrowed down into "finding a simpler and more suitable system to reduce the energy-waste in high school". It also helps showing that my work is beneficial because there are more than ten billions of high schools around the world—— even more than university buildings. So, finding out the best system to control heating, cooling, and lighting in high school can lead to millions of economic benefits and a much more sustainable living environment.

Some emerging tech and companies information:

Buddy Platform Limited a leader in IoT and cloud-based technology, provides simple, affordable and engaging solutions for customers of any size to make their spaces smarter and their occupants more efficient, environmentally-aware and informed.

WattTime real-time data from power grid operators that detect moments when using electricity will be cleaner and enable automatic adjustments to actually choose which types of power plants your buildings rely on https://api.watttime.org/docs/.

Obvius is a leading energy solutions provider offering meters, wireless metering, data acquisition, software, and monitoring technologies used to display and manage energy usage. Obvius serves a global clientele and continues to drive innovation by simplifying data collection and connectivity.

The emerging companies that focus on solving the environmental problems and smart control system show that building a smart control system to help reduce energy-use is not easy, while it is really in an urgency.

III. Methodology, Testing and Redesign

The project is based on the feedback control system shows below, which is used to control the overall heating, cooling, and lighting system in high school dimensions. Beside the system proposed, separate algorithms and equations are shown for the separate two parts: heating & cooling, and lighting.

A. Feedback control system

This system included heating&cooling and lighting. It is mainly functions to help accurate the system since the technology today is not smart enough to fully control the buildings.

Functions:

- School schedule control
- Feedback
- Warning & Awarding

By applying this system, students and teachers can adjust the system easily. What's more, it can also help the control system to adjust itself into different modes.

More details in the solution section.

B. Heating & Cooling

First, I listed out all the input I assume to have access to and other preparation information:

Inputs:

- Occupancy sensors
- Weather Forecast
- Electricity Carbon footprint
- Students' study schedule in the building (includes holidays)

Control Inputs:

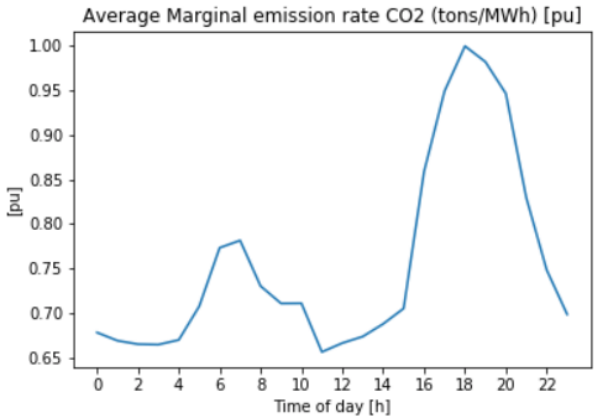
- Heating/Cooling Load
- Air Quality: CO_2 min < CO_2 < CO_2 max
- Humidity
- Air Velocity (Fan speed)
- Thermal comfort: $T_{min} < T < T_{max}$ (Constraints)

Tasks:

Identify applicable funding agency here. If none, delete this text box.

1. Features selection
   - forward selection
2. Linear regression
3. Cross-validation
4. Provide estimate value
5. Why it's important
6. Egrids
7. The creativity of data stream
8. Overall view right up front

Implement real-time BMS:
The Carbon footprint of the electrons during the day is a function of the energy mix.



Three Megatrends that came out:

- Cheaper and cleaner electricity available from RES
- Big data sets available, low-cost sensors, IoT
- The increasing cost of carbon due to climate change

Objectives:

objectives function:

$$Min\left[\sum_{t=t_0}^{T_{fin}} Em(CO2_t)\right]$$

Constraints:

- Air Quality: CO_2 min < CO_2 < CO_2 max
- Thermal comfort: $T_{min} < T < T_{max}$
- Humidity: $w_{min} < w < w_{max}$
- Air Velocity: $V_{min} < V < V_{max}$

Inputs:

- Occupancy sensors
- Weather Forecast [Temperature, Solar Irradiance, Rain]
- Electricity Carbon footprint [tCO_2/MWh]
- Students' study schedule in the building (including holidays and season)

Control Inputs:

- Heating/Cooling: Q
- Air Velocity: V

By building the model of the heating & cooling control system, I used available data from the school and came out with a solution equation that will be shown in the solution section.

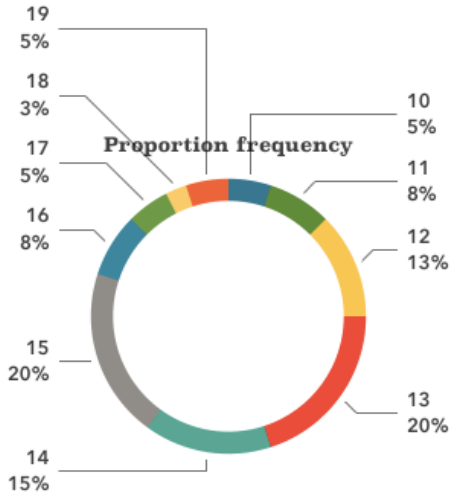
C. Lighting

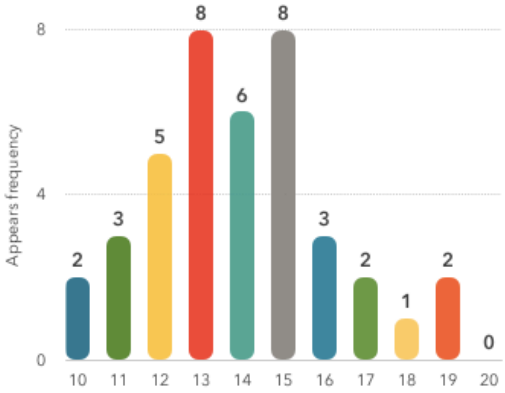
The goal:
Reduce the lighting energy by close the light when unnecessary and when the natural light is enough to light up the classroom.

Needed Inputs:

- number of people in the classroom right now
- where they sit
- natural light condition

Inputs about the average number of teachers stayed in the office during class time:





Appears frequency

10	11	12	13	14	15	16	17	18	19	20
2	3	5	8	6	8	3	2	1	2	0

Several solutions and their problems——
First solution:

1. Use photoresistor to test the real-time lighting condition outside.
2. Use a visual identity to measure the number of people sit inside and where do they sit.

Problems: Too complicated for a high-school building.

Second solution:

1. Put pressure sensors under the seat to test whether the people are sitting on their chairs.
2. Set the pre-set data into a high level that putting bags on it wouldn't be measured.

Problems: More complex and inaccurate because it cannot measure the people who are standing.

Third solution:

1. Use wifi signal to test how many people are in the room

Problems: It cannot do what I want.

Final solution will be shown in the solution section.

IV. RESULTS

The following content is also divided into three parts, where heating&cooling and lighting are sections belongs to the feedback control system.

A. Feedback control system

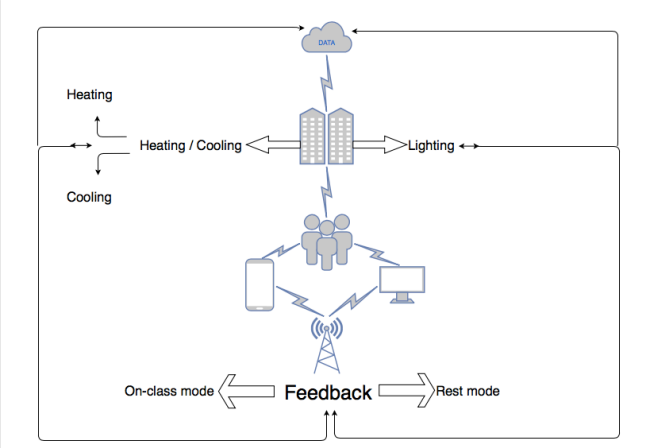
The feedback control system contains the smart model of heating&cooling section and lighting section, besides that, it is mainly built for collecting students' feedback, here are the details of applying this.

I'm designing a website that has the following application:

- On-time in-person feedback of the temperature in the room.
- On-time control of the light.
- On-time teachers' feedback to the electricity needs.
- The schedule-controlled system that allows students and teachers to see their schedule (which also used as data in the data-sets)
- Wifi-based control.

Different work modes:

- Teaching: lighting sensor will not operate.
- Rest: lighting sensor operating.
- Night: lighting sensor more sensitive.



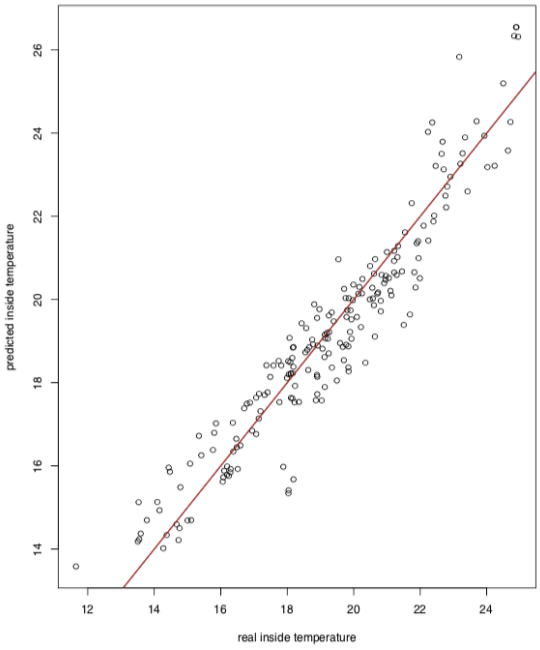
The graph above simply summarized the basic process of Feedback Control System.

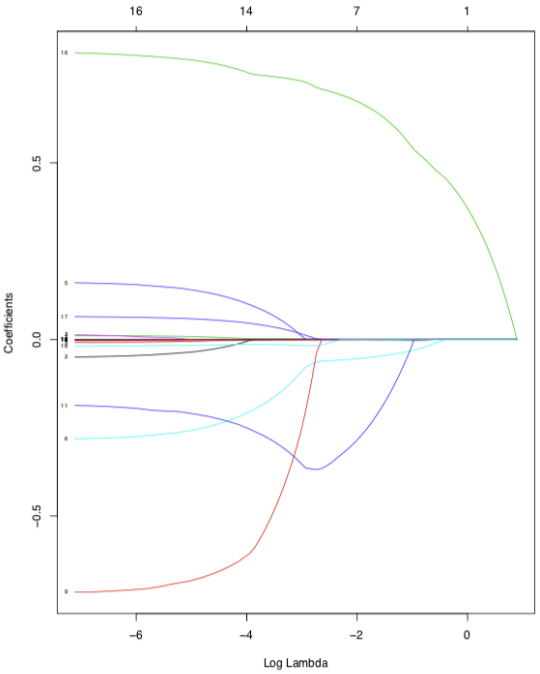
B. Heating & Cooling

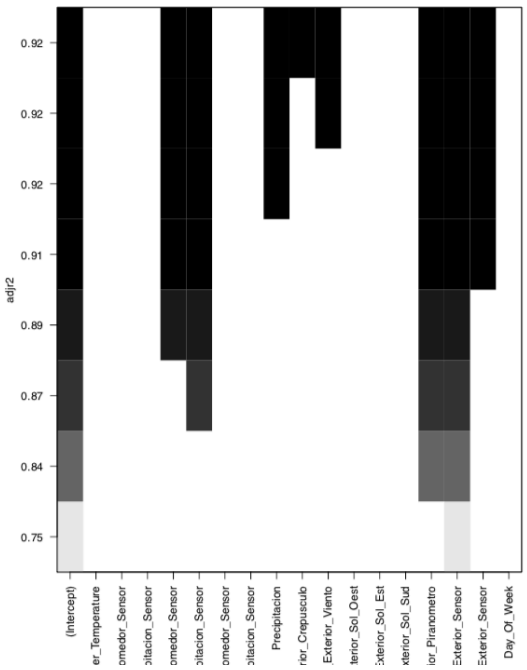
Part I: Modelling

- Use Machine Learning to learn the input-output relationship describing the state transitions in the building, using past operations points.

$$T_{t+1}^{In} = f(T_t^{In}, T_{t+1}^{Out}, T_t^{Out}, S_t, R_t, Occ_{t+1}, q_{t+1}, Q_t, V_t)$$





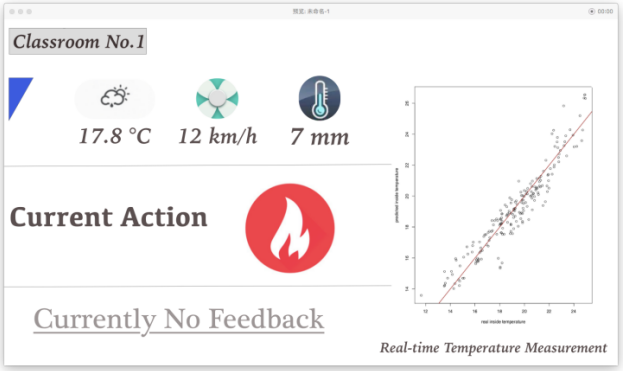


Part II:
Use Reinforcement Learning based BMS as a control strategy

- States: Indoor Temperature, Humidity, CO_2 content
- Actions: Heating/Cooling Q, Ventilation V
- Rewards/Penalization:
  - Constraint the states to remain within the desired range
  - Penalize the energy use proportionally to the electricity footprint.

The approach used here is similar to GoogleDeepMind.

The information above is the calculation model, and here is the system prototype:



These are part of the code used while modeling:
CLIMATE:

```
import pyowm
def data():
  owm = pyowm.OWM()
  observation =
owm.weather_at_place('f22907ebe5cbd95f9918f4065b2b8ee0')
  print(observation)
  w=observation.get_weather()
  w.get_humidity()
  print(w.get_humidity)
  print(w.get_humidity)

data()
```

C. Lighting

The following lighting model can solve these problems:

1. Unused lighting resources while there are only a few people in the room.
2. The inefficient system of controlling lighting.
3. Too light or too dark in the room.

Project outline:

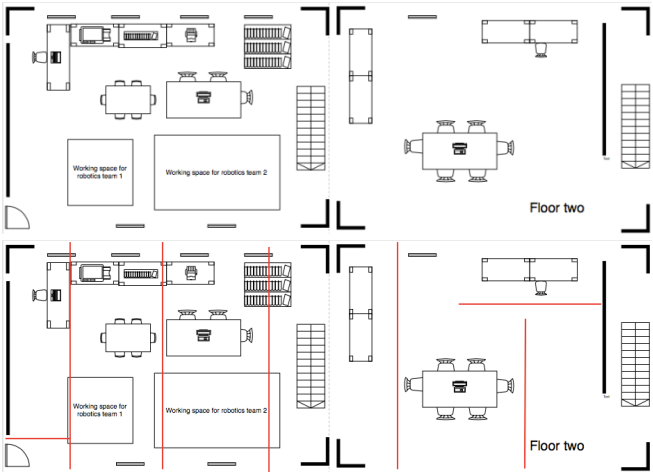
1. Divided the classroom into few parts depends on the location of the light.
2. Use two Infrared Ranging Sensor per line to set up quarters.
3. Use them to test whether there are people in the area. (Like fences)
4. While there are people entering the places, open the light (also consider lighting conditions).
5. Close the light if people are leaving.

Materials I used are:
Infrared Ranging Sensor
Infrared Sensor Switches HC-SR501

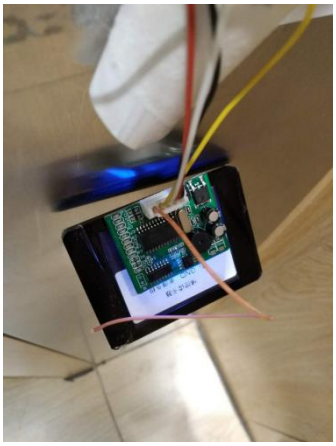
3D-printed box

Explain: Infrared Ranging Sensor is used to build up the "fence". Infrared Sensor Switches can open the light when people are coming in a range of area are used in corridors.

Details in applying this lighting system in the school lab:



The second figure is basically how the light is divided.



Here are the problems while dividing the classroom into distinct parts:

- The light may flash while too many people walking.
- It's hard to divide the area into exact parts.

Solutions:

- Setting the timing: light will only closed when there is nobody step in the area again in 8s.
- Across areas.

Project's benefits and outputs:

1. Save nearly 13.9 kwh a day per floor.
2. While there are only 10/20 teachers in the office during the class-hours, it can help close the unnecessary lights.
3. Helps people to close the light while leaving.
4. Identify the lighting condition.

V. Conclusion

As a conclusion, my project achieves the following points:

- Real-time monitoring and machine learning models help to continuously update the forecast of the main inputs, such as space heating/cooling demand
- The energy mix footprint informs the optimization process to minimize emissions
- The algorithm self-learn from data and is adaptive
- In a future scenario including Heat Pumps could contribute to reducing the emissions giving the system more flexibility and higher efficiency.
- Dividing lighting into areas that turn big energy-use into small.
- Great system that can avoid mistakes and flash of light.
- On-time in-person adjusting system that allows the project to be more accurate.
- Different modes that allow students and teachers to choose.

The final output of my project can save about 12.5 - 18.1kwh (45000-65000 KJ) per day for a single floor in my high-school, which is very worth-applying because of the low cost of sensors and feedback control system.

Details about low-cost sensors used in this paper:
Use the school as a model, 14 Infrared Sensor Switches are needed, which will cost about 18.5 USD for a whole lab. Besides that, 1 Infrared Ranging Sensor is needed, which will cost about 1.3 USD. Totally, it will cost up to 20 USD for a whole lab (excluded the cost of building system), and the cost can be paid back in 15-20 days.

As the problem proposed at first is how to reduce the energy use by setting up models, my experiment answers this question in heating & cooling, lighting two particular parts under the basic feedback control system. The findings in this paper support my previously expected outcome that machine-learning can have smarter control of the building, and we can easily reduce the use of lighting by setting up sensors.

Though the project done in this paper is very huge, difficult and common. I have already started applying this project in my school lab and school classrooms. However, since the project is still not an "all-fit model", we cannot copy it to occupy directly in another school. But—— the overall structure is the same and I will keep on figuring out the "universal model".

In my perspective, the experiment is successful in some aspects because it is started to apply in my high-school, and more helps is needed from the society and the school to complete this project. If I can redesign the project, I will not change my goal even though it's so hard since I think it is useful to my community and I want to develop it for all high schools. The research is still during its process. I will add up more sections under the feedback control system, for example, I will build up smart control models toward teaching equipment after I finish heating&cooling and lighting. This paper is only part of the process I took in the whole experiment.

Acknowledgment

Thanks for Grishma Atul Thakkar, Pratik Kumar Kundanmal Jain, Chirag Soni, Davide Innocenti, Nutchapol Dendumrongsup, and Xinyue Wang, who are the teammates of mine during the MIT Energy Hackathon 2018. We did the heating & cooling sections' ideas and basic model. I really appreciate all the hard works we've finished during the 38 hours in MIT. I learned a lot from them so that I can finish the rest of the project including feedback control system and lighting on my own for my high-school afterward.

Thanks for Jiahao Li, who is my computer science teacher and the administration of the Farol robotics lab. He gives me the access to use the materials and do the experiments in the lab, and many tips to finish the project.

Thanks for Yuxiang Chen, my physics teacher, who gives me a lot of advice during my experiments and helps me to build up my structure.

Thanks for my parents, Yexiao Yan and Qing Cui. They support me so much and encourage me every time when I am working through a hardship.

All the figures and pictures in this project are made by myself, and all the parts of "feedback control system" and "lighting" are made by myself individually. It is a very

pleasing experience on doing this project and thanks my school, Guangzhou Foreign Language school, for helping me to do so.

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