2019 电子科技大学美国数学建模竞赛模拟赛

承　诺　书

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我们的题目编号是：B

我们报名队伍号是：H153

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是否愿意参加 2019 年美国赛（是，否)：是

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日期：2018 年 11 月 16 日

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Applied Mathematicians to Create Cozy Smart House: Fully automatic thermostat

Team Number:

Abstract

No one wants to spend more money than necessary on heating and air conditioning. But, everyone wants to be comfortable and cozy while at home. However, you must have these experience: when you arrive home from an entire day of busy work in winter, you were extremely cold, but after you arrived, you had to turn on the heating and wait a long time for it to warm the house; when you too hot because many people were having fun at your house you had to lower the temperature by yourself.

The development of fully automatic thermostats was an initial effort to assist in reducing energy costs. With a programmable thermostat and connect the system to your phones, the smart home climate control systems will automatically and appropriately adjust the temperature of your house in response to your departure and in anticipation of your arrival no matter how irregular your schedule. The smart climate system is able to incorporate some measure of ambient outside temperature variations, as well as geographical/regional conditions such as humidity. Also, the system can integrate your preferences for temperature (day, night, weekday, weekend) and other factors, such as humidity and air purity levels.

By modeling the changes in many variables, such as season, humidity, time, etc. Take Mathematics, Physics, Geography and Biology into consideration. We connect the system to users' phones or computers, so that there is no need of a remote control, and we also made use of the GPS technology. Through a number of algorithms we aim to create a programmable thermostat benefit to user's health, environment, and also energy-saving and very convenient.

We create two mathematical models to make the system smarter and more user-friendly.

- We combine the GPS technology with the first model to determine the needing advance running and shutdown time.
- We design questionnaire to choose the most reasonable temperature among three different choices which we given in the questionnaire, and find a numerical solution by applying the analytic hierarchy process (AHP) to the equation using MATLAB.
- We consider efficiency and changes in external environmental factors, use the second model to define the most energy-efficient operation way of the main system.

We perform sensitivity analysis on a couple of parameters and discuss the strengths and weaknesses of our model.
We strongly recommend our model because of its reasonable assumptions, convincing estimation of key parameters, and clear but robust results.

Background

History of air conditioner

Early in 1924, a shopping mall in Detroit first installed three central air conditioners. After that air conditioner starting to enter people's lives and people began to benefit from air conditioners and enjoy the cozy environment it brings to them. Up to this day, air conditioning has become an inseparable part of people's lives.

In order to make precise improvements, we have taken large amounts of parameters of different types of air conditioners into consideration. We divided all kinds of temperature regulation system into two parts roughly, one is traditional air conditioner, the other is modern thermostats connected to cell phones or computers which can be controlled remotely by APPs or software.

Limitations of air conditioners in the market

Traditional air conditioners hold very simple functions, users have to control the system manually by remote control within a very limited distance (as table 1 shows below).

Table 1
Telecontrol distance of traditional air conditioner of 5 different brands

Brand	Gree	Midea	AUX	Haier	TCL
Telecontrol distance (m)	8	9	9	10	7

With user forget to turn off the system carelessly, that will result in additional energy consumption and pollution, some business use the harmful refrigerant which will cause damage to health and pollute the atmosphere. For example, Freon deplete the Ozone layer and aggravate global warming (In October 1984, the United Nations adopted the “Montreal Protocol on Substances that Deplete the Ozone Layer).

Recent years, thermostats were made more and more environmental-friendly, some smart thermostats can preset the opening and closing time but it has limitation with irregular schedule. And the unsuitable running time will lead to temperature/humidity too high or too low that would make people sick and waste of energy.

Content

7.reference	

1. Arrival and Departure

1.1 Purpose

We aimed to let the smart home climate control systems adjust the temperature of user's house automatically and appropriately in response to their departure and in anticipation of their arrival no matter how irregular your schedule. As a result of this, users can live in a cozy temperature environment while they are at home, and after they leaving ,the main system (fully automatic thermostats) will be in standby mode and the heating and air conditioning subsystems will be shut down by the main system.

1.2 Key Symbols Table

Table 1

symbol	unit	meaning
R	km	Distance between home and user when system start to work
	km/h	Speed of user when run into a traffic jam
	km/h	Speed of user when the road is clear
	h	Time spend in a traffic jam
	h	Time spend on a clear road
	h	Total time spend on the way back home
S		Area of house
h	m	Hight of house
		Volume of gas in house
		Volume of house
t	h	time
	Pa	Standard atmospheric pressure(1.01)
	w	Refrigeration power
	w	Heating power
	degree centigrade	Temperature inside the house
	degree centigrade	Temperature outside the house
ΔT	degree centigrade	|
	J/(mol.K)	constant

1.3 Assumptions

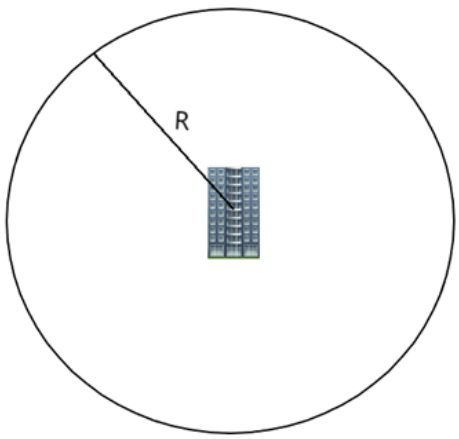
- The back-home path is a straight line.
- The location of the house is in Chengdu, and we ignore the energy change

in vapor of air.

- The atmosphere is 99% made of and ,
- The temperature inside cannot reach the point that make the molecule to have the vibrational degreed of freedom (i=5)
- Assume atmospheric pressure as standard atmospheric pressure(1.01)
- Assume the morning jam is from 7a.m to 9a.m, evening jam is from 17p.m to 19p.m.
- The speed out of morning and evening jam is equal to
- We will discuss how to decide preset in the next part, so we take =25 as an example in order to show the relationship between t and R.
- Ignore the impact of windows and doors, because we only consider about a single room here so that the heat transfer through the windows and doors can be ignored.
- The related error is A%
- Assuming statics

=0 km/h	48.18 km/h[i]	S=18 [ii]	h=2.5m[iii]

1.4 Solution and Calculation



path sketch

We use the GPS system in cell phone to locate distance(R) between user and house(at the center of circle in the above graph), take the road and traffic condition into consideration, we divide the situation into two types according to seasons: SUNMMER and WINTER. Consider about saving energy and efficiency, we design that user will not use air conditioner in Autumn and Spring, because temperature in these two seasons are close to 25. The system can predict to start air conditioner when the user arrive at the point R kilometer away from home, but if the user continue being in the ‘circle’ , after a period of certain time , the system will send message to your cell phone so that you can turn off the air conditioner with your phone. We create a function R(t) to achieve the goal.

Congestion delay index D=

Congestion delay index(morning) =1.64

Congestion delay index(evening) =1.93

The average speed of way back home

Average speed in the morning jam

Average speed in the morning jam

S=18 h=2.5m

molar heat capacity at constant volume

(i=5, because and both are rigid diatomic molecules)

1.4.1 Arrival (Summer Time)

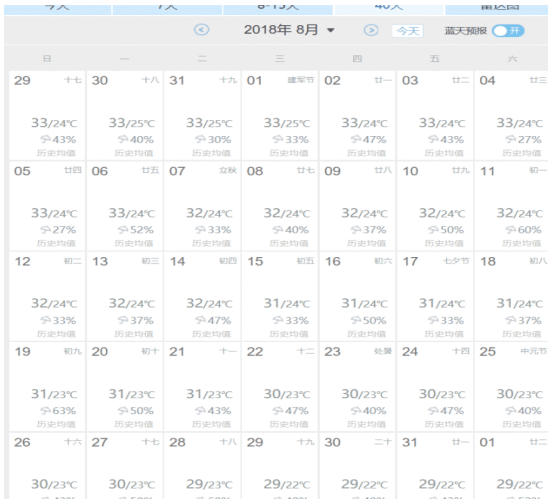
The absolute value of heat required to achieve the required temperature:

We use the refrigeration power of a brand of air conditioner as the benchmark:

t=(s)=(h)=0.00976(h)

R(t)=

Simulation of diurnal variation of temperature using sinusoidal segmentation method[v]:



= 23.57°C

3.86

Figure 2

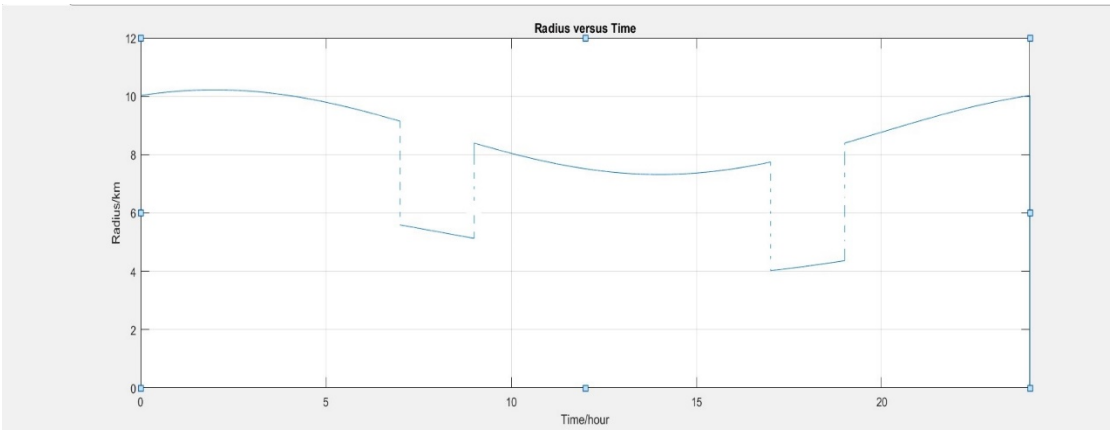


Figure 3

The vacant part in graph means at that period of time the outside temperature is below 25, we consider that there is no need to use the air conditioner for protection of environment and saving energy.

1.4.2 Arrival (Winter Time)

The absolute value of heat required to achieve the required temperature:

We use the heating power of a brand of air conditioner as the benchmark:

t=(s)=(h)=0.0094(h)

R(t)=

Simulation of diumal variation of temperature using sinusoidal segmentation method[vii]:

3.10

Figure 4

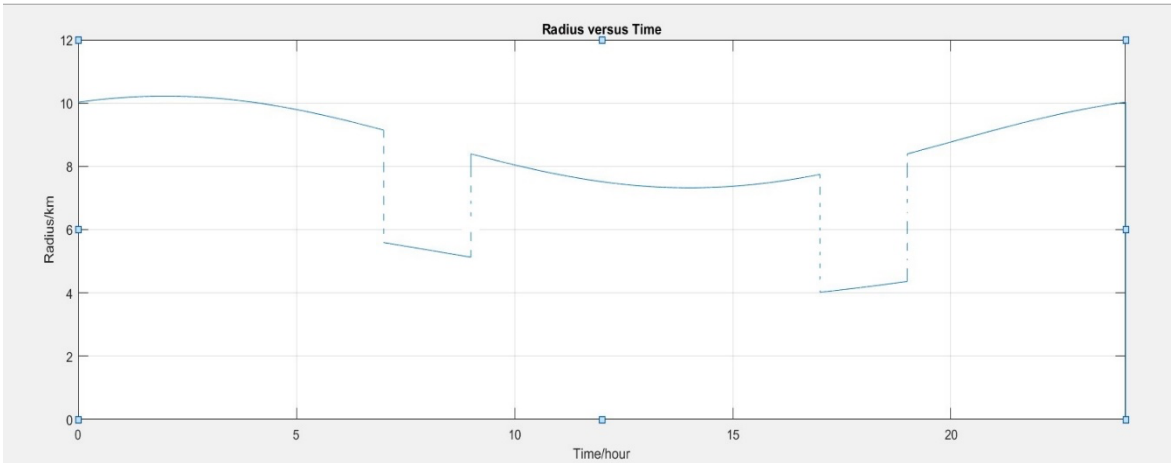


Figure 5

1.4.3 Departure

The departure problem is not as complex as arrival problem. Our solution is that, when the user(with cell phone installed GPS system) leave their house, the temperature control system will shut down immediately, so that there will not be additional energy cost. Meanwhile it can also contribute to environment protection.

2. Preset of temperature

2.1 Background

When considered about how to determine the preset temperature, we found something interesting.

Formaldehyde[viii], which is widely used. It is a popular chemical product with simple production process and sufficient supply of raw materials. It is can be detected almost everywhere in our daily life, especially in house after renovation. On October 27, 2017, the World Health Organization International Agency for Research on Cancer published a list of carcinogens, formaldehyde in a list of carcinogens, so it is a vital harmful chemical substance to human's health. As the figure 6[ix] shows below, after temperature higher than around 35°C, formaldehyde volatilization increase rapidly.

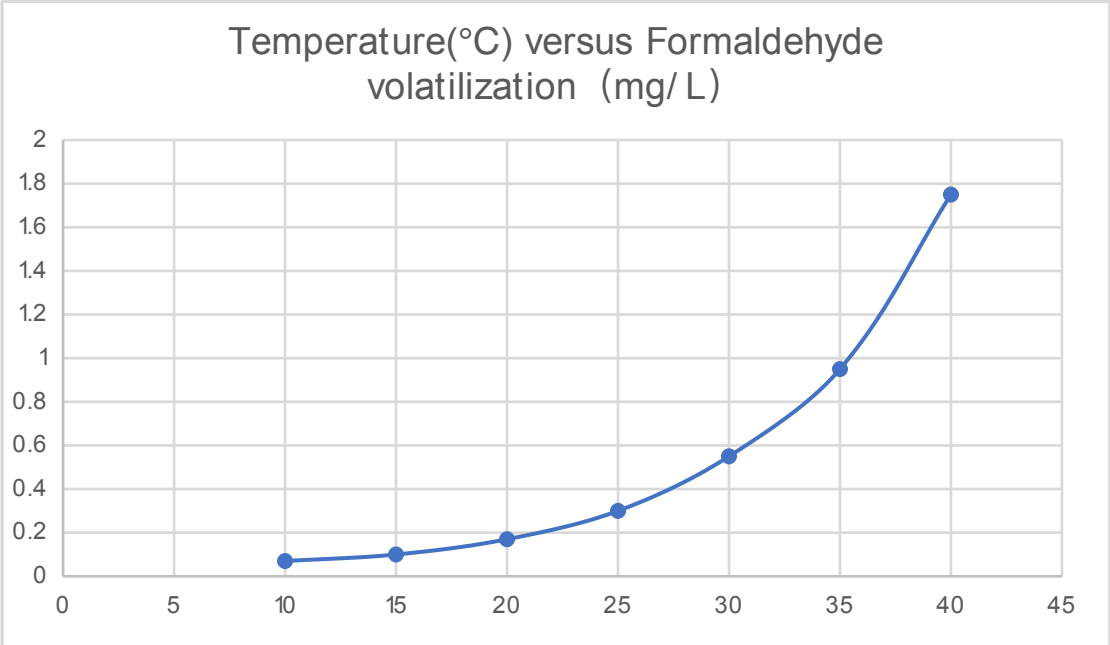


Figure 6

Because of this, we collect temperature range of different brand air conditioners and the table 2 indicates that the maximum temperature the air conditioners can achieve are all under 35°C.

Table 2
Temperature Range of Different Brand Air Conditioners

Brand	Type	Minimum T(°C)	Maximum T(°C)
Midea	KFR-35GW/WDAD3	17	30
AUX	KFR-35GW/(35592)FNhDa-A3	16	30
Gree	KFR-35GW/BpTYC1+1	16	32

Haier	KFR-36GW/16GAB13U1	17	30
TCL	KFRd-35GW/FC23+	16	31
Yair	KFRd-35GW/080-E3	16	32
CHANGHONG	KFR-35GW/DHG3+2	16	32

2.2 Purpose

We use mathematical model Analytic Hierarchy Process (AHP), we use this kind of model twice under two different conditions respectively. We decided conditions based on four seasons, the first type is 'Spring and Autumn' and the second type is 'Summer and Winter'.

The reason for why we make classification as above: in these four seasons, Spring and Autumn are both very close to the assumed preset temperature, while Summer and Winter are both 'extreme'.

We set three different consideration factors: energy-saving degree, comfort degree, impact on health. And we also set three different data types for preset temperature: temperature under the maximum efficiency, the temperature which is most comfortable for human, the temperature outside.

2.3 Solution

2.3.1 Assumption

A (determine preset temperature)

Consideration factor:

data type

Table 3

Matrix order	1	2	3	4	5
RI	0	0	0.58	0.90	1.12

(CR should smaller than 0.1)

2.3.2 Spring and Autumn

Table 4

A			
	1	2	3
	1/2	1	2
	1/3	1/2	1

CI= 0.0046 CR=0.0097

Matrix B1—C

Table 5

B1	C1	C2	C3
C1	1	1/2	1/3
C2	2	1	1/2
C3	3	2	1

CI= 0.0046 CR=0.0079

Matrix B2—C

Table 6

B2	C1	C2	C3
C1	1	1/3	1/2
C2	3	1	2
C3	2	1/2	1

CI= 0.0046 CR=0.0079

Matrix B3—C

Table 7

B3	C1	C2	C3
C1	1	2	1/2
C2	1/2	1	1/2
C3	2	2	1

CI= 0.0268 CR=0.0462

Table 8

arrangement	B1	B2	B3	Total sort weight
C1				0.1875
C2				0.3525
C3				0.4599

As the result of all data above, the preset temperature for spring and autumn should be set as temperature outside.

2.3.2 Summer and Winter

Table 9

A			
	1	1/4	2
	4	1	3
	1/2	1/3	1

CI= 0.0539 CR=0.0930

Matrix B1—C

Table 10

B1	C1	C2	C31
C1	1	3	1/4
C2	1/3	1	1/5
C3	4	5	1

CI= 0.0429 CR=0.0739

Matrix B2—C

Table 11

B2	C1	C2	C3
C1	1	1/5	3
C2	5	1	7
C3	1/3	1/7	1

CI= 0.0324 CR=0.0559

Matrix B3—C

Table 12

B3	C1	C2	C3
C1	1	3	4
C2	1/3	1	2
C3	1/4	1/2	1

CI= 0.0091 CR=0.0158

Table 13

arrangement	B1	B2	B3	Total sort weight

C1				0.2626
C2				0.5184
C3				0.2188

As the result from the data above, the preset temperature for summer and winter should be set as the temperature which is most comfortable for human.

3. outside temperature variations(humidity)

3.1 purpose

we aim to find the most energy-saving preset temperature by taking the outside temperature and humidity into consideration. As we have proved in the third part, in fall and spring he most energy-saving and comfortable preset temperature is the same as outside temperature which means there is no need to operate the system. So in this part of problem, we divide problem into two situation: Summer and Winter.

3.2 Key Symbol

Table 14

symbol	unit	meaning
c	J/(kg·°C)	Specific heat capacity of water
m	kg	Mass of the water of the air in the rom
V		Area of the house
e	pa	Actual vapor pressure of the water
RH	None	relative humidity
SVP	pa	Saturated vapor pressure
	J	The energy used to cool the room
	J	The energy used to heat the room

3.3 Assumption

- We assume EER as a stable constant.
- We assume COP as a stable constant.
- The air only contains water vapor and and
- Assume atmospheric pressure as standard atmospheric pressure(1.01)
- The temperature inside cannot reach the point that make the molecule to have the vibrational degreed of freedom (i=5)
- The relative humidity is 50%,which is the optimum humidity of humans[x].

3.4 Solution (Summer Time)

The Energy Efficiency Ratio of air conditioner is known as: EER=

Let

Firstly, we want let:

,

so that we can get the minimum of W, which means the system has the highest efficiency, and obtain the function about with the change of . However, we found that MATLAB cannot calculate this complex equation above, so we use two method instead MATLAB to estimate the result.

3.4.1 The First Method:

let 16x30(Because it is the range of most of air conditioners in the market) 25y40(according to the figures in part one), then randomly generate one hundred point (x , y) at this interval, we found that after putting these points into calculation, the value of is always smaller than 0, from which we can say is always smaller than 0 at this interval.

This method make use of Monte Carlo method, which would have probability of error.

3.4.2The Second Method:

Let in which equals to, from this can make the derivative of W become easier to calculate. From calculation, we can get:

3.4.3 Conclusion

the result of both of these two methods is , which means W is a decreasing function ofin summer, means the preset temperature should be set to the maximum temperature the air conditioner can reach, with that the W can

achieve the minimum value . This is why our parents will ask was to set an higher temperature in summer.

3.5 Solution (Winter Time)

The Coefficient of Performance of air conditioner is known as: COP=

Let

Let , we can get:

(1)When we plot this equation on MATLAB(as y-axis, as x-axis),we can get:

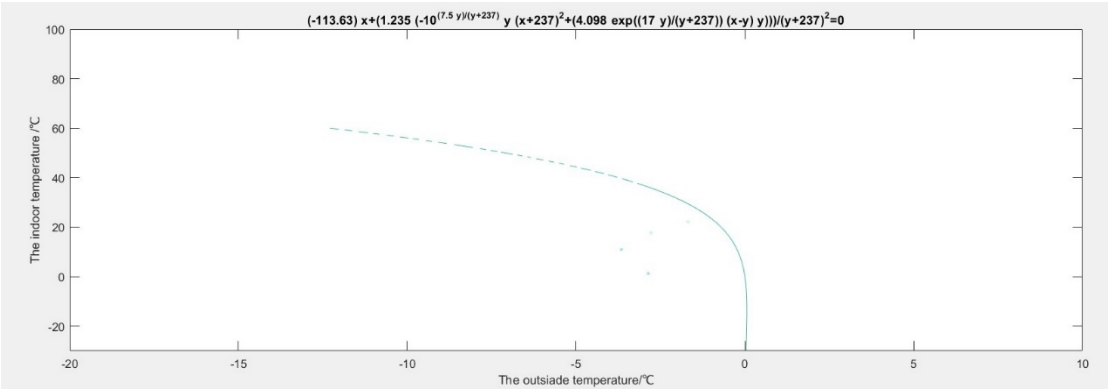


Figure 7

(2) when we use Monte Carlo method again , we randomly generate one hundred points in16 and 0, also can get , so we can speculate reasonably that when0.

3.6 Conclusion

if we want to get the minimum of W under the situation that , we need to pick out under different to make (but the data is useless when). is always smaller than 0 when which proved that when, we need to preset the temperature to the maximum value that the air conditioner can reach in order to achieve the maximum operating efficiency of system.

4. weekday and weekend(more than one person)

4.1 purpose

we talk about how to deal with the situation that one person live in a single-room apartment. However, nowadays, many house has many people

live in a big house with many rooms so they may need multiple thermal control system, even some people choose to live by himself but there always be visitors. At this part, we would like to discuss how to decide which of these air conditioners to be put into use while the user need more than one air condition. However, since there are so many house type in the world, we will firstly discuss the situation of two-rooms-and-one-hall type. Later, we will discuss n-room situation.

4.2 Assumption

- let to be the room, when means the system in this room is operated, when means the system in this room is shut down.
- at weekends, people will all gather around in the hall, while at weekdays people will stay in their own room (one room one person)
- according to part 2 we assume the preset temperature is remain 25°C
- barometric pressure is 1 atm and we ignore the energy the vapor released or absorbed
- according to the annual temperature variation chart below, we regard as , where x represent month
- every room has stable , and
- the air conditioner of every room changes the temperature one time per day
- only the windows will have energy exchange with the environment
- every room has only one air conditioner

4.3 Key Symbol Table

Symbol	unit	meaning
x	none	month
	J	Absolute value of energy every room need to reach 25 degree centigrade
	J	Absolute value of the energy change from windows of every room per day
	w	Absolute value of the power change from windows of every room
	w	Heating/cooling power of every air conditioner in every room
	w	Electric-consuming power of every air conditioner in every room
		The volume of the room
		Area of window
	J	Energy consumed by each room per day
	Degree centigrade	Average outdoor temperature per month

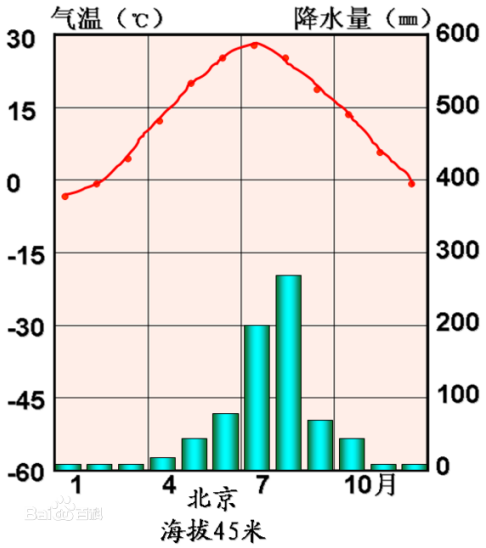


Figure 8

4.4 solution

Figure 9

Because as we discuss before ,,in the spring and fall ,we do not to open the system, and we use the mean of an 1 unit (show in the figure below) and use it to replace the temperature in a day every month, which means that is a constant in every day of every month

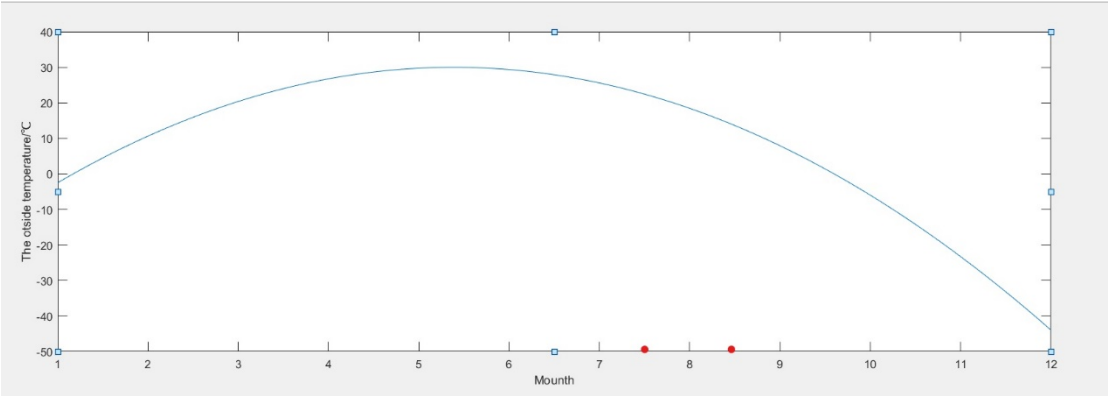


Figure 10

in December °C
in January °C
in February °C
in June °C
in July 25.4°C
in August °C

In the main bedroom :

=

In the secondary bedroom

=

=

In the main bedroom:

=

In the secondary bedroom

=

In the hall:

=

According to the regulations of the national refrigeration Department , we choose=1470w from the main bedroom , the secondary bedroom, the hall respectively. We have chosen a brand in the market.
The electricity energy needed a day is:

4.5 Conclusion: After we code in MATLAB, using zero-one programming
Finally, we know that at weekends ,we can use the least energy by only turn on the air conditioner in the hall , and in every month of weekdays, the most efficient way is to only open the system in bedrooms.
And it is to see that, the most energy-saving way is just opening the system in where we need. So to be more general, in n rooms situation, we can use the equation:
to calculate the minimum energy cost.

5. comparation

5.1 Room Air conditioning systems (RAC)

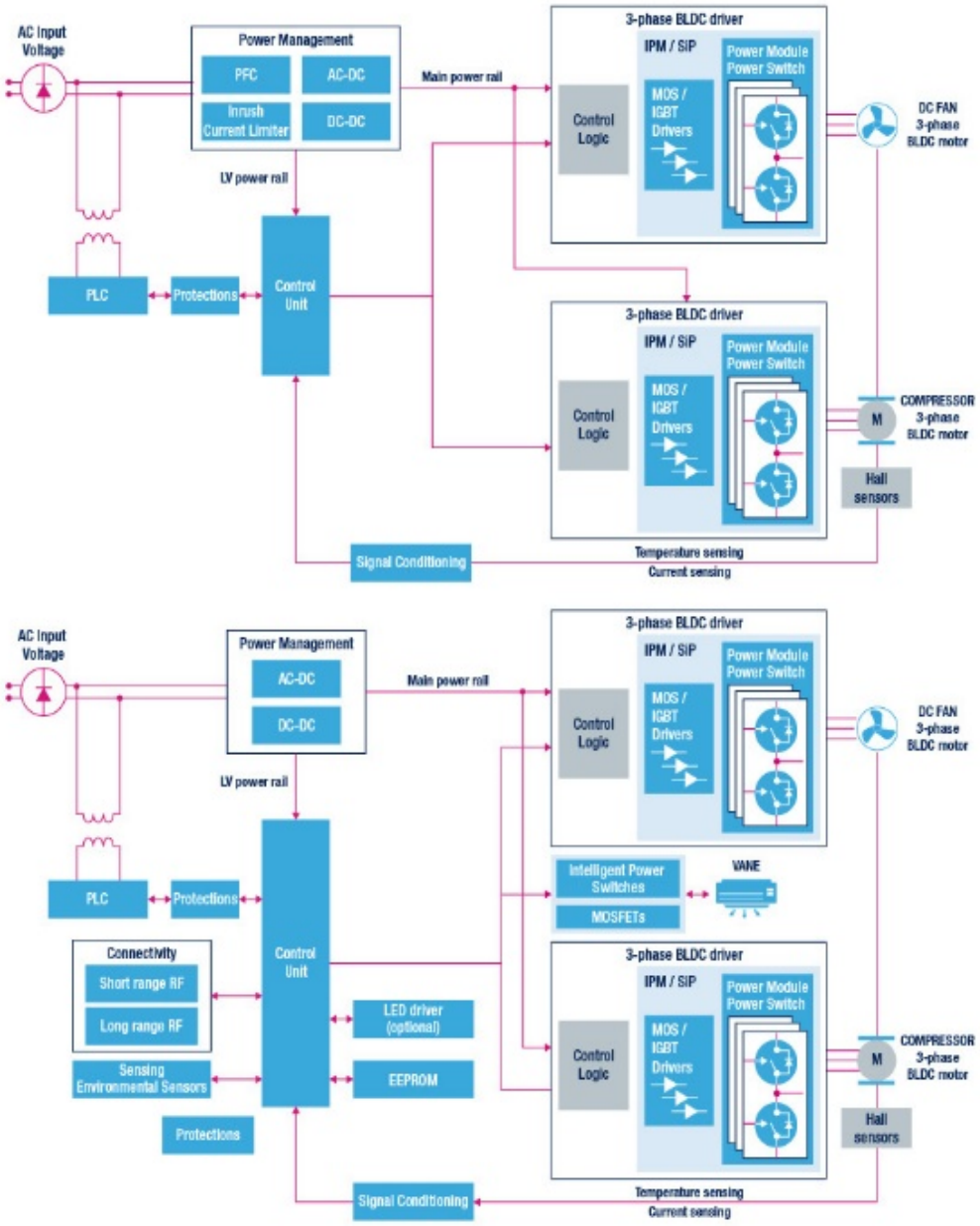


Figure 11

RAC provide a large selection of IGBTs, power MOSFETS and intelligent power modules (IPM) as well as integrated motor drivers and STM32 microcontrollers to build high-efficient motor control solutions as well as a wide selection of MEMS environmental sensors and wireless connectivity solutions to enable building more connected and efficient Air conditioning solutions.

In addition it provide a comprehensive set of HW and SW evaluation and development tools and reference designs to help compress time to market.

5.2 Heating control system

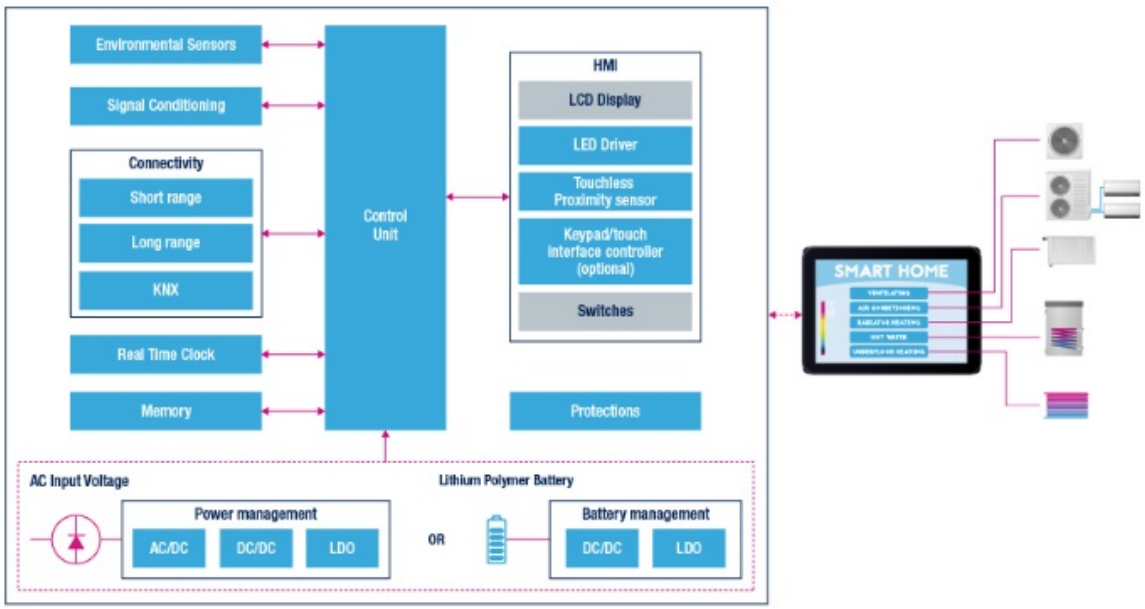


Figure 12

In a heating control system inputs from sensors are used to control valve and heating components – including electric radiators of gas furnaces – to regulate temperature in the different rooms in a house or commercial building. New generation of heating control leverage cloud connectivity to enable control temperature from anywhere using a mobile app.

It has a large offer of ultra-low power STM32L 32 bits microcontrollers and ultra-low wireless connectivity solutions – including Bluetooth low energy and sub-GHz as well as cloud connectivity sw packages and temperature sensors.

In addition it provide a comprehensive set of HW and SW evaluation and development tools to help design ultra-low power heating control systems.

5.3 Conclusion

5.3.1 Advantages:

- our system is much more convenient for people who do not have very regular schedule, users just need to preset the temperature he or she prefer and then the smart system can operate by itself.
- The system is also very energy-saving , because it will turn off automatically when owners were away.

- Another point is that users can enjoy better using experience result from the function that it can operate in advance , so when people arrived home, the house is already be in a nice temperature.
- What's more, our system did not need too much high technology sensors to manufacture, which means, its production expense could be really low.

5.3.2 Disadvantages:

- Our system is not accurate and precise enough.
- Because one of its main target is to save energy so that it efficiency might not be as good as other air conditioner systems.

6. *News Release*

Early in 1924, a shopping mall in Detroit first installed three central air conditioners. After that air conditioner is starting to enter people's lives and people began to benefit from air conditioners and enjoy the cozy environment it bring to them. Up to this day, air conditioning has become an inseparable part of people's lives.

No one wants to spend more money than necessary on heating and air conditioning. But, everyone wants to be comfortable and cozy while at home. However, you must have these experience: when you arrive home from an entire day of busy work in winter, you were extremely cold, but after you arrived, you had to turn on the heating and wait a long time for it to warm the house; when you too hot because many people were having fun at your house you had to lower the temperature by yourself.

What can our Fully automatic thermostat do?

- Automatic control system (prediction) - turn on when you arrive, turn off when you departure
- Saving energy – high efficiency
- Environmental friendly – less air pollution
- Convenient – system connected to you electronic devices, you can control it from everywhere

In order to make precise improvements, we have taken large amounts of parameters of different types of air conditioners into consideration. We divided all kinds of temperature regulation system into two parts roughly, one is traditional air conditioner, the other is modern thermostats connected to cell phones or computers which can be controlled remotely by APPs or software.

We aimed to let the smart home climate control systems automatically and appropriately adjust the temperature of user's house automatically and appropriately in response to their departure and in anticipation of their arrival no matter how

irregular your schedule.

7. Reference

[i] https://wenku.baidu.com/view/36f751530a4e767f5acfa1c7aa00b52acec79c51.html
[ii] https://wenku.baidu.com/view/cad98ee49fc3d5bbfd0a79563c1ec5da50e2d6af.html
[iii] https://wenku.baidu.com/view/28af6716bf23482fb4daa58da0116c175f0e1e95.html
[v] https://wenku.baidu.com/view/2318ad0976c66137ee0619f4.html?sxts=1542008121634
[vii] https://wenku.baidu.com/view/2318ad0976c66137ee0619f4.html?sxts=1542008121634
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