Intelligent Thermostatic

Elemental Programming: Workshop 2 (Gr.Prog.)

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Student Report

Aalborg University

Contents

Chapter 1

Introduction

The rising prices of electricity is proving to be quite an economic hurdle for a local restaurant. Because of this they are looking into having a smarter control-system implemented for keeping their refrigerated food store room cool. Such a system should be capable of lowering the consumption electricity of the compressor and it should be able to regulate when to cool determined by the cost of electricity.

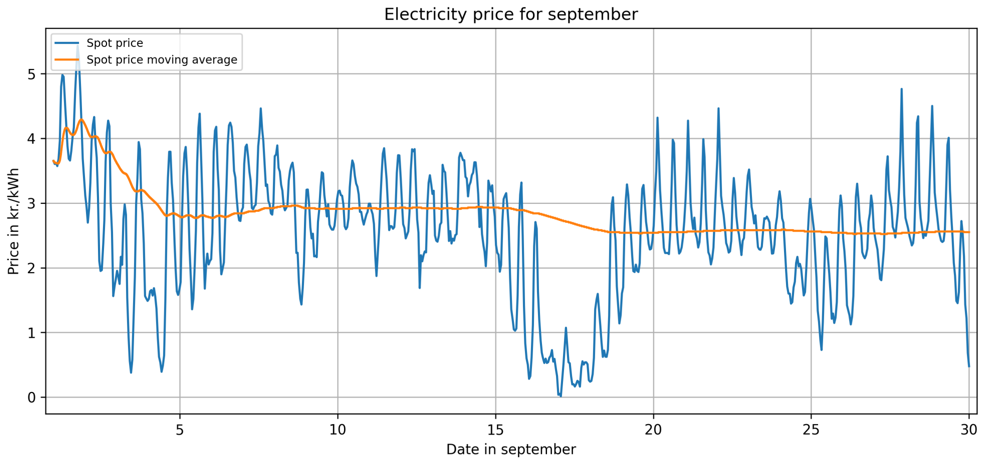

Figure 1.1: Spot and Moving average electricity prices of September 2022

1.1 Tasks

A. Simulate the temperature of the refrigerated room with the current thermostat

- Simulate when the compressor is cooling and when it is not
- Simulate when the door to the cooling room is open and closed

B. Calculate the total cost of running the refrigerated room from:

- The cost of electricity with variable spot prices
- The cost of food deteriorating if the temperature is nonoptimal

C. Calculate the average monthly cost of running the refrigerated room over many siumulations

D. Design and implement a smarter thermostat to lower the usage and cost of electricity

E. Compare the performance of the new solution to that of the old one

Chapter 2

Intelligent Thermostat

One of the main pitfalls with the conventional thermostat is that it runs more or less all of the time, even when the price of electricity is very high. A simple way to design a more effective solution would be to introduce a price limit where, if the price is too expensive in regards to the limit, the compressor will not run unless it is absolutely necessary.

Considering the restaurant has already done the research determining the optimal temperature zone for the refrigerated room where the food does not deteriorate, such a system is quite easy to design and implement.

2.1 Design

The intelligent thermostat has an upper and a lower temperature limit. If the temperature *rises above the upper limit*, the compressor will run no matter the price in order to bring the temperature down to a safe temperature. If the temperature *falls bellow the lower limit*, the compressor will stop and not start until the temperature is over the limit.

Food deteriorates over	6.5°C
Upper comfort limit	6.0°C
Safe Zone	–
Lower comfort limit	4.0°C
Food deteriorates under	3.5°C

Table 2.1: Comfort- and deterioration temperature limits for food

The comfort zone is positioned 0.5°C from the deterioration limits on both ends, so the working comfort zone is 4.0 - 6.0°C. The system aims to always stay inside of this comfort zone to keep the food waste at a minimum.

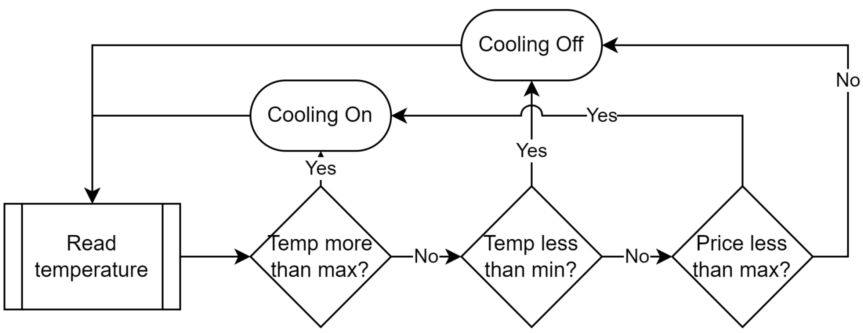

Figure 2.1: The basic logic behind the intelligent thermostat

2.1.1 Criteria for success

For the intelligent thermostat to be considered a success in comparison to the conventional thermostat the following requirements should be met:

i. Intelligent thermostat can effectively bring down the electricity cost for September

ii. Food waste is kept at a minimum

iii. The total cost is overall lower than with the conventional thermostat

2.1.2 Limitations

Picking out a single limit price for this method works well on a static data set, but if the method were to be instated in reality, it is expected that some months the method will perform very poorly if the spot prices are too low or too high compared to the limit price.

Since the hourly price of electricity (spot price) is known no more than 36 hours ahead, this would not be a very effective solution for a intelligent thermostat, as simulations determining the optimal limit price for the following day would have to be run each day. A smarter and more dynamic solution will be discussed briefly in the conclusion (*Chapter 3*)

2.1.3 Limit price

It is important that the limit price is set correctly. *If The limit is too high*, the compressor is allowed to run all the time and will not be an improvement over the conventional thermostat. *If the limit is too low*, the compressor will not have enough time to recover the temperature after the door is opened, and the food will deteriorate.
The Monte Carlo-method is used to test for the optimal limit price.

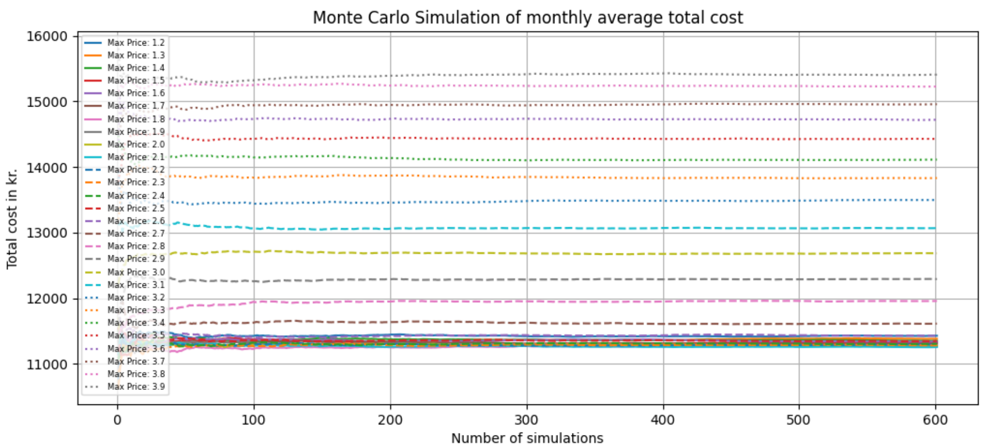

Figure 2.2: Using the Monte Carlo-method to find the optimal limit-price

Looking at the data set it is evident that a lower limit price leads to an overall lower total cost since the compressor will be running less often. It is however also evident that as we approach the monthly total cost of 11.500 kr., the improvement in price seems to stagnate. The whole interval of limit prices from 1.2 to 2.6 kr./kWh is present in the range of around 11.500 - 11.250 kr.

Filtering out the higher totals from the plot allows us to zoom into the best performers. This reveals, that the top performers are all close to 2.1 kr./kWh, which is the limit that results in the lowest monthly price. *The top performer and worst performer in this plot are* $2,31\%$ *apart which is about 260 kr. in the monthly total.*

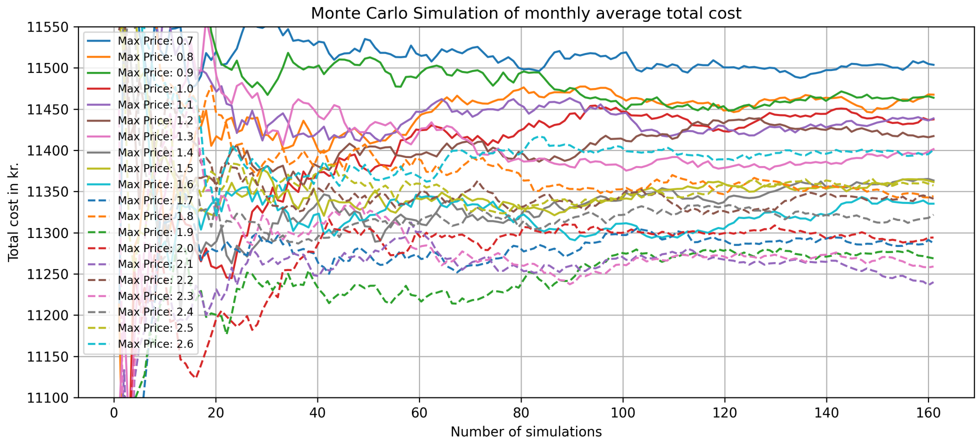

Figure 2.3: Using the Monte Carlo-method to find the optimal limit-price - Zoomed in

2.2 Comparison to conventional thermostat

Visible in the two graphs below, the intelligent thermostat with a limit price of 2.1 kr./kWh performs overall better than the conventional thermostat. The temperature is kept around the maximum allowed, and the compressor only runs when the need arises or if the electricity is cheap. The intelligent thermostat takes advantage of the low prices seen on day 4 in *figure 1.1*, where the temperature is bought down to the lower comfort limit.

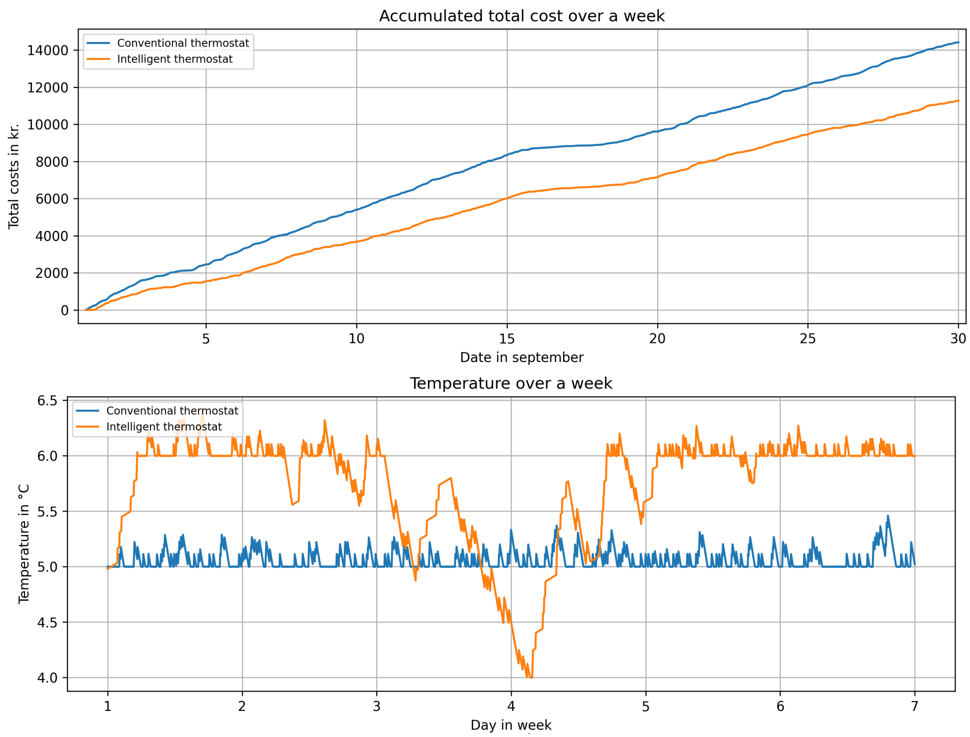

Figure 2.4: Plots comparing the intelligent thermostat to the conventional thermostat

Chapter 3

Conclusion

The intelligent thermostat is very basic and simple to implement, yet it boasts an average 2.500 kr./month lower total cost, which is a reduction of expenses by about 19%. It is possible to implement the intelligent thermostat in a real life deployment, but since the hourly spot price of electricity is only known a maximum of 36 hours in advance, the Monte Carlo Simulation will have to be run every day, when new prices are released, with the optimal limit price matching the data set. This can easily be automated, but will introduce a not insignificant expense to cover the compute.

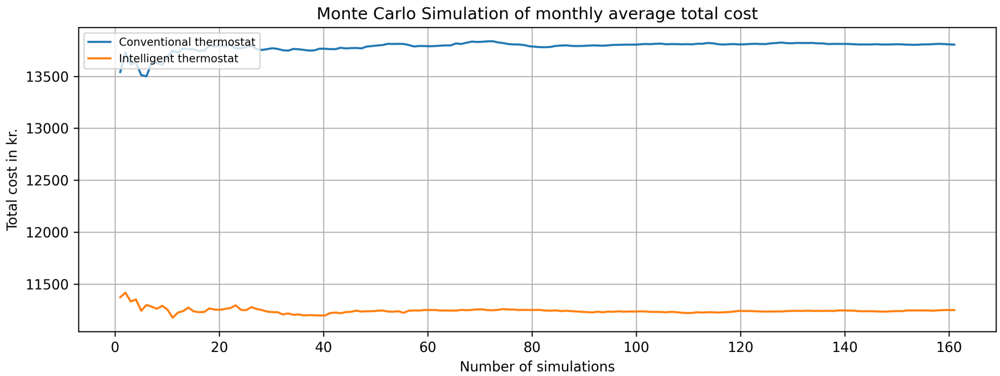

Figure 3.1: Monte Carlo simulation of the total monthly cost - conventional thermostat versus intelligent thermostat.

3.1 Food Waste

Looking at *figure A.4* on page Appendix A.4, it is evident that for all of the tested limit prices, the cost of food waste is negligible averaging at less than 0.10 kr. for an entire month.

3.2 Critique of the intelligent thermostat

Like mentioned above the intelligent thermostat only works efficiently on a single data set of prices if the limit price has been optimized. This means that it will not work «out of the box».

3.2.1 Alternative solution

An alternative solution to the hard limit price could be using a forward average as the limit price. An alternative to implementing expensive software to solve the problem would be to train employees to batch entries to the refrigerated room and/or to keep the door open only on entry and exit, and not for the whole duration of accessing the room. A simple two-door-airlock/interlock could also be installed to lessen the amount of cold air escaping the room when accessing it from outside.

Appendix A

Full size graphs

Plots used throughout the report can be found in full size in this appendix

A.1 Finding the optimal limit price: total cost

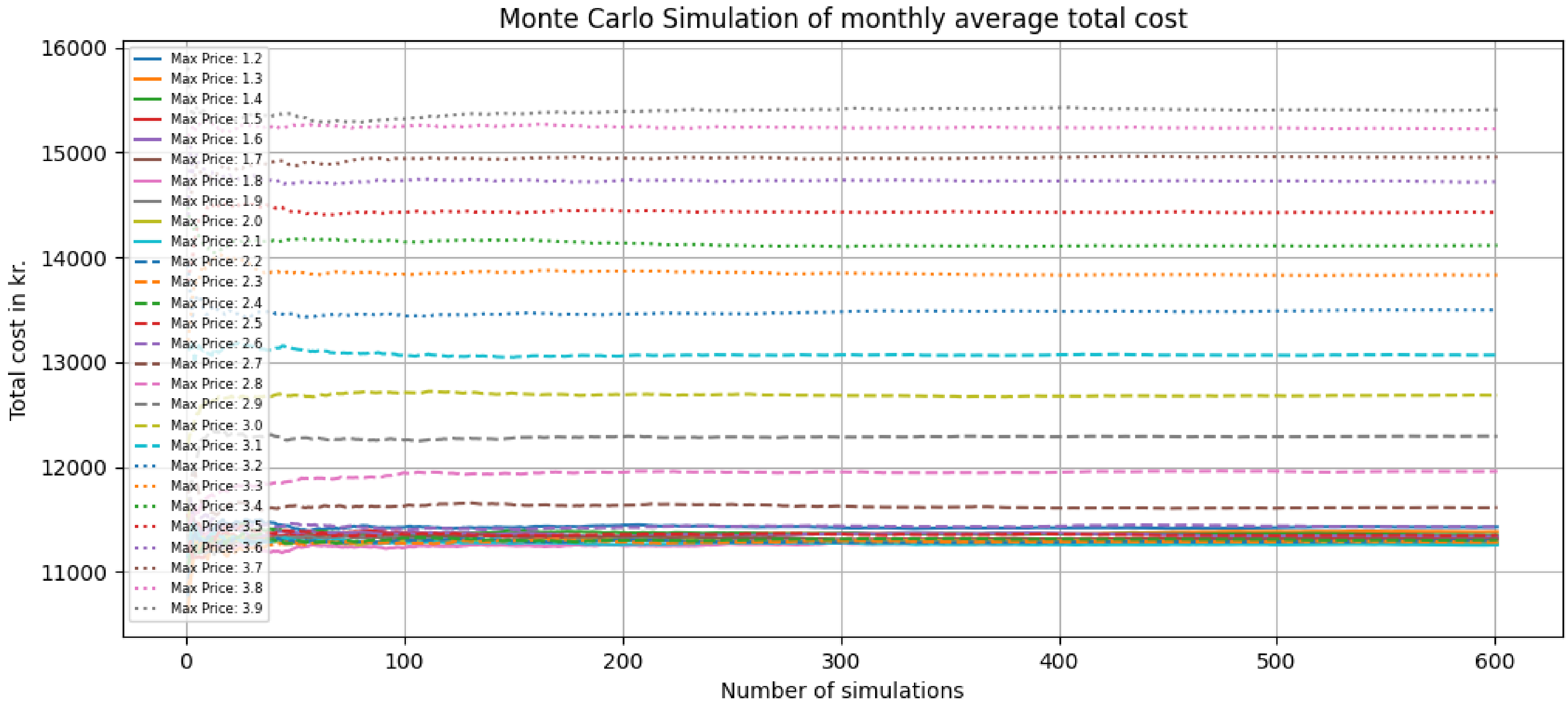

Figure A.1: The basic logic behind the intelligent thermostat

A.2 Finding the optimal limit price: total cost(zoomed)

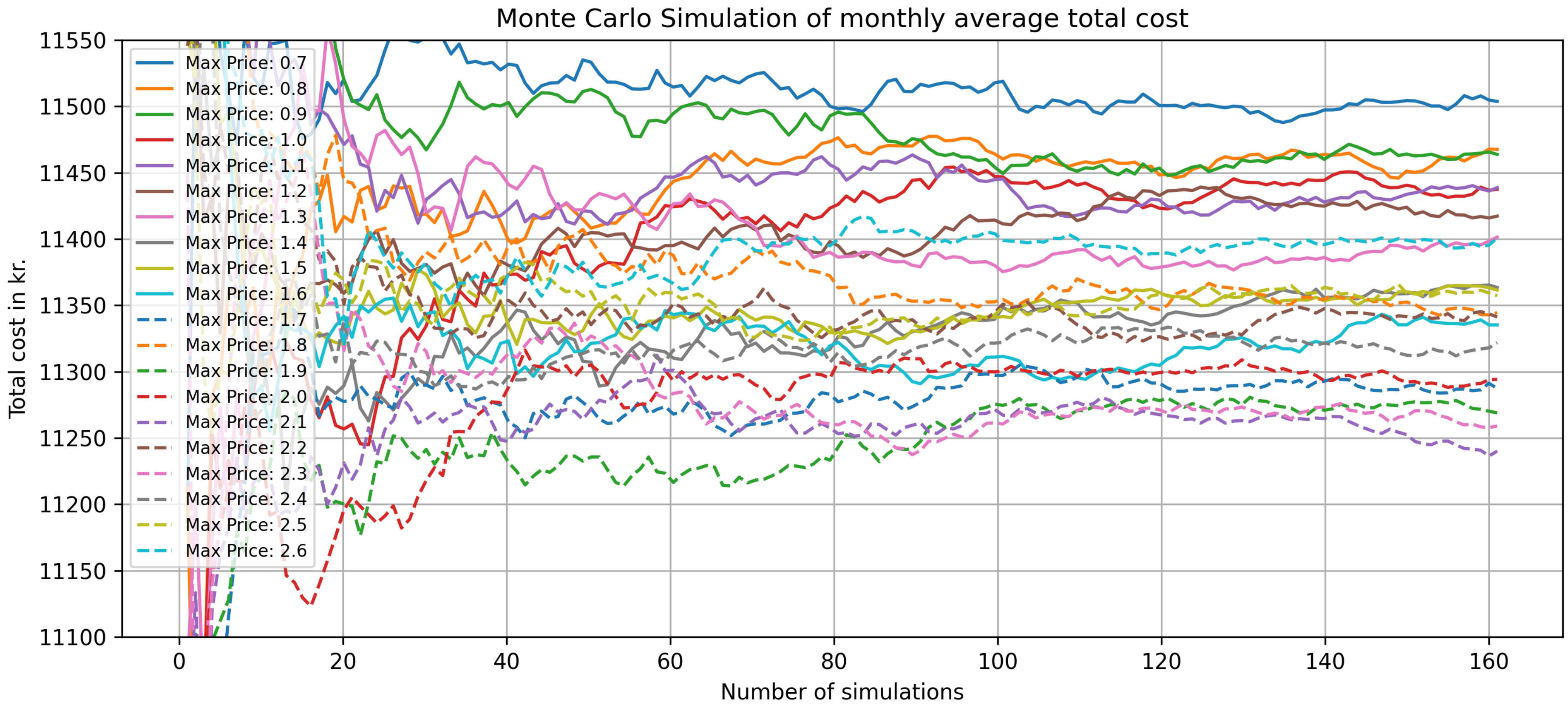

Figure A.2: The basic logic behind the intelligent thermostat

A.3 Finding the optimal limit price: temperature

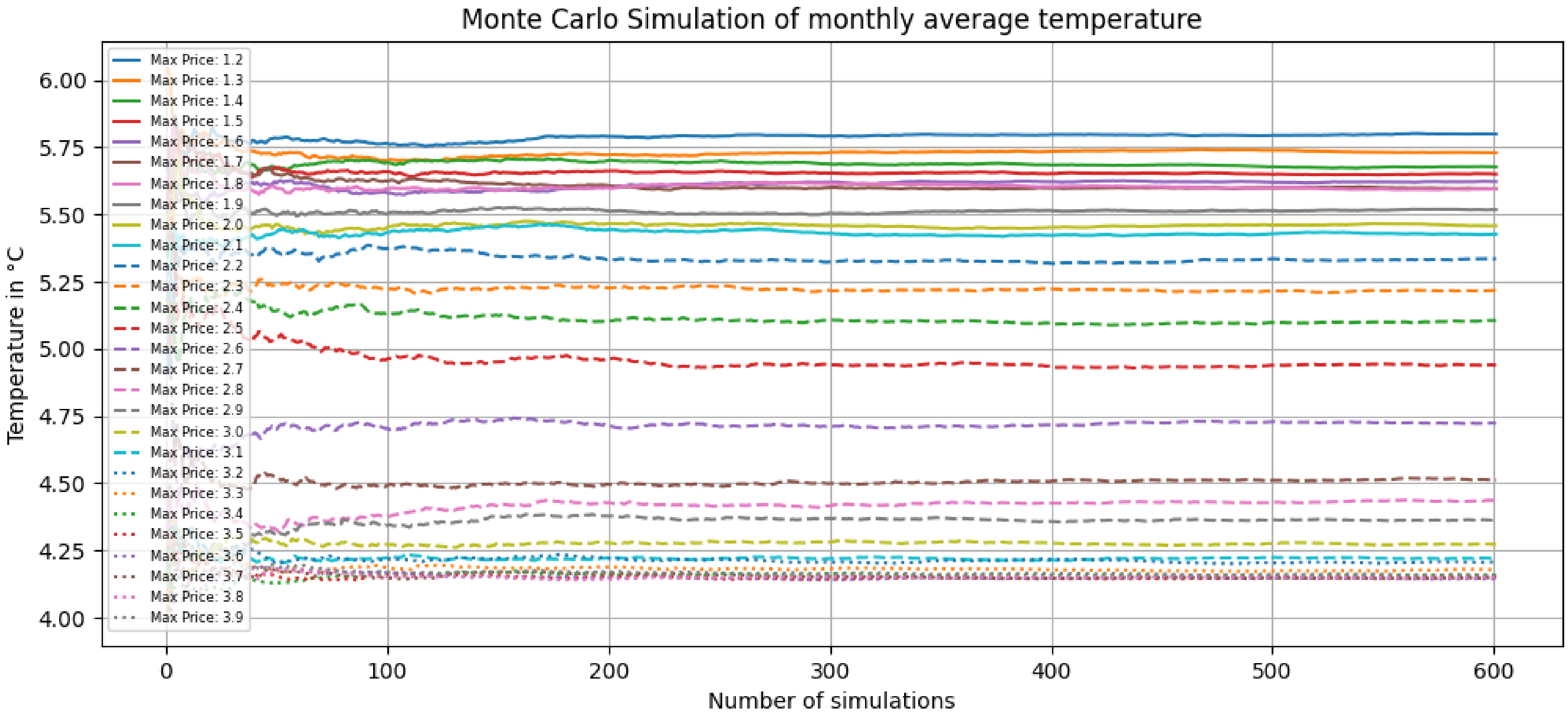

Figure A.3: The basic logic behind the intelligent thermostat

A.4 Finding the optimal limit price: food waste

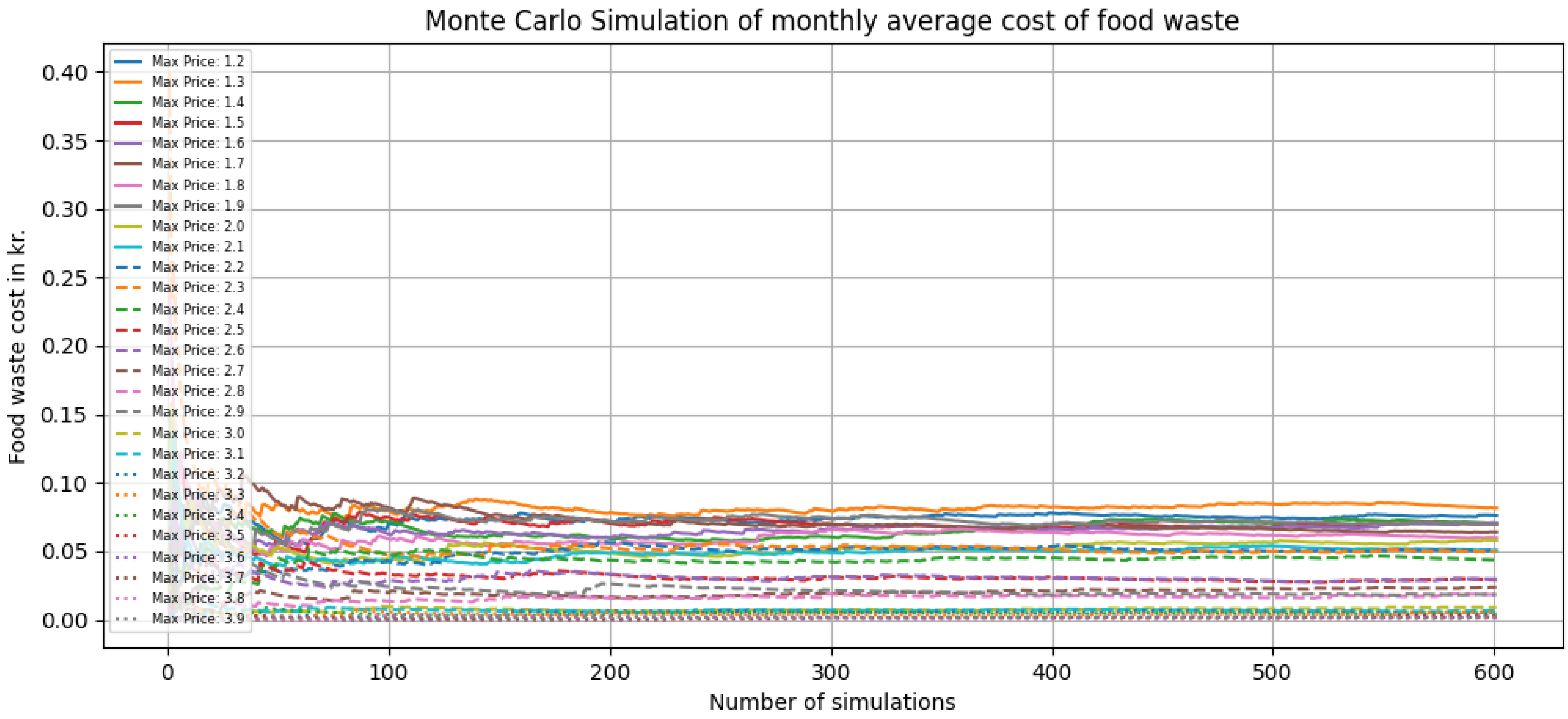

Figure A.4: The basic logic behind the intelligent thermostat

A.5 Comparison: Accumulated total cost

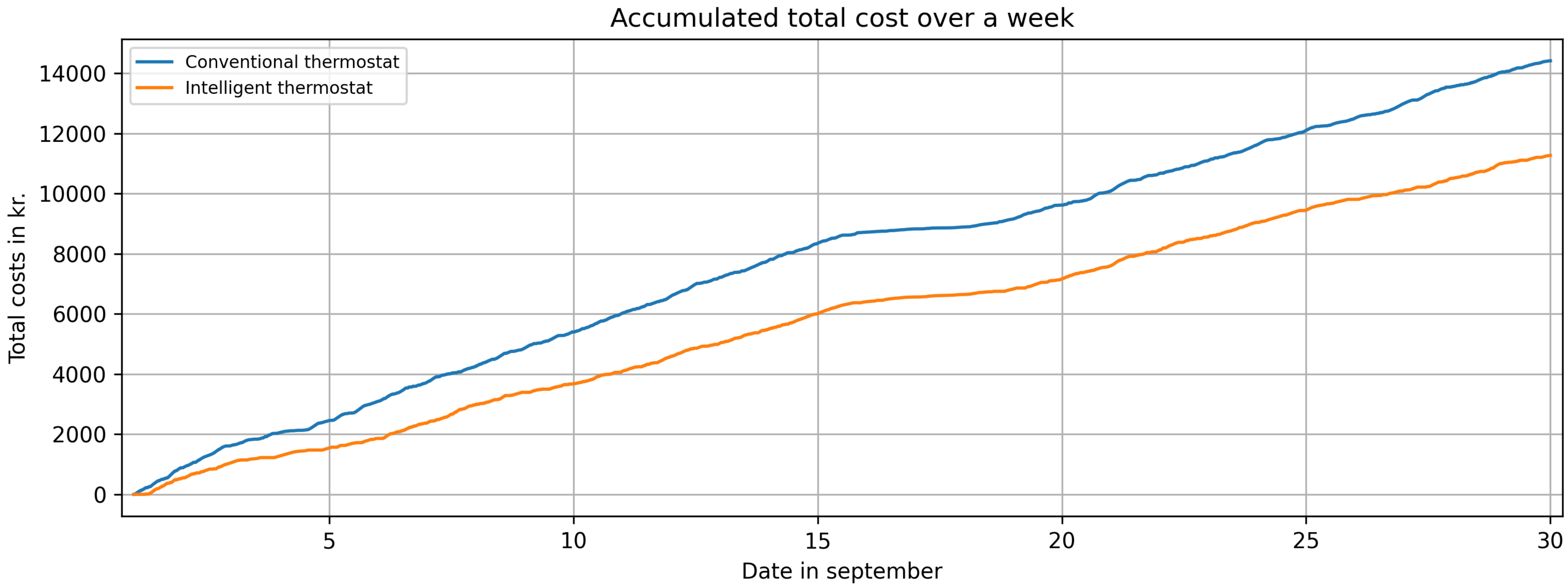

Figure A.5: The basic logic behind the intelligent thermostat

A.6 Comparison: Temperature over a week

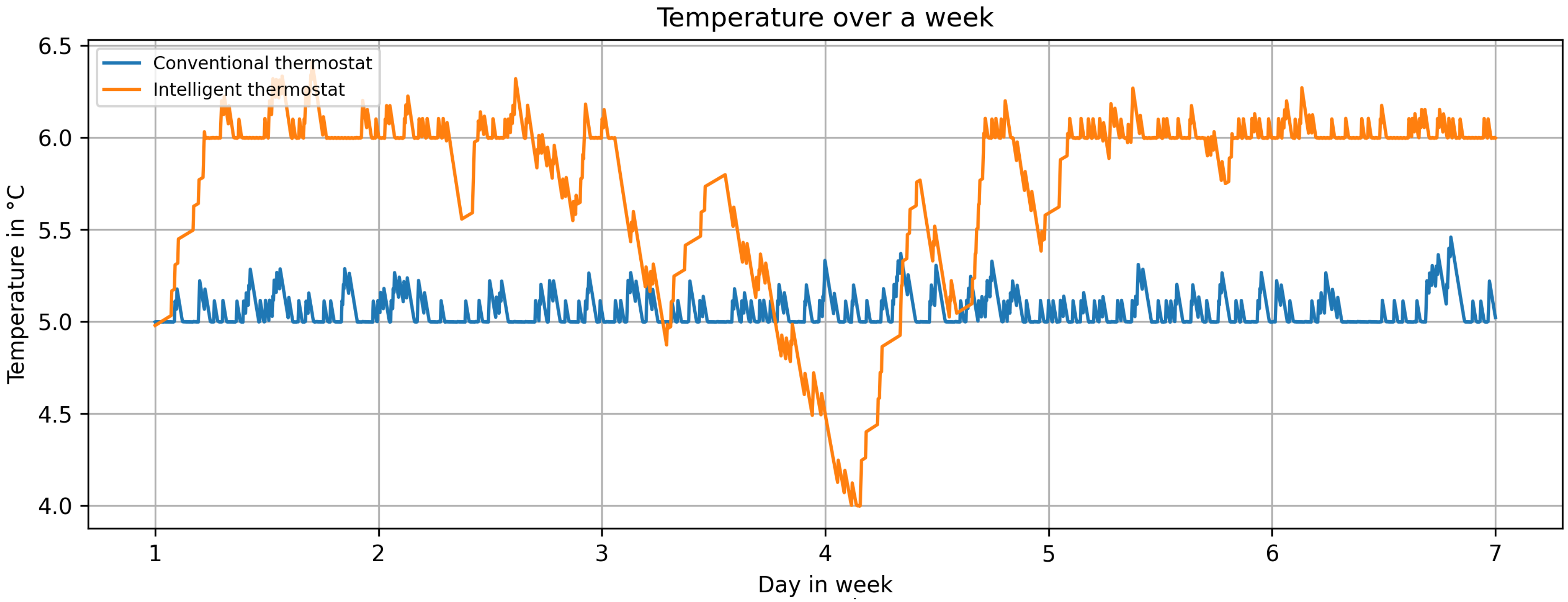

Figure A.6: The basic logic behind the intelligent thermostat

A.7 Comparison: Monte Carlo total cost

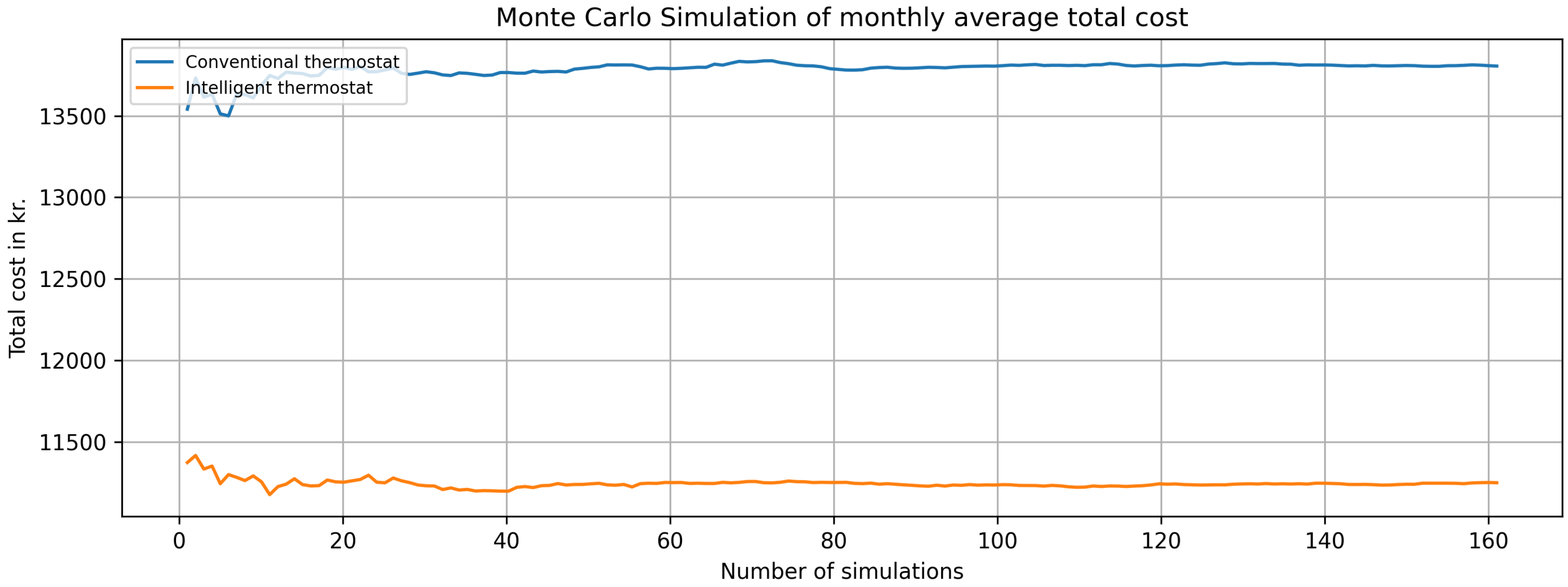

Figure A.7: The basic logic behind the intelligent thermostat