IoT Lab Light

IoT and Big Data

Presented by Group 4: Manon Groza, Vittorio Menini, Angel Ramos Buiza, Yalin Telkin

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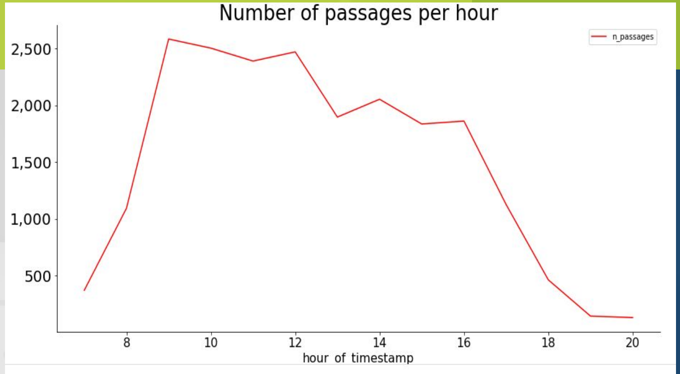
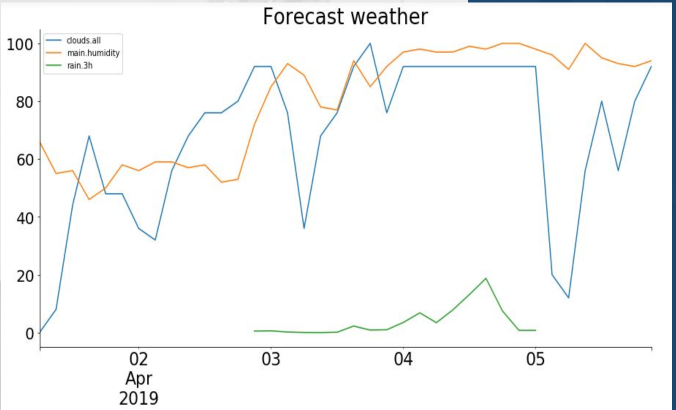
Introduction - Goal and Assumptions

The goal of the game is to identify the optimal illumination setting for the IoTLab of Polimi. It is thereby important to minimize the cost for lack of comfort (compared to luminosity), as well as the cost of energy consumption and the amortized investments.

- The curtains are initially only setable on a weekly basis, during the week-end. In others words, the position set during the week-end lasts for the entire week.
- The LED consumption in kW/h given is the price for the entire LED system (i.e all LED bulbs).
- The number of passages data have been used as a reference of the analyzed time period. In other words, we only considered the hours of the day in which some passages have been recorded.
- The emphasis has been put first on the minimization of the costs for lack of comfort. After these costs being reduced, we figured out how to reduce the energy/investment costs.
- When comparing cost of lack of comfort and cost of lighting with amortization cost, we implicitly assume that cost of comfort will be similar for the following 520 weeks. It might be an arguable assumption, however, we cannot have weather forecasts over such long period.

Data Exploration and Cleaning





- A first data exploration showed that there were no missing values and no outliers.
- The movement datasets were merged in a single table (as zones will not affect the analysis) and the columns ‘id’, ‘zone’ and ‘sensor’ were dropped
- Records show that passages have been detected only from 7AM to 8PM. Also, only weekdays report a significant number of passages. Thus, only light level during this period of time has been considered.
- From the forecasted weather JSON file, only cloud percentage has been extracted in order to compute the forecasted luminosity level.
- The forecasted week is likely to be predominantly cloudy (cloud levels above 60%).

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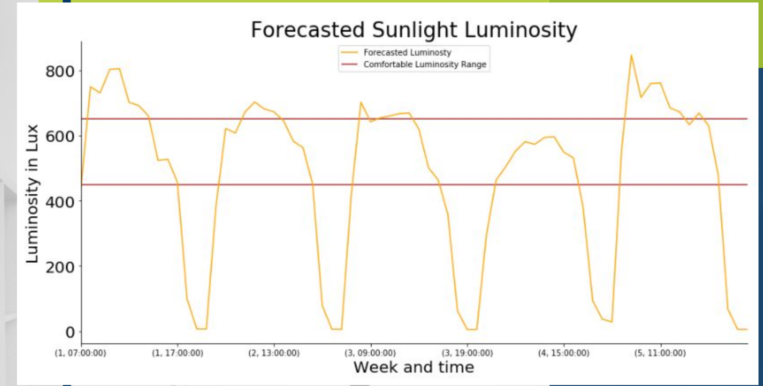
Data Exploration and Cleaning



- We computed the average light value for every hour of every single day of the previous 5 weeks in the table named *Lux_f2*.
- Secondly we merged the Databases, using the timestamp structure of the lux hour (left join) creating the *Forecast_Lux* table.
- As the forecast weather is only estimated every three hour, missing values have been filled with the previous values using *forward fill* Python function.
- For the Forecast_Lux we have used the given formula combined with the cost of discomfort caused by an out-of-range luminosity level.
- For 23 observations, the forecasted light was over 650 and there were 25 observations for which the forecasted_Lux was below 450.

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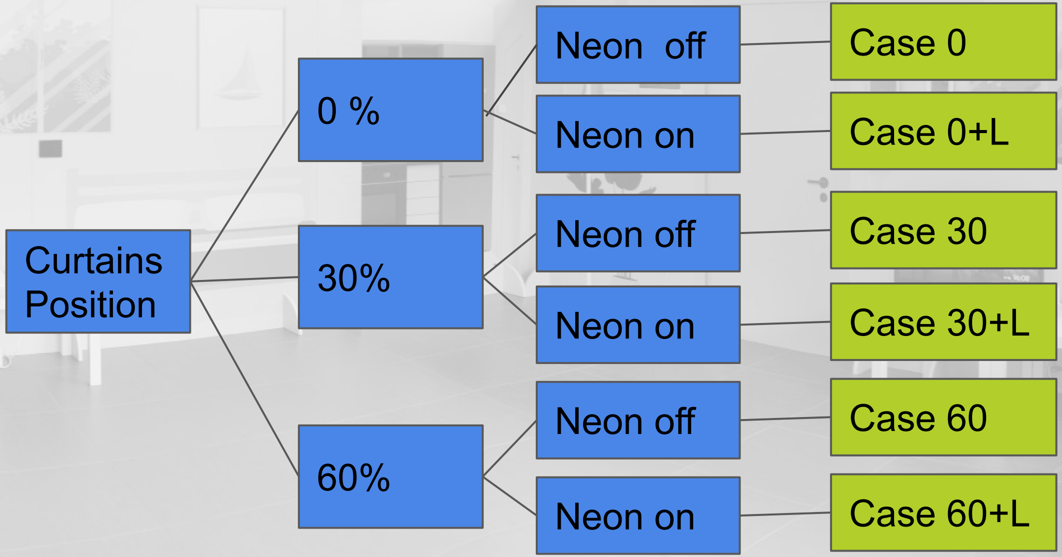
Cost minimization process - The Original Scenarios

In order to find the best optimal scenario before undertaking any investment, we followed this schema to explore all possibilities:



Cost minimization process

	Weekday	hour_of_timestamp	Fore_Lux	cost_lack_of_comfort
0	1	7	523.84	0.0000
1	1	8	810.69	1.6069
2	1	9	819.21	1.6921
3	1	10	879.55	2.2955
4	1	11	898.95	2.4895
...	...	...	...	...
65	5	16	605.30	0.0000
66	5	17	459.94	0.0000
67	5	18	74.15	3.7585
68	5	19	9.65	4.4035
69	5	20	8.42	4.4158

70 rows × 4 columns

We considered *Case0* as the original scenario in which *Fore_Lux* represent the natural light for the forecasted week assuming curtains are set in position 0 (i.e. no light filtering) and no light has been switched on; we first determined the total cost of comfort defining the COC function:

```
def COC(x):
    if x < 450:
        global r
        r = (450 - x)*0.01
    elif x > 650:
        r = (x-650)*0.01
    else:
        r = 0
    return (r)
```

The total Cost of Comfort applied to the forecasted light column is equal to 80.55€

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Cost minimization process

For each curtains positioning the *Fore_Lux column,* representing natural light level, have been reduced by 0%,30%,60% for those values above 650.

Secondly we created a new function *Neon_On* to increment light by +450 for those value below 450. However, we noticed some cases in which it is not convenient to turn on the light even thought forecasted values are below 450. That is because increasing luminosity by +450 generates a delta above the comfort area which is larger than the original. This issue can be solved by the following equation:

Delta_up = Delta down
x + Delta_light - 650 = 450 - x
Neon case) x + 450 - 650 = 450 - x ||| x = 325
Led case) x +225 -650 = 450 - x ||| x = 437,5
Where:
x = light level after which it is not convenient to turn on the light
Delta_down = luminosity missing to reach the minimum comfort level
Delta_up = luminosity exceeding the maximum comfort level
Delta_light = luminosity increase given by turning on the light

```python
def Neon_on(l):
    if l < 325 :
        global a
        a = l+450
    else:
        a = l
    return (a)
```

We should also consider the cost of neon light in determining the limit after which for turning the light on (ex. 325-0.432). However, given the small cost we assume that the generous rector of the Politecnico di Milano will prefer employees' comfort compared to saving few cents per hour.

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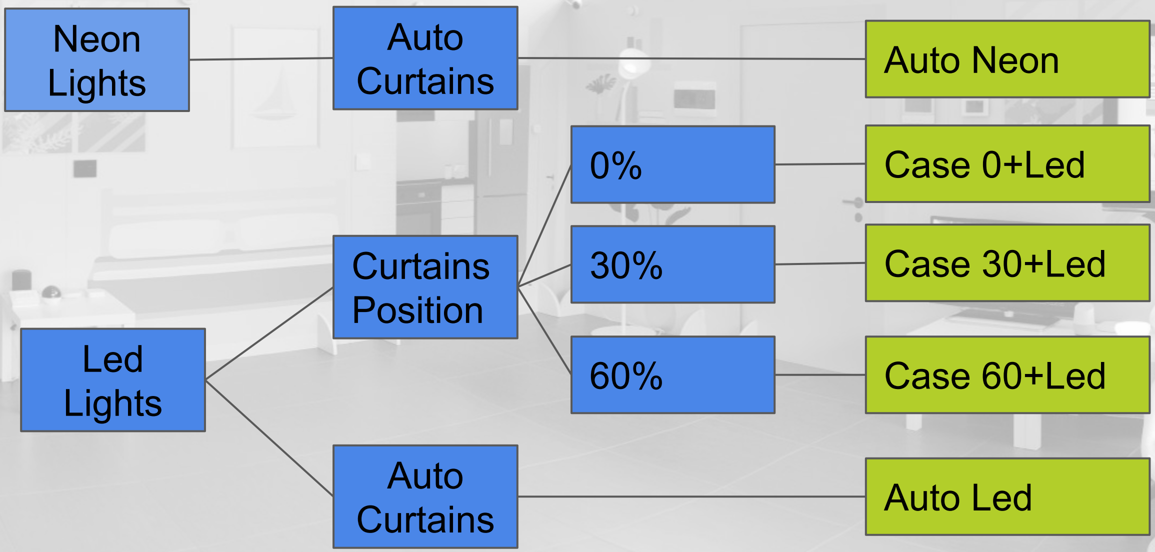
Analyzed Investments’ Scenarios

Hereby are the possibilities we explored: the curtains automatization with neon, the led light system in the three different curtains settings and a combination of the two investments, automatization and leds.



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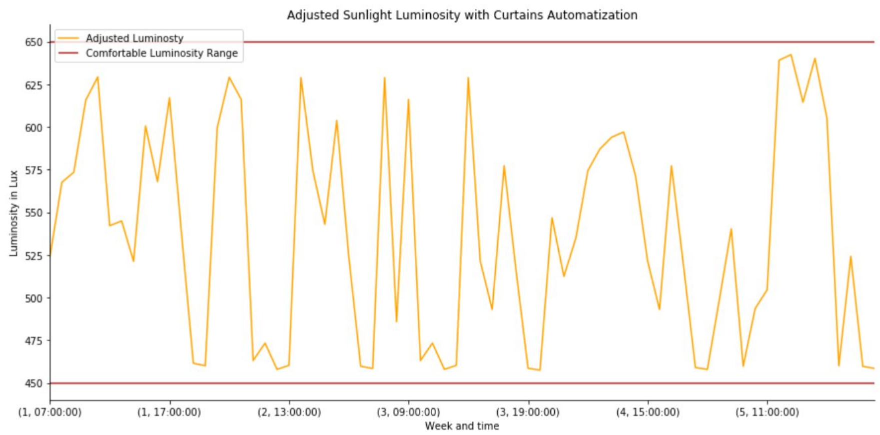
Curtains Automatization System




```
for i in auto["Fore_Lux"]:

    if i > 650:
        auto.loc[forecasted_lux['Fore_Lux'] >650, 'f_lux_adj'] = auto.Fore_Lux *0.7 #(1-0.3)
        auto.loc[forecasted_lux['Fore_Lux'] >650, 'curtains'] = 0.3

    elif i < 450:
        auto.loc[forecasted_lux['Fore_Lux'] < 450, 'f_lux_adj'] = forecasted_lux.Fore_Lux +450
        auto.loc[forecasted_lux['Fore_Lux'] < 450, 'lights'] = 1
        auto.loc[forecasted_lux['Fore_Lux'] < 450, 'neon_cost'] = 0.0003*30*12*4

    else:
         auto.lights=0
for i in auto['f_lux_adj']:
    if i>650:
        auto.loc[auto['f_lux_adj']>650, 'curtains'] =0.3
        auto.loc[auto['f_lux_adj']>650, 'f_lux_adj'] = auto.f_lux_adj *0.7
```

The curtains automatization system allows to adapt the curtains position to the sunlight luminosity hourly.

In order to minimize the cost for lack of comfort, an optimization between neons light and curtains position has been estimated by creating a loop. Thus, this cost has been reduced until being null. For instance, this enabled if the sunlight was too low, to adjust the position of the curtains and not exceed the maximum comfortable luminosity level. Each time it was required to change the curtains position, a column previously created was registering this movement with the curtain level. In the same way, each time the neon lights needed to be turned on, a column lights saved the on/off switching. After this, another following loop changes the curtains position to filter the sunlight if the adjusted luminosity (*f_lux_adj*) by the neon light is too high.

The only cost remaining is thereby the electricity cost, because no investment required.

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LED System Investment

```
def Led_On(l):
    if l > 225 and l < 437.5:
        global a
        a = l+225

    elif l > 0 and l < 225:
        a = l+450
    else:
        a = l
    return (a)
```

With the introduction of the new led light system we can have an increase of +450 of luminosity or only +225 if necessary. This **flexibility** is also accompanied by **cheaper cost** of lightning per hour of the whole system. From 12 * 4* 0.03* 0.3= 0.432 € in the Neon Scenario, to 0.3 * 0.3 = **0.09€** and 0.3 * 0.5 = **0.15€** per hr. for the **50%** and **100% power** consumption respectively. For such reasons we intuitively expect better result in terms of total cost of comforts.

Three new scenarios were analyzed according to the three usual curtains week positioning (0%,30%,60%). In order to do so a new function *Led_On* was defined. The function takes into account the necessary luminosity increase according to the original light value, and also the margin below 450 for which it is not convenient to turn on the light.

Even though the cost of comfort was significantly reduced due to more flexibility, there is no scenario in which COC is equal to 0.

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Automatic Curtains and LED System Investment

```
def move_curtains(l):
    if l > 650 and l < 928:
        global a
        a = l*0.7
    elif l > 928:
        a = l*0.4
    else:
        a = l
    return (a)
```

Although it was out of the project scope, we were interested to discover weather opting for both investments would have led to a better result.

We first optimized the curtains schedule because, contrary to turning the led system on, the curtains positioning is free. Thus, it is more convenient to adjust the curtains and secondly pay the cost of lightening in case the comfort zone for certain hour has not been reached.

The *move_curtains* function determines the light values that need to be reduced in order to reach the comfort level. 928 is the limit after which light need to be reduced by more than 30% to enter that trshold. As the max Forecasted lux value is 898, it was not applied in our specific case.

After this transformation the Led_On function was applied. However there was still a value that did not reach the comfort area.

	weekday	hour_of_timestamp	Avg_Lux	clouds_%	Fore_Lux	cost_lack_of_comfort
0	1	7	434.992937	0.0	434.992937	0.150071

Therefore another use of the move curtains applied to the adjusted light values was necessary to reach a cost of comfort = 0. In the end the lightening cost was the only cost of this scenario.

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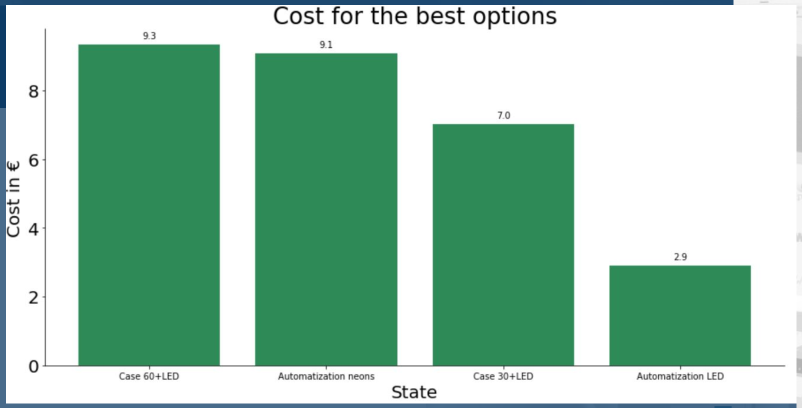
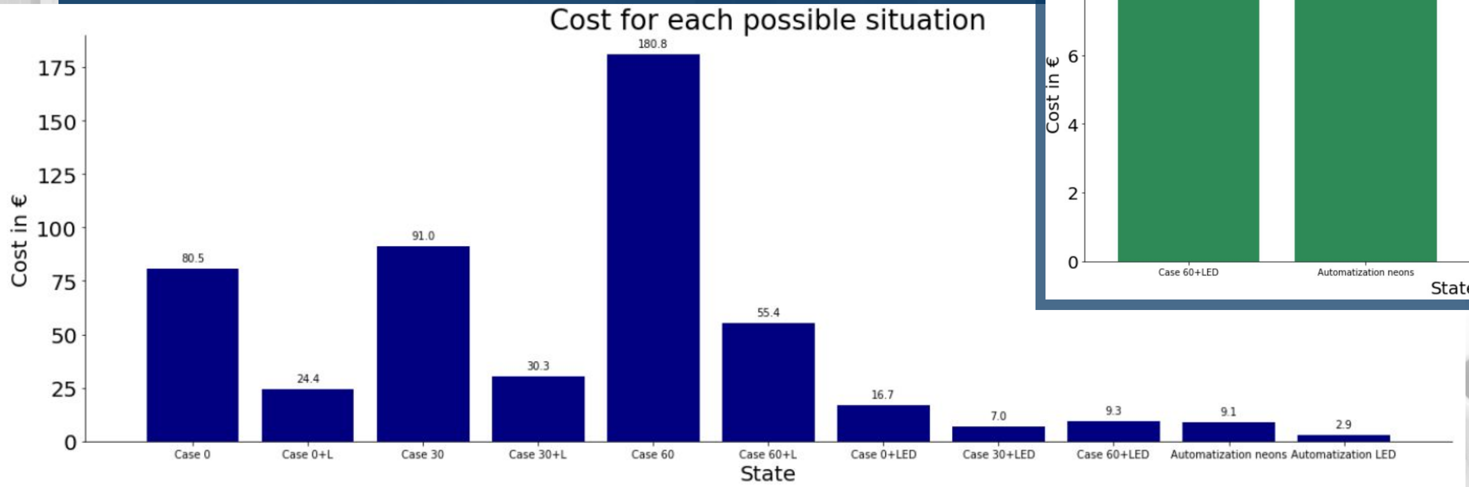
Consumption and Lack of Comfort Costs Comparison

If we take a first glance at the cost estimated for each possible case mentioned previously (comfort + electricity costs), we observe the following repartition. On the surface, the investment in both LED and curtains system seems to be the most appealing, as its cost has been reduced to only 2.90€ for the entire week of April. Yet, this is without taking into account the investment costs needed to obtain such results.





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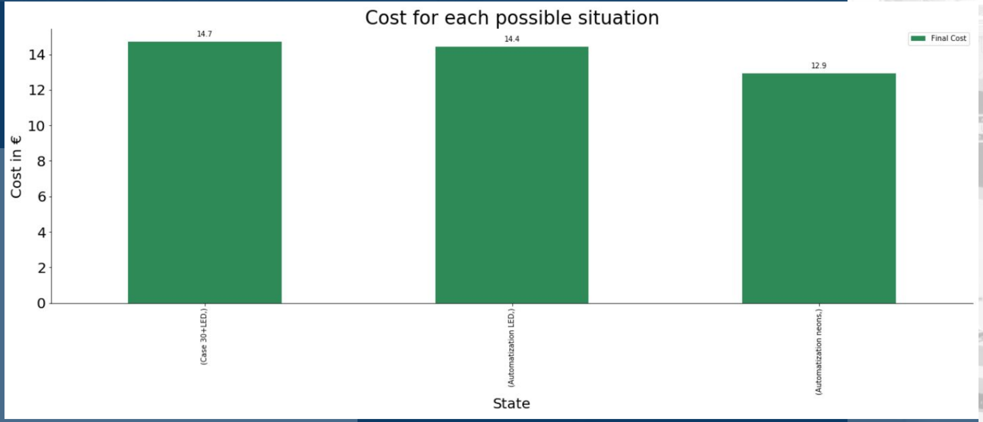
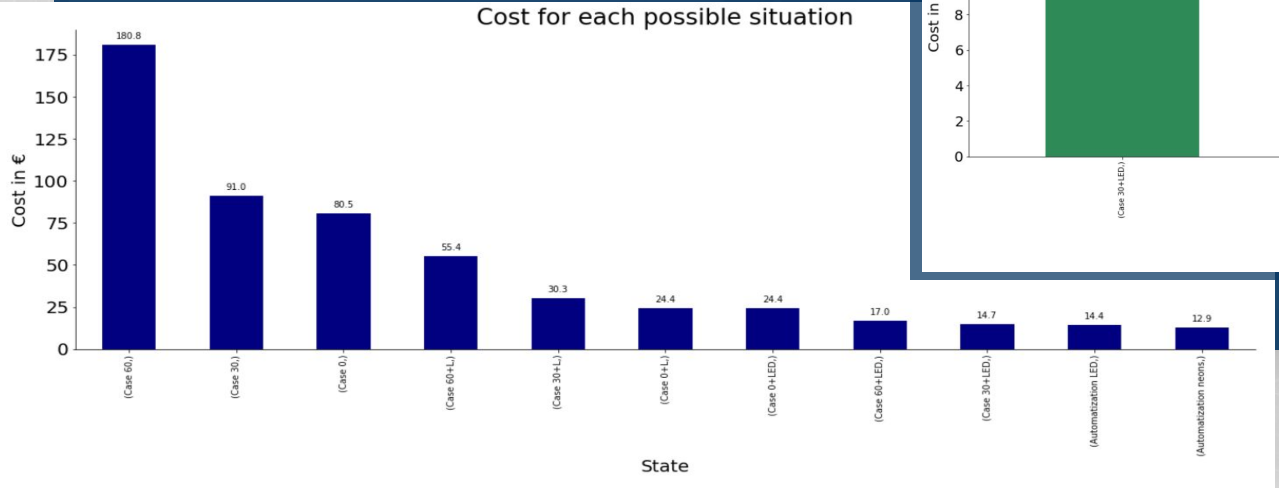
Long Term Costs Comparison

Eventually, the most efficient case is the curtains' automatization system investment only.
Indeed, by computing the amortized investment costs over 10 years with the following formula: initial investment / (10*52), and summing to this results the previous costs estimated, the curtains system leads to the final cost of 12.90€, reducing the costs by 11.50€ from the initial situation (Case 0+L), which means reducing them by almost 53% (12.9/24.4).





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Final Results Table

Ranked by total economic costs

Scenario	Lights	Light Type	Curtains	Cost of comfort	Cost of light power	Total variable cost per week	Cost Of Investment	Amm. Cost per week	Tot Variable and Amm.cost
Auto+neon	On	Neon	Automatic	- €	9,07 €	9,07 €	2.000,00 €	3,85 €	**12,92 €**
Auto+led	On	Led	Automatic	- €	2,79 €	2,79 €	6.000,00 €	11,54 €	**14,33 €**
Case30+led	On	Led	30	0,32 €	6,69 €	7,01 €	4.000,00 €	7,69 €	**14,70 €**
Case60+led	On	Led	60	0,98 €	8,33 €	9,31 €	4.000,00 €	7,69 €	**17,00 €**
Case0+led	On	Led	0	13,91 €	2,79 €	16,70 €	4.000,00 €	7,69 €	**24,39 €**
Case0+neon	On	Neon	0	17,52 €	6,91 €	24,43 €	- €		**24,43 €**
Case30+neon	On	Neon	30	19,48 €	10,80 €	30,28 €	- €		**30,28 €**
Case60+neon	On	Neon	60	25,58 €	29,80 €	55,38 €	- €		**55,38 €**
Case0	Off	-	0	80,55 €	- €	80,55 €	- €		**80,55 €**
Case30	Off	-	30	90,96 €	- €	90,96 €	- €		**90,96 €**
Case60	Off	-	60	180,78 €	- €	180,78 €	- €		**180,78 €**

Note: Amortized cost per week is the result of Initial Investment cost / (10 years X 52 weeks per year)

Disclaimer: these results have been estimated within Python, the usage of another software was only for visualization purposes. More details can be seen in the Notebook

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Best Schedule for next week

As noticed in the Results Table, the option that minimize the Total cost, which is given by the sum of cost of comfort, cost of power and amortization costs, is the curtains automatization system with no further investment. We report the best schedule that minimize all the variable costs:

Day of the Week	Day 1		Day 2		Day 3		Day 4		Day 5	
Parameters	Light	Curtains	Light	Curtains	Light	Curtains	Light	Curtains	Light	Curtains
7:00	1	0.3	1	0.3	1	0.3	1	0.3	0	0
8:00	0	0.3	0	0	0	0.3	0	0	0	0.3
9:00	0	0.3	0	0	0	0	0	0	0	0.3
10:00	0	0.3	0	0.3	0	0.3	0	0	0	0.3
11:00	0	0.3	0	0.3	0	0.3	0	0	0	0.3
12:00	0	0.3	0	0.3	0	0.3	0	0	0	0.3
13:00	0	0.3	0	0.3	0	0.3	0	0	0	0.3
14:00	0	0.3	0	0	0	0	0	0	0	0
15:00	0	0	0	0	0	0	0	0	0	0.3
16:00	0	0	0	0	0	0	0	0	0	0
17:00	0	0	0	0	1	0.3	1	0.3	0	0
18:00	1	0	1	0	1	0	1	0	1	0
19:00	1	0	1	0	1	0	1	0	1	0
20:00	1	0	1	0	1	0	1	0	1	0

Disclaimer: these results have been estimated within Python, the usage of another software was only for visualization purposes. More details can be seen in the Notebook

Conclusions

- In the original scenario, where curtains are weekly scheduled and neon lights hourly scheduled, the best option for the considered week is to set curtains in position 0% and thanks to light scheduling it is possible to reach a cost of comfort of 17,15€ with a cost of power of 6,91€.
- If we had to choose between investing in led system and curtains automatization, the former allows to obtain a very low cost of comfort and cheaper weekly power consumption compared to the latter. However, if we include the weekly cost of amortization of the initial investment over ten year, curtains automatization is the best option. Moreover it has more flexibility and we can reach a cost of comfort equal to 0.
- If we consider to undertake both investments, we obtain the minimal variable cost of lightnin and a cost of comfort equal to 0. On the other hand, because of the high initial cost of investment, the amortization cost makes it a more expensive option compared to the only-curtains automatization.

Considerations and Suggestions

- There were several weeks during which there were no passages. Different schedules among the Lab zones could have reduce costs and increase optimization.
- Giving cardinal orientation, the sunlight could hit differently. Thus, it could have been interesting to take into consideration each zone (window orientation to the natural sunlight) of the Lab.
- The humidity would have been another interesting parameter to analyze as it can induce fog, which influences the sunlight luminosity.
- The investment in such installations is tax deductible, and this has not been considered.
- The color of the walls could also influence the clarity of a room, indicated by the LRV (Light Reflectance Value) of the painting used. From the pictures provided, we can observe that the walls must be white, which reflect from 70 to 90% of the light. Nevertheless, pastels could have an even higher LRV than white paintings. Eventually, a white dusty wall loses his LRV capacity.[1]
- LED light installation advantages are not only the possibility of reducing the costs but additionally reduction on the environmental impact. Indeed, LED lights have the advantage to turn on immediately at their full brightness level, whereas a neon bulb could take some more time to do so. Moreover, LED bulbs have a higher life expectancy (50,000h) compared to neon ones (10,000h).[2] Therefore, maintenance costs are reduced as well. Finally, LED lights do not contain any potentially dangerous materials. They will not require handling or disposal precautions, making them a far safer option.[3]

[1] *https://www.energie-environnement.ch/le-saviez-vous/1402-la-couleur-d-une-peinture-peut-influencer-la-consommation-d-energie*

[2] *http://www.ledbenchmark.com/faq/life-expectancy.html*

[3] *https://www.precisionsignandawning.com/blog/replace-your-neon-sign/*