1 Title

A well-formed office
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2 Supervisor

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5 Attachments

- Accel code

Contents

Summary

This report contains a model for a well-formed office. We looked at the costs and profit of a building. What aspects of a building cost money and what aspects make money or make the costs less? For the costs we looked at two aspects: construction costs and usage costs. For the profit we also looked at two aspects: rent and the produce of solar panels. The most important question in this report is: what is the smartest ratio between these two? How can we minimize the costs of the building and maximize the profit. In this report our process of making the model can be found, together with a reflection on this process.

6 Context

A new office requires a healthy financial balance, which is negatively affected by the costs of construction and maintenance. The costs depends on the building's shape. For example, there's a trade-off to be made when the ground surface size is chosen: savings on the ground may be undone by the need for a taller building, which increases the consumption of energy by the elevators.

7 Definition and Purpose

The purpose of the model is optimization. We want to maximize the profit of the building by finding the best balance between the number of people in the building and the construction and usage costs. We're mainly interested in the energy costs, and the price of the materials to get the building to appear. More people means higher revenues, but also increased construction costs.

8 Sub-questions

- Does the use of multiple stories reduce the construction and usage costs?
- Does the value of complying with the users' requirements outweigh the costs of constructing and using the building?
- What wall-window ratio results in the lowest energy usage?
- Does the use of solar panels reduce the overall costs?

9 Concepts, properties, values and relations

- `Lights`
  - Amount of lights = { 0 , ... }
  - Energy usage = 12,5 W
  - Amount of hours used per day = 11 hours
  - Emitted light = 800 lux
  - Lifespan = 7 years
  - Replacement costs = €13,21
- `Solar panels`
  - Total surface = N m^2
  - Price per m^2 = €256
  - Produce per m^2 = 86 kWh/m^2/year
- `Climate control system`
  - Amount of climate control systems = N
  - Price per climate control system = €6850,57
  - Amount of checks per year = N
  - Price per check = €374
  - Required energy = N kWh
- `Sides`
  - Surface windows = N m^2
  - Price per m^2 window = €600
  - Surface walls = N m^2
  - Price per m^2 wall = €51,61
  - Surface floor = N m^2
  - Price per m^2 floor = €81,15
  - Heat loss through window = 289,1 kWh/m^2
  - Heat loss through wall = 2,01 kWh/m^2
- `Storey`
  - Amount of stories = N
  - Length = { 1 , 1000 }

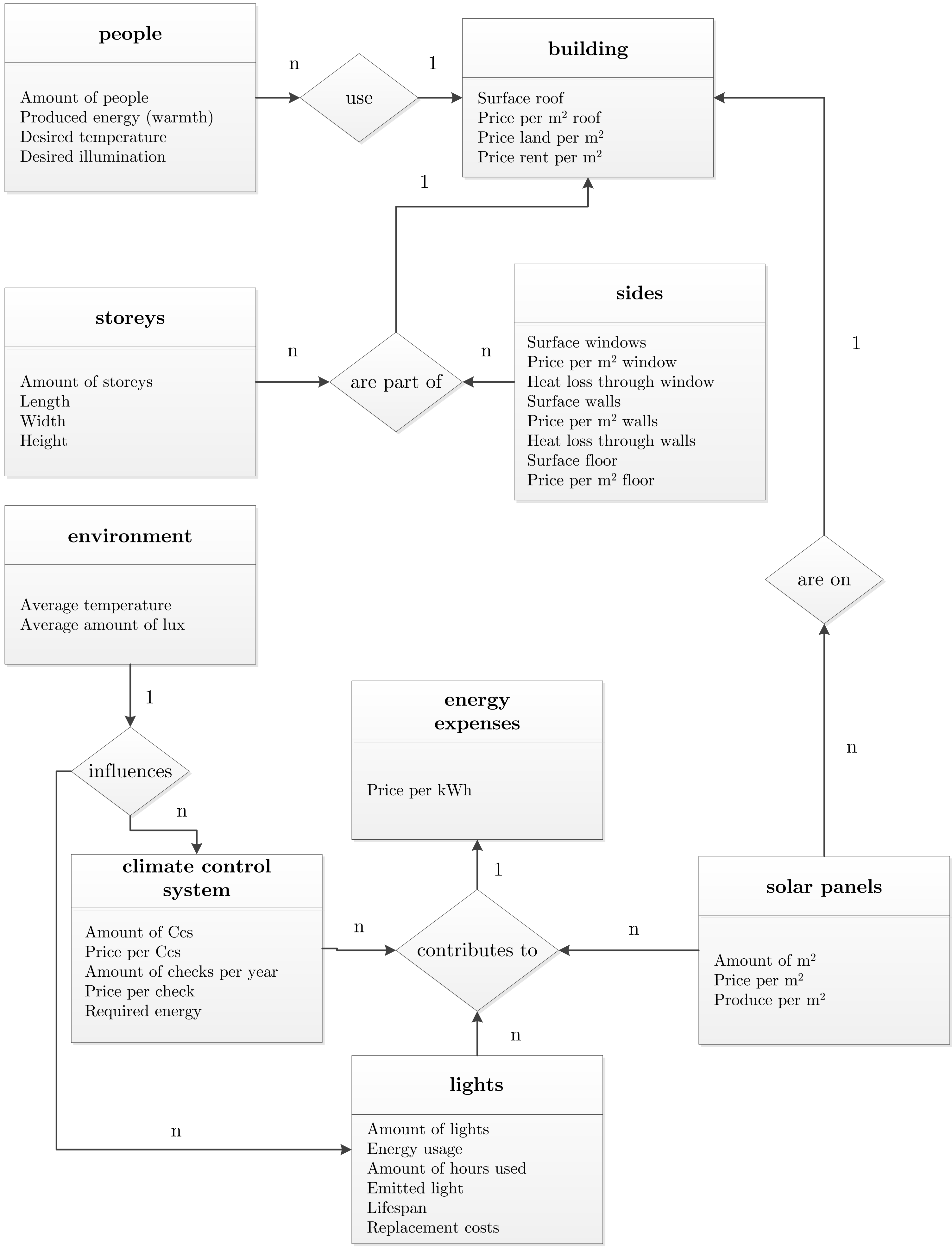
- Width = N m
- Height = 3 m

- `Environment`
  - Average temperature = 10 °C
  - Average amount of illumination = N lux
- `People`
  - Amount of people = { 1 , 1000 }
  - Produced energy (warmth) = 286 kWh
  - Desired temperature = 20 °C
  - Desired illumination = 500 lux
  - Desired surface = 5,54 m^2
- `Building`
  - Surface roof = N m^2
  - Price per m^2 roof = €105,93
  - Price land per m^2 = €350
  - Rent per m^2 = €180
- `Energy expenses`
  - Price per kWh = €0,22

Relations:

- `AreOn(solar panels, building)`
- `ArePartOf(storeys, building)`
- `ArePartOf(sides, building)`
- `ContributesTo(lights, energy expenses)`
- `ContributesTo(climate control system, energy expenses)`
- `ContributesTo(solar panels, energy expenses)`
- `Incluences(environment, lights)`
- `Influences(environment, climate control system)`
- `Use(people, building)`

The entity relation graph for this model is shown on the next page.



people
Amount of people
Produced energy (warmth)
Desired temperature
Desired illumination
n
use
1
building
Surface roof
Price per m² roof
Price land per m²
Price rent per m²
1
storeys
Amount of storeys
Length
Width
Height
n
are part of
n
sides
Surface windows
Price per m² window
Heat loss through window
Surface walls
Price per m² walls
Heat loss through walls
Surface floor
Price per m² floor
1
environment
Average temperature
Average amount of lux
1
influences
n
are on
energy expenses
Price per kWh
n
climate control system
Amount of Ccs
Price per Ccs
Amount of checks per year
Price per check
Required energy
1
n
contributes to
n
solar panels
Amount of m²
Price per m²
Produce per m²
n
lights
Amount of lights
Energy usage
Amount of hours used
Emitted light
Lifespan
Replacement costs
n

10 Quantities and their Relationships

The list of all properties and their categories can be found in section 29. The relations are shown in the table in section 12 (Derivations).

11 Approximations and Assumptions

See the third column of the table in section 12, (Derivations).

12 Derivations

Relations	*Dimensions*	*Assumptions*
COSTS		
CONSTRUCTION COSTS		
constrCo = LandCo + CcsCo + SolPanCo + LightsCo + SidesCo	[€] = [€] + [€] + [€] + [€] + [€]+ [€]	Construction costs only consist of these five factors.
Land costs		
LandCo = surGround * ppm²Land	[€] = [m^2] * [€/m^2]	
ppm²Land= 350	[€/m^2]	* for source see 14
Climate control system costs		
CcsCo = ppCcs * amCcs	[€] = [€/system] * [system]	
ppCcs = 6.850,57	[€/system]	* for source see 14
amCcs= amCubm / CubmpCcs	[system] = [m^3] / [m^3/system]	
CubmpCcs = 208,33	[m^3/system]	* for source see 14
amCubm= surGround * H * amStorey	[m^3]= [m^2] * [m/storey] * [storey]	
Solar panel costs		
SolPanCo = surSolPan * ppm²SolPan	[€] = [m^2] * [€/m^2]	

$ppm^2SolPan$ = 256	[€]	* for source see 14
surSolPan = surRoof	[m^2] = [m^2]	Solar panels are only placed on the roof. The whole roof is covered with solar panels. The roof is flat. Surface roof is in whole m^2.
surRoof = surGround = surStorey	[m^2] = [m^2] = [m^2]	Length and width are not important for constructions costs. The building has the shape of a cuboid.
surGround = amPeoplepStorey * surreqpP	[m^2] = [people/storey] * [m^2/(people/storey)]	
amPeoplepStorey = amPeople / amStorey	[people/storey] = [people] / [storey]	Amount of people is the same on every storey.
amPeople = {1,1000}	[people]	
amStorey = {1,47}	[storey]	
surreqpP = 5,54	[m^2]	Surface per people includes surface for offices and surface for other spaces. * for source see 14
Lights costs		
LightsCo = amLights * ppLight	[€] = [lights] * [€/lights]	All the lights are the same. All the lights are LEDs.
ppLight= 13,21	[€/lights]	* for source see 14

amLigths = amLightspStorey * amStorey	[lights] = [lights/storey] * [storey]	All stories have the same amount of lights.
amLightspStorey= amLightspm^2 * surStorey	[lights/storey] = [lights/m^2] * [m^2/storey]	
amLightspm^2 = amLuxpm^2 / amLuxpLights	[lights/m^2] = [lux/m^2] / [lux/lights]	
amLuxpm^2 = amLuxpm^{2}need – amLuxpm^{2}there	[lux/m^2] = [lux/m^2] - [lux/m^2]	
amLuxpm^{2}need = 500	[lux/m^2]	* for source see 14
amLuxpm^{2}there = amLuxthere/ amm^2	[lux/m^2] = [lux]/[m^2]	
amLuxthere = amLuxpm^{2}window * surWindow	[lux] = [lux/m^2] * [m^2]	The lights that comes through the window will be evenly distributed along the surface of the storey. In real life this isn't the case, however, the amount of light that falls in will be there so you will need less lights close to windows. We make the assumption that evenly distributing the light of the windows will give you the same number of lights needed.
amLuxpm^{2}window =	[lux/m^2]	There is an equal amount of lux per m^2 on every side of

5437		the building * for source see 14
amLuxpLights = 800	[lux/lights]	* for source see 14
Sides costs		
SidesCo = ppStorey * amStorey + pRoof	[€] = [€/storey] * [storey]+ [€]	
ppStorey = WallCopStorey + WinCopStorey + FloorCopStorey	[€/storey] = [€/storey] + [€/storey] + [€/storey]	Sides only consist of walls, windows and floors. Wall/window ratio is the same on every storey.
WallCopStorey = surWallpStorey * ppm^2Wall	[€/storey] = [m^2/Storey] * [€/m^2]	
ppm^2Wall = 51,61	[€/m^2]	* for source see 14
WinCopStorey = surWinpStorey * ppm^2Win	[€/storey] = [m^2/storey] * [€/m^2]	
ppm^2Win = 600	[€/m^2]	* for source see 14
FloorCopStorey = surStorey * ppm^2Floor	[€/storey] = [m^2/storey] * [€/m^2]	
ppm^2Floor = 81,15	[€/m^2]	* for source see 14
pRoof= surRoof * ppm^2Roof	[€]=[m^2]*[€/m^2]	
ppm^2Roof = 105,93	[€/m^2]	* for source see 14

surSidepStorey = 2(L * H) + 2(B * H)	[m^2/storey] = (2([m] *[m]) + 2([m] * [m])) / storey	
H = 3	[m]	Wisdom of the crowds
L = {1,1000}	[m]	
B = surGround / L	[m] = [m^2]/[m]	
procWin= {0,100}	[%]	
proWin=procWin/100	1 = [%] / [%]	We calculate with values from 0 to 1. Not 1 to 100 Example: 50% = 0.5
surWinpStorey= proWin* surSidepStorey	[m^2/storey] = 1 * [m^2/storey]	
surWallpStorey = surSidepStorey - surWinpStorey	[m^2/storey] = [m^2/storey] -[m^2/storey]	
surWin = surWinpStorey * amStorey	[m^2] = [m^2/storey] * [storey]	
surWall = surWallpStorey * amStorey	[m^2]=[m^2/storey] * [storey]	
USAGE COSTS		
amYears = 50	[year]	
UsageCo =(MaintCo + EnergyCopYear)* amYears	[€] = ([€/year] + [€/year])*[year]	Maintenance and replacement costs are calculated as an annual average.

Maintenance		
MaintCo = MLightsCo + MCcsCo	[€/year] = [€/year] + [€/year]	We assume that all the materials, stay the same after maintenance.
Maintenance lights		
MLightsCo = LightsRCo / LifespLights	[€/year] = [€] / [year]	All lights will be replaced at the same time.
LifespLights = 7	[year]	* for source see 14
LightsRCo= amLights * RCopLight	[€] =[Lights] * [€/Light]	
RCopLight= 14,93	[€/Light]	* for source see 14
Maintenance climate control system		
MCcsCo = amMCcs * ppMCheckCcs	[€/year] = [checks/year]* [€/check]	
amMCcs = 3,5	[checks/year]	* for source see 14
ppMCheckCcs = 374	[€/check]	* for source see 14
Energy		
EnergyCopYear= (ELightspYear + ECcspYear – EsolarIncomepYear) * ppkWh	[€/year] = ([kWh/year] + [kWh/year] - [kWh/year])*[€/kWh]	Energy costs only consist of these three factors.
ppkWh= 0,22	[€/kWh]	* for source see 14

Energy usage of lights		
ELightspYear = EoneLightpYear * amLights	[kWh/year] = [(kWh/year)/light] *[light]	
EoneLightpYear = amWatt * amHoursOn	[(kWh/year)/light] = [P/light] * [hour/year]	
amWatt = 12,5	[P/light]	* for source see 14
amHoursOn = 4015	[hour/year]	* for source see 14
Energy solar panels		
EsolarIncomepYear = surSolPan * Eppm^{2}SolPanpYear	[kWh/year] = [m^2]*[kWh/m^2/year]	
Eppm^{2}SolPanpYear= 85	[(kWh/m^2)/year]	* for source see 14
Energy climate control system		
ECcspYear = Ewarmth + Eair	[kWh/year] = [kWh/year] + [kWh/year]	The climate controller only controls the air and the warmth of the building.
Ewarmth= ElossWinpYear + ElossWallpYear - Epeople	[kWh/year] = [kWh/year] + [kWh/year] - [kWh/year]	The energy costs of the climate controller only depend on the amount of kWh lost through the sides
ElossWinpYear=ElosWinpm^{2}pYear *surWin	[kWh/year] = [(kWh/m^2)year] * [m^2]	
ElossWallpYear=ElosWallpm^{2}pYear * surWall	[kWh/year] = [(kWh/m^2)year] * [m^2]	
ElosWallpm^{2}pYear = 2,01	[kWh/m^2]	* for source see 14

Eair = amCubmpYear * kWhpCubm	[kWh/year] = [m^3/year] * [kWh/m^3]	
kWhpCubm = 3,2	[kWh/m^3]	* for source see 14
amCubmpYear= amCubmpRefreshment * amRefreshmentspYear	[m^3/year]=[m^3/refresh]* [refresh/year]	
amCubmpRefreshment = amCubm	[m^3/refresh]=[m^3]	Per refreshment of the air, all the air within the building will be refreshed.
amRefreshmentspYear = 52560	[refresh/year]	* for source see 14
Epeople = amPeople* kWhpPeoplepYear	[kWh/year]=[People]*[kWh/People/year]	
kWhpPeoplepYear = 143	[kWh/People/year]	* for source see 14
PROFIT		
RENT		
ProfitRent = ProfitpYear * amYears	[€] = [€/Year] * [Year]	
ProfitpYear = Rentpm^{2}pYear * amm^2	[€/Year]= [(€/m^2)/Year] *[m^2]	Rent is paid per m^2 building We assume the maximum of the rent so every m^2 of the building will be rented
Rentpm^{2}pYear = 180	[(€/m^2)/Year]	* for source see references
amm^2= surStorey * amStorey	[m^2]=[m^2/Storey]*[Storey]	

13 Special cases

The model takes 5 input variables. We check what happens if extreme values, such as zero and infinite are used as input values:

- Amount of People = 0: If the amount of people is equal to 0, then also the amount of storeys will be equal to 0, so the building will not exist and the costs will be zero.
- Amount of People = inf: If the amount of people is inf, then the amount of people per storey will be infinite. This will lead to infinite costs because the people have infinite needs. This is not possible.
- Amount of Storeys = 0: If the amount of storeys is equal to 0, the building will not exist and the costs will be zero.
- Amount of Storeys = inf: If the amount of storeys is inf, the building and the costs will have an incredibly high value.
- Length of the building = 0: If the length of the building is equal to 0, the building will not exist and the costs will be zero.
- Length of the building = inf: If the length of the building is inf, the building and the costs will be incredibly high.
- Amount of years = 0: If the amount of years is equal to 0, the building will exist but will only cost the amount of money needed for the construction.
- Amount of years = inf: If the amount of years is inf, the building will require an infinite amount of money to maintain.
- Wall/window ratio = 0: If the ratio is zero, no ground is used, so no building exists. This costs nothing.
- Wall/window ratio approaches 0: There will be only windows and no walls in the building.
- Wall/window ratio approaches inf: There will be only walls and no windows in the building.

14 Estimates

Properties	Values	Reference
Environment		
Average temperature in NL	3...18° C } We use 10 ° C in the model	http://nl.wikipedia.org/wiki/Klimaat_van_Nederland
Average amount of Lux	{1000...20000}	http://nl.wikipedia.org/wiki/Lux
People		
Produced energy	100W 50% of the produced energy of a person, consists of heat.	http://www.physlink.com/education/askexperts/ae420.cfm http://www.menselijk-lichaam.com/algemeen/lichaamstemperatuur
Ampeople	{1...1000}	We need at least 1 person to make a building. Our model reaches to 1000 people max.
Working hours	100W 50% of the produced energy of a person, consists of heat.	Common sense
Produced kWh per person per year	People work 11 hours a day The produce 100W*0,5=100W of heat/person (11*50) = 0 ,55kWh/day. They work 52*5 days = 260 days => 0,55*260= 143 kWh/pp/year	
Desired temperature	{20...26} °C We use 20° C in our model	http://books.google.nl/books?id=JJhwjCnlyo0C&pg=PA428&dq=Praktijkgids+Arbeidsveiligheid++temperatuur&hl=nl&sa=X&ei=pA4-UazHNuG57AaPlIDgAg&ved=0CDcQ6AEwAA#v=onepage&q=Praktijkgid

		s%20Arbeidsveiligheid%20%20temperatuur&f=false
Desired illumination	{500...1000} lux We use 500 lux in the model.	http://www.dijkstra.com/luxwaarden.html
Desired amount of m^2 room	{4...8} m^2/people We use $4m^2$/people	http://www.euronorm.net/content/template2.php?itemID=423
Desired amount of m^2 room + Extra room.	{5,5...9,1} m^2/people $5{,}54m^2$/people	There is 27,85% extra space needed per workingarea for hallways, cantine, toilets etc. (In the attachment you can find the calculations for this) 4m2 = (100% – 27,85%) → 100% = $5{,}54m^2$/people
Window		
Costs	Cost €600,- per m^2 with frame	http://www.casadata.nl/Default.aspx?tvId=5452
Average heat loss	3,00 w/m^2K	http://www.engineeringtoolbox.com/heat-loss-transmission-d_748.html
Incoming light	5437 lux/m^2 window	In the attachment you can find the calculation for this value.
Elosspm²	Average heat loss = 3,00 W/m^2 K, temperature inside = 20° and outside 10° (see previous assumptions). ΔT = 20° - 10°=10°. So average heat loss = 3,00*10= 30W/m² Throughout the year this is = 0.03*24*365=262,8 kWh/m² per year	
Side		
Surface	2*(L*h)+2*(B*h) => 2(L*3)+2(B*h) = [m²] 2(m*m)+2(m*m) h=3m L= ... m (variable)	

	B=... surGround/L (cariable)	
Costs	Concrete panels with a 60mm isolating PUR coating. €51,61 per m²	http://casadata.nl/Default.aspx?tvId=6077
Heat transfer 8 inch poured concrete and 60mm PUR	60mm PUR 0,023 W/m²K	http://www.isolatiemateriaal.nl/dakisolatie-hellenddak-isolatie-pir-isolatie-zijdig-alu-1200x600x60-rd260-8plpak-p-82.html?oscsid=99bd55c9a39876c129f7ae6211e13298
Elosspm²	Average heat loss Wall = 8.9 W/m^2 K, temp inside = 20°C, temp outside = 10°C. But average heat loss of 60mm PUR = 0,023W/m^2K → So ΔT = 10°. So average heat loss = 0,023*10=0,23W/m². Throughout the year 0.00023*24*365= 2,01 kWh/m²	
Story		
Height	3m	Same as the height of the side
Length	L=...m (variable)	
Floor	200mm €81,15 /m²	http://casadata.nl/Default.aspx?tvId=6077
Solar Panels		
(Replacement) Costs	€ 160/m^2 Replacement costs per year 160/32.5= €4.92/m²/year	http://www.energieleveranciers.nl/zonnepanelen/opbrengst-zonnepanelen#.UT4UoByjOSo
Lifespan	{30...35} years	http://www.energieleveranciers.nl/zonnepanelen/opbrengst-

	We use 32,5 years	zonnepanelen#.UT4UoByjOSo
Average produce of Energy	{80…90}kWh/m²/year We use 85kWh/m²/year	http://www.energieleveranciers.nl/zonnepanelen/opbrengst-zonnepanelen#.UT4UoByjOSo
Light		
Energy usage	12,5W (120 V)	http://download.p4c.philips.com/files/0/046677422158/046677422158_pss_aen.pdf
Amount of light emitted	800 lumen	http://download.p4c.philips.com/files/0/046677422158/046677422158_pss_aen.pdf
Lifespan	20.000 hours The lights are turned on during the whole working day → 11 hours. Lifespan is 20.000/(11*365) = 5 years	http://download.p4c.philips.com/files/0/046677422158/046677422158_pss_aen.pdf
(replacement) costs	Costs lamp = €13,21 Costs work = €14,39 per hour Say 3 min per light = 14,39*(3/60) = €0,72 Total = €13,21 + €0,72 = €14,93 per light	http://www.amazon.com/exec/obidos/ASIN/B004IUMGV4/ref=nosim/6688506-rg1112-0020-20?s=merchant (Philips retailer link on site http://www.usa.philips.com/c/energy-saving-light-bulbs/ambientled-12.5w-a19-soft-white-dimmable-046677409906/prd/en/) salary concierge http://www.loonwijzer.nl/home/salaris/salarischeck?job-id=5153010000000
Produced warmth	negligible kWh	We assume that the LED lights produce an negligible small amount of heat.

Temperature controller		
Cost	Costs per unit €6.850,57 per CCS with a capability of 1.250 m3/hour	http://www.casadata.nl/Default.aspx?tvId=5962
Service intervals	Every 2500 hours	http://blog.actra.nl/luchtbehandelingskast-case-34/
Service Costs	€374 per check System is turned on 24/7 so it has to be checked every 2500/24= 104 days. So that is 365/104=3,5 times per year. Per year → 3,5 * 374 = €1309	http://www.casadata.nl/Default.aspx?tvId=5962
Amount of refreshments per year	Amount of refreshments per hour has to be {4...8}. We use 6 in the model. Per year → 6*11*5*52= 85800	http://www.soler-palau.be/_nl/pdf/aeraulique.pdf
Amount of kWh per m3 air refreshment	The ccs uses 440W for 1200m^3 per/hour air refreshment. 440/1200=0,366W/m^3 → 0,366*24*365 = 3,2 kWh/m^3	http://www.ventilair.nl/Repository/KOMPAKT-KOMFOVENT/VentilairKompaktcatalogus2012NL.pdf
Energy expenses		
Electricity price	€0,22 per kWh	http://www.milieucentraal.nl/themas/energie-besparen/energieprijzen
Gas price	€0,65 per m^3	http://www.milieucentraal.nl/themas/energie-besparen/energieprijzen

Land price		
Land price	Average price per m^2 -Amsterdam €700,- -Utrecht /Tilburg€400,- -Heerlen €200,- -Geleen/Sittard€100,- We use an average of €350 in our model.	http://www.vbowonenenzo.nl/content.asp?id=753
Roofing		
Costs	Price per m^2 = €105,93	http://www.casadata.nl/Default.aspx?tvId=6033
Rent		
Rent	Average in The Netherlands €180,- per m^2 for a new building	http://www.nvm.nl/~/media/NVMWebsite/Downloads/Zakelijk/Kantoren/Jaarcijfers%202012.ashx

15 Rephrase the problem statement in formal terms

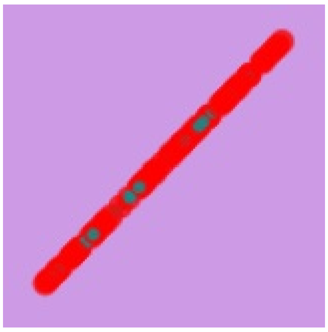
For a given number of people, amount of stories, wall/window ratio, length, and period (in years), find the optimal balance between the construction costs (costs solar panels + cost sides + costs lights + costs climate control system) and usage costs (maintenance costs + energy costs).

Optimal means that the sum of both is minimal. If multiple close-to-minimal values exist, pick the one with the minimal construction costs.

16 Calculations / Implementation / Simulation

We implemented our formal model in "Accel". For the script see Accel code. First we played a bit with the model just by playing with the sliders and look at what happens. We observed that when you have a very long building and a small number of persons, the usage costs becomes negative. After investigating the values we saw that in this case the amount of lights is negative since there is already enough light for such a small surface. In order to exclude this from our model we set a minimum of 0 for the amount of lights. (programmed as take the maximum number between 0 and the amount of lights) In this case when the amount of lights is bellow 0 it will be seen as 0. If the amount is above 0, this amount of lights will be taken into account.

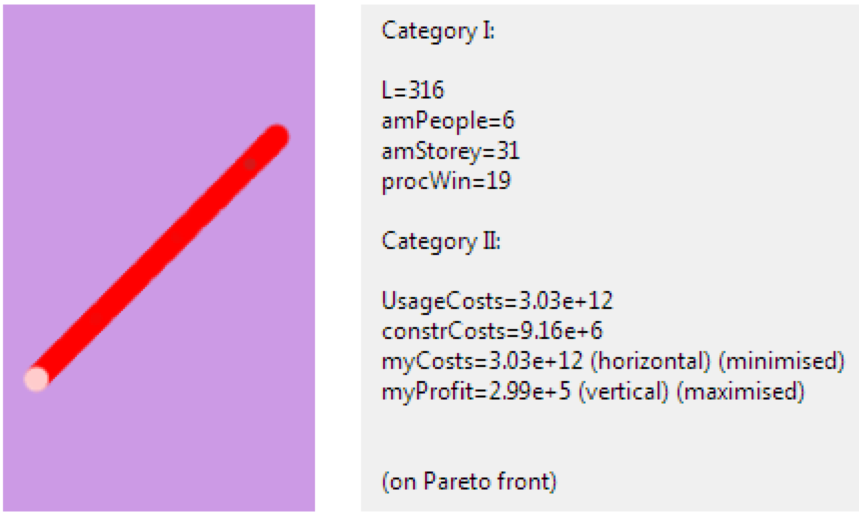
With the model we made a Pareto-front in which we minimize the total costs (`myCosts` = `Usage Costs` + `Building Costs`) of the system and in which we maximize the profit (`myProfit` = profit gained from rental). This graph is drawn at the right side.



Pareto-front.
x=`myCost`, y=`myProfit`

This Pareto-front consists of a high percentage of results lying on the front, which results in a stable front. This means that no values really dominate each other. However this Pareto-front is interesting to investigate. We will look at the end points of the line and see if we can optimize those outcomes.

The lower end point, which means the minimum costs, but also the minimum profit consists of the values:



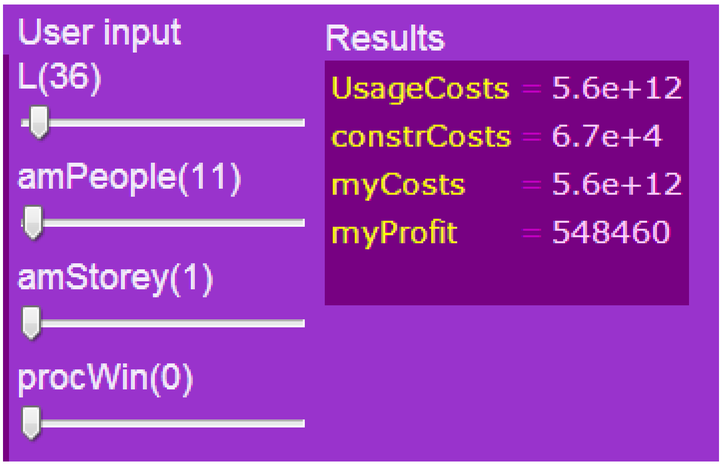
If we fill in those values and start playing with the sliders we see that the length of the building has an impact on the building costs. The shorter the length the smaller the construction costs. This is a remarkable outcome since the surface remains the same and most of the costs depend on the surface. However if we make the length to short the costs become higher, the optimal length is 36 meters.

The amount of people have a big influence on the results, however they don't have an optimizing influence. This is because the more people, the more profit you make with rental and on the other hand the more you have to pay to for building and usage costs.

Changing the amount of storeys only has an influence on the construction cost, the fewer storeys the fewer the construction costs are. This change is so small that is doesn't have a noticeable influence on the total costs. Then we have the last slider which influences the percentage of window the building has. The only influence that the windows have which is noticeable within the results is that more windows means more construction costs. This means that in this case with not so many people the fewest total costs will be to have no windows. Even though the results don't show in the total costs, no window does mean the fewest construction costs. The conclusion is that to optimize this lower point even more we take the shortest length -1 meter. We can't go shorter since we work with whole meters and 0 meter means there is no building left-. We leave the amount of people the way it was, since changing those both have a negative and a positive influence.

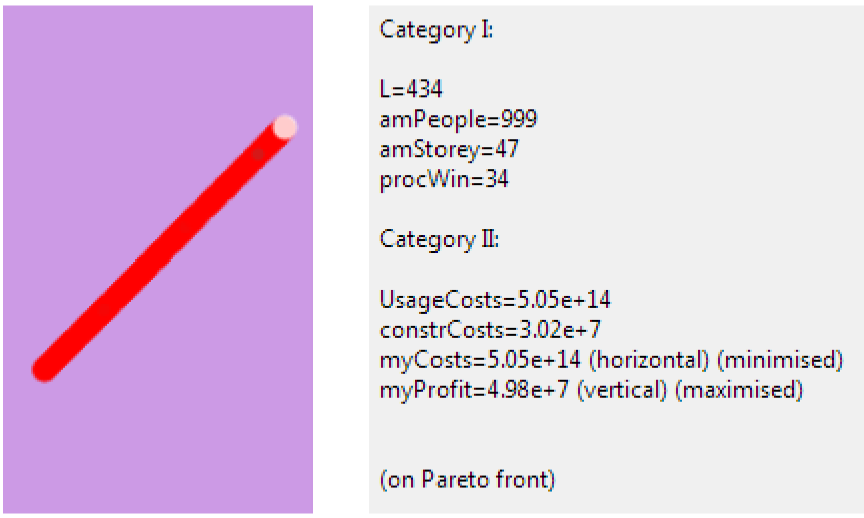
If we now want to minimize the costs by changing the amount of storeys something unexpected happens. We just saw that the fewer the amount of storeys, the fewer the construction costs. If we look at this now we see that a fewer amount of storeys means more constructions costs. In this case we take more storeys to make the construction costs less and we see that there is a shift at 16 till 22 storeys. Here the construction costs remain the same and after the 22 the costs get more again. Now in order to optimize the amount of storeys we take 22 storeys, since this is the maximum number where the construction costs(in this case) are the least.

The conclusion is that to optimize this lower point even more we take the shortest optimal length -36 meter. We leave the amount of people the way it was, since changing those both have a negative and a positive influence. If we now want to minimize the costs by changing the amount of storeys. We take 1 storey since here the construction costs are the lowest.
Now we do the last optimization on the percentage of window. We see that we have the least amount of construction when we have no windows. Now we have reached the optimal results at the low end of the Pareto-front. These are the results:



We see that we have lowered the amount of usage costs and the construction costs and therefore the total `myCosts`. We also gained an amount of the profit, however this is influenced by the fact that the sliders aren't so precise that we can have the exact same amount of people as the results of the Pareto-front.

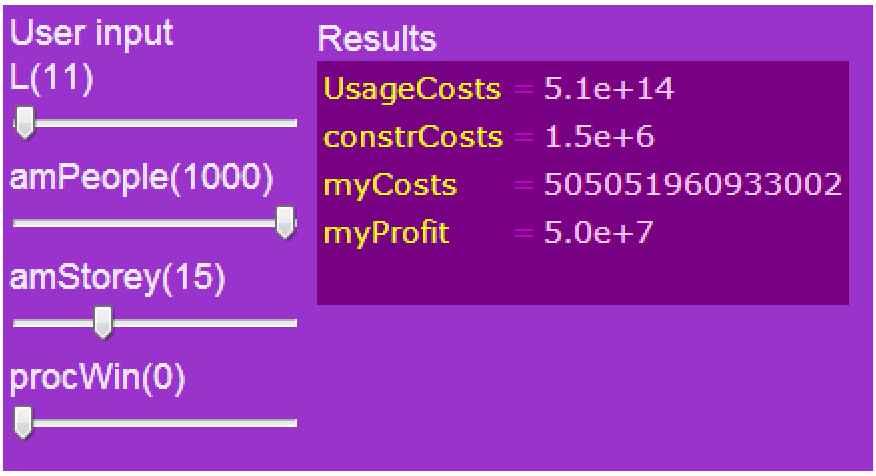
Now we have optimized the lower point of the Pareto-front we are going to optimize to higher end and see if there are any remarkable solutions. The higher end point, which means the maximum costs, but also the maximum profit consists of the values:



If we now start shifting the sliders we see the same phenomenon for each individual slider as we saw with the lower point.

In order to optimize the higher end point of the Pareto-front we start with changing the length to get the minimum costs and maximum profit. In this case the length will be 11 meter since this results in the minimum construction costs. We don't change the amount of people. We can do this to make more profit but then we will also have more costs. If we change the amount of storeys we see that any number between 11 and 23 means the less construction costs. This means to optimize this we can take any number between 11 and 23, in this case we take 15 storeys. The last part for optimization is the percentage of windows. To optimize those costs we still have no windows in order to optimize the construction costs.

Now we have reached the optimal results at the high end of the Pareto-front. These are the results:



From those results we see that we have approximately the same usage costs as before the optimization. We have lowered the construction costs and therefore lowered the total costs just a little bit. Furthermore we kept the profit almost as high as it was before, due to the fact that the sliders are less precise.

Now we played with the model and the Pareto-front we can draw our conclusions from these findings. For the conclusions see chapter 18.

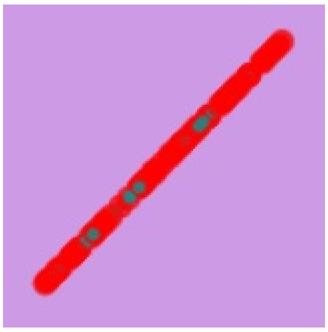
17 Validation and Verification; Accuracy and Precision

Our constants are most of the time averages of different values we found in different sources. This is why some constants are not very precise (for example the average temperature in the Netherlands, which varies from three to eighteen years). This is, however, not a bad thing for our model because the insecurity of these constants is too small to influence the outcome of the model.

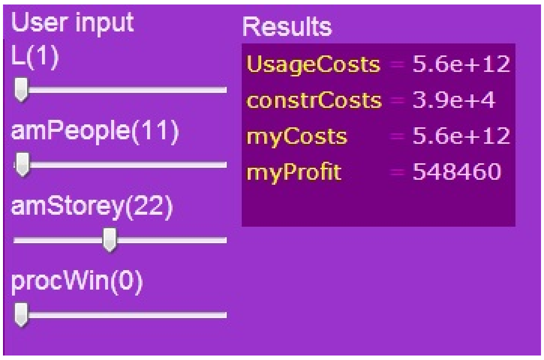
Another way to make our model more accurate is at some points work out the formulas even further instead of making an assumption. Assumptions make it easier for us to complete the model, but at the same time they make the model less accurate. For example, we assumed that from seven to six all the people who will work in the building are present. In real life, this will not be true of course. By working this fact out in formulas, the model would be more reliable. However, expand all these functions like this would have been impossible to do for us in the given time. And it will always be a question if including all these extra formulas will actually change the outcome of the model.

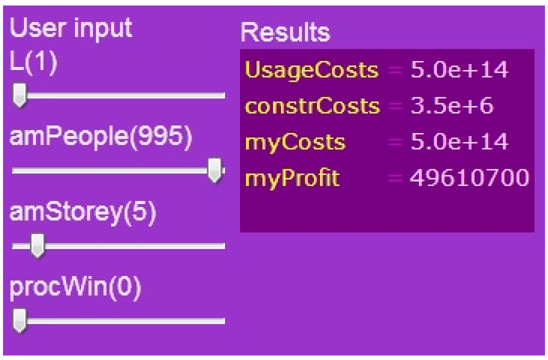
18 Presentation and Interpretation

The purpose of our model was to find the optimal dimensions for the building in order to minimize the construction and usage costs and maximize the profit made by renting the building. We looked at a period of 50 years. The model's results are visualized in a Pareto front:



The high and low end results, found in chapter 16, are interesting:





The low end result (at the left) means that you the building's width is 1 meter and offers room for 11 people over 22 windowless storeys.
The high end result (at the right) means that the building has a width of 1 meter, a capacity of 995 people over 5 storeys, and again no windows.

With those results we calculate the profit by subtracting the costs from the revenues (`myProfit - myCosts = amount of money left`).

For the low end results: $548460 - 5.6 \cdot 10^{12} = -5599999451540 = -5.6 \cdot 10^{12}$
For the high end results: $5.0e \cdot 10^{14} - 505051960933002 = -505051910933002 = -5.1 \cdot 10^{14}$

From these results we conclude that the low end result is in total more optimal since you lose less money on the model. Even though you gain less profit you also pay less for the building and therefore in total you lose less money.
This is due to the fact that we only look at a period of 50 years and the only profit if for rental of the building.
From this model the realistic answer would be that it is best to just don't build a building if you are only going to make profit from it with rental, since the costs you have are far more than your profit from the rental, and within the 50 years you will never make money on the building.

Besides this overall question for our model we also had some sub-questions which we will also answer here:

Does the use of multiple storeys reduce the construction and usage costs?

The amount of storeys has an influence on the usage costs. In chapter 16 we saw that in one case the more storeys the more the costs are. However later in that chapter we saw that more storeys first caused fewer construction costs, until a certain amount of storeys and after that the costs went more again. So the amount of storeys does influence the construction costs only not always in the same way. The amount of storeys also influences the usage costs, only the same as construction costs, this is not always with the same quantities. Also the amount of storeys has a significant smaller influence on the usage costs compared to the construction costs.

Does the value of complying with the users' requirements outweigh the costs of constructing and using the building?

To answer this question we will analyze the influence the amount of people have on the total costs of the construction and using of the building. From this we conclude that the people have a "negative" influence on those costs, since the more people the more construction and usage costs. This is a predictable outcome since more people means a bigger building. However people do have a positive influence on the building, because they make sure you can ask money to rent the building.

What wall-window ratio results in the lowest energy usage?

The wall-window ratio has an insignificant influence on the energy usage, which also is so that more windows result into more energy usage. This may come due to the fact that lights may be more expensive than the climate controller costs. However the wall-window ratio does have a significant influence on the building costs. The most optimal is to have no windows at all, since windows are far more expensive than walls and don't have a noticeable influence on the energy usage costs.

Does the use of solar panels reduce the overall costs?

From the analysis of the model we see that the amount of solar panels does reduce the overall costs. This can't be seen directly from the model since the solar panels are restricted to the surface of the roof. Only the bigger the surface of the roof, the bigger the surface of the ground, which will result into more costs for the ground surface.

19 Discussion after the Conceptual Model

We've decided to leave out the influence of location and orientation of the building, because in our model we used the averages of the properties involved. For instance, the average temperature, the average amount of sun hours and the average price for land surface. Afterwards, this was a wise decision according to the time we had, because we would have had a lot more variables if we chose to consider location and orientation. The climate control system and the lights in the office are both contributing to the energy expenses. In our conceptual model the solar panels are also contributing. But they are in fact decreasing the overall energy expense.

20 Discussion after the Formal Model

In the formal model we made the assumption that the total construction costs consist only out of the given properties. We stated that the building process will go as planned, with no delays or exceeding the budget. We choose to do this because these real world problems would not arise nor influence our modeled office building. However we could have made a property.

We chose to leave out the costs for facilities such as a kitchen in the canteen, toilets and sinks, writing desks, chairs and even the carpet. We decided that the office will be yielded completely empty. Only the structure will be provided. We made this decision because it safes us lots of time. And every company or business has a different demands.

The surface required for a single person is 5,54 square meter. This seems like a lot of working space for just one person. But included in this surface are all the collectively used rooms, for instance a canteen, a reception, the hallways, toilets and even the storage rooms. we calculated this number with the use of floor maps of other buildings. We did this because now the required floor surface is directly linked to the amount of people utilizing the building.

The light that enters the building through the windows is spread evenly over the entire floor surface. We made this assumption because we wanted to have a relation between the amount of lux provided by artificial lighting and the amount of lux provided by the sun. So that we can easily calculate the amount of lights required per m^2.

We have some points for improvement. We have set that the amount of people in the building is evenly distributed on every floor. But if for instance we have 8 floors and only 4 people, there would be half a person on every floor. A great solution would be that the maximum amount of floors is equal to the amount of people.

There is an issue with the relation between the length of the building and the construction costs. In our model, when the length is added the construction costs increase. This should not be happening. this is also an issue that is a point of improvement.

21 Discussion after the Result

Some of the results need some elaboration, because the results we got could be alternated by our assumptions. The credibility of the results in chapter 16 are a point of discussion. The results from the calculations with a low valuable are implausible because there would be more floors than people. In the case where the building has 10 floors and there are only 5 employees that would mean that there are 0.5 person per floor.

There is a weird case with the length of our office. The model shows that the optimal length of the building is 1 m. This would mean that the building will have a really unpractical shape. This is definitely a point of improvement. Also the windows do not have as much effect on the model as we anticipated. They do not have a positive influence in the building costs or the maintenance costs.

The results of chapter 15 are questionable. The results of the highest point are more plausible than that of the low point. When there are 993 employees on 5 floors there would be whole persons on every floor. This would result in a case where there is a lot of ground surface needed for the office. But this is not implausible as is.

When we have a look at the financial picture there are a lot of things that need improvements if we want to make a profit. We should find ways to decrease expenses. For instance decreasing the construction costs, by decreasing material costs. for instance getting a discount for the materials because they are purchased in bulk. Also we could decrease the energy costs when we would use environmental friendly that have a lower energy usage. And of course we should focus on other ways to make money with the building other than just rent.

22 Discussion after the Solution of the Initial Problem

The purpose of the model is to find an optimal. We aimed to find the best balance between the number of people who will be utilizing the building and the costs of construction and usage. This question is indeed solved by our model, because the model gives a reasonable output which are immediately relevant for the initial problem.

23 Extension I

What would we do if we had an extra week to work on the model? One thing we would do to make our model even better, is delete some assumptions we made and work out the points where these assumptions were made even better. This would make our model more realistic. For example, we made an assumption that the light coming through the windows is evenly distributed along the surface of the storey. This is not very realistic, because the illumination close to the window will be bigger than the illumination further from the window. With an extra week of time, we would expand this aspect of the model. If we had more time, we would also be able to do more research to our constants and their values. We would make better calculations based on more sources than we have now. This would make our model even more realistic and reliable.

24 Extension II

In order to get precise estimates in our model, we had to specify things like location, weather, costs etc. This influenced the possibility to use the model for a larger class of problems. Our model can only be applied to the matching specifications we used to come to our estimates. We can't think of a case that tackles a slightly larger class of problems and still complies with our assumptions.

25 What are you Proud of in your own work?

What we are proud of in our work, is that our model is very broad. We took into account many aspects of a building's costs and profit and at some points we even included the smallest things (for example, the energy people themselves produce when working). Because our model is this broad, it is a good basis for an architect if he or she wants to take a look at the costs of the building he or she is designing. It can help the architect to make decisions about the dimensions of the building. For example, when the amount of people is known, the optimal amount of storeys can be found with our model. Another thing that we are proud of in our work is that our constants are very realistic. We took a long time to find good sources for these constants and make good calculations. Sometimes, this led to surprising outcomes that we did not expect ourselves (for example, the produced warmth of a person was much higher than we expected).

26 Where is Room for Improvement in your own work?

The improvement for our work lies within the execution of the model in Accel. When we implemented the model in Accel, it showed some surprising outcomes. For example, the windows in the building do not have a positive influence on the energy costs, they are just increasing the construction costs. Our expectation was that more windows would decrease energy costs. So, at some points, the model "says" something different than our instinct. With more time, we would have controlled and improved the functions about the windows (in this example).

27 What have you learned?

By making this model, we learned how all the theoretical steps of making a model (definition, conceptualization, formalization and execution) can be put into practice by actually make one. We now know the best ways to complete these steps. We also learned that these steps seem to be static, but in practice all the steps are mixed up and need to be changed all the time (for example, when something changes in the formal model, the conceptual model also needs to chance).

28 Used Literature

All sources are referenced in section 14.

29 List of definitions

The next table shows the category and description for each abbreviation.

amCcs	4	Amount of climate control systems.
amCubm	4	Amount of cubic meter.
amCubmpRefreshment	4	Amount of m3 per refreshement of the air.
amCubmpYear	4	Amount of cubic meter refreshed per year
amHoursOn	3	Amount of hours one light is on.
amLights	4	Amount of lights.
amLightspm2	4	Amount of lights per square meter.
amLightspStorey	4	Amount of lights per storey.
amLuxpLights	3	Amount of lux shining per light.
amLuxpm2	4	Amount of lux per square meter.
amLuxpm2need	3	Amount of lux needed per square meter.
amLuxpm2there	4	Amount of lux there per square meter.
amLuxpm2window	3	Amount of lux per square meter window.
amLuxthere	4	Amount of lux there.
amm2	4	Amount of rentable square meter.
amMCcs	3	Amount of Climate control system checks per year.
amPeople	1	Amount of people
amPeoplepStorey	4	Amount of people per storey.
amRefreshmentspYear	3	Amount of refreshment of the air per year.
amStorey	1	Amount of storeys.
amWatt	3	Amount of watt used by one light.
amYears	3	Amount of years the building is used.
B	4	Width of the building.
CcsCo	4	Total costs for the climate control system.
constrCo	2	The total costs for constructing the building.
CubmpCcs	3	Cubic meter per climate control system.
Eair	4	Energy used to refresh air.
ECcspYear	4	Energy used by climate control system per year.
ELightspYear	4	Energy used by lights per year.
ElossWallpYear	4	Energy loss by the walls per year.
ElosWallpm2pYear	3	Energy loss wall per square meter per year.
ElossWinpYear	4	Energy loss by the windows per year.
ElosWinpm2pYear	3	Energy loss window per square meter per year.
EnergyCpYear	4	Energy costs of the building per year.
EoneLightpYear	4	Energy used by one light per year.
Eppm2SolPanpYear	3	Energy produced per solar panel per year.
EsolarIncomepYear	4	Energy made by the solar panels per year.
Ewarmth	4	Energy used to warm up the building.
FloorCopStorey	4	Floor costs per storey.
h	3	Height of storey.

kWhpCubm	3	kWh needed to refresh one cubic meter.
L	1	Length of the building.
LandCo	4	Total costs for the land.
LifespLights	3	Life span of the lights.
LightsCo	4	Total costs for the lights.
LightsRCo	4	Replacement costs of the lights.
MaintCo	4	Maintenance costs of the building.
MCcsCo	4	Maintenance costs of the climate control system.
MLightsCo	4	Maintenance costs of the lights.
ppCcs	3	Price per climate control system.
ppkWh	3	Price per kilo watt hour.
ppm2Land	3	Price per square meter land.
ppLight	3	Price per light.
ppMCheckCcs	3	Price per check of the climate control system.
ppm2Floor	3	Price per square meter floor.
ppm2Roof	3	Price per square meter roof.
ppm2SolPan	3	Price per square meter solar panel.
ppm2Wall	3	Price per square meter of wall.
ppm2Win	3	Price per square meter of window.
procWin	1	Percentage of windows of the building.
ProfitRent	2	Profit of the rent.
ProfitpYear	4	Profit per year.
pRoof	4	Price of the roof.
ppStorey	4	Price per storey.
RCopLight	3	Replacement costs per light.
Rentpm2pYear	3	Rent per square meter per year.
SidesCo	4	Total costs for the sides of the building.
SolPanCo	4	Total costs for the solar panels.
surGround	4	Surface of the ground.
surReqpP	3	Required surface per people.
surRoof	4	Surface of the roof.
surSidepStorey	4	Surface of the sides per storey.
surSolPan	4	Total surface of solar panels.
surWall	4	Total surface of walls in the building.
surWallpStorey	4	Surface of wall per storey.
surWin	4	Total surface of windows in the building.
surWinpStorey	4	Surface of window per storey.
UsageCo	2	Usage costs of the building.
WallCopStorey	4	Wall costs per storey.
WinCopStorey	4	Window costs per storey.
Epeople	4	Energy made by all people.
RCpLight	3	Replacement Costs per light.
kWhpPeoplepYear	3	Amount of kWh produced per person per year.

surStorey	4	Surface of one storey.

30 List of illustrations

Accel code

```
L=slider(620,1,1000)
amPeople=slider(7,1,1000)
amStorey=slider(7,1,47)
procWin=slider(35,0,100)
UsageCosts=UsageC
constrCosts=constrCo
myCosts=paretoMin(paretoHor(totCo))
myProfit=paretoMax(paretoVer(ProfitRent))
CubmpCcs=208.33
ElosWallpm2pYear=2.01
ElosWinpm2pYear=262.8
Eppm2SolPanpYear=85
LifespLights=5
MinLights=0
RCpLight=14.93
Rentpm2Year=180
amHoursOn=4015
amLuxpLights=800
amLuxpm2need=500
amLuxpm2window=5437
amMCcs=3.5
amRefreshmentspYear=52560
amWatt=12.5
amYears=50
h=3
kWhpCubm=52560
kWhpPeoplepYear=143
ppCcs=6850.57
ppLight=13.21
ppMCheckCcs=374
ppkWh=0.22
ppm2Floor=81.15
ppm2Land=350
ppm2Roof=105.93
ppm2SolPan=256
ppm2Wall=51.61
ppm2Win=600
```

```
surreqpP=5.54
B=surGround/L
CcsCo=ppCcs*amCcs
ECcspYear=Ewarmth+Eair
ELightspYear=EoneLightpYear*amLightss
Eair=amCubmpYear*kWhpCubm
ElossWallpYear=ElosWallpm2pYear*surWall
ElossWinpYear=ElosWinpm2pYear*surWin
EnergyCpYear=(ELightspYear+ECcspYear-EsolarIncomepYear)*ppkWh
EoneLightpYear=amWatt*amHoursOn
Epeople=amPeople*kWhpPeoplepYear
EsolarIncomepYear=surSolPan*Eppm2SolPanpYear
Ewarmth=ElossWinpYear+ElossWallpYear-Epeople
FloorCopStorey=surStorey*ppm2Floor
LandCo=surGround*ppm2Land
LightsCo=amLightss*ppLight
LightsRC=amLightss*RCpLight
MCcsC=amMCcs*ppMCheckCcs
MLightsC=LightsRC/LifespLights
MaintC=MLightsC+MCcsC
ProfitRent=ProfitpYear*amYears
ProfitpYear=Rentpm2Year*amm2
SidesCo=ppStorey*amStorey+pRoof
SolPanCo=surSolPan*ppm2SolPan
UsageC=(MaintC+EnergyCpYear)*amYears
WallCopStorey=surWallpStorey*ppm2Wall
WinCopStorey=surWinpStorey*ppm2Win
amCcs=amCubm/CubmpCcs
amCubm=surGround*h*amStorey
amCubmpRefreshment=amCubm
amCubmpYear=amCubmpRefreshment*amRefreshmentspYear
amLights=amLightspStorey*amStorey
amLightspStorey=amLightspm2*surStorey
amLightspm2=amLuxpm2/amLuxpLights
amLightss=max(MinLights,amLights)
    //  // value=0
amLuxpm2=amLuxpm2need-amLuxpm2there
amLuxpm2there=amLuxthere/amm2
amLuxthere=amLuxpm2window*surWin
amPeoplepStorey=amPeople/amStorey
amm2=surStorey*amStorey
constrCo=CcsCo+SolPanCo+LightsCo+SidesCo+LandCo
pRoof=surRoof*ppm2Roof
ppStorey=WallCopStorey+WinCopStorey+FloorCopStorey
proWin=procWin/100
```

```
surGround=amPeoplepStorey*surreqpP
surRoof=surGround
surSidepStorey=2*(L*h)+2*(B*h)
surSolPan=surRoof
surStorey=surGround
surWall=surWallpStorey*amStorey
surWallpStorey=surSidepStorey-surWinpStorey
surWin=surWinpStorey*amStorey
surWinpStorey=proWin*surSidepStorey
totCo=UsageC+constrCo
```