KTH Kungliga Tekniska Högskolan

MJ2437, Modelling of Energy Systems

Energy Utilisation

# Systematic Energy Utilisation Optimisation in DesignBuilder

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# 1 Introduction

The Royal Institute of Technology in Stockholm and J.A. Enterprises have been working together on a joint project to evaluate various energy-efficient measures for the operation of its academic buildings. This report focuses on and evaluates the energy performance of the M building at Brinellvagen 64. We simulate weather, occupancy, and utilities usage to model the energy flow required by the building, and suggest a number of techniques to brings its performance to within Gold Level Standard-requisite levels.

The building in question, Brinellvagen 64, was constructed in 1966. Currently it is a very popular place for Maskin students, seeing peak occupancies around noon and declining gradually into the evening. It has, however, not reached its peak energy performance. Currently it uses 131 kWh/m$^2$/year total energy - 32% of which is electricity, 45% of which is heating, and 22% of which is cooling. Ideally, we can bring Brinellvagen 64 to a total energy usage of 84kWh/m$^2$/year, which qualifies for Miljöbyggnad levels.

We also simulate the performance of this building in foreign weather conditions (New York City), to quantify how much of the building's performance is locational. A detailed outline of the measures taken to reduce the yearly energy usage is shown below.

# 2 CAD Model of M Building

The energy flow simulation software DesignBuilder was used to create a CAD model, (see Figure 1), schedule its behaviour, and evaluate the energy flow within it. The actual building is has a square meterage of 3400m$^2$, and our CAD model is accurate in proportion to 97.5% (simulated square meterage of 3315m$^2$).

The M building consists of four floors, the bottom-most one being partially below ground. Three two-story lecture halls transverse the first and second floors, and two stair/elevator shafts transverse all four floors. The second and third floors have small classrooms and the fourth floor has six high-energy computer labs. Each zone was isolated in CAD and given individualised schedules and occupancies. The model was dimensioned realistically. Due to the relatively simple geometry of the building, very few simulations or approximations were made. Interior doors were auto-generated, but multi-floor rooms were placed by hand. Window were placed and proportioned realistically. Occupancy schedules were approximated from experience, and heating/cooling schedules were determined relative to occupancy.

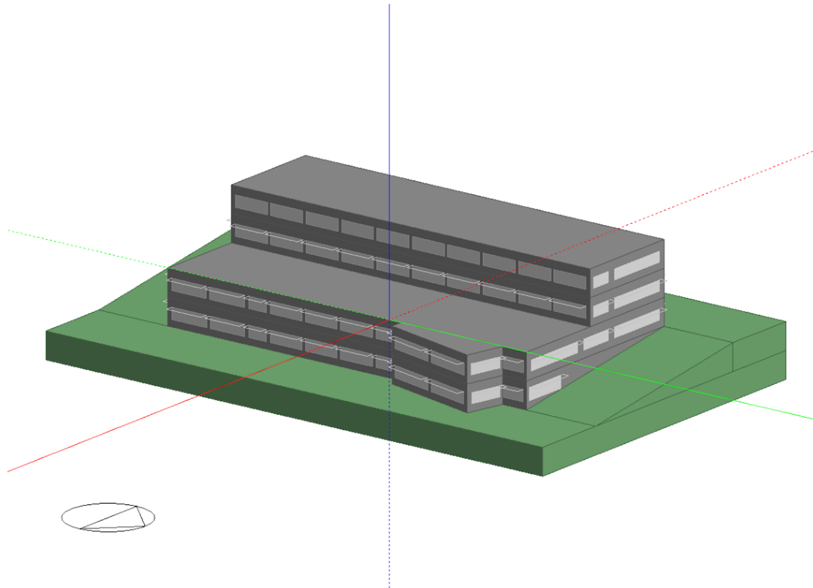
# 3 Energy Performances

## 3.1 Actual Load - Before Optimisation

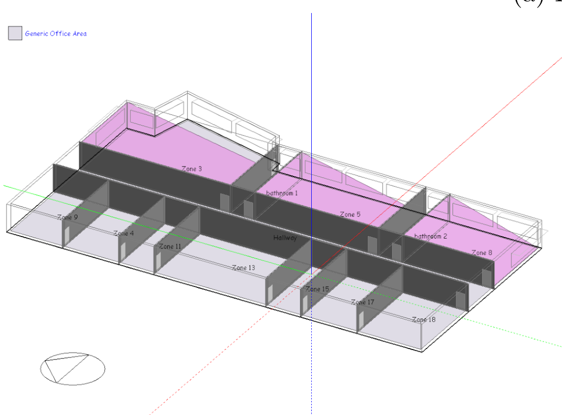
In optimising the building performance, we first had to construct an accurate model of the current behaviour, occupancy, and energy consumption. Using real data of consumption levels by energy type, we assign different floors their realistic functions and matched the data.

### 3.1.1 Activity

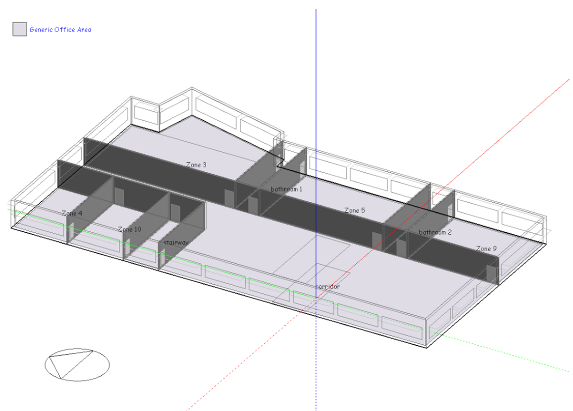
All four floors use the Generic Office Area template, with all Heating and Cooling set-point temperatures at 21C, with Heating setback at 12C and Cooling setback at 12C. All floors use a custom



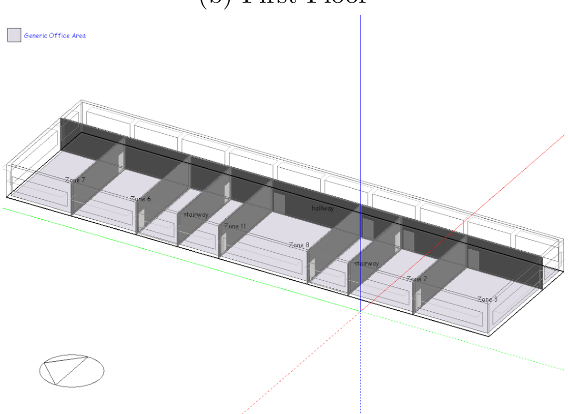
(a) Entire



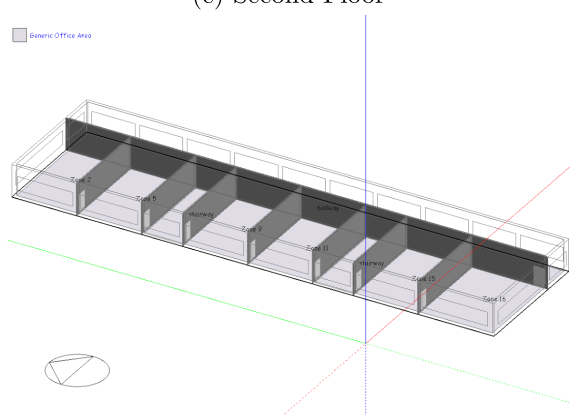
(b) First Floor



(c) Second Floor



(d) Third Floor



(e) Fourth Floor

Figure 1: CAD Model of Building by Floor

Occupancy schedule, accounting for variable behaviour in Summer vs. Winter, as well as Weekdays vs. Weekends. The variable floors are rated with different densities, taking into account the sparsely populated basement vs. the densely packed lecture halls and medium-density computer labs. Only the fourth floor is given Computer activity, at a gain of 12 W/m$^2$. All floors have Office Equipment, at a gain of 13 W/m$^2$. Both operate on a custom Office Equipment Schedule, which takes into account the on-but-latent nature of a computer left on overnight, or over a long weekend. A reasonable Miscellaneous Energy component is also modelled, drawing Natural Gas power from the grid - meant to represent the additional load of students charging phones, laptops, etc. throughout the day.

#### 3.1.2 Construction

The entire building uses an industry-standard Project Construction Template rated for native Swedish construction codes, with layered Project Walls composed of an outer leaf of brickwork, a layer of XPS Extruded Polystyrene, a Concrete Block layer for insulation, and an innermost aesthetic Gypsum Plastering layer. In terms of Airtightness, the entire building uses a constant Model Infiltration rate of 0.300 ac/h, set to a schedule of constant ventilation.

#### 3.1.3 Openings

In accordance with Swedish industry standards, all windows are Triple-Glazed, Clear, with No Shading, and a 3mm/6mm Air Glazing Gap. All windows have a Preferred Height of 1.5m, 30% Glazed, with a realistic Window-to-Wall percent of 30%. Each window is spaced 5m apart, with a Sill Height of 0.80. No internal windows, roof windows, skylights, or shading is employed at this time.

#### 3.1.4 Lighting

Lighting is a constant across floors. Lighting energy is set to a realistic 10.00W/m$^2$, on a custom Lighting Schedule which takes into account the lessened need to light rooms during sunny winter and summer days during which sunlight comes in at a bright enough angle. The lights are Suspended, with a Radiant Fraction of 0.420. Lighting control is Linear. There is no Task/Display Lighting or Exterior Lighting.

#### 3.1.5 HVAC

The entire building uses a Hot Water Radiator / Mechanical Ventilator system, with Auxiliary Energy of 3.26kWh/m$^2$, and Central Heating using Air Distribution. The Mechanical Ventilation is contingent upon building Occupancy, which is set to a custom Occupancy Schedule designed around anecdotal evidence of M-building occupancy during peak hours, as well as at nights and on weekends. Ventilation is set on a 4-Min Fresh Air timer, which accounts for per-person and per-area needs. Heating is fuelled by Natural Gas from the grid, with an idealised coefficient of performance CoP = 1.0, constantly on. Cooling is fuelled by electricity of the grid, with a similar CoP = 1.0, constantly on. DHW is set to Instantaneous Hot Water Only, a CoP 0 1.0, and draws electricity from the grid with delivery temperature of 72C and mains supply temperature of 10C. Natural Ventilation is defined by zone, with an average outside air flow rate of 1.5 ac/h, also contingent upon the custom Occupancy Schedule.

#### 3.1.6 Performance

In accordance with measured statistics, as seen in Table 1, our before-optimisation model subscribes closely to reality. Critically, operating temperature remains at an average of 21.51C, a comfortable room temperature. During optimisation, this will be the most important variable to keep steady - room temperature is a very good indicator of comfort and the performance of a system.

### 3.2 Simulated Load - After Optimisation

A number of measures were taken to directly improve the performance of the building and bring it to within acceptable levels of energy consumption to qualify for the Miljöbyggnad standard.

#### 3.2.1 Activity

The water consumption rate was decreased by reducing the occupancy schedule, and closing the building between midnight and 7am, reducing the need for heating, lighting, and completely powering off all office equipment and computers between those hours. The Lighting, Computers, and Office Equipment schedules were decreased accordingly.

#### 3.2.2 Construction

Local shading and window sunshades were added above all windows. Additionally, the window-to-wall ratio was increased from 30% to 40% – in practice, new windows would be added to the exterior during renovations. Best Practice templates were chosen, which helped with modern construction methods and better materials. Similar Best Practice templates were chosen for all lighting.

#### 3.2.3 HVAC

Major conservations were achieved by adjusting the heating and cooling set-point temperatures to more conservative levels. Additionally, the DHW delivery temperature was lowered, and natural ventilation was turned off.

#### 3.2.4 Performance

The building was brought to a Total Site Energy load of 398 411 kWh per year, or 121 kWh/m$^2$ per year. Discounting the energy costs of office equipment, this brings our total Net Energy Usage with acceptable levels. (See Table 2).

### 3.3 Simulated Load - in Auxiliary Location

#### 3.3.1 Location

The same building with the same pre-optimisation settings was simulated under foreign conditions, as if it were on Central Park West in New York City, New York. The latitude and longitude, temperature, climate, sunlight angle, building codes, room temperature, and building materials were all changed accordingly. Three separate optimisation measures were then taken to determine potential methods of saving power in a building. The measures, labelled A, B, and C, are detailed below and are documented thoroughly in Table 3.

| | Electricity $kWh/year$ | Cooling $kWh/year$ | Heating $kWh/year$ | Water $kWh/year$ | Total $kWh/year$ | Total per Area $kWh/m^2/year$ |
|---|---|---|---|---|---|---|
| Actual | 306,140.00 | 98,705.00 | 202,039.00 | 750.00 | 607,634.00 | 183.19 |
| Simulated | 303,560.00 | 99,191.00 | 252,482.00 | 782.00 | 656,015.00 | 197.77 |
| Percent Difference | 0.84% | -0.49% | -24.97% | -4.27% | -7.96% | -7.96% |

Table 1: Accuracy of Model Before Optimisation

| | Electricity $kWh/year$ | Cooling $kWh/year$ | Heating $kWh/year$ | Water $kWh/year$ | Total $kWh/year$ | Total per Area $kWh/m^2/year$ |
|---|---|---|---|---|---|---|
| Before Optimisation | 303,560.00 | 99,191.00 | 252,482.00 | 782.00 | 656,015.00 | 197.77 |
| After Optimisation | 241,394.00 | 14,165.00 | 142,850.00 | 459.00 | 398,868.00 | 120.25 |
| Percent Reduction | 20.48% | 85.72% | 43.42% | 41.30% | 39.20% | 39.20% |

Table 2: Effects of Optimisation, Current Location

| | Electricity $kWh/year$ | Cooling $kWh/year$ | Heating $kWh/year$ | Water $kWh/year$ | Total $kWh/year$ | Total per Area $kWh/m^2/year$ |
|---|---|---|---|---|---|---|
| No Measures | 816,752.00 | 88,937.00 | 183,105.00 | 782.00 | 1,089,576.00 | 328.48 |
| Measure A | 303,552.00 | 37,571.00 | 283,280.00 | 782.00 | 625,185.00 | 188.48 |
| Measure B | 816,752.00 | 88,392.00 | 162,349.00 | 782.00 | 1,068,275.00 | 322.06 |
| Measure C | 816,752.00 | 88,579.00 | 167,977.00 | 782.00 | 1,074,090.00 | 323.81 |
| All Measures | 303,552.00 | 37,006.00 | 243,143.00 | 782.00 | 584,483.00 | 176.21 |

Table 3: Effects of Optimisation, Auxiliary Location

### 3.3.2 Differences

**Measure A: No Misc. Load** In the current building simulation, a constant miscellaneous load is applied, simulating the need of office workers to fluctuate above their allotted equipment parameters. In an optimisation measure, this miscellaneous load would be removed - people in the building would no longer have free access to outlets, complimentary wi-fi, etc. This is an unrealistic measure, but the addition of miscellaneous load to the model was itself an unrealistic approximation necessary to match realistic, observable energy consumption levels. Thus we can recommend it as a measure taken with the real-world implementation being an effort to reduce occupant electricity usage.

**Measure B: Heat Recovery** In the current building simulation, the HVAC system does not utilise heat recovery. Here, we switch heat recovery on. Heat recovery allows heat to be captured from outbound air flow and recycled into the inbound air, which reduces the need to artificially heat inbound air. It is a relatively small measure in terms of cost. Heat recovery doesn't benefit energy consumption much by itself, but there is a verifiably magnified effect when coupled with Measure C.

**Measure C: Variable Air Volume** In the current building simulation, the HVAC system uses mechanical ventilation. Here, it is changed to a VAV system with outside air reset and mixed mode enabled. VAV, Variable Air Volume, aims to keep a constant temperature while allowing the airflow rate to fluctuate. Computer-controlled systems are required to maintain VAVs, but they come at the benefit of less energy and more precise control in all systems. The change includes an option to activate mixed-mode ventilation, which reflects a more accurate model of the building in which windows are opened and closed manually according to occupant comfort levels. AC, natural ventilation, and open windows are switched off between organically. Thus, there is little-to-no loss in stability of room temperature, while the diminished effects on energy consumption are noticeable.

### 3.3.3 Performance

In the end, all three measures taken together reduce energy consumption in the building by 46,5%. As seen in Table B, this is achieved by a large (62,8%) decrease in electricity usage, at the cost of a similar increase in district heating (32,8%). The weighted marginal offset is a net benefit, so we recommend this implementation despite the raised district heating costs. Note here we weight and analyse here based on raw energy consumption. In this case, as in others, the most energy-efficient value may not be the most money-efficient. If electricity is markedly cheaper or more expensive than district heating on a per-watt-basis, the simulation would need to be re-run with other priorities in mind. Water consumption remains a constant throughout. None of the energy-saving measures undertaken affected water consumption or water usage.

## 4 Analysis and Results

Because the electricity usage in classrooms for lighting, computers, and electricity (47 kWh/m$^2$/year) is not counted in measuring energy performance by Swedish regulation, the energy usage used to determine Miljöbyggnad (Gold Level) standard must be summed manually, as in Table 4. Here it is possible to break down electricity consumption by floor and region, and use the sum total, 94,613.42 kWh/year to calculate the total energy use by type, both total and per area, as in Table 5. Here we see the final *per area* usage to be 76.79 kWh/$m^2$/year, which is less than the designated cutoff for Miljöbyggnad levels, 84kWh/$m^2$/year.

# 5 Costs

Refurnishing and renovating a building is always expensive. The DesignBuilder software allows us to calculate the cost of constructing the original building vs. the cost of constructing the optimised building, from scratch. This does not address the cost of labor or renovation, only the hypothetical cost of construction if the building had been built in this way originally.

## 5.1 Original Location

The structural cost, HVAC cost and sub-structure costs are unchanged during renovation. Lighting costs 22.2% more to construct in the optimised building, due to the newly instituted best practice template, which recommends more modern, expensive lighting. The super-structure of the building costs 6.6% less. This can be attributed to the larger windows and less drywall and insulation required. Surface finishing decreases by 4.1% for similar reasons. The major cost is an increase of 50% in glazing costs, from 869 thousand krona to 1,76 million krona. This is a consequence of installing triple-glazed widows in the optimised building, which helps regulate heat and lighting, but the bulk of the increase in window costs is to do with the additional installation of window shading and blinds. A detailed breakdown can be found in Table 6.

## 5.2 Auxiliary Location

Because so few things were changed during auxiliary optimisation, almost all subcategory summations remain unchanged during the optimisation process. Instead, the use of a VAV instead of mechanical ventilation for the HVAC system drove category prices up 53.7% from 4.2 million krona to 9.1 million krona. Another major cost was an increase of 12.4% in glazing costs, for similar reasons as above – the windows are now triple-glazed, which brings costs up from 869 thousand krona to 993 thousand krona. However, both the HVAC and Glazing subcategories are small in comparison to the cost of the building's superstructure - 11 million krona - so the overall cost increase is only 14.4% for optimisation, mostly on the VAV ventilation system. A detailed breakdown can be found in Table 7.

## 5.3 Payback Period

A good metric for the viability of a renovation is the payback period; how long it takes to recoup the costs of the construction. After all, the point of making a building more energy-efficient is to spend less in electricity, heating, and cooling bills. We consider two factors: the potential cost of a renovation, and the potential savings in energy bills. The renovation costs are difficult to calculate due to a variable cost of both uninstallation and labor, but a good approximation is the difference in cost between the two buildings, as measured from the ground up. Energy savings are calculated on a per-year basis, measured as the difference in operating energy required from one building to another. The savings per year is calculated with the Swedish cost of electricity in mind for the original location, and the American cost of electricity in mind for the auxiliary location. Monetary savings per year is a product of energy savings per year and the cost of electricity. In this case,

| | Hallway | Coridor | Stairway | Bathroom | Sum by Floor |
|---|---|---|---|---|---|
| Floor 1 | 20,374.76 | 0.00 | 0.00 | 3,881.07 | 24,255.83 |
| Floor 2 | 0.00 | 39,058.96 | 13.01 | 3,827.52 | 42,899.49 |
| Floor 3 | 11,367.65 | 0.00 | 0.00 | 0.00 | 11,367.65 |
| Floor 4 | 16,090.46 | 0.00 | 0.00 | 0.00 | 16,090.46 |
| Sum by Type | 47,832.87 | 39,058.96 | 13.01 | 7,708.59 | |
| Total Electricity | | | | | 94613.43 |

Table 4: Energy Uses by Floor, Usage Type in Optimised Model, Original Location ($kWh/year$)

| | Total $kWh/year$ | Total Per Area $kWh/m^2/year$ |
|---|---|---|
| Electricity | 94,613.43 | 28.85 |
| Cooling | 14,365.00 | 4.38 |
| Heating | 142,862.86 | 43.56 |
| Total | 251,841.29 | 76.79 |

Table 5: Energy Uses by Source in Optimised Model, Original Location

| | Original *SEK* | Optimized *SEK* | Difference *SEK* | Difference % |
|---|---|---|---|---|
| Structure | 7,116,243.70 | 7,112,470.00 | -3,773.70 | -0.05% |
| HVAC | 4,235,859.40 | 4,233,613.10 | -2,246.30 | -0.05% |
| Lighting | 2,372,081.20 | 3,048,201.40 | +676,120.20 | +22.18% |
| Sub-Structure | 1,597,548.00 | 1,597,548.00 | 0 | 0.00% |
| Super Structure | 11,929,809.70 | 11,193,079.80 | -736,729.90 | -6.58% |
| Glazing | 869,397.80 | 1,760,738.00 | +891,340.20 | +50.62% |
| Renewable | 0 | 0 | 0 | 0.00% |
| Surface Finishing | 1,738,598.00 | 1,670,519.00 | -68,079.00 | -4.08% |
| Building Total | 29,859,537.00 | 30,616,169.00 | +756,632.00 | +2.47% |

Table 6: Effects of Optimisation, Current Location

| | Original *SEK* | Optimized *SEK* | Difference *SEK* | Difference % |
|---|---|---|---|---|
| Structure | 7,116,243.70 | 7,116,243.70 | 0.00 | 0.00% |
| HVAC | 4,235,859.40 | 9,149,456.00 | +4,913,596.60 | +53.70% |
| Lighting | 2,372,081.20 | 2,372,081.20 | 0.00 | 0.00% |
| Sub-Structure | 1,597,548.00 | 1,597,548.00 | 0.00 | 0.00% |
| Super Structure | 11,929,809.70 | 11,929,809.70 | 0.00 | 0.00% |
| Glazing | 869,397.80 | 992,775.70 | +123,377.90 | +12.43% |
| Renewable | 0.00 | 0.00 | 0.00 | 0.00% |
| Surface Finishing | 1,738,598.00 | 1,738,598.00 | 0.00 | 0.00% |
| Building Total | 29,859,537.80 | 34,896,512.30 | +5,036,974.50 | +14.43% |

Table 7: Effects of Optimisation, Auxiliary Location

the renovation is always more expensive than the potential savings of a single year, but the rate of return is just under two years for the current location, and just over six for the auxiliary location. This indicates that, despite the high cost of a renovation, it would save money in the not-so-long term. See Table 8.

## 6 Environmental Impacts

DesignBuilder facilitated the generation of $CO_2$ production graphs by month for each test case. (See Figure 2 for the charts, and Table 9 for the data.) Overall, carbon dioxide levels peaked during the summer, with the exception of the original-location optimisation case, when it peaked locally during the winter. The average carbon production in the optimised original-location test case was 36,131 kg $CO_2$ per month. After the optimisation procedure, $CO_2$ emissions were decreased by 49.9% to an average of 18,108 kg $CO_2$ per month. In our auxiliary location, New York City, $CO_2$ levels peaked during the summer across the board. Production decreased 55.2% from 79,391 kg $CO_2$ per month to 35,594 kg $CO_2$ per month. For total improvement metrics, see Table 10.

While reducing $CO_2$ emissions is primarily an environmental measure, designed with no particular monetary benefit in mind, it is socially and ethically responsible, and is also indicative of an energy-efficient building. With these measures implemented, it becomes possible to achieve the gold standard of Miljöbyggnad, decreasing the overall production for the original and auxiliary locations by half.

## 7 Evaluations and Conclusions

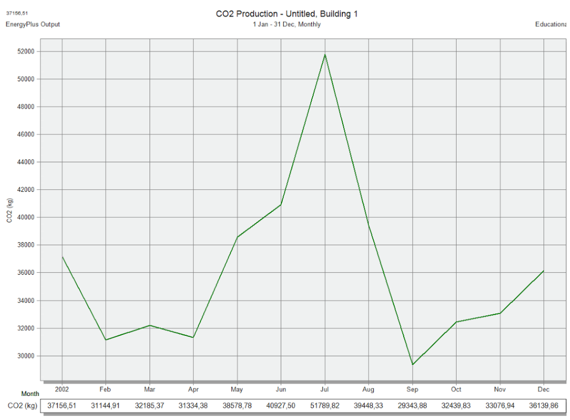
Many of the energy-saving measures undertaken in the above models are, admittedly, unlikely. Cost is often large problem, and construction and renovation take time and energy, often negating any potential short-term savings. Human behaviour, in terms of schedule, activity, and hours of occupancy, is difficult to change and enforce. There are simpler measures, like sun-shades and lighting, but large-scale operations like window glazing or the renovation of an entire HVAC system can be anywhere between costly and impossible, in practice.

However, this simulation has some positive results. Even small activity changes had a large impact on the success of the optimisation process. Things like sunshades and the reduction of waste or phantom power had large reductive effects. These could be instituted with automatic timers, stricter closing hours for computer labs, or even stricter closing hours for the building at large. Much of the heavy lifting of a renovation can be done by these costless optimisations. In addition, future renovations could conform to these higher standards, and help bring the building closer to the desired energy efficiency standard.

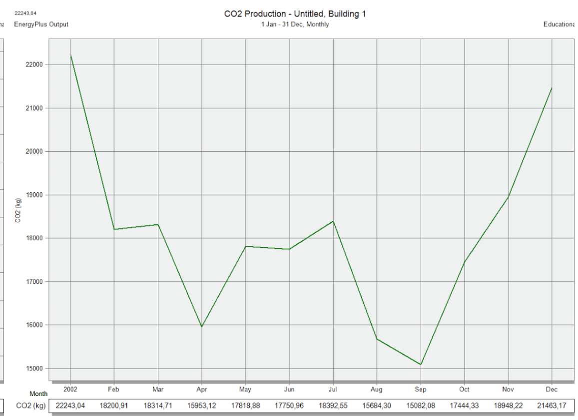
Furthermore, in consideration of the short payback periods and relatively high rate of return, a full-scale renovation is recommended by this firm. In only two years, the cost of electricity savings could more than offset the cost of construction necessary to bring about a higher energy efficiency standard. The optimised building cuts annual carbon production in half, cut electricity consumption by a fifth, cut cooling costs by nearly 90%, and overall reduced the operating cost of the building by nearly 40%. The cost of renovation is, as such, truly an investment in the future ledgers of the building itself, and would lead to as much as 420 thousand krona-savings per year.

| | | Current | Auxiliary |
|---|---|---|---|
| Cost of Construction | $SEK$ | 756,632.00 | 5,036,974.50 |
| Energy Savings | $kWh/year$ | 257,147.00 | 505,093.00 |
| Monetary Savings | $SEK/year$ | 421,721.08 | 828,352.52 |
| Payback Period | $years$ | 1.79 | 6.08 |

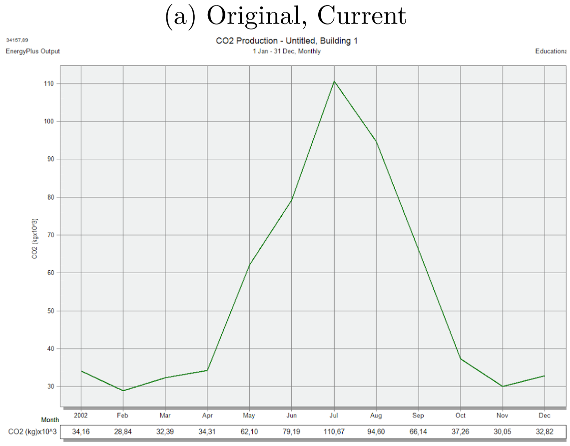
Table 8: Payback Period for Each Location



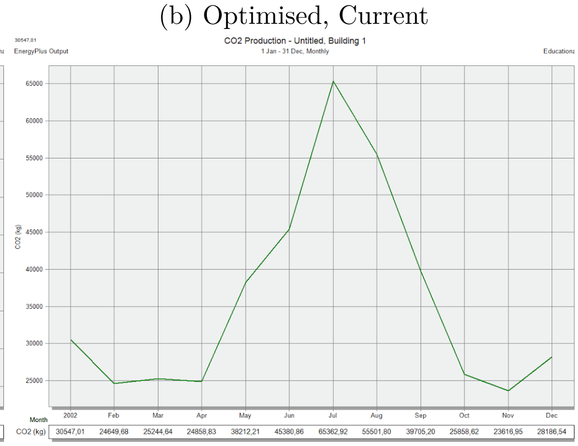

(a) Original, Current




(b) Optimised, Current




(c) Original, Auxiliary




(d) Optimised, Auxiliary

Figure 2: $CO_2$ Production for Original vs. Optimised and Current vs. Auxiliary Locations

| | Current Location | | Auxiliary Location | |
|---|---|---|---|---|
| | Original | Optimized | Original | Optimized |
| | *kg* | *kg* | *kg* | *kg* |
| 1 | 37,156.00 | 22,243.00 | 34,160.00 | 30,547.00 |
| 2 | 31,144.00 | 18,200.00 | 28,840.00 | 24,649.00 |
| 3 | 32,185.00 | 18,314.00 | 32,390.00 | 25,244.00 |
| 4 | 31,334.00 | 15,953.00 | 34,310.00 | 24,858.00 |
| 5 | 38,578.00 | 17,818.00 | 62,100.00 | 38,212.00 |
| 6 | 40,927.00 | 17,750.00 | 9,190.00 | 45,380.00 |
| 7 | 51,789.00 | 18,392.00 | 110,670.00 | 65,362.00 |
| 8 | 39,448.00 | 15,684.00 | 94,600.00 | 55,501.00 |
| 9 | 29,343.00 | 15,082.00 | 66,140.00 | 39,705.00 |
| 10 | 32,439.00 | 17,444.00 | 37,260.00 | 25,858.00 |
| 11 | 33,078.00 | 18,948.00 | 30,050.00 | 23,616.00 |
| 12 | 36,139.00 | 21,463.00 | 32,820.00 | 28,186.00 |
| Total | 433,560.00 | 217,291.00 | 572,530.00 | 427,118.00 |
| Average | 36,130.00 | 18,107.58 | 47,710.83 | 35,593.17 |

Table 9: $CO_2$ production for All Simulations

| | | Current | Auxiliary |
|---|---|---|---|
| Net Improvement | *kg* | 216,269.00 | 145,412.00 |
| Percent Improvement | % | 49.88% | 25.40% |

Table 10: $CO_2$ Production Optimisation Improvement Metrics

# 8 Bibliography


- Commercial Energy Efficiency. Rep. NYC Buildings, 2012. Web. 11 May 2015. <http://www.nyc.gov/html/dob/apps/pdf_viewer/viewer.html?file=2014ECC_CHC4.pdfďion=energy_code_2014>.

- "Energy Management." Building Regulations, BBR. Stockholm, Sweden: Boverket, 2012. N. pag. Web. 11 May 2015. <http://www.boverket.se/globalassets/publikationer/dokument/2012/bbr-engelsk/bfs-2011-26-bbr-eng-9.pdf>.

- Miljöbyggnad (n.d.): n. pag. Swegon Air Academy. Web. 11 May 2015. <http://www.swegonairacademy.com/wp-content/uploads/2013/01/3.pdf>.