Conceptual Energy Analysis: Scaife Hall

48-722 BUILDING PERFORMANCE MODELING

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Scaife Hall information

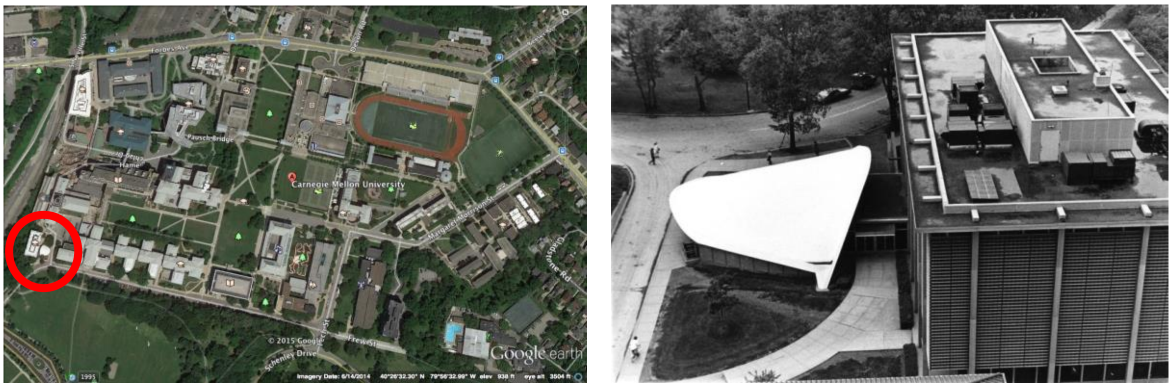

Figure 1 Scaife Hall aerial location and detail

Scaife Hall is a small academic building that houses the Mechanical Engineering Department at Carnegie Mellon University. It is located on the southwest corner of the main campus, on Frew Street, just north of Schenley Park. Its distinguishing architectural feature may be the main auditorium, which is covered by a shell that students describe as being shaped like a potato chip. The total square footage of the building is around 3,400 square meters.

The building consists of lecture halls, an auditorium, classrooms and some offices. It is a four-story building with a basement and mechanical penthouse. The main entrance is on the first floor, on the south side of the building.

Pittsburgh climate

The precise location of Scaife Hall is 40°26′23″N 79°58′35″W. Pittsburgh is located in a humid continental climate that is common to the Mid-Atlantic region of the United States. It experiences cold, cloudy and snowy winters, spring and fall seasons with moderately mild sunshine and summers are warm. Buildings in Pittsburgh, because of four distinct seasons, require extensive heating and cooling, depending on the time of year.

Conceptual mass modeling

One method for studying how early design specifications have an impact on the energy consumption and costs over the life of a building is to run a Conceptual Energy Analysis (CEA) on a model. Autodesk REVIT contains a built-in CEA feature for analyzing such features. The CEA is performed on a conceptual mass model, which represents the actual structure using simple geometric shapes and the appropriate levels and dimension. The energy model contains highly customizable parameters that change the building's construction as well as material and thermal properties, in addition to accurate climate data automatically tied to location. Many simulations can be run, and concise reports are easily extractable to determine the effects of a parameter change.

Baseline model (Pittsburgh,PA)

Model construction, orientation, assumptions

A conceptual mass model representing Scaife Hall was constructed in REVIT using dimensions from AutoCAD drawings. Four geometric masses were created: foundation, main structure, penthouse, and lecture auditorium. Proper level heights were designated. The first level was assumed to be even with the ground, 4.6 meters above basement grade. Levels 2 through the main roof sit 3.5 meters apart from each other, with the penthouse 2.9 meters above the roof. Once the masses were created and placed in position on proper levels, they were integrated.
Using Google Earth satellite imagery, the orientation of the building was determined to be approximately 16 degrees east of north. The baseline model was orientated to reflect this, with the lecture auditorium notable orientated towards the southeast, and the largest exposed exterior of the building facing west-northwest.

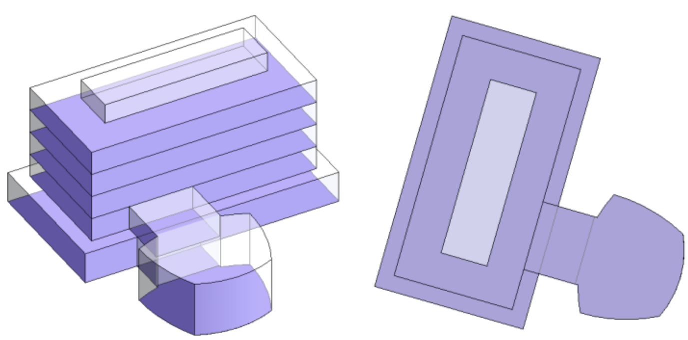

Figure 2 Scaife Hall 3D conceptual mass model and plan view

Default parameters

The default energy settings contain parameters such as conceptual construction materials. The software allows for precise specifications, which lead to differing energy consumptions. The default parameters help making a baseline model relatively quickly. Specifications include alternative options for adjusting the location, ground plane, and building type, as well as energy properties. Regarding initial settings for different materials, the default choices were typically set to moderate (for example, mild climate instead of hot or cold). This seems sufficient as a starting point, but it was expected that the Pittsburgh model will require settings that are beneficial to cold climates.

As shown below, the default energy settings and default conceptual constructions indicate basic energy choices that are not extreme. In some cases, the default settings will remain the same throughout the study—parameters such as Analytical Space Resolution, HVAC System, Building Operating Schedule, Core Offset, and Sill Height are considered to be adequate enough for a simple conceptual model.

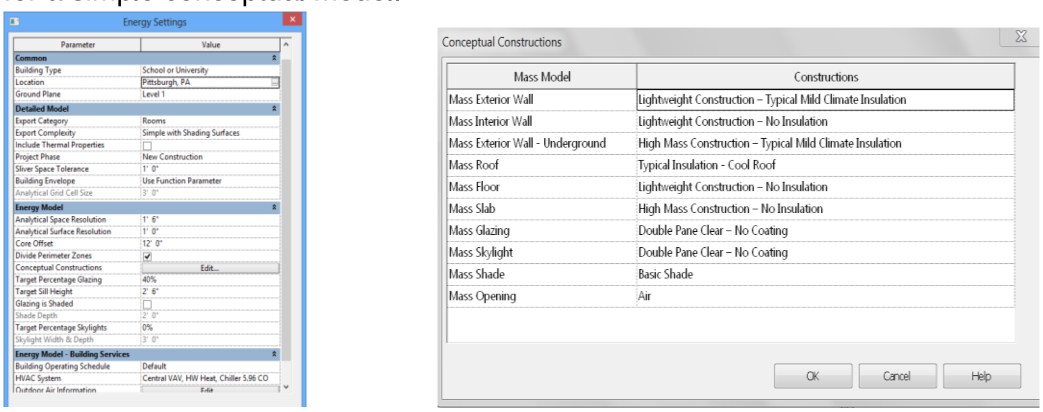

Figure 3: Default REVIT CEA Energy and Conceptual Construction Settings

Results: Baseline Pittsburgh Energy and Costs

Building Performance Factors

Location:	Pittsburgh, PA
Weather Station:	45258
Outdoor Temperature:	Max: 32°C/Min: -18°C
Floor Area:	3,439 m²
Exterior Wall Area:	1,737 m²
Average Lighting Power:	10.66 W / m²
People:	746 people
Exterior Window Ratio:	0.36
Electrical Cost:	$0.10 / kWh

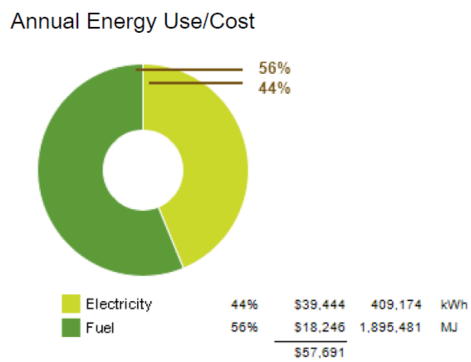

Figure 4: Baseline model information for Pittsburgh

	Energy Use: Fuel		Energy Use: Electricity		
	HVAC	Domestic Hot Water	HVAC	Lighting	Misc Equipment
Load	1,550,000 MJ	346,000 MJ	211,500 kWh	89,200 kWh	104,000 kWh
Cost	$14,900	$3,300	$20,400	$8,600	$10,000

Table 1: Scaife Hall Baseline (Pittsburgh) Energy Loads and Costs

The total energy use intensity comes out to be 980 MJ/sm/yr while the life cycle cost comes out to be $786,000.

Results: Baseline Pittsburgh Emissions

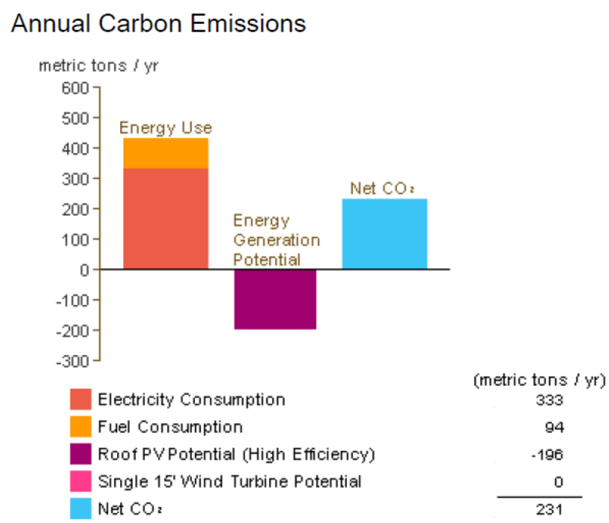

Figure 5 Pittsburgh Baseline Model CO2 Emissions:

The important number to report here is the 427 metric tons of CO_2 released by operating the building under the model's conditions. The Net CO_2 is shown as 231 metric tons, but that is assuming that the roof is adequately outfitted with highly-efficient solar PV panels. Throughout the study, the CO_2 emissions reported are electricity plus fuel consumption, and solar PV is not considered in the final numbers. In general, the Pittsburgh models have solar PV potential for offsetting about 200 metric tons of CO_2.

Parametric Analysis - Pittsburgh

Geometric changes: orientation, mass segregation

The first task in the parametric study involved changing physical aspects of the building without altering the overall square footage or number of floors. This included orientation (i.e. rotation), and overall form alteration. Orientation of the building changes the way sunlight interacts with the spaces, so various orientations can be expected to result in different load requirements. Likewise, alterations of the physical forms (without changing floor area) can change the way systems heat or cool the building spaces.

The baseline model was rotated clockwise by 90 degrees, and also counterclockwise 90 degrees from the realistic, baseline position of 16 degrees east of north. CEA was performed on each iteration of the oriented model.

To investigate the changing of the mass form, the main structure of the building (floors 1-4, plus main roof and penthouse) were split and segregated evenly. The resulting structure had two tower rises instead of one, with the overall square footage remaining the same. Because of this square footage restriction, it is difficult to come up with justifiable and meaningful alterations to the mass model, so the two-tower approach provides a radical shift in form and should reveal consequences of heating and cooling two smaller forms instead of one larger form.

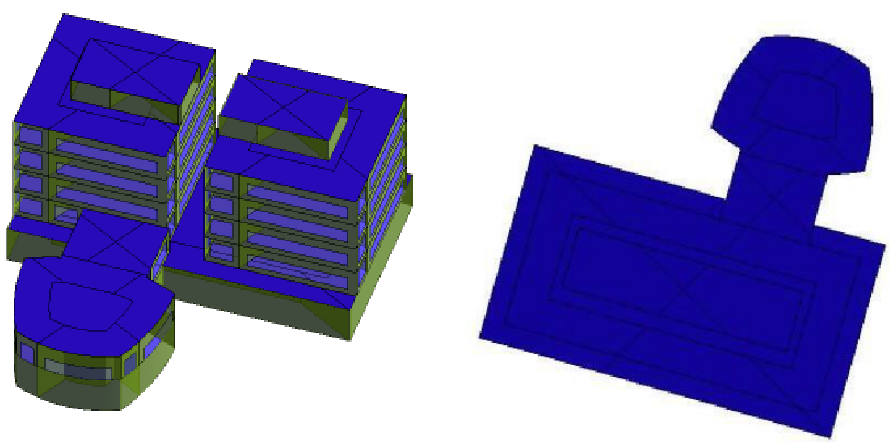

Figure 6: Scaife Hall Twin Rise Concept; 90 degree rotation plan view

	Annual energy use intensity	Annual energy cost	Annual carbon emissions (Fuel + Electricity)
Baseline	980 MJ/sm/yr	$57,700	427 mt/yr
90 degrees counterclock wise	949 MJ/sm/yr	$55,700	412 mt/yr
Two tower rise	1,009 MJ/sm/yr	$62,000	457 mt/yr

Table 2: Comparison of Geometrical Modifications to Pittsburgh Model

Modification of construction properties

Among the next obvious parameters to alter for the model include glazing ratio (window-to-wall ratio), insulation for slab, floor, and walls, and roof types. The best geometric model was carried forward for the remaining parametric analysis for Pittsburgh, and that is the model that is rotated 90 degrees counterclockwise from the original orientation. We believe this is the best one because the largest face of the building faces south, and receives more sunlight during the winter months. Initially, a study of wall, floor, slab, and roof parameters was conducted.

	Annual energy use intensity	Annual energy cost	Annual carbon emissions (Fuel + Electricity)
Baseline (Typical mild climate insulation)	949 MJ/sm/yr	$55,700	412 mt/yr
Exterior wall insulation	917 MJ/sm/yr	$54,300	402 mt/yr
Typical floor insulation + cold climate slab insulation	1,149 MJ/sm/yr	$64,600	470 mt/yr
Typical dark roof	1,148 MJ/sm/yr	$64,400	468 mt/yr
High insulation cool roof	1,147 MJ/sm/yr	$64,200	467 mt/yr

Table 3: Roof, Wall, Floor, and Slab parameter study for Pittsburgh

Most of the study results above indicate a negative impact on load, cost, and emissions. The extra wall insulation resulted in a slightly positive impact over the baseline, but insignificant enough to carry that parameter through to future models, based on capital cost.

Modification of thermal parameters

Certain modifications to the model will change the way heat flows in and out of the building. The most important change involves the window-to-wall ratio, which is controlled by the glazing ratio or percentage. The amount of glazing was varied from 0% to 60%, with the default value of 40% also considered. Note that the baseline model is the best geometric model: the rotated model with 40% glazing, with the largest wall facing the southwest.

	Annual energy use intensity	Annual energy cost	Annual carbon emissions (Fuel + Electricity)
Baseline rotated (Glazing 40%)	949 MJ/sm/yr	$55,700	412 mt/yr
Glazing 20%	910 MJ/sm/yr	$53,000	391 mt/yr
Glazing 60%	995 MJ/sm/yr	$58,700	435 mt/yr
Glazing 0%	664 MJ/sm/yr	$38,800	285 mt/yr
Glazing 40% / 10%	813 MJ/sm/yr	$47,900	355 mt/yr

Table 4: Comparison of Glazing study, Pittsburgh Model

Upon initial glazing results, it was determined that no windows (0% glazing) is the most energy and cost-efficient choice. But this is not a realistic option for an academic building, where occupants need natural light and airflow for productivity and health. So, a hybrid mixed glazing was selected. The south-facing wall of the building was assigned 40% glazing, to receive optimal sunlight, while the other surfaces were assigned 10% glazing, for good natural light but not enough window area to lose significant heat in the cold months. The benefits of both large glazing and minimal glazing are therefore achieved.

Up until this point, the thermal zoning of the building had been set to default, or simply “building” status. Within the CEA, REVIT allows for customizable thermal zones, according to their usage. The core of the building area contains one type of zone, and the areas closer to the exterior walls contain a separate, customizable zone. This makes the most sense for an academic building, because the center of the building contains enclosed offices, likely with different thermal properties than the windows.

The penthouse was set to electrical/mechanical (unconditioned) zone. Floors 1 and 4 contain office (enclosed) zoning in the core, and classroom/lecture/teaching space on the exterior. Floor 3 contains corridor zoning in the core, with classroom/lecture/teaching space on the exterior. Floor 2 contains a restroom zone, in addition to the office zone core and classroom exterior. The basement contains active storage and office zones, while the lecture auditorium is zoned for auditorium space.

After a thermal zone simulation was run, the 40%/10% optimized glazing was added. After this, lowE cold climate high thermal gain double pane window types were added.

	Annual energy use intensity	Annual energy cost	Annual carbon emissions (Fuel + Electricity)
Baseline (no thermal zones)	949 MJ/sm/yr	$55,700	412 mt/yr
Thermal zones	881 MJ/sm/yr	$55,900	426 mt/yr
Thermal zones + 40%/10% glazing	730 MJ/sm/yr	$48,200	372 mt/yr
Thermal zones + 40%/10% glazing + lowE High SHGC double pane	**696 MJ/sm/yr**	**$47,000**	**365 mt/yr**
Thermal zones + 40% glazing	804 MJ/sm/yr	$53,100	410 mt/yr

Table 5: Thermal zoning and other thermal properties (Pittsburgh)

Baseline model (Miami,FL)

Miami climate

Geographical location: 25°46′31″N 80°12′32″W
Miami is located in a tropical monsoon climate with hot and humid summers and short warm winters. A building must be air-conditioned for most of the year, with minimal heating periods.

Orientation and assumptions

For the baseline model simulation, the conceptual mass model of Scaife Hall was placed in Miami, FL, in order to study the difference of building's performance in different climate keeping all the parameters similar.

Results: Baseline Miami Energy and Costs

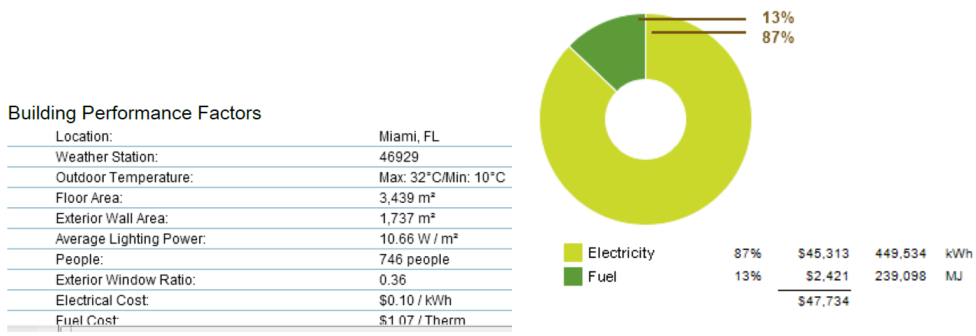

Figure 7: Baseline Model Information for Miami

	Energy Use: Fuel		Energy Use: Electricity		
	HVAC	Domestic Hot Water	HVAC	Lighting	Misc Equipment
Load	23,573 MJ	215,524 MJ	251,820 kWh	89,165 kWh	104,098 kWh
Cost	$238	$2,182	$25,383	$8,900	$10,500

Table 6: Scaife Hall Baseline (Miami) Energy Loads and Costs

Results: Baseline Miami Emissions

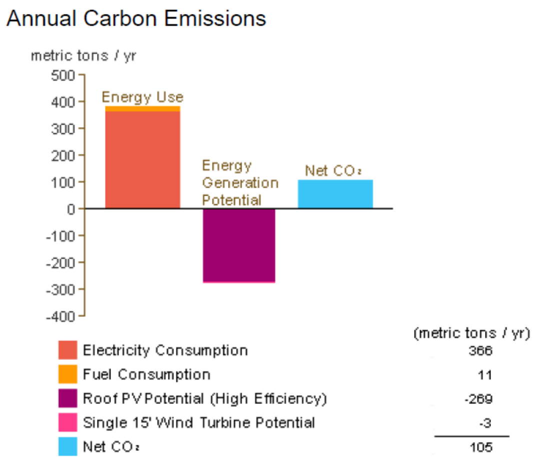

Figure 8: Baseline CO2 Emissions for Miami

The annual carbon emissions in Miami are less than half of Pittsburgh's carbon emissions (see comparative study). It is suspected that ample sunshine and the lack of heating results in less emissions.

Parametric Analysis - Miami

The baseline model for Miami was oriented in the original way as that in Pittsburgh. For the parametric analysis, the orientation was changed in order to find a stronger alternative for proper placement of this model in Miami. So, it was rotated 90 degree counterclockwise and then the CEA showed better results comparatively. The baseline model with original orientation showed EUI of 540 MJ/sm/yr, while after rotating the model counterclockwise by 90 degrees, the EUI was 527 MJ/sm/yr. Hence, it was considered for further parametric analysis as the new baseline.

	Annual energy use intensity	Annual energy cost	Annual carbon emissions (Fuel + Electricity)
Baseline	540 MJ/sm/yr	$47,700	377 mt/yr
90 degrees counterclock wise	527 MJ/sm/yr	$46,700	360 mt/yr

Table 7: Orientation study for Miami

	Annual energy use intensity	Annual energy cost	Annual carbon emissions (Fuel + Electricity)
Baseline (Rotated)	527 MJ/sm/yr	$46,700	370 mt/yr
Exterior wall high insulation	505 MJ/sm/yr	$46,200	369 mt/yr
Lightweight High Insulated floor + High mass no insulation Slab	508 MJ/sm/yr	$46,500	370mt/yr
Typical Dark Roof	497 MJ/sm/yr	$45,500	360mt/yr

Table 8: Roof, Wall, Floor, and Slab parameter study for Miami

Also, a study of wall, floor, slab, and roof parameters was conducted, which can affect the building's performance significantly once changed according to the need. The amount of glazing was varied from 0% to 60%, with the default value of 40%. The baseline model is the rotated model with 40% glazing.

	Annual energy use intensity	Annual energy cost	Annual carbon emissions (Fuel + Electricity)
Baseline rotated (Glazing 40%)	527 MJ/sm/yr	$46,700	370 mt/yr
Glazing 20%	482 MJ/sm/yr	$42,500	336 mt/yr
Glazing 60%	571 MJ/sm/yr	$50,600	401 mt/yr
Glazing 0%	442 MJ/sm/yr	$38,600	304 mt/yr
Glazing 40%/10% + shades + double pane lowE hot climate low SGHC	460 MJ/sm/yr	$40,300	318 mt/yr

Table 9: Comparison of Glazing study, Miami Model

The roof types were also compared and the model with the Dark Roof showed lowest energy use for the Miami region. Thermal zones were assigned in similar fashion as the Pittsburgh model.

While performing simulations with different parameters, the most energy-efficient model was obtained had the following significant properties:

- Typical Mild Climate Insulation
- Shades, 1.0 m, only on the individual surface of the facade facing south
- 10% Glazing on the north, east and west facade
- 40% Glazing on south facade
- Windows glazing with LowE hot climate Low SGHC double pane
- Detailed thermal zoning as described
- Dark roof

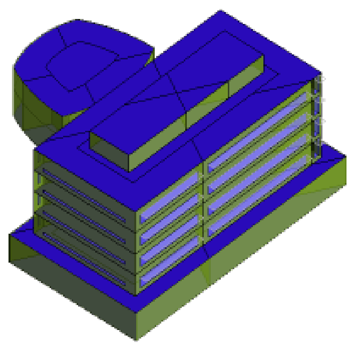

Figure 9: Most energy-efficient and cost-effective Miami model, with shades

Comparative Study Analysis: Pittsburgh vs. Miami

As described above, the energy model on Scaife Hall was performed in Miami to investigate the effects of having the same building in similar climates. The climates differ significantly, evidenced by the average temperature ranges in the following histograms.

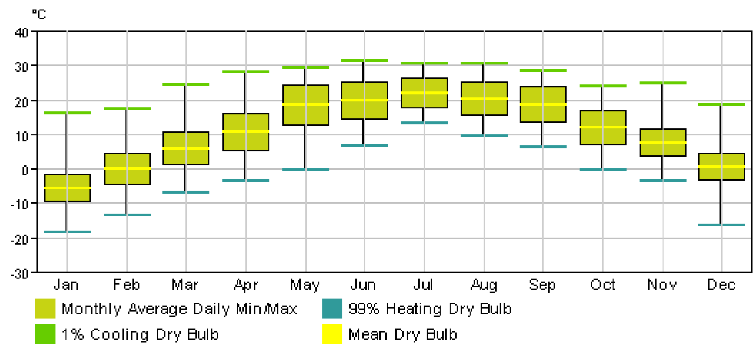

Figure 10: Average temperature ranges, Pittsburgh

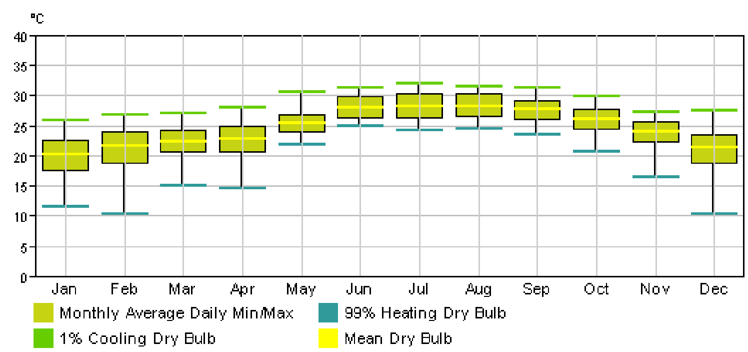

Figure 11: Average temperature ranges, Miami

Most of the year, the temperature in Miami falls between 20 and 30 degrees Celsius (68 to 86 degrees Fahrenheit). Further, Miami experiences sunshine on 70% of days each year. Pittsburgh, meanwhile, experiences winter temperatures between minus-10 and 10 degrees Celsius (14 degrees to 50 degrees F), and most summer temperatures under 30 degrees C (86 degree F). Pittsburgh only experiences sunshine on 45% of days during the year (NOAA.gov).

As an academic building, electricity and fuel loads can be expected to be relatively low during the summer months when school is not in session. However, a Pittsburgh building requires extensive heating during the winter months. Thus we can expect to see a dramatic difference between summer and winter loads for a Pittsburgh CEA model. The following figures illustrate the differences in heating requirement in each climate.

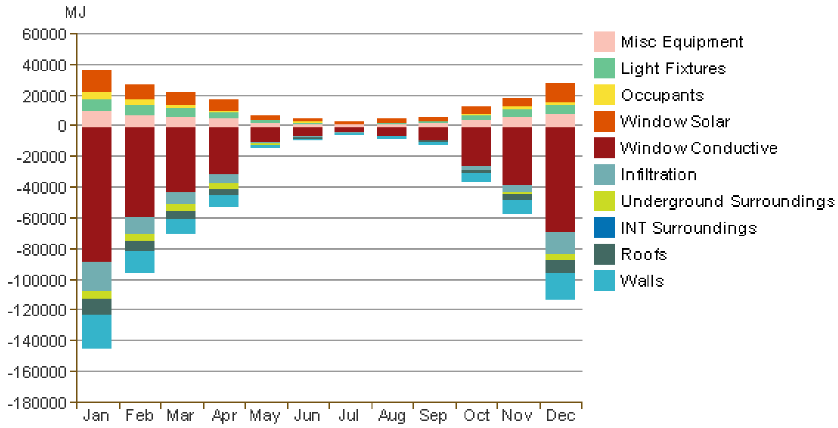

Figure 12: Baseline heating requirements in Pittsburgh

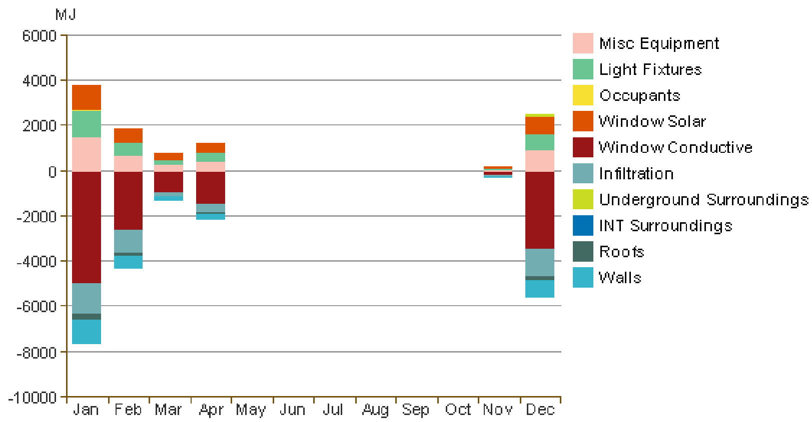

Figure 13: Baseline heating requirements in Miami

The following figure represents comparisons in energy use intensity for baseline models and their rotated orientations for Pittsburgh and Miami.

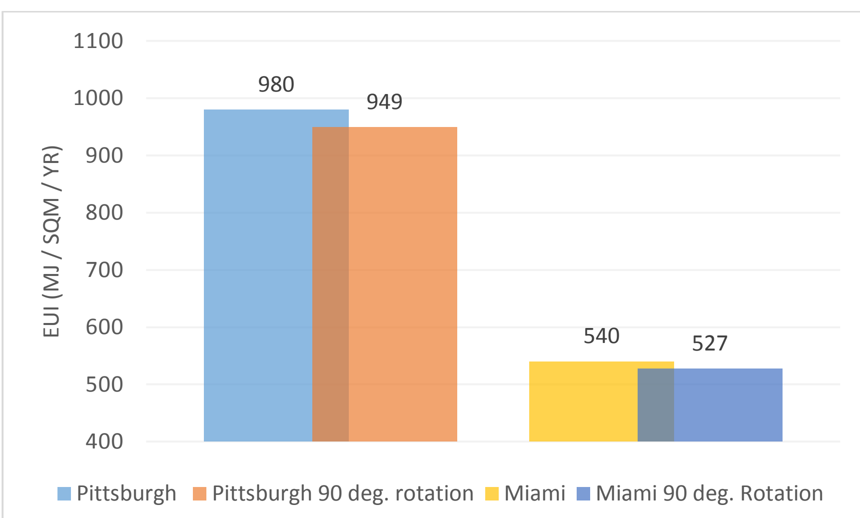

Figure 14: Baseline Geometric Models EUI Comparison

In both locations the rotated models were more energy efficient, but only slightly. The difference is perhaps due to these orientations experiencing more southern sunlight, which may reduce heating costs. For Pittsburgh, this is more substantial because of its cold winters.

Annual and life cycle energy costs for electricity and fuel consumption are summarized in Table 10.

	Annual Energy Cost		Life Cycle Cost
Baseline Model Location	Electricity	Fuel	30-years, 6.1% discount rate
Pittsburgh	$39,400	$18,200	$786,000
Miami	$45,300	$2,400	$650,000

Table 10: Energy and Life Cycle Costs Comparison

Electricity costs are similar in each location, but the fuel costs are noticeably higher in Pittsburgh, likely due to heating cost. Over the life of a building, this results in likely over $100,000 in savings in Miami.

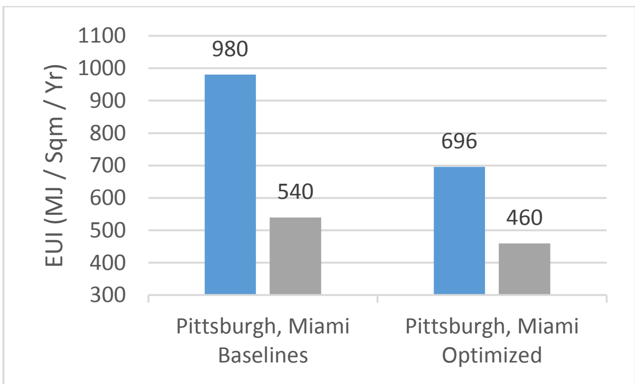

Figure 15: Baseline and Optimized Model EUI Comparison

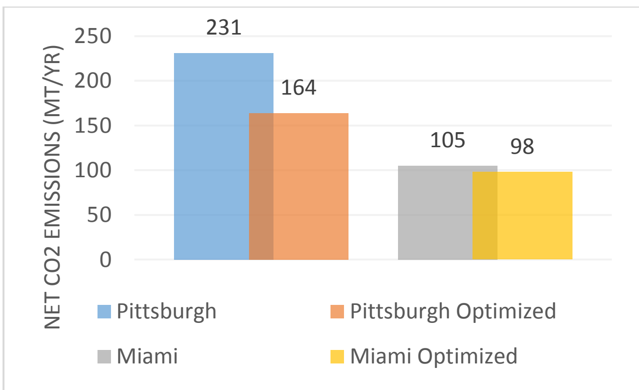

Figure 16: Baseline and Optimized Model CO2 Emissions Comparison

Figures 15 and 16 give an overall impression of the energy use and carbon emissions at the two locations, and the impact that parametric changes had. Clearly, the optimized models (with improved thermal and construction features) use less energy and therefore emit less.
The parameter changes had a larger impact on the Pittsburgh model, reducing energy consumption by up to 30%. Miami model optimization only resulted in a 15% decrease, which is still notable.

Likewise, CO_2 emissions were reduced by about 30% in the optimized Pittsburgh model. CO_2 emissions were reduced by 7% in the optimized Miami model.

Summary

A conceptual mass model was created in REVIT to represent Scaife Hall, a small academic building in Pittsburgh, PA. The built-in Conceptual Energy Analysis feature in the software allows for specific properties in the model that affect energy consumption to be changed. A parametric study was conducted to change thermal and construction values in order to determine an improved, more energy-efficient alternative model.

In Pittsburgh, model optimization resulted in a 30% decrease in energy use, and an annual energy cost decrease of more than $10,000. CO_2 emissions are also reduced by about 30%. Improvements resulted from more direct sunlight as a result of rotation, optimized glazing ratios for individual surfaces, some minor changes in insulation, thermal zoning, and double-pane windows with high solar heat gain coefficient.

The location of the baseline model was changed to Miami. Due to the hot climate, electricity loads remained high but fuel consumption plummeted. The model was optimized with sun shades, individual customized surface glazing, double-pane windows with low solar heat gain coefficient. This resulted in a 15% decrease in energy consumption, and a 7% reduction of CO_2 emissions.

References

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http://www.contrib.andrew.cmu.edu/~yesong/scaife/pic/1968%20ca%20Scaife%20Hall%20by%20David%20Chou.jpg