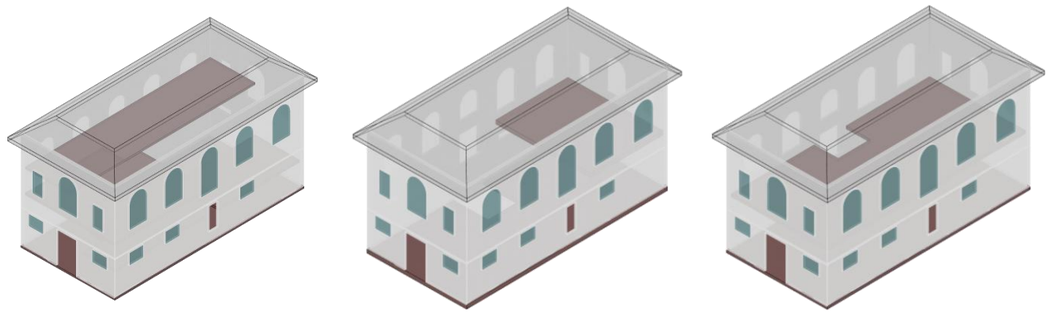
Design Space Exploration for High-Efficiency Building



> **Academic Project –** Special Topic collaboration with Perkins and Will
>
> **Location** – Atlanta, USA
>
> **Software Used** – Rhino, Climate Consultant, Ladybug and Honeybee Tools

The project focuses on designing an exploration for retrofitting 792 Donald Lee Hollowell Parkway NW, Atlanta, Georgia, USA. The project is located in Climate Zone 3, with an area of 1,680 sqf.

The aim is to design exploration for building renovation to understand the tradeoff between occupancy (density), comfort and energy use intensity while balancing operational energy, reducing the overall carbon emission, and maintaining daylight performance (UDI/ASE). Additionally, explore rainwater harvesting potential.

PROBLEMS

- Leaky – Infiltration
- Glare
- Energy consumption
- Excess glare
- Limited changes – Historical building

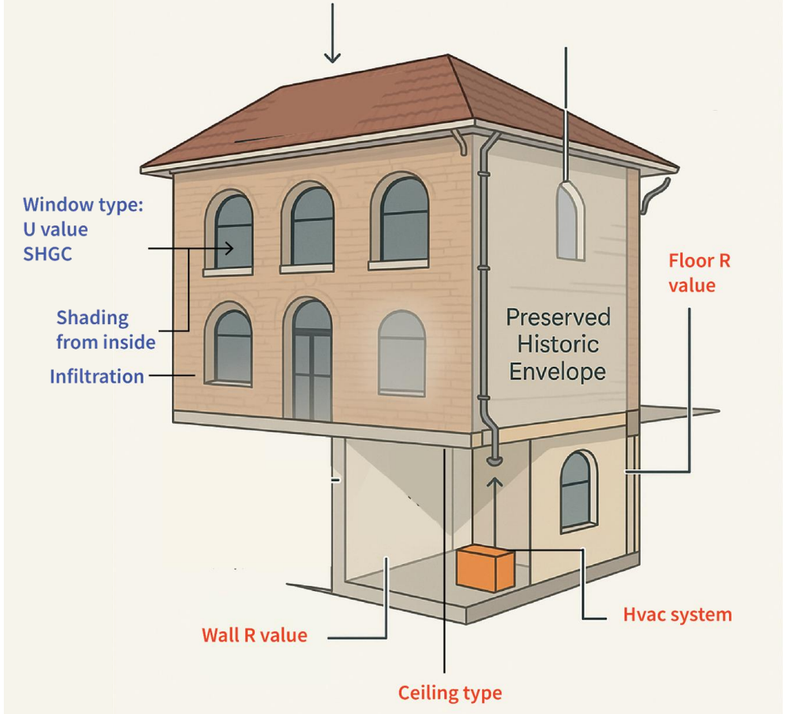
OPPORTUNITIES

- Height
- Occupancy (could be increased)
- Facade in good condition and can be upgraded
- Sufficient day lighting
- Potential to reduce radiation using indoor shades

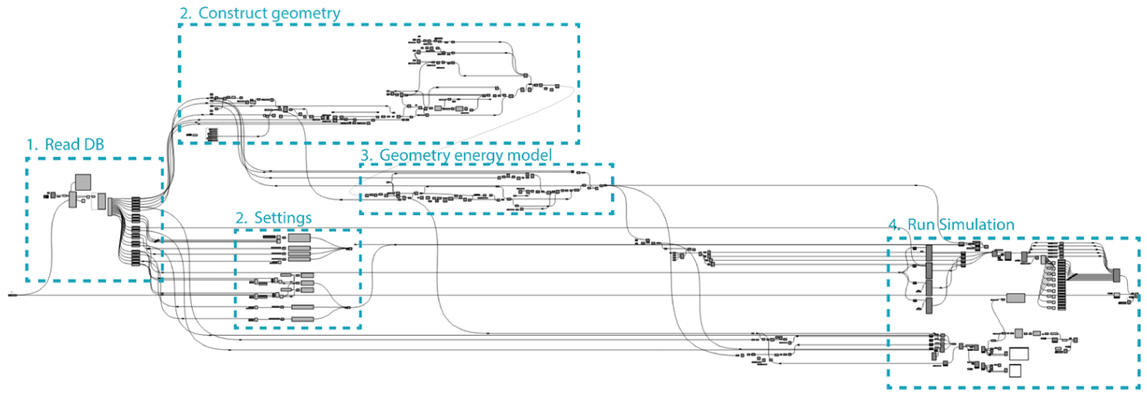
Category	Component	Upgrade / Enhancement	Purpose
Shell - Level	Roof	Retain existing roof (increase the insulation property)	Retain enhance performance without replacement
	Facade (Walls)	Preserved exterior (no thermal change externally)	Maintain historic character
	Windows (Frames)	Retained historic frames (optional sealing upgrade)	Facade integrity + minor air infiltration fix
Core - Level	Interior Walls	Interior Insulation (R-value upgrade)	Improve thermal resistance
	Ceiling / Roof Deck	Interior Roof Insulation (High R-value)	Reduce heat gain / loss from above
	Floors	Subfloor Insulation (R-value upgrade)	Minimize ground - contact thermal losses
	Windows (Glazing)	High-performance Glazing Inserts (lower U-value)	Enhance insulation without changing frames
	Interior HVAC / MEP	High-efficiency HVAC	Reduce operational energy demands

RETROFITTING STRATEGY:

“Preserve the shell. Reline the core. Retrofit from inside out.”

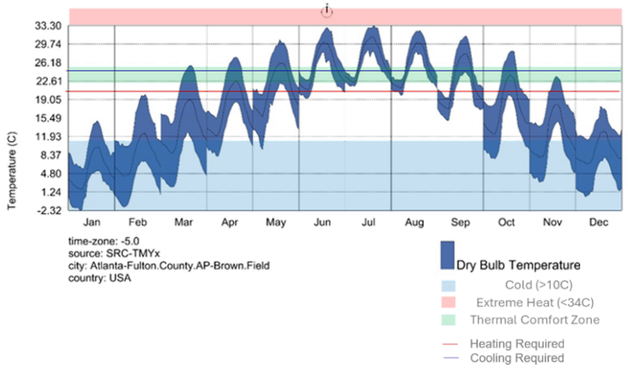


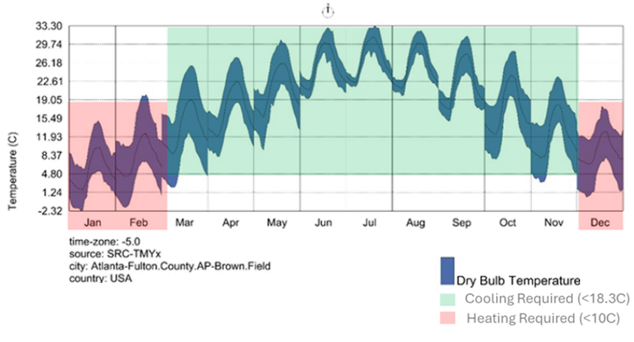
METHODOLOGY



Computationally designed to parametrize the entire workflow focusing on buildings total floor area, daylighting, energy performance, carbon emission and overall cost.

CLIMATE ASSESSMENT

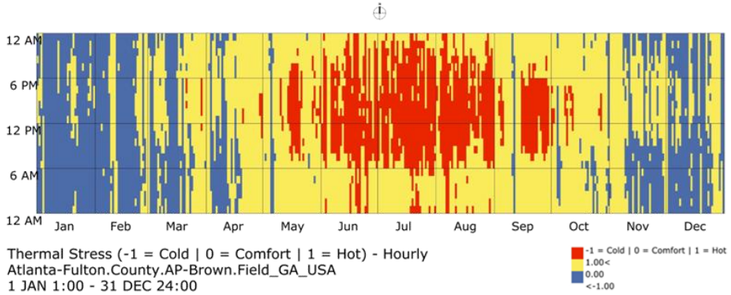




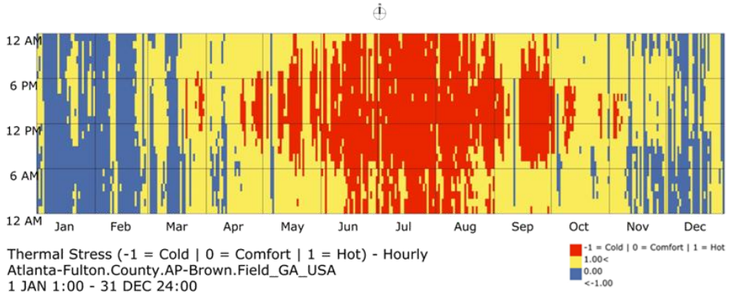
Summer temperatures:
Are within ASHRAE specified range while winter temperatures fall significantly below minimum (11.76°C below). Resulting heating systems required for winter comfort.

Humidity:
Both seasons exceed ASHRAE standard maximum of 60%. With summer at 13.22% above limit and winter: 3.44% above limit. Dehumidification needed year-round

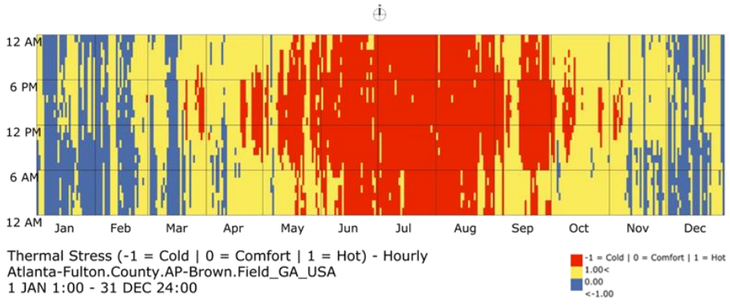
According to ASHRAE Standard 55-2017, mechanical systems are required for both temperature and humidity control, with humidity control being the more significant challenge throughout the year.



Current Weather File: 2009-2023

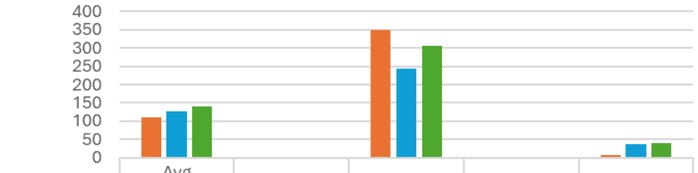


Morphed Weather File: 2050

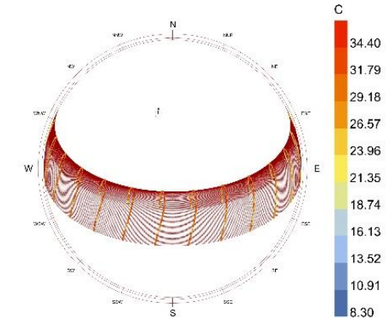


Morphed Weather File: 2050

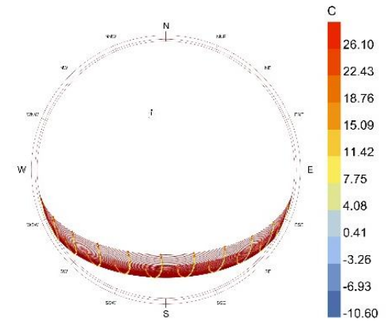
Average Rainfall



	Avg Precipitation (mm)	Wettest Month	(mm)	Driest	(mm)
2009-2023	110	July	350	November	6
2050	126.67	August	244	November	38
2080	141.58	August	305	November	39



Dry Bulb Temperature (C)
time-zone: -5.0
source: SRC-TMYx
city: Atlanta-Fulton.County.AP-Brown.Field
country: USA
Summer: May-September: 6:00-20:00



Dry Bulb Temperature (C)
time-zone: -5.0
source: SRC-TMYx
city: Atlanta-Fulton.County.AP-Brown.Field
country: USA
Winter: November-February: 7:00-18:00

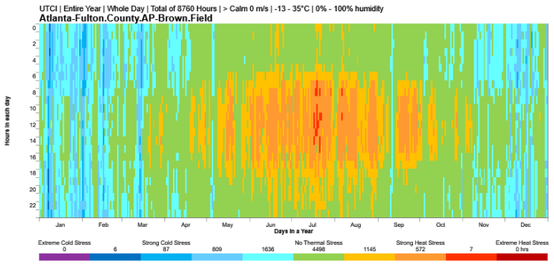
Average annual temperature will increase by +1.6°C by 2050. However, by 2080 the average temperature will increase by +3°C.

- ASHRAE climate zone shifts from Warm (3) to Hot (2) by 2080
- Thermal stress graphs show expansion of hot periods (red areas) in summer months
- Winter cold stress periods (blue areas) decrease significantly
- Comfort periods (yellow areas) shift seasonally.

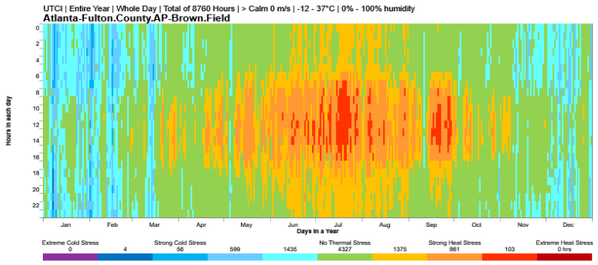
Significant change in the seasonal distribution of rainfall, a trend toward wetter conditions.

ASSUMPTIONS

Weather Files



Current Weather File:
USA_GA_Atlanta-Fulton.County.AP-Brown.Field.722195_TMYx.2009-2023.epw



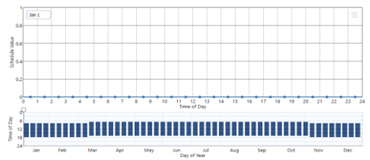
Morphed Future Weather File:
USA_GA_Atlanta-Fulton.County.AP-Brown.Field.722195_TMYx.2050.epw

Space and Schedule

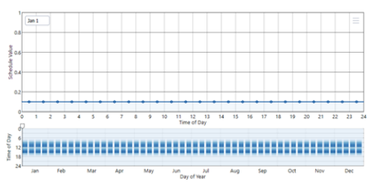
Zone Settings : Loads

Space program: Office — Space Use

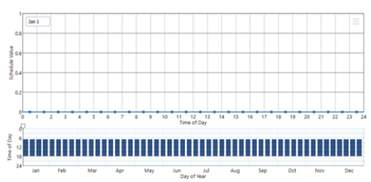
People:
People — On
0.2 — People Density [P/m²]
1.2 — Metabolic Rate [met]
8am-6pm Weekdays with DST — Occupancy Schedule
AirSpeed 0 — Airspeed Schedule [m/s]
Dynamic Clothing Model ASHRAE55 — Clothing [clo]



Equipment:
Equipment — On
8.1 — Equipment Power Density [W/m²]
equipOffice — Equipment Availability Schedule
EPD = 8.1 W/m2 (0.75 W/ft2) ~ ASHRAE Standard 90.1



Lighting:
Lighting — On
10.54, 13.99, 21.52 — Lighting Power Density [W/m²]
lightsOffice — Lights Availability Schedule
300-500 — Illuminance Target [Lux]
Off — DimmingType



Conditioning

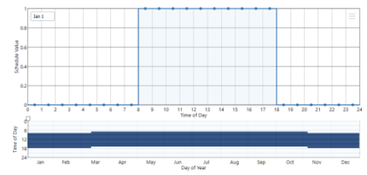
Thermostat:
Thermostat
20 Constant — HeatingSetpoint [°C]
27 Constant — CoolingSetpoint [°C]
Cooling Set Point = 24-27°C (75.2-80.6°F) ~ ASHRAE Standard 90.1

Mechanical System:
Mechanical Ventilation
2.5 — Min Fresh Air Person [L/s/p]
0.3 — Min Fresh Air Area [L/s/m²]

HVAC Settings

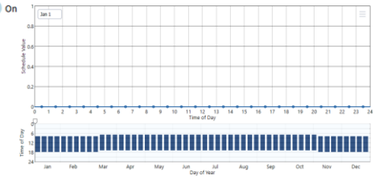
Conditioning

Heat Recovery:
Airloop — On
8am-6pm with DST — MechVent Availability [Schedule]
0, 0.75 — Heat Recovery Efficiency Latent [0-1]
DifferentialEnthalpy — Economizer Type [enum]
NoEconomizer
DifferentialDryBulb
DifferentialEnthalpy



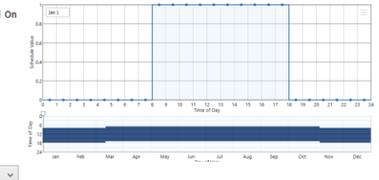
Heating:
Heating — On
NG (0.8, 0.9) , E (3.1, 4.5) — HeatingCOP
NaturalGas / Electricity — Heating Energy Source [enum]
8am-6pm Weekdays with DST — Heating Availability [Schedule]
1.15 — Heating Sizing Factor [Factor]
35 — Maximum Supply Air Temperature [°C]

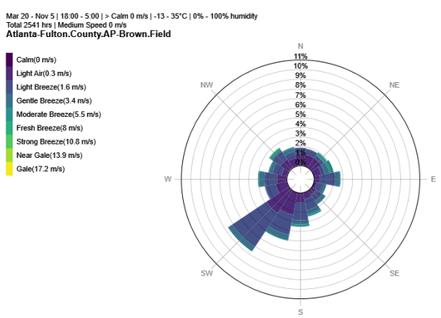
Cooling:
Cooling — On
NG (0.7, 1.2) , E (3.3, 5.3) — CoolingCOP
NaturalGas / Electricity — Cooling Energy Source [enum]
8am-6pm Weekdays with DST — Cooling Availability [Schedule]
1.15 — Cooling Sizing Factor [Factor]
12 — Minimum Supply Air Temperature [°C]

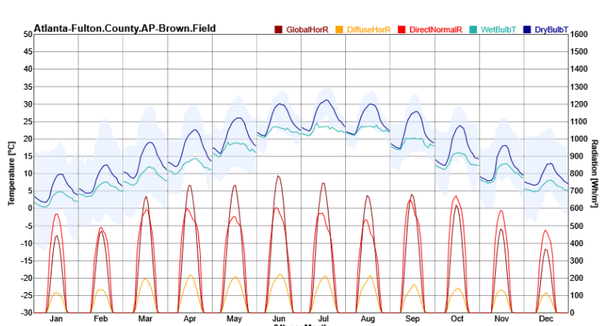


DHW:
Hot Water — On
1 — COP [unitless]
10 — Inlet Water Temperature [°C]
65 — Water Supply Temperature [°C]
8am-6pm Weekdays with DST — Water Schedule
0.001 — Flow Rate Per Person [m3/h/P]
NaturalGas — Hot Water Energy Source [enum]

Natural Ventilation:
Natural Ventilation — On
22 — Nat Vent SetPoint [°C]
8pm-5am with DST — Natural Ventilation Schedule
0 — Nat Vent Min Out Air Temp [°C]
30 — Nat Vent Max Out Air Temp [°C]
90 — Nat Vent Max Relative Hum [RH%]
Natural Ventilation
Stack Driven Flow — Crossventilation







ASSUMPTIONS

Envelope - Wall

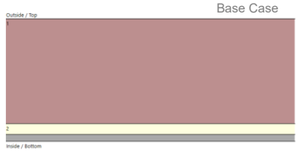
W0

U-Value[W/(m² K)] = 2.494
R-Value[m²K/W] = 0.231
Thermal Capacitance[kJ/K/m²] = 323.639
Embodied Energy[MJ/m²] = 34.58
Embodied Carbon[kgCO2/m²] = 5.746

Layers: (Outside - Inside)

1 - Brick 0.194 [m]
2 - Plaster 0.013 [m]

Base Case



W1

U-Value[W/(m² K)] = 0.072
R-Value[m²K/W] = 13.771
Thermal Capacitance[kJ/K/m²] = 323.657
Embodied Energy[MJ/m²] = 34.58
Embodied Carbon[kgCO2/m²] = 5.746

Layers: (Outside - Inside)

1 - Brick 0.194 [m]
2 - Insulation Mineral Fiber - Processed From Rock - Slag - Or Glass - 250-330mm - 6.4-32 Kg/M3 0.02 [m]
3 - Plaster 0.013 [m]

W2

U-Value[W/(m² K)] = 0.058
R-Value[m²K/W] = 17.156
Thermal Capacitance[kJ/K/m²] = 323.662
Embodied Energy[MJ/m²] = 34.58
Embodied Carbon[kgCO2/m²] = 5.746

Layers: (Outside - Inside)

1 - Brick 0.194 [m]
2 - Insulation Mineral Fiber - Processed From Rock - Slag - Or Glass - 250-330mm - 6.4-32 Kg/M3 0.025 [m]
3 - Plaster 0.013 [m]

W3

U-Value[W/(m² K)] = 0.048
R-Value[m²K/W] = 20.541
Thermal Capacitance[kJ/K/m²] = 323.666
Embodied Energy[MJ/m²] = 34.58
Embodied Carbon[kgCO2/m²] = 5.746

Layers: (Outside - Inside)

1 - Brick 0.194 [m]
2 - Insulation Mineral Fiber - Processed From Rock - Slag - Or Glass - 250-330mm - 6.4-32 Kg/M3 0.03 [m]
3 - Plaster 0.013 [m]

Envelope - Wall

R0

U-Value[W/(m² K)] = 6.923
R-Value[m²K/W] = 0.004
Thermal Capacitance[kJ/K/m²] = 642.662
Embodied Energy[MJ/m²] = 0
Embodied Carbon[kgCO2/m²] = 0

Layers: (Outside - Inside)

1 - MediumOffice-3A_METAL ROOFING 0.2 [m]

Base Case

R1

U-Value[W/(m² K)] = 0.047
R-Value[m²K/W] = 21.364
Thermal Capacitance[kJ/K/m²] = 642.698
Embodied Energy[MJ/m²] = 0
Embodied Carbon[kgCO2/m²] = 0

Layers: (Outside - Inside)

1 - MediumOffice-3A_METAL ROOFING 0.2 [m]
2 - Insulation Mineral Fiber - Processed From Rock - Slag - Or Glass - 210-250mm - 6.4-32 Kg/M3 0.04 [m]

R2

U-Value[W/(m² K)] = 0.033
R-Value[m²K/W] = 30.442
Thermal Capacitance[kJ/K/m²] = 642.714
Embodied Energy[MJ/m²] = 0
Embodied Carbon[kgCO2/m²] = 0

Layers: (Outside - Inside)

1 - MediumOffice-3A_METAL ROOFING 0.2 [m]
2 - Insulation Mineral Fiber - Processed From Rock - Slag - Or Glass - 210-250mm - 6.4-32 Kg/M3 0.057 [m]

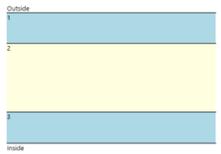
R3

U-Value[W/(m² K)] = 0.025
R-Value[m²K/W] = 40.054
Thermal Capacitance[kJ/K/m²] = 642.73
Embodied Energy[MJ/m²] = 0
Embodied Carbon[kgCO2/m²] = 0

Layers: (Outside - Inside)

1 - MediumOffice-3A_METAL ROOFING 0.2 [m]
2 - Insulation Mineral Fiber - Processed From Rock - Slag - Or Glass - 210-250mm - 6.4-32 Kg/M3 0.075 [m]

Envelope - Glazing

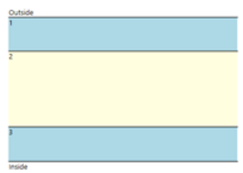


Vistacool on Pacifica - Clear (Krypton)

U-Value[W/(m² K)] = 2.48
SHGC = 0.311
TVIS = 0.286
Embodied Energy[MJ/m²] = 431.25
Embodied Carbon[kgCO2/m²] = 26.162

Layers: (Outside - Inside)

1 - Vistacool on Pacifica 6mm 5.7 [mm]
2 - Krypton - EN673 12.7 [mm]
3 - Clear Float Glass Clear 5.8 [mm]

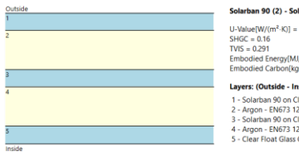


DoublePaneLoEe2

U-Value[W/(m² K)] = 1.493
SHGC = 0.373
TVIS = 0.444
Embodied Energy[MJ/m²] = 20
Embodied Carbon[kgCO2/m²] = 2

Layers: (Outside - Inside)

Simple Glazing Model

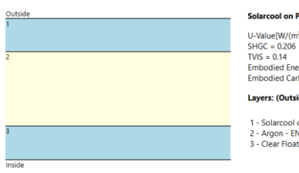


Solarban 90 (2) - Solarban 90 (4) - Clear (Argon)

U-Value[W/(m² K)] = 0.66
SHGC = 0.16
TVIS = 0.291
Embodied Energy[MJ/m²] = 645
Embodied Carbon[kgCO2/m²] = 39.13

Layers: (Outside - Inside)

1 - Solarban 90 on Clear 6mm 5.7 [mm]
2 - Argon - EN673 12.7 [mm]
3 - Solarban 90 on Clear 6mm 5.7 [mm]
4 - Argon - EN673 12.7 [mm]
5 - Clear Float Glass Clear 5.8 [mm]



Solarcool on Pacifica - Clear (Argon)

U-Value[W/(m² K)] = 2.53
SHGC = 0.206
TVIS = 0.14
Embodied Energy[MJ/m²] = 431.25
Embodied Carbon[kgCO2/m²] = 26.162

Layers: (Outside - Inside)

1 - Solarcool on Pacifica 6mm 5.7 [mm]
2 - Argon - EN673 12.7 [mm]
3 - Clear Float Glass Clear 5.8 [mm]

Slab on Grade - Floor

F1

U-Value[W/(m² K)] = 1.815
R-Value[m²K/W] = 0.211
Thermal Capacitance[kJ/K/m²] = 210.263
Embodied Energy[MJ/m²] = 0
Embodied Carbon[kgCO2/m²] = 0

Layers: (Outside - Inside)

1 - Wood 0.02 [m]
2 - MediumOffice-4A_MAT-CC05 4 HW CONCRETE 0.102 [m]

F2

U-Value[W/(m² K)] = 0.12
R-Value[m²K/W] = 8.004
Thermal Capacitance[kJ/K/m²] = 215.254
Embodied Energy[MJ/m²] = 0
Embodied Carbon[kgCO2/m²] = 0

Layers: (Outside - Inside)

1 - Wood 0.025 [m]
2 - Insulation Mineral Fiber - Processed From Rock - Slag - Or Glass - 75-100mm 6.4-32 Kg/M3 0.04 [m]
3 - MediumOffice-4A_MAT-CC05 4 HW CONCRETE 0.102 [m]

Air Infiltration

Infiltration — On

Air Changes per Hour

0.1 — InfiltrationAch [ACH]

Interior Shading Material

Sunvision Ecru

Inset	5.08 cm
Permeability	14 %
VLT	35 %
VLR	59 % / 59 %

Golden low-E fabric WBI2W

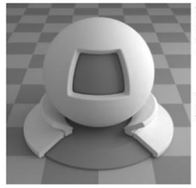
Inset	5.08 cm
Permeability	1 %
VLT	1 %
VLR	44 % / 44 %

Interior Shading	On (1) / Off (2)
If On	Option1, Option 2

Daylight Analysis Work-plane

0.8 — Workplane Height [m]

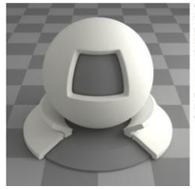
Ceiling



Ceiling LM83

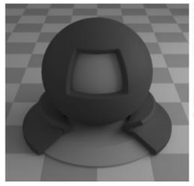
Type	Matte
Reflectance	70.00 %
Specular	0.00 %
Diffuse	70.00 %
R	0.700
G	0.700
B	0.700
Roughness	0.000
Measurement Type	Standard
Credit	IES LM-83

Base Case



White Ceiling

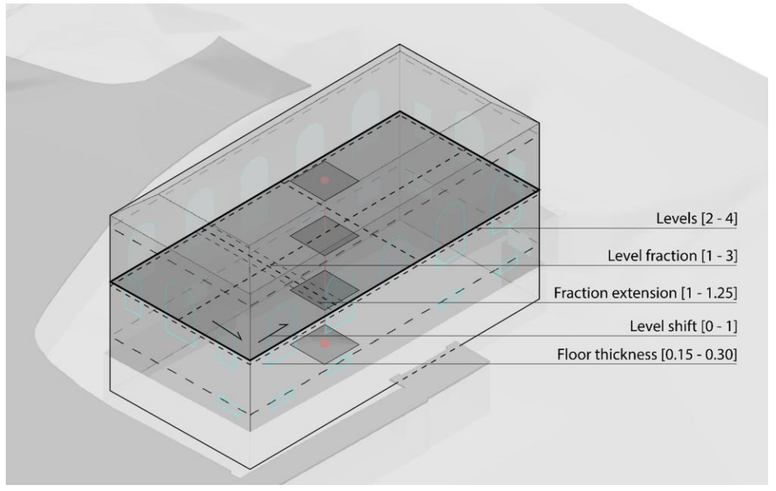
Type	Glossy
Reflectance	85.67 %
Specular	0.35 %
Diffuse	85.31 %
R	0.863
G	0.856
B	0.784
Roughness	0.200
Measurement Type	Spectrophotometer
Credit	Design for Climate and Comfort Lab



Black Ceiling

Type	Glossy
Reflectance	5.07 %
Specular	0.52 %
Diffuse	4.56 %
R	0.046
G	0.045
B	0.046
Roughness	0.200
Measurement Type	Spectrophotometer
Credit	Design for Climate and Comfort Lab

Building geometry settings



Levels [2, 3 ,4]
Total height divided by the amount of desired levels.

Level fraction [1, 2, 3]
Subdivision ratio of floors based on total length.

Fraction extension [1, 1.1, 1.25]
Percentage of level fraction extension based on subdivision parameter.

Level shift [0, 1]
Shift of the level fraction positioning.

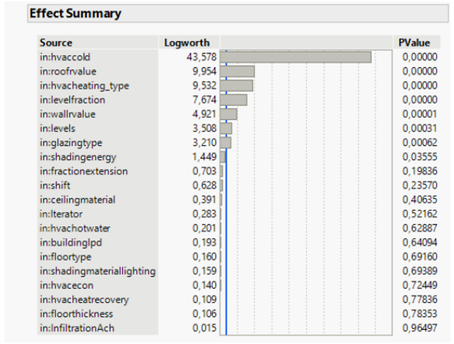
Floor thickness [0.15, 0,20, 0,30]

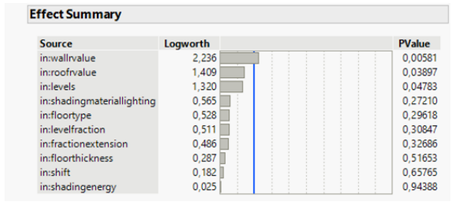
DESIGN SPACE CONSTRUCTION

PARAMETER	VALUES	TOTAL
Exterior Wall R-Value	[0.231, 13.771, 17.156, 20.541]	(4)
Exterior Roof R-Value	[0.004, 21.364, 30.442, 40.054]	(4)
Interior Floor R-Value	[0.211, 8.004]	(2)
Interior Ceiling Reflectance (%)	[70, 85.67, 5.07]	(3)
Glazing U-value	[2.48, 1.493, 0.66, 2.53]	(4)
Glazing SHGC	[0.311, 0.373, 0.16, 0.206]	(4)
Interior Shading	[0, 1]	(2)
Shading Permeability (%)	[14, 1]	(2)
Shading VLT (%)	[35, 1]	(2)
Air Infiltration	[0.1, 1.5, 3.0]	(3)
HVAC Heating Nat_Gas COP	[0.83, 0.95]	(2)
HVAC Cooling Nat_Gas COP	[0.7, 1.2]	(2)
HVAC Heating Electricity COP	[3.1, 4.5]	(2)
HVAC Cooling Electricity COP	[3.8, 5.3]	(2)
Domestic Hot Water type	[0, 1]	(2)
HVAC Economizer	[0, 1]	(2)
HVAC Heat Recovery	[0, 1]	(2)
Building LPD	[13.99, 10.54, 21.52]	(3)
Building EPD	[8.1]	(1)

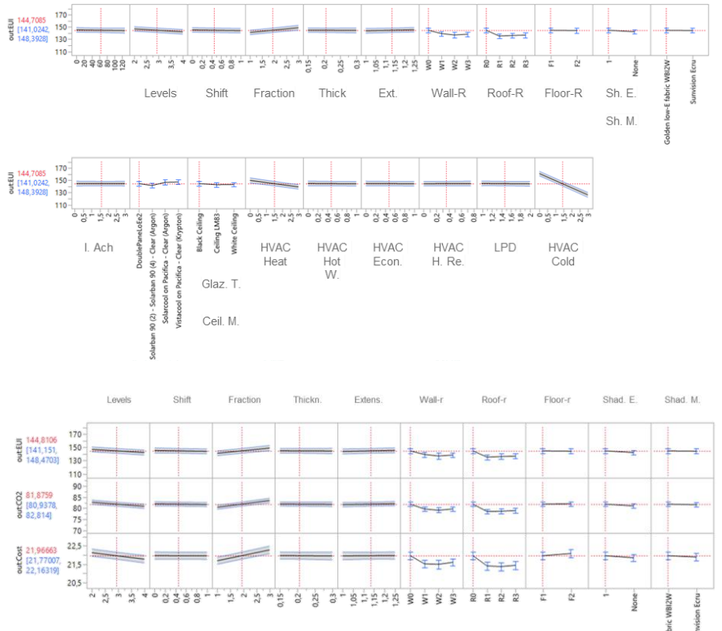
Design space of **7077888 solutions** → Fractional Factorial → **128 samples**

RESULTS - Analysis for EUI, Energy Model



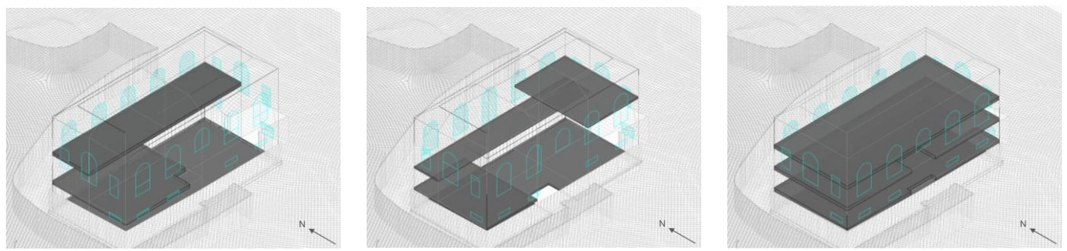


Sensitivity analysis



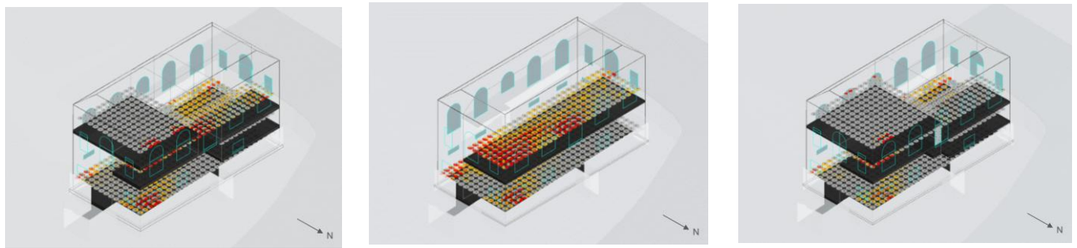
Profilers for EUI, CO2, and Cost sensitivity

RESULTS – FLOOR AREA



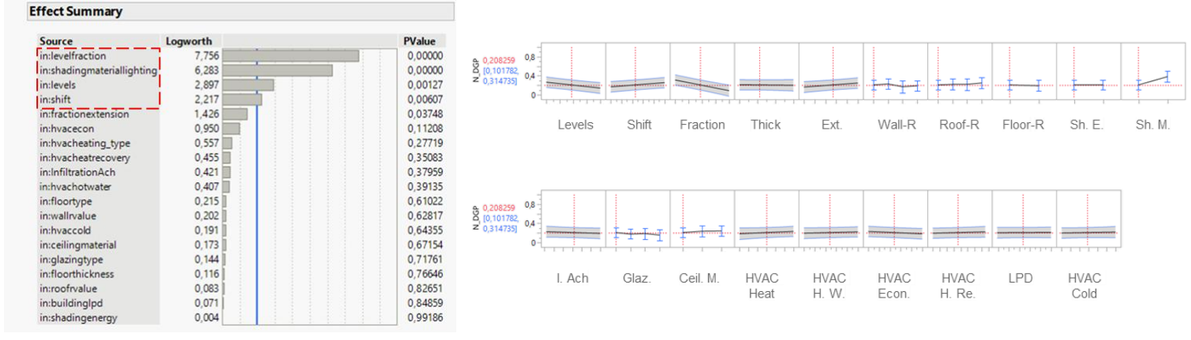
out:EUI	out:Baseline	out:CO2	out:Cost	out:Area
180,66	283,91	91,17	22,66	183,78
151,46	283,91	82,15	21,47	537,89
150,79	283,91	81,94	21,44	537,89
147,32	283,91	80,87	21,3	537,89
143,16	283,91	79,97	21,3	537,89
164,69	283,91	86,24	22,01	268,95
139,89	283,91	78,57	20,99	537,89
137,19	283,91	77,88	20,94	537,89
154,22	283,91	84,44	22,2	302,56
140,19	283,91	78,67	21,01	537,89
150,93	283,91	83,15	21,95	268,95

RESULTS – DGP

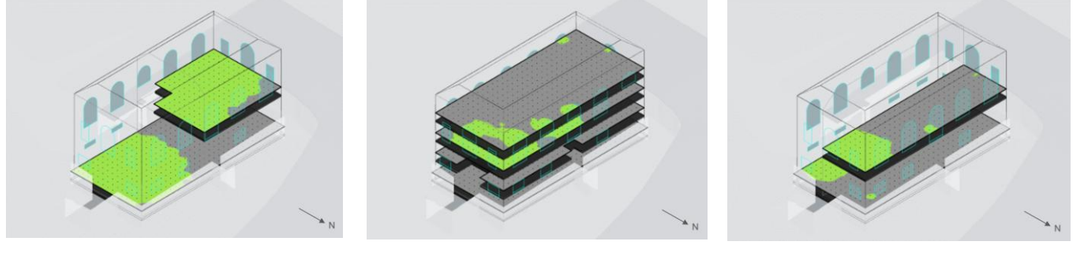


out:dgp_0	out:dgp_1	out:dgp_2	out:dgp_3
7,82	6,39	0	0
0,03	2,21	0,05	5,86
0	2,23	0,06	6,94
0	2,22	0,05	5,95
0	2,35	0,08	7,35
9,24	0,74	0	0
0	2,22	0,07	5,53
0	2,2	0,08	5,93
1,38	3,57	0,57	1,09
0	2,35	0,07	7,17
13,89	0,74	0	0

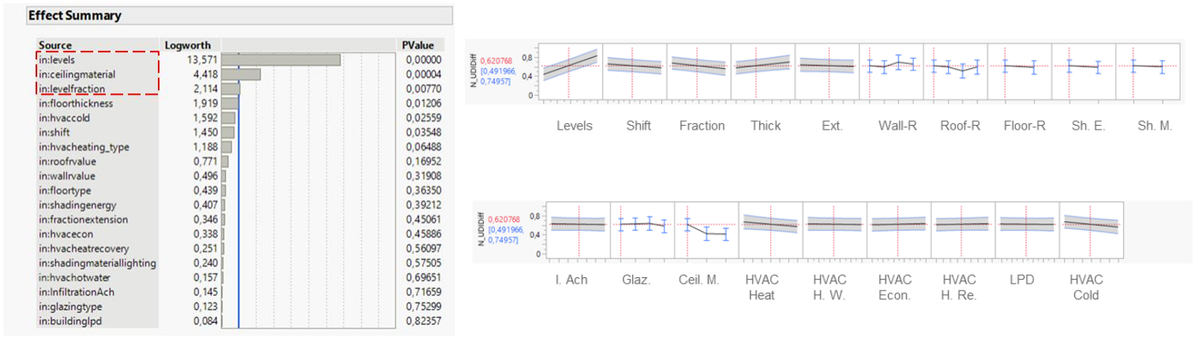
RESULTS – ANALYSIS FOR MAXIMUM DGP



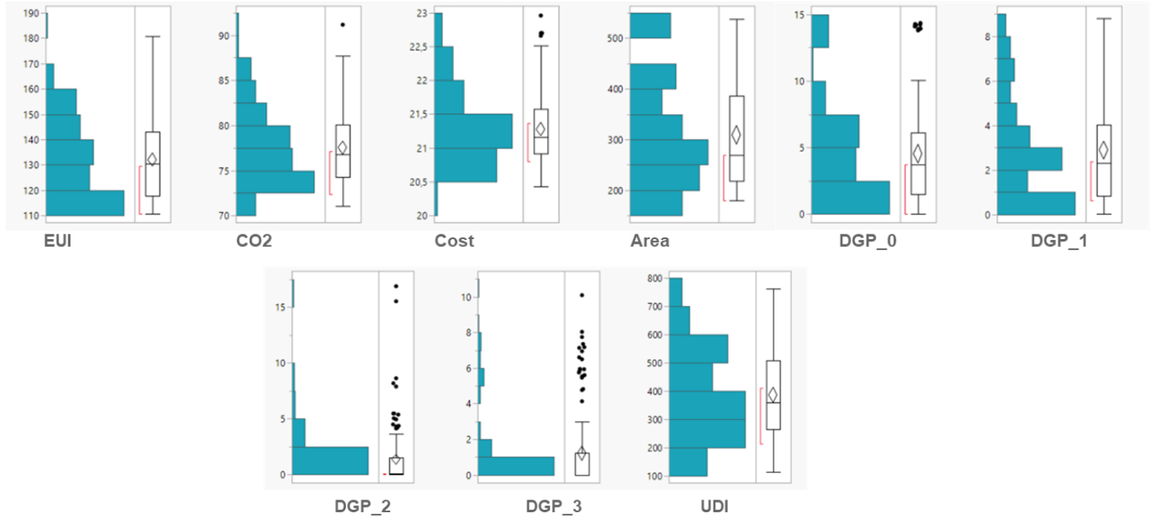
RESULTS – UDI



out:EUI	out:Baseline
761,31	0,67
118,69	0,98
204,28	0,76
171,15	0,85
214,01	0,74
362,16	0,35
115,09	0,99
114,8	1
189,72	0,8
194,82	0,78
409,36	0,23



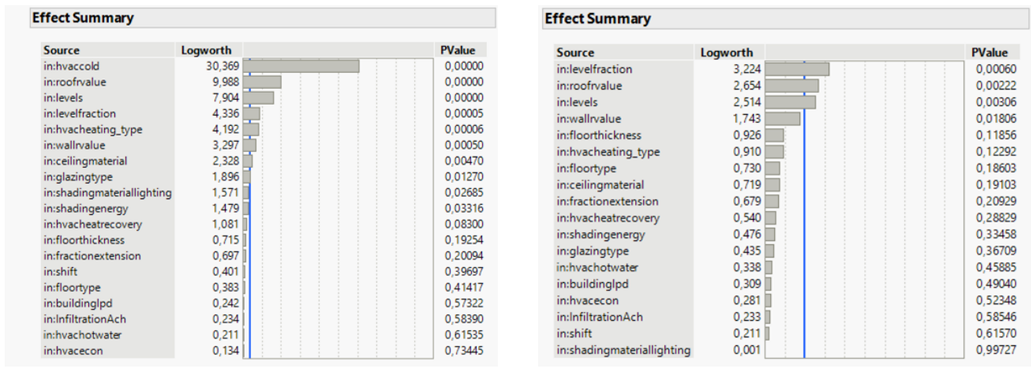
RESULTS – RESULT DISTRIBUTION



RESULTS – WEIGHTED SUM SCORE

Weights	Site EUI	CO2	Area	Cost	UDI	DGP
	27.5%	12.5%	15%	10%	17.5%	17.5%

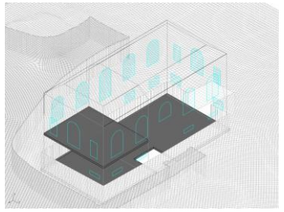
(EUI*0,275) + (CO2*0,125) + (Area*0,15) + (Cost*0,1) + (UDI_Diff*0,175) + (DGP*0,175)



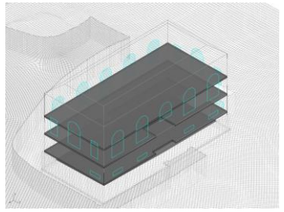
Removing HVAC_Cold

Analysis shows that cooling is the most demanding factor followed by roof and wall insulation. While the no of floors (level fraction) makes significant change in the overall EPI, DGI and DGP

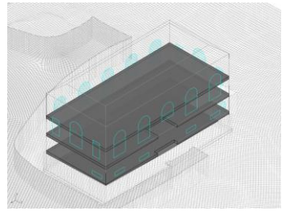
RESULTS – TOP 8 BASED ON WEIGHTED SCORE



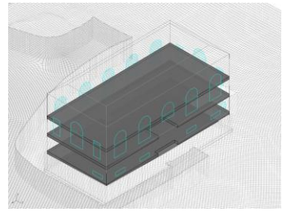
Iter	**50**
EUI	**180,66**
CO2	**91,17**
Cost	**22,66**
Area	**183,78**



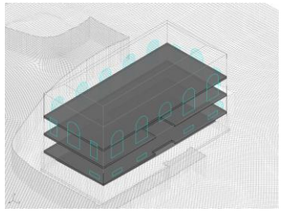
Iter	**62**
EUI	**151,46**
CO2	**82,15**
Cost	**21,47**
Area	**537,89**



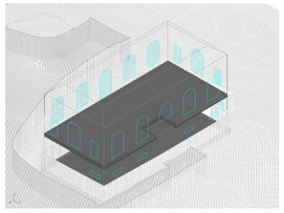
Iter	**113**
EUI	**150,79**
CO2	**81,94**
Cost	**21,44**
Area	**537,89**



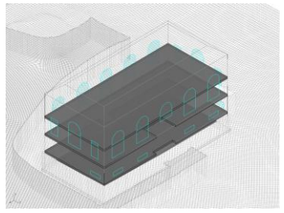
Iter	**126**
EUI	**147,32**
CO2	**80,87**
Cost	**21,3**
Area	**537,89**



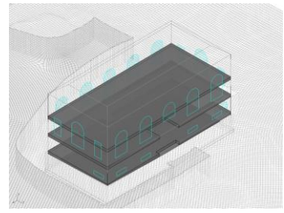
Iter	**95**
EUI	**143,16**
CO2	**79,97**
Cost	**21,3**
Area	**537,89**



Iter	**84**
EUI	**164,69**
CO2	**86,24**
Cost	**22,01**
Area	**268,95**

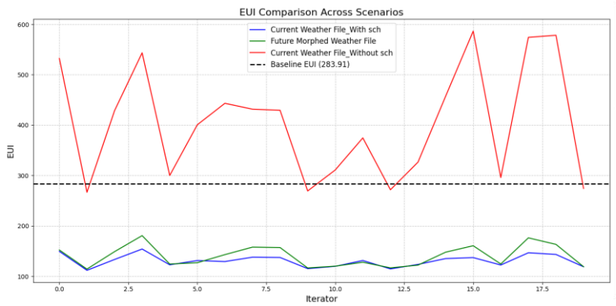


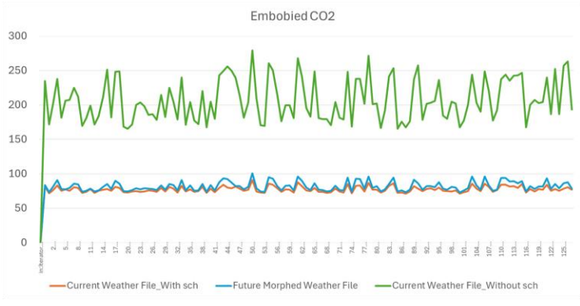
Iter	**125**
EUI	**139,89**
CO2	**78,57**
Cost	**20,99**
Area	**537,89**



Iter	**15**
EUI	**137,19**
CO2	**77,88**
Cost	**20,94**
Area	**537,89**

FLEXIBILITY AND FUTURE PROOFING

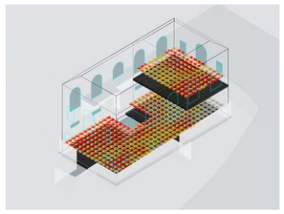




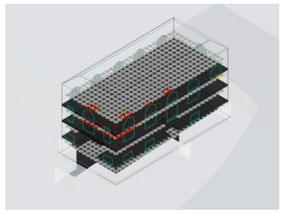
Iteration: 100

Site EUI (kBtu/ftÂ²)

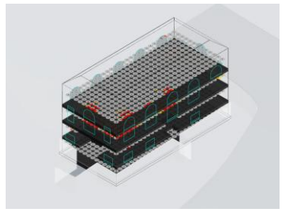
Case	Baseline	Minimum	Improvement
Current Weather file with Schedule	283.91	110.51	60.93%
Current Weather file without Schedule	283.91	113.35	60.08%
Future Morphed Weather file with Schedule	283.91	257.46	9.32%



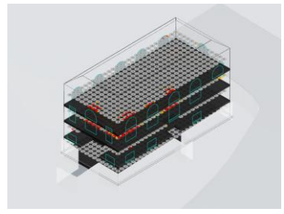
Iter	**50**
DGP_N	**0,38**



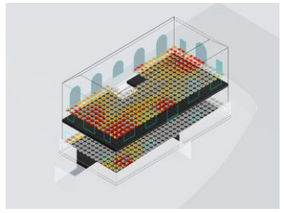
Iter	**62**
DGP_N	**0,24**



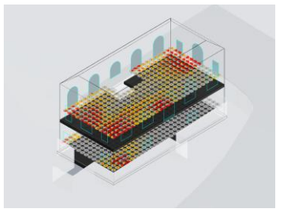
Iter	**113**
DGP_N	**0,32**



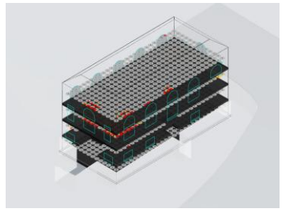
Iter	**126**
DGP_N	**0,25**



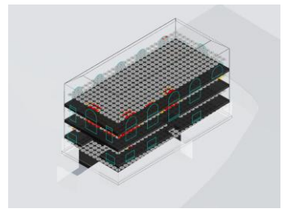
Iter	**95**
DGP_N	**0,34**



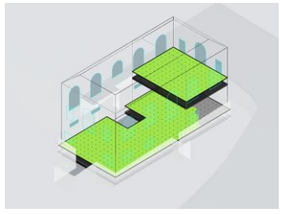
Iter	**84**
DGP_N	**0,47**



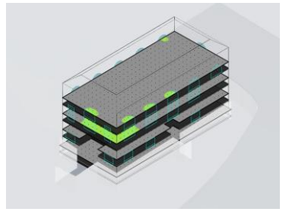
Iter	**125**
DGP_N	**0,22**



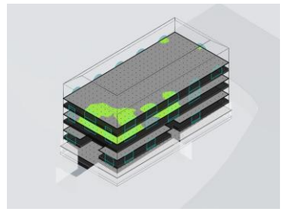
Iter	**15**
DGP_N	**0,25**



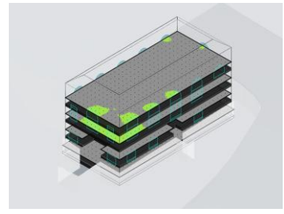
Iter	**50**
UDI	**761,35**



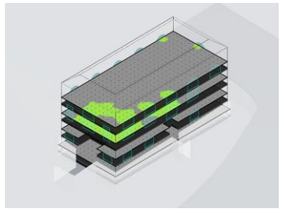
Iter	**62**
UDI	**118,69**



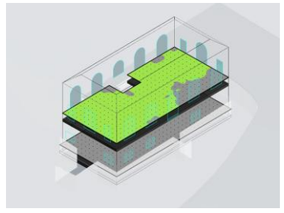
Iter	**113**
UDI	**204,28**



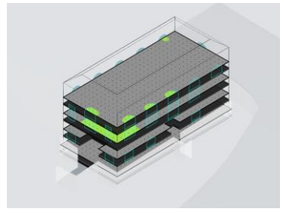
Iter	**126**
UDI	**171,15**



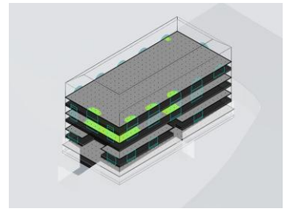
Iter	**95**
UDI	**214,01**



Iter	**84**
UDI	**362,16**



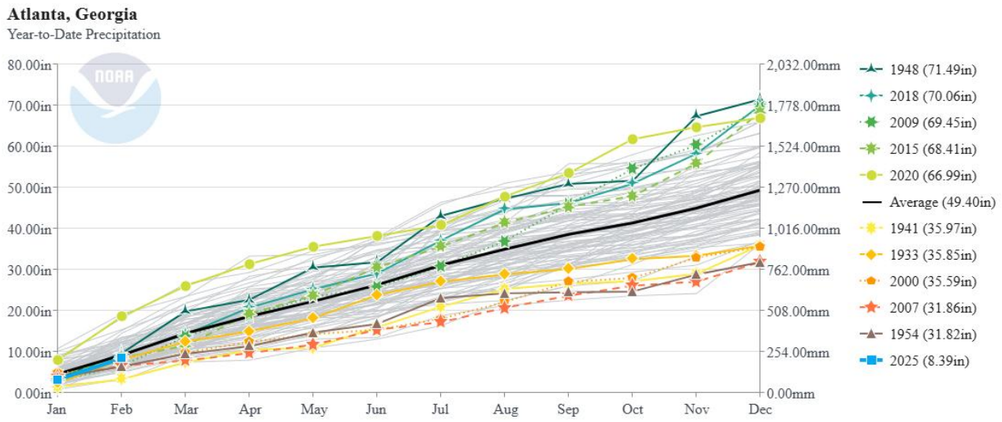
Iter	**125**
UDI	**115,09**



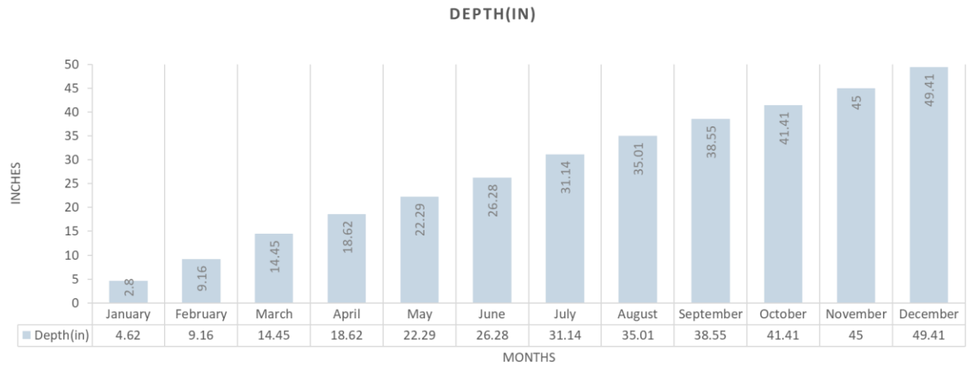
Iter	**15**
UDI	**114,8**

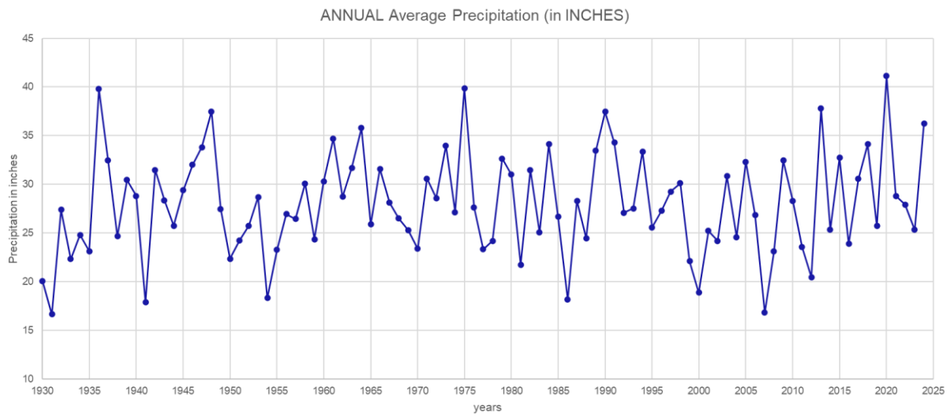
NOAA Climate At a Glance Haywood Plots

Historical averaged precipitation depth for 792 Donald Lee Hollowell at Atlanta, Georgia

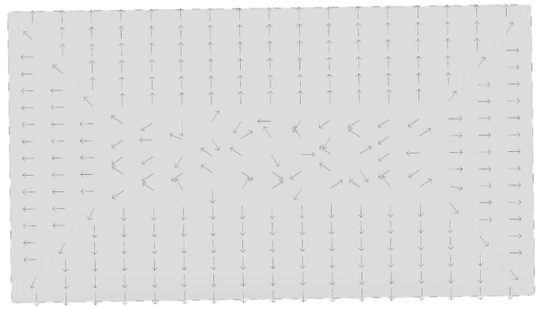


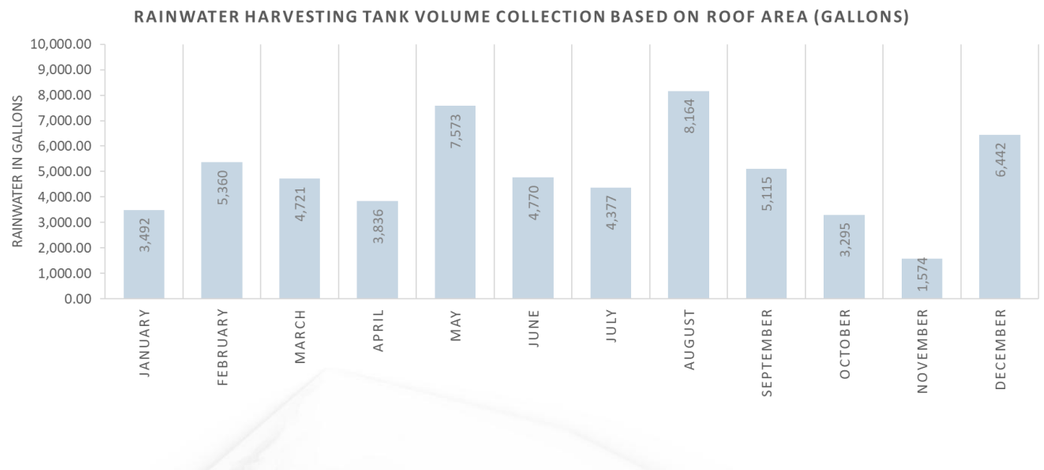
Atlanta Annual Precipitation Rainwater Depth (in)

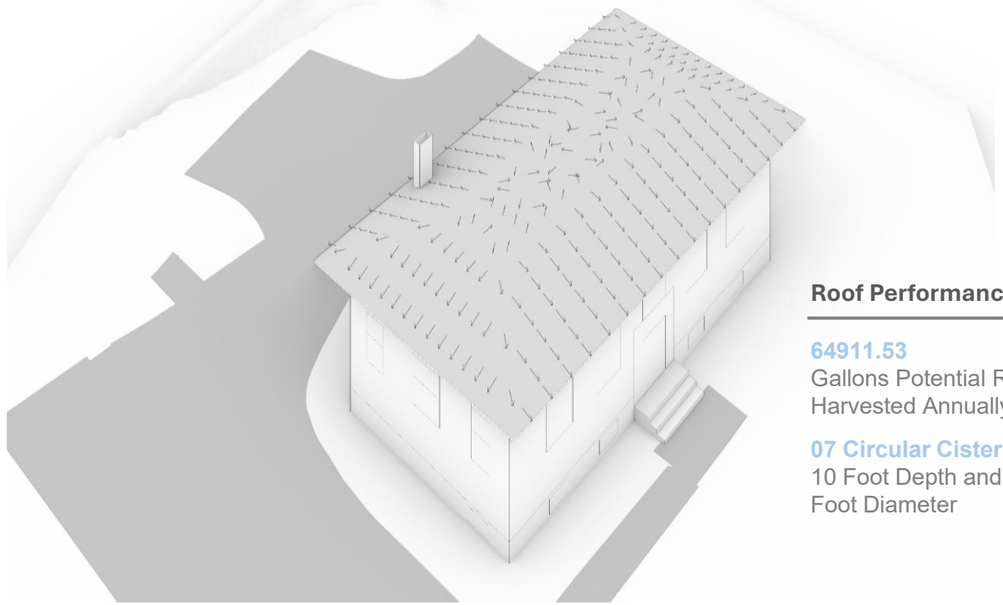




The project sites considers 100% yearly average rainfall and does not evaluate the monthly indoor demand, or plant and irrigation requires. The project roof design does not possess significant opportunities for a roof rainwater harvesting catchment system, particularly during early summer through to mid-fall.







Roof Performance

64911.53
Gallons Potential Rainwater Harvested Annually

07 Circular Cistern
10 Foot Depth and Width with 13 Foot Diameter

Note: All values are taken from ASHRAE Standard 90.1

- **Exterior Wall R-Value**
  W0 - 0.231, W1-13.771, W2 -17.156, W3 - 20.541
  Note: R-13 cavity insulation and R-5 continuous exterior insulation, R-13: Minimum requirement per IECC for walls in Zone 3.
- **Exterior Roof R-value**
  R0 - 0.004, R1 - 21.364, R2 - 30.442, R3 - 40.054
  Note: Minimum R-49 for attic insulation as per IECC 2021 standards if occupied.
- **Interior Floor R-Value**
  F1 - 0.211, F2 - 8.004
- **Interior Ceiling Reflectance (%)**
  Ceiling LM83 - 70, White Ceiling - 85.67, Black Ceiling - 5.07
- **Glazing:**
  Vistacool on Pacifia - Clear (Argon)
  U-Value: 2.48
  SHGC: 0.311
  DoublePanelLoEe2
  U-Value: 1.493
  SHGC: 0.373
  Solarban 90 (2) - Solarban 90 (4) - Clear (Argon)
  U-Value: 0.66
  SHGC: 0.16
  Solarcool on Pacifica - Clear (Argon)
  U-Value: 2.53
  SHGC: 0.206

  ***NOTE:** U-Factor of 0.32 or less: Suitable for ENERGY STAR compliance.*
  U-Factor of 0.30: This meets the International Residential Code (IRC) requirements for energy efficiency in Climate Zone 3
  ***NOTE:** SHGC between 0.20 and 0.25: Ideal for reducing solar heat gain while maintaining some natural light, especially for east- and west-facing windows*
  Low SHGC (≤ 0.20): Best for heavily sun-exposed windows, such as those on the west or east facades
  Maximum SHGC of 0.25: This is the building code requirement and the maximum allowed for ENERGY STAR-certified windows

- **Interior Shading: On (1) , Off (0)**
  Sunvision Ecru
  Permeability: 14%
  VLT: 35%
  Golden low-E fabric WBI2W
  Permeability: 1%
  VLT: 1%

- **Air Infiltration:**
  ACH per hour: 0.1, 1.5, 3.0
  NOTE: Natural (unpressurized) air changes per hour for design conditions typically range from 0.20 to 0.29 ACH for heating and 0.11 to 0.16 ACH for cooling. ≤0.6 ACH at 50 Pa, representing high-performance or passive house standards
- **HVAC Heating System Electrification**
  Natural Gas :
  HEATING: (Conventional Boiler)
  COP - 0.83, 0.95
  COOLING: (Gas Absorption Chillers)
  COP - 0.7, 1.2
  Electrification:
  HEATING: (Air-Source Heat Pumps)
  COP – 3.1, 4.5
  COOLING: (Water-Cooled Chillers)
  COP – 3.8 5.3
  NOTE: for heating with High-efficiency natural gas boilers with economizers
  Electrification: Heat pumps will reduce GHG emissions by 30–60% versus gas systems.
- **Domestic Hot Water**
  Natural Gas: 0
  Electricity: 1

- **HVAC Economizer**
  Economizer: options
  NoEconomizer
  DifferentialEnthalpy

  ***NOTE:** Differential Enthalpy is preferred over Differential Dry Bulb for high-performance systems because it accounts for both temperature and humidity, which is critical in humid climates, ensuring better energy efficiency and indoor comfort. High-limit shutoff: Outdoor air enthalpy > 28 Btu/lb or outdoor air temperature > 75°F*

- **HVAC Heat Recovery**
  Heat Recovery:
  Heat Recovery – None (Both values 0)
  Heat Recovery Efficiency Latent – 0.75
  NOTE: Latent Heat Recovery is preferred for high-performance HVAC systems in Climate Zone 3 due to its ability to manage humidity effectively, which is critical in humid climates
- **Building Level Lighting Power Density**
  VALUES: 13.99, 10.54, 21.52 W/m²
- **Building Level Equipment Power Density**
  VALUES: 8.1 W/m²
- **Schedule :**
  Option 1: All on
  Option 2: 8am to 6pm with DST