San Francisco Alternative Zero

Naturally minimizing energy use

Catherine De Wolf - John Sullivan - Mingxi Zou - Trygve Wastvedt - SunMin May Hwang

1.5 Density [FAR]

9.5 Finance [IRR %]

25.4 Energy [kWh/m² a]

100 Day-lit Area [%]

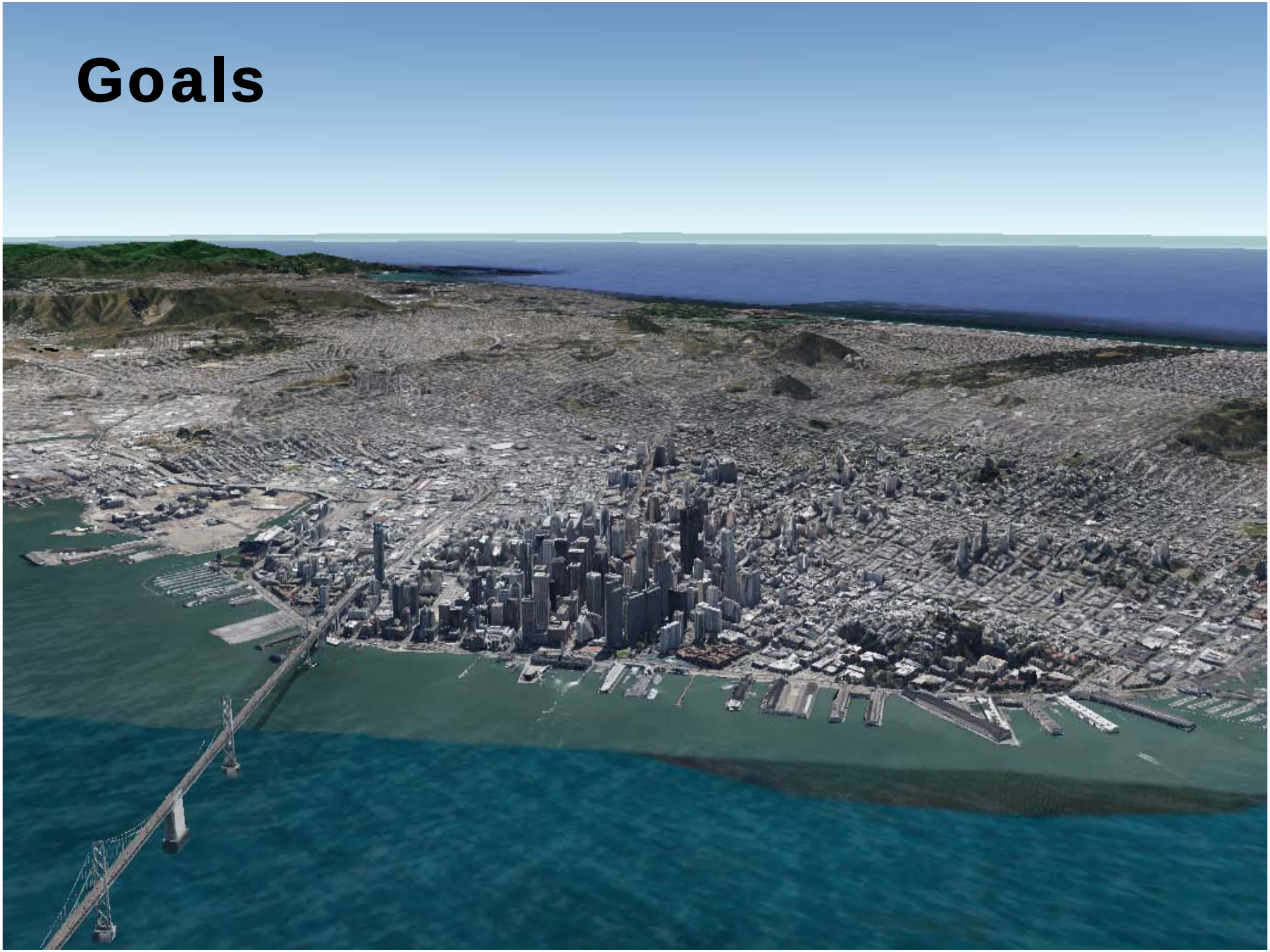
85 Accessibility [%]

470 Carbon [$kgCO_2e/m^2$]

95 Comfort [%]

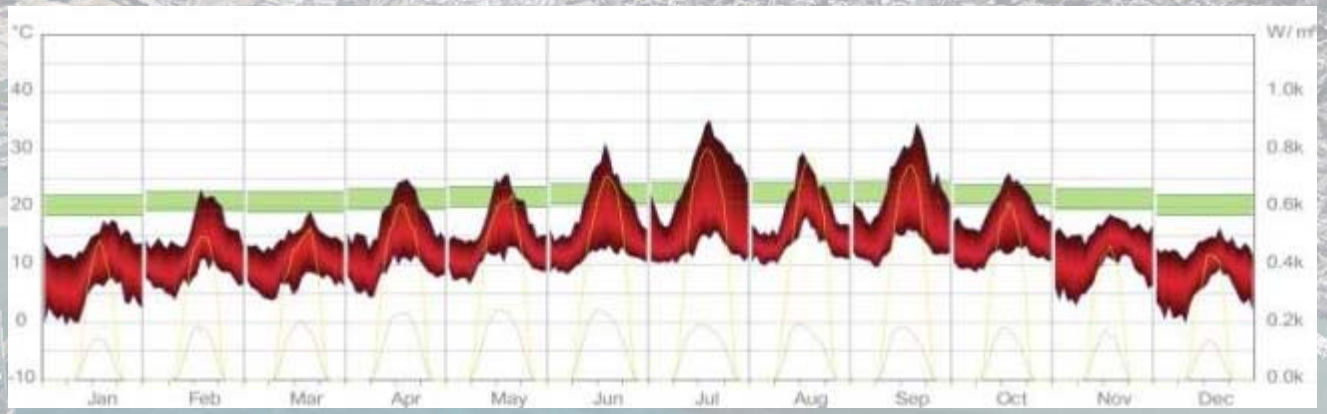
1. Sustainability Goals
2. Urban Design – Meet the Protoblock
3. Walkability
4. Building Design
5. Embodied carbon
6. Energy Consumption – Optimizing to Alternative Zero
7. Finance
8. Conclusions

Goals



Goals

Moderate Temperature



1.5 Density [FAR]

9.5 Finance [IRR %]

20.4 Energy [kWh/m² a]

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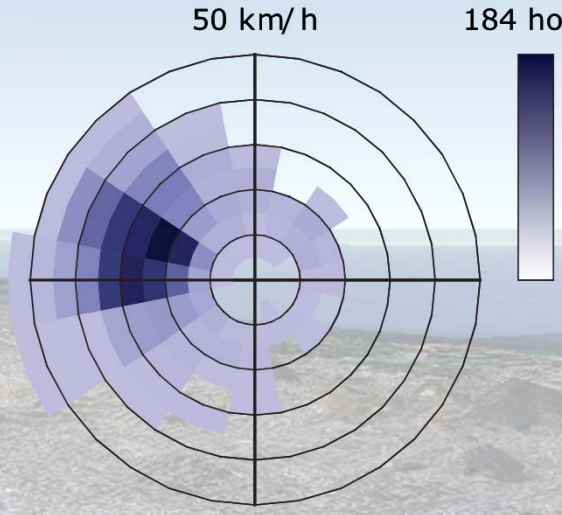
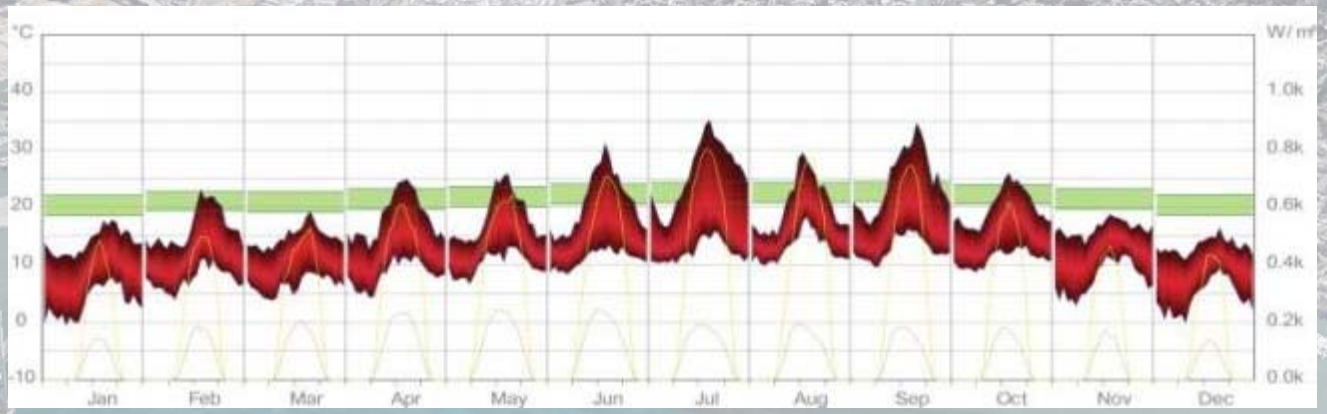
Goals

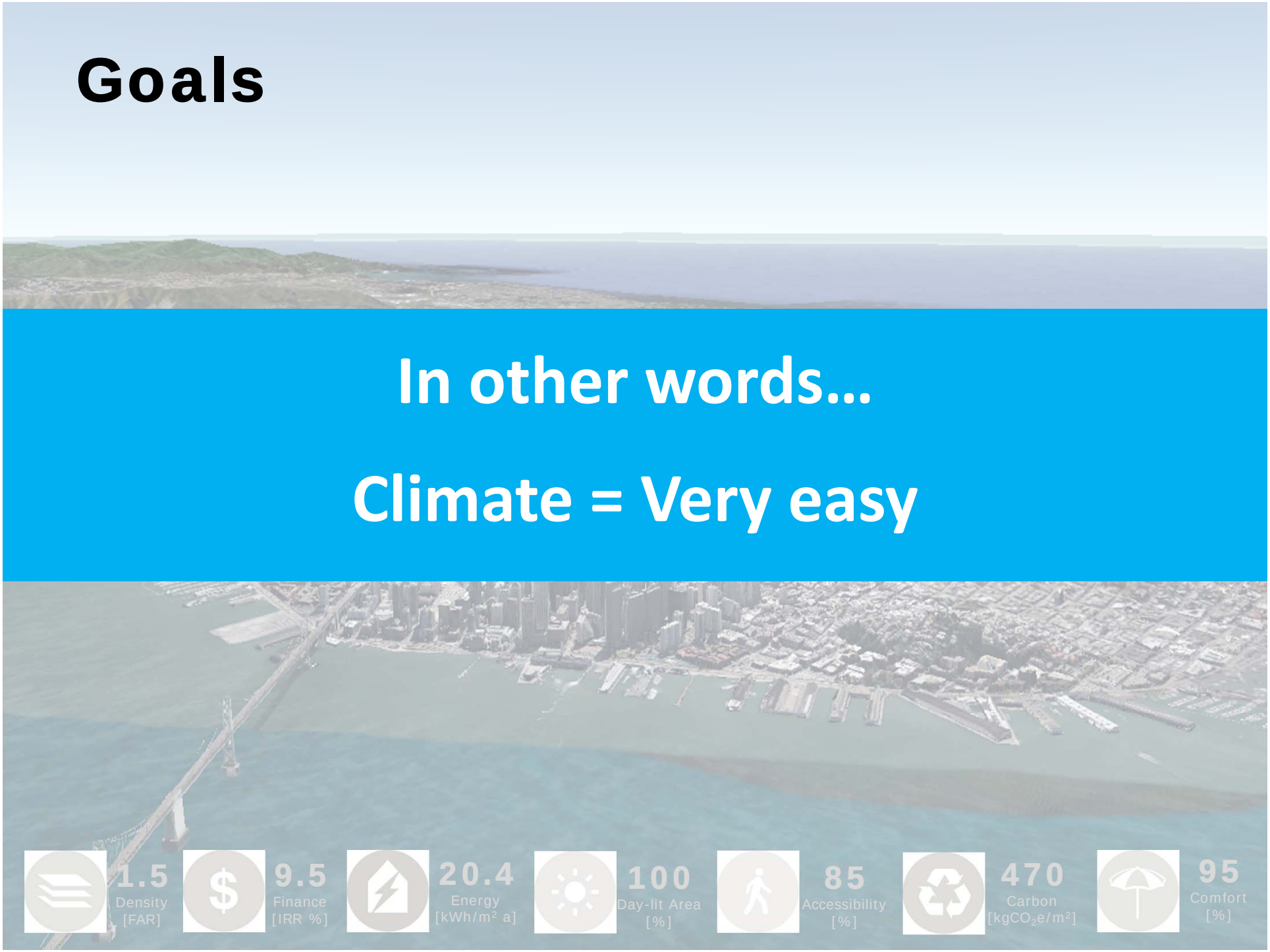


Cool Summer Wind

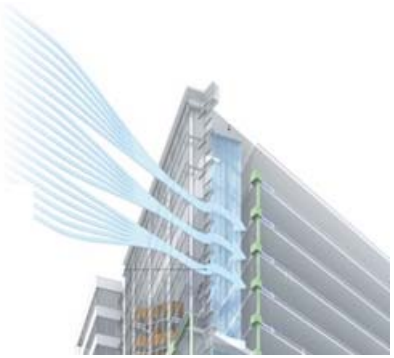


1.5	9.5	20.4	100	85	470	95
Density [FAR]	Finance [IRR %]	Energy [kWh/m² a]	Day-lit Area [%]	Accessibility [%]	Carbon [kgCO_2e/m²]	Comfort [%]

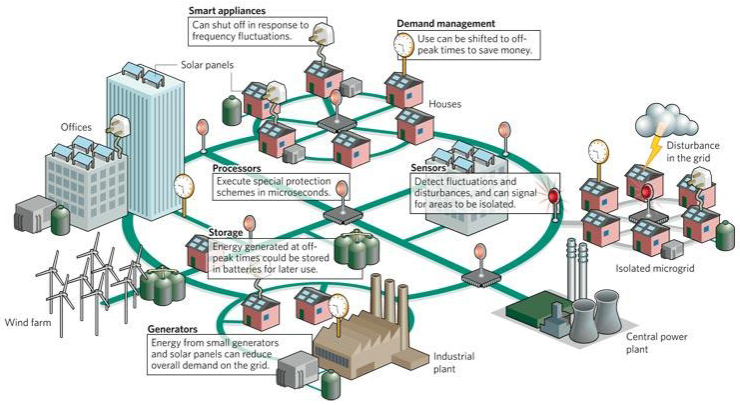
Goals


In other words…
Climate = Very easy
1.5
Density
[FAR]
9.5
Finance
[IRR %]
20.4
Energy
[kWh/m² a]
100
Day-lit Area
[%]
85
Accessibility
[%]
470
Carbon
[kgCO2e/m²]
95
Comfort
[%]

Goals



Ambitious Goal?



1.5 Density [FAR]

9.5 Finance [IRR %]

20.4 Energy [kWh/m² a]

100 Day-lit Area [%]

85 Accessibility [%]

470 Carbon [$kgCO_2e/m^2$]

95 Comfort [%]

Goals

Net-Zero Neighborhood?

1.5 Density [FAR]

9.5 Finance [IRR %]

20.4 Energy [kWh/m² a]

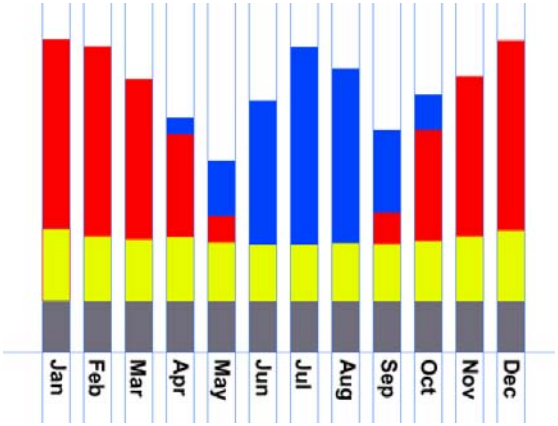
100 Day-lit Area [%]

85 Accessibility [%]

470 Carbon [$kgCO_2e/m^2$]

95 Comfort [%]

Goals



=

Sum(energy consumed)

Sum(energy generated)

Net-Zero

Goals

The ultimate in sustainable neighborhoods!

1.5 Density [FAR]

9.5 Finance [IRR %]

20.4 Energy [kWh/m² a]

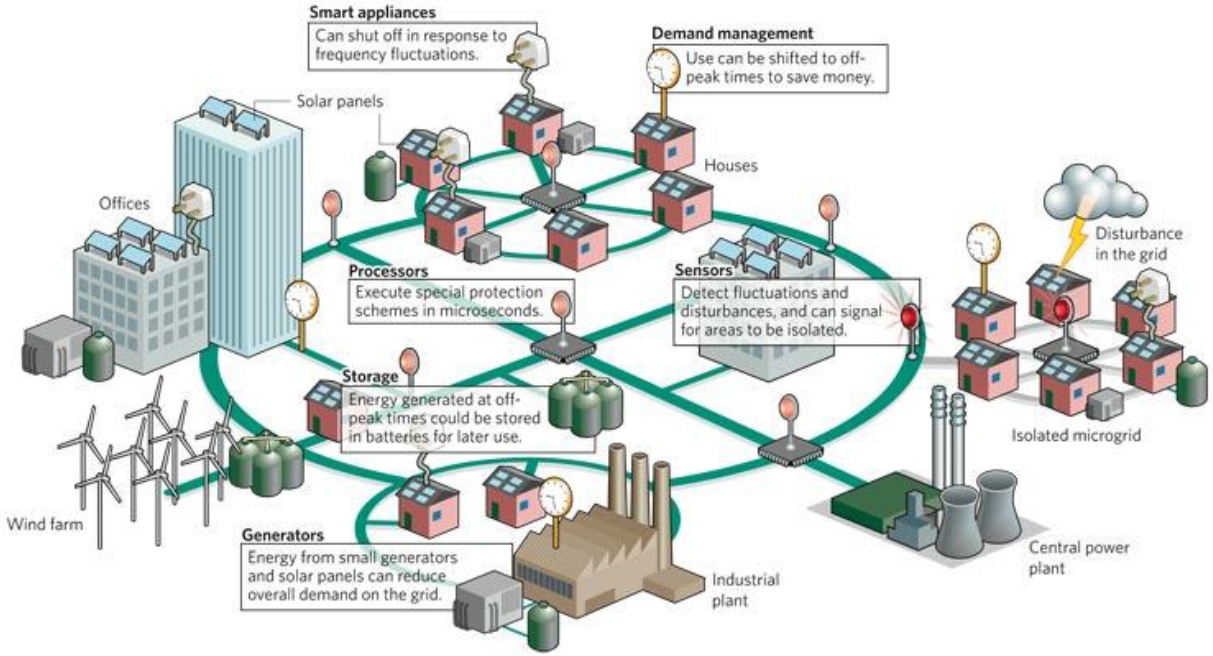
100 Day-lit Area [%]

85 Accessibility [%]

470 Carbon [kgCO$_2$e/m²]

95 Comfort [%]

Goals



Power distribution in California

http://www.caiso.com/Pages/Today's-Outlook-Details.aspx

1.5 Density [FAR]
9.5 Finance [IRR %]
20.4 Energy [kWh/m² a]
100 Day-lit Area [%]
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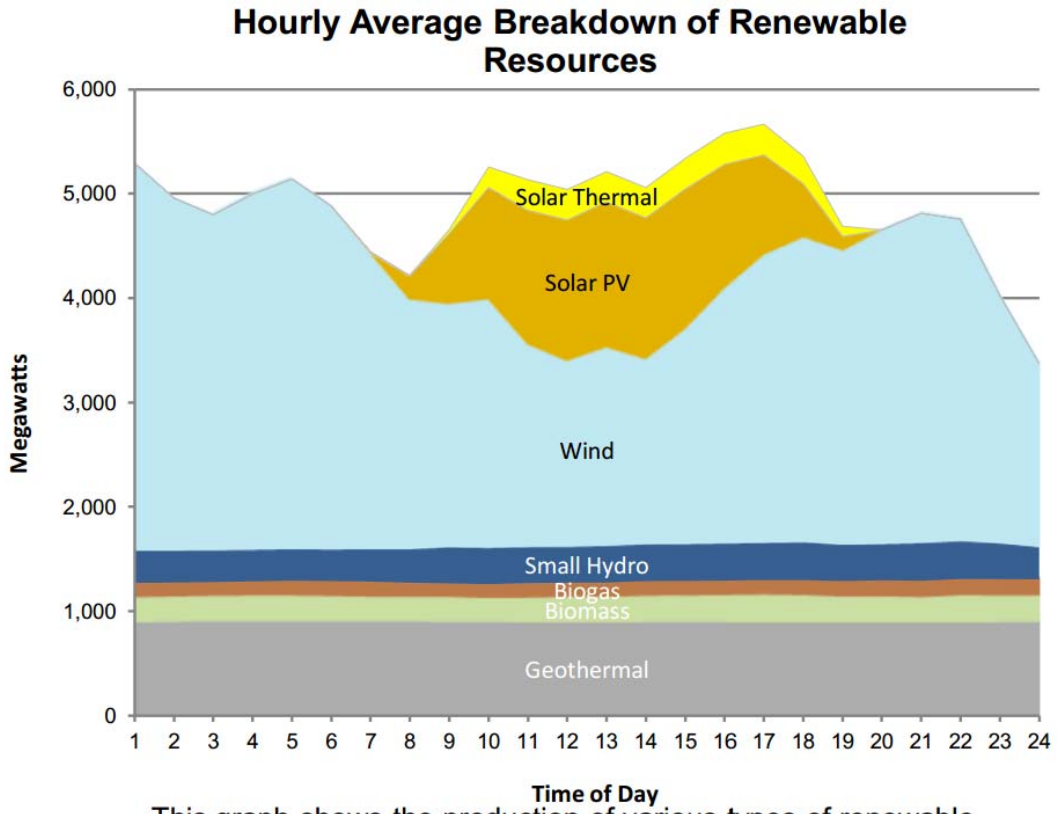
Goals



This graph shows the production of various types of renewable generation across the day.

1.5 Density [FAR]

9.5 Finance [IRR %]

20.4 Energy [kWh/m² a]

100 Day-lit Area [%]

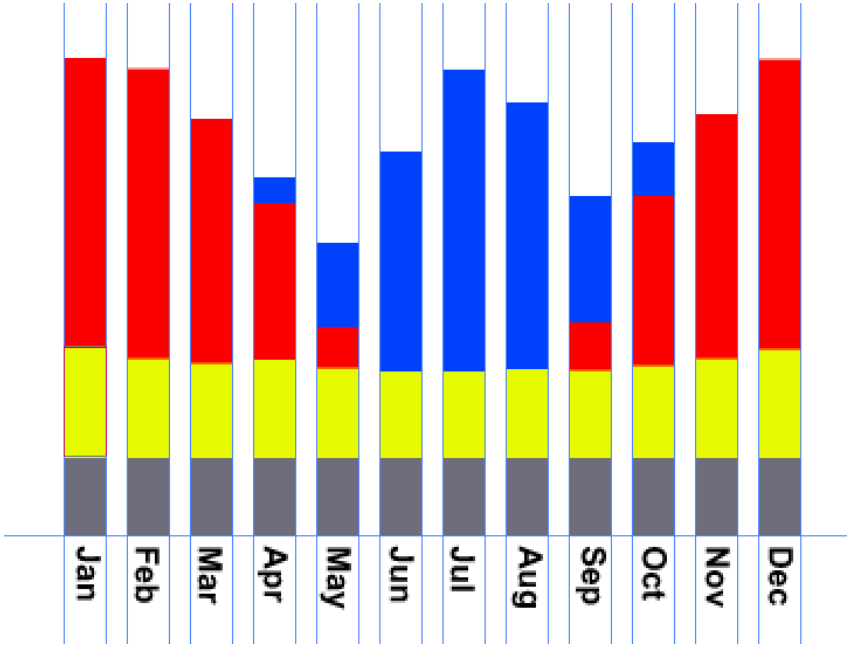
85 Accessibility [%]

470 Carbon [$kgCO_2e/m^2$]

95 Comfort [%]

Goals

Goals:



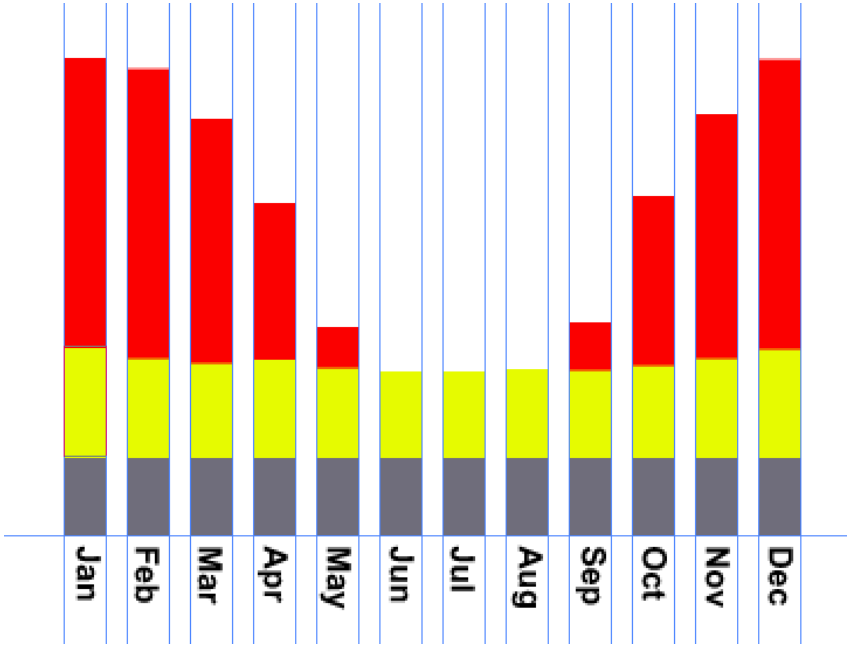
Sum of energy consumed

1.5 Density [FAR]
9.5 Finance [IRR %]
20.4 Energy [kWh/m² a]
100 Day-lit Area [%]
85 Accessibility [%]
470 Carbon [kgCO₂e/m²]
95 Comfort [%]

Goals

Goals:

1) Remove all mechanical cooling need



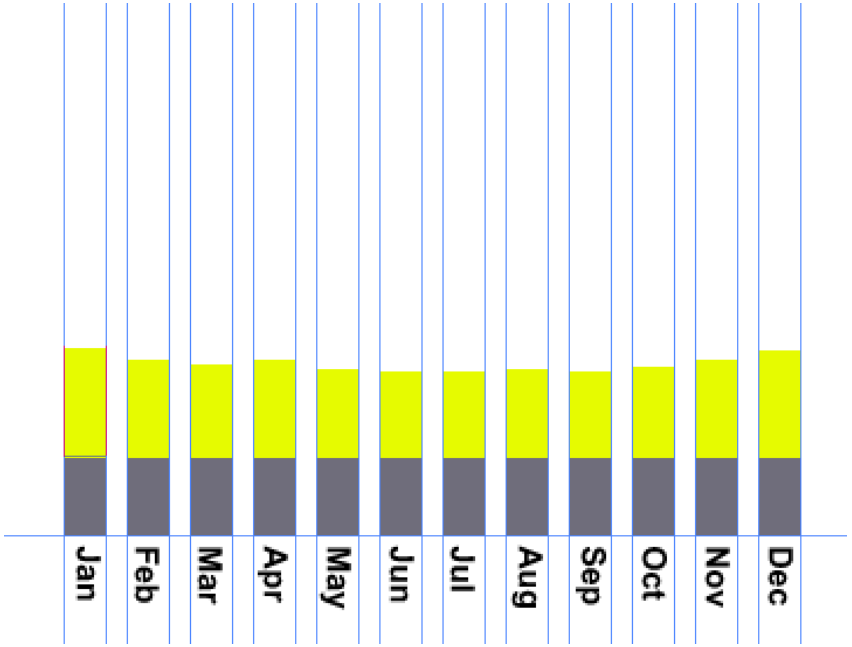
Sum of energy consumed

Goals

Goals:

1) Remove all mechanical cooling need

2) Remove all mechanical heating need



Sum of energy consumed

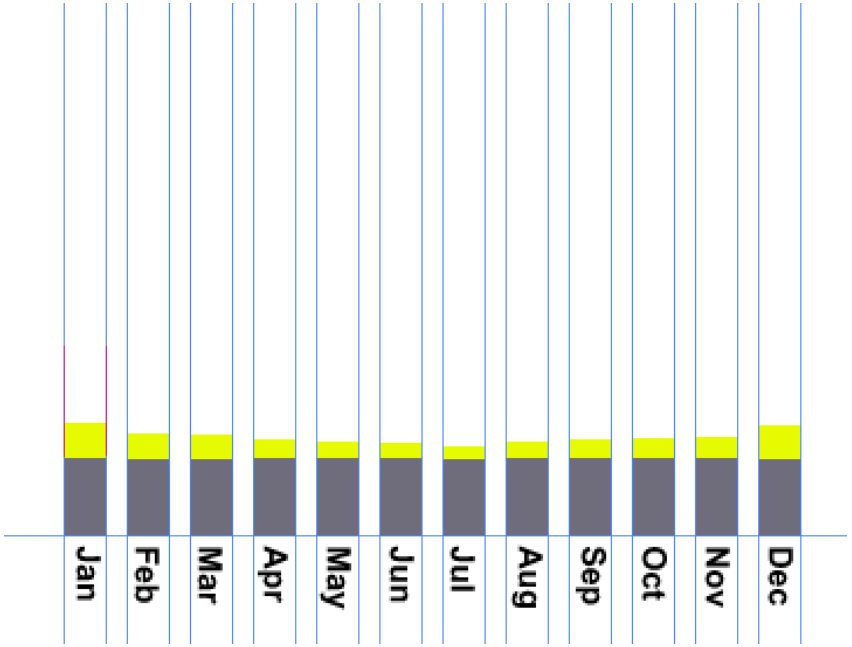
Goals

Goals:

1) Remove all mechanical cooling need

2) Remove all mechanical heating need

3) Remove all artificial lighting when the sun is up



Sum of energy consumed

Goals

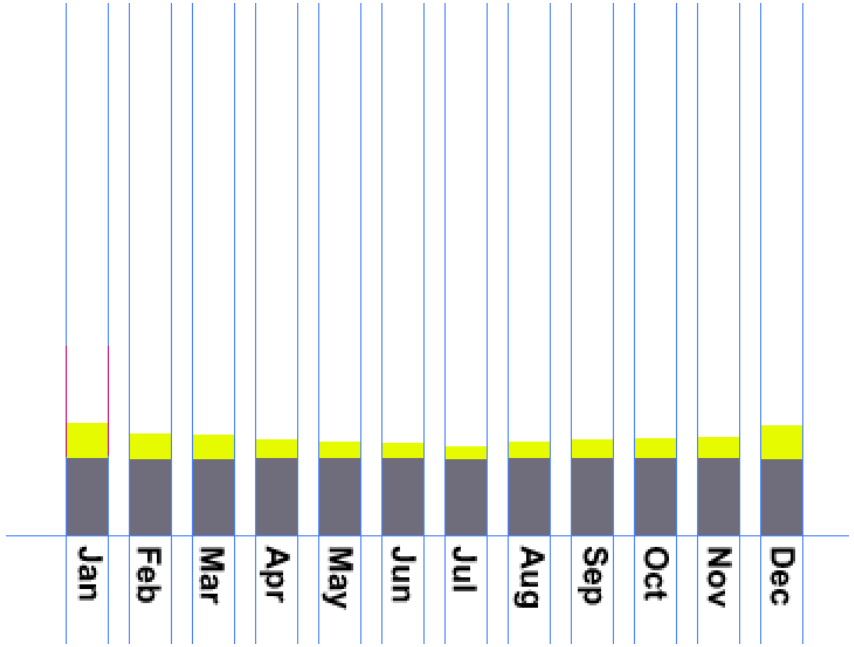
Goals:

1) **Remove all mechanical cooling need**

2) **Remove all mechanical heating need**

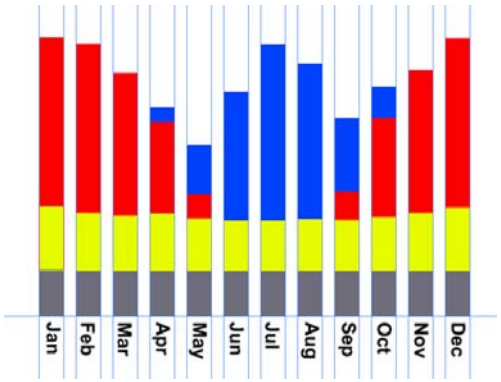
3) **Remove all artificial lighting when the sun is up**

* Ignore plug loads

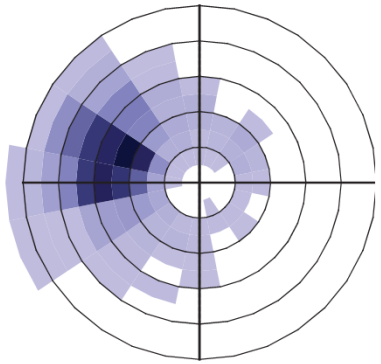


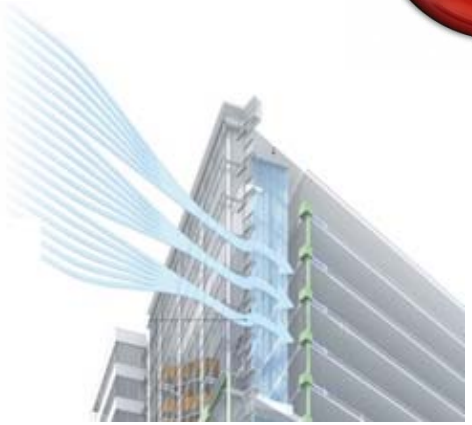
Sum of energy consumed

Goals



Cooling





Cool Wind

(Available almost 100% of year)

1.5 Density [FAR]

9.5 Finance [IRR %]

20.4 Energy [kWh/m² a]

100 Day-lit Area [%]

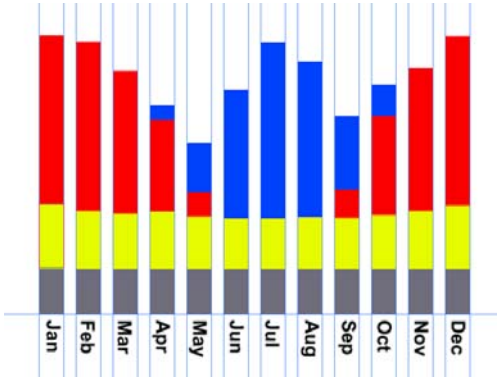
85 Accessibility [%]

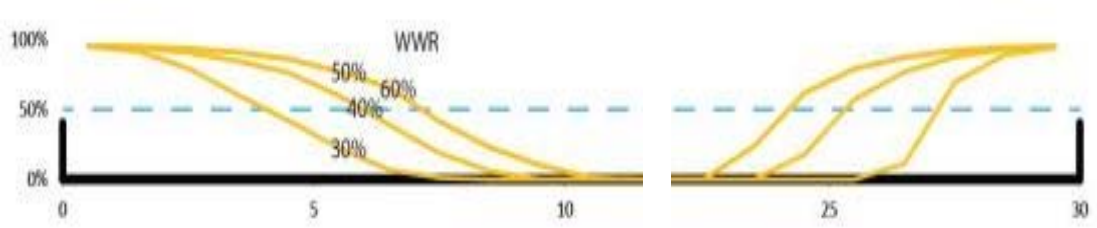
470 Carbon [$kgCO_2e/m^2$]

95 Comfort [%]

Goals

Daylight





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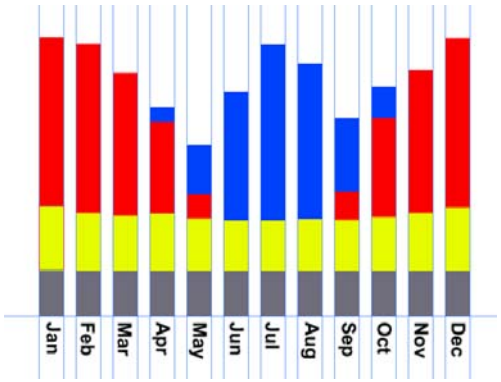
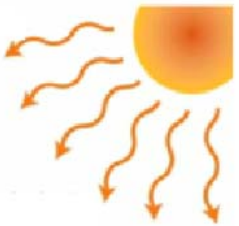
470 Carbon [kgCO₂e/m²]

95 Comfort [%]

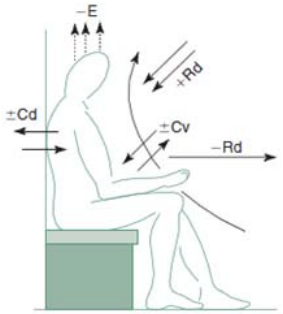
Goals





Sun

+



Occupants

+

Equipment

Heating

Free internal gains

Goals

Don’t control people. Advise people.

1.5 Density [FAR]

9.5 Finance [IRR %]

20.4 Energy [kWh/m² a]

100 Day-lit Area [%]

85 Accessibility [%]

470 Carbon [$kgCO_2e/m^2$]

95 Comfort [%]

Goals

People Centered

1.5 Density [FAR]

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20.4 Energy [kWh/m² a]

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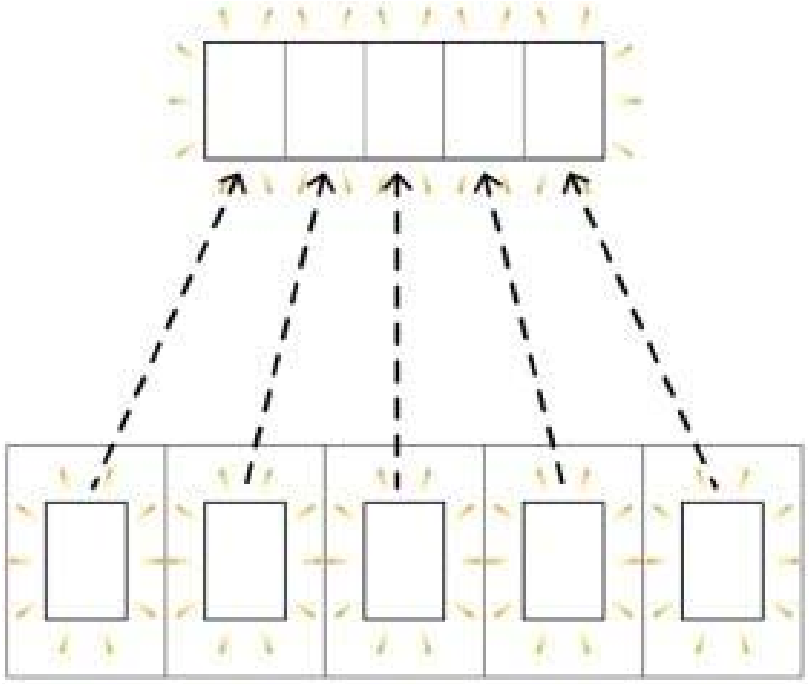
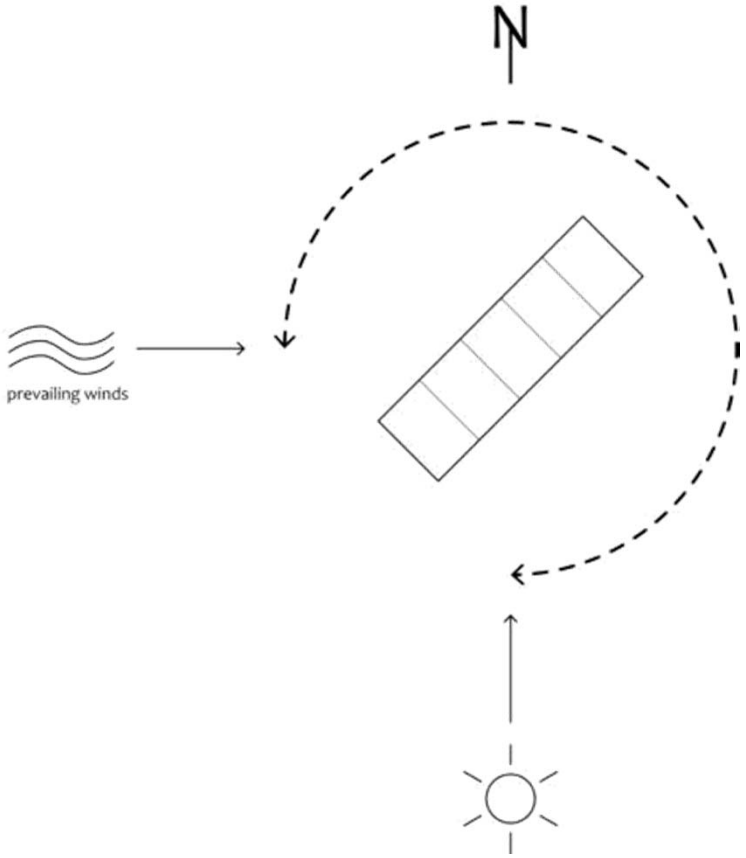
470 Carbon [$kgCO_2e/m^2$]

95 Comfort [%]

Density: Protoblock



Density: Protoblock

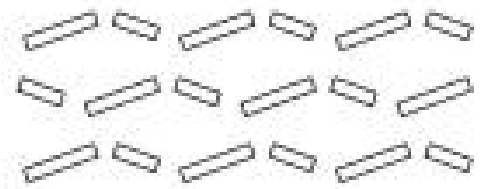


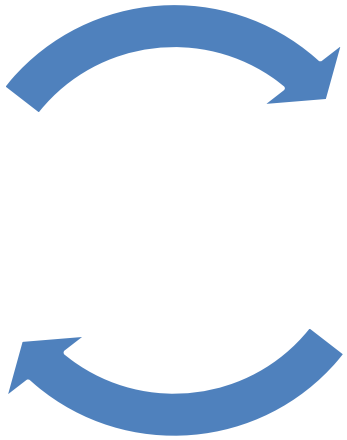
Density: Protoblock

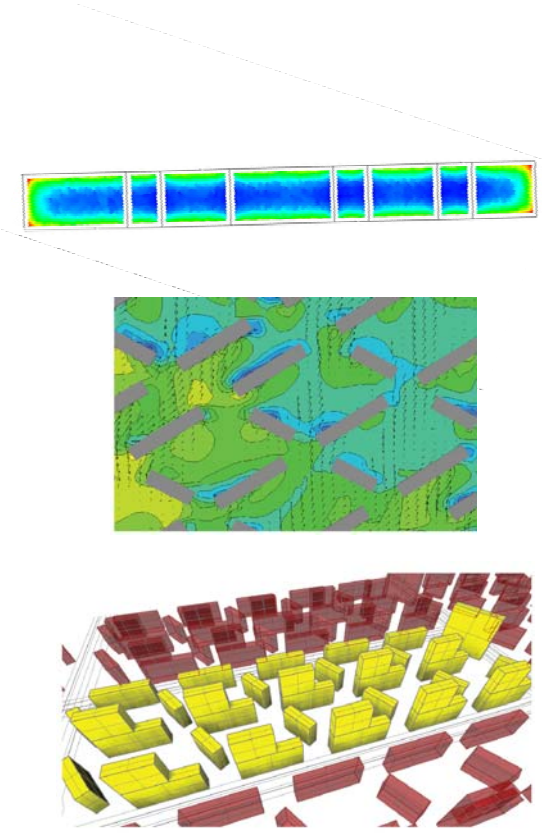
Set of thin Buildings with Solar exposure

1.5
Density
[FAR]

Density: Protoblock



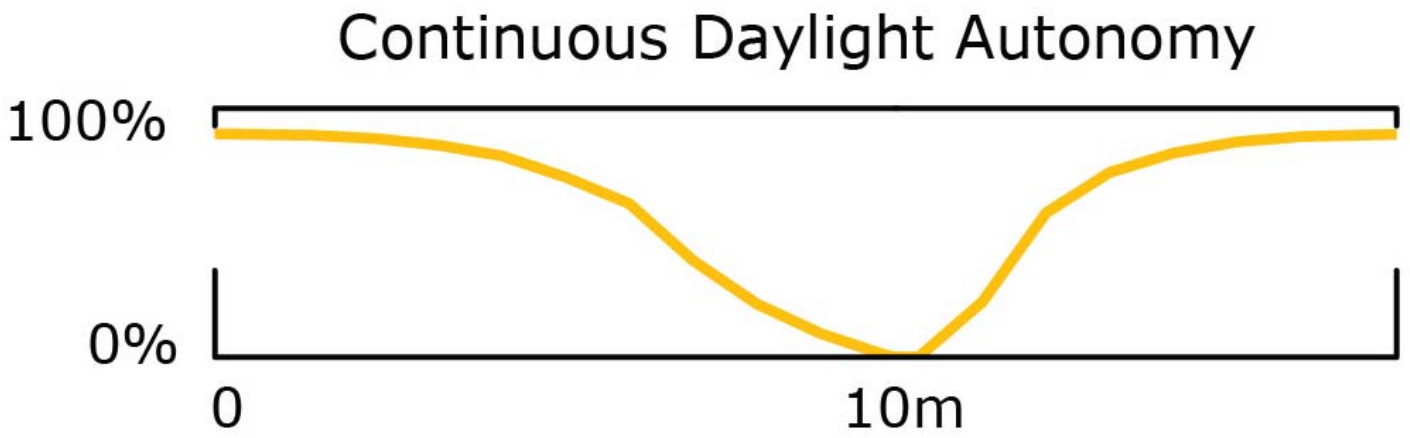




Protoblock

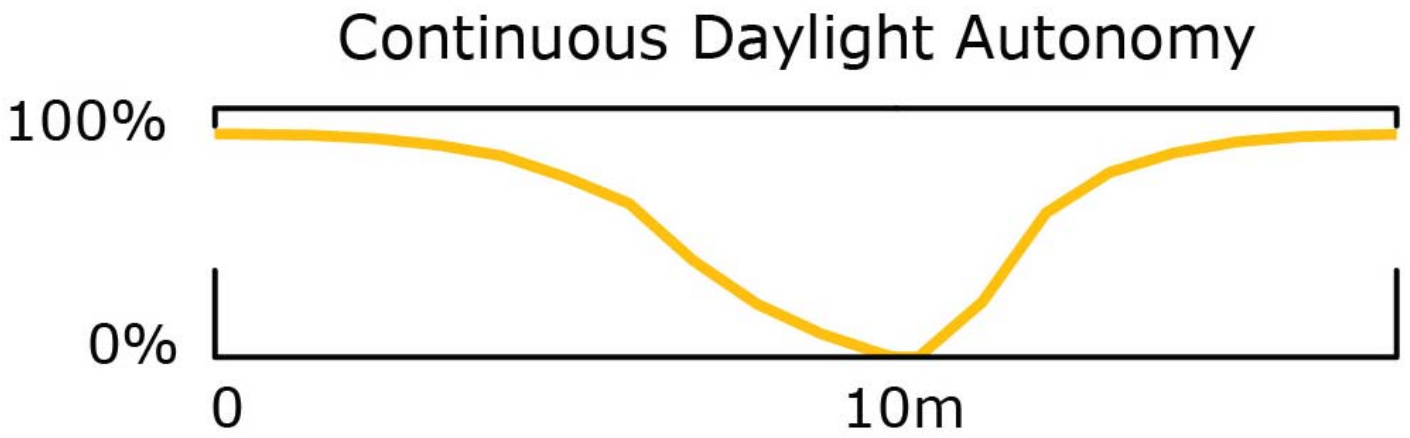
Analysis

Density: Protoblock



Daysim:
Maximum Building Depth

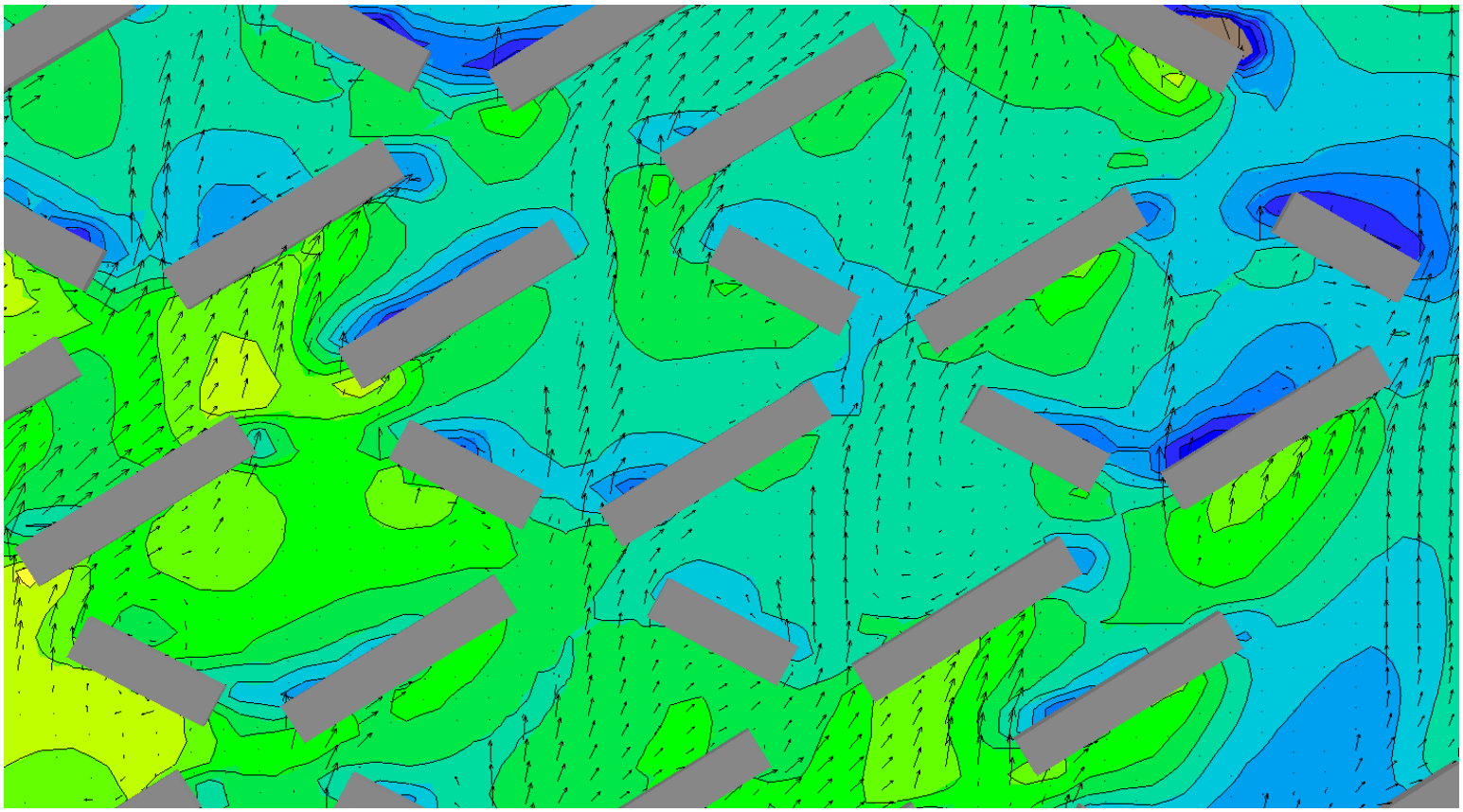
Density: Protoblock



Daysim:
Maximum Building Depth

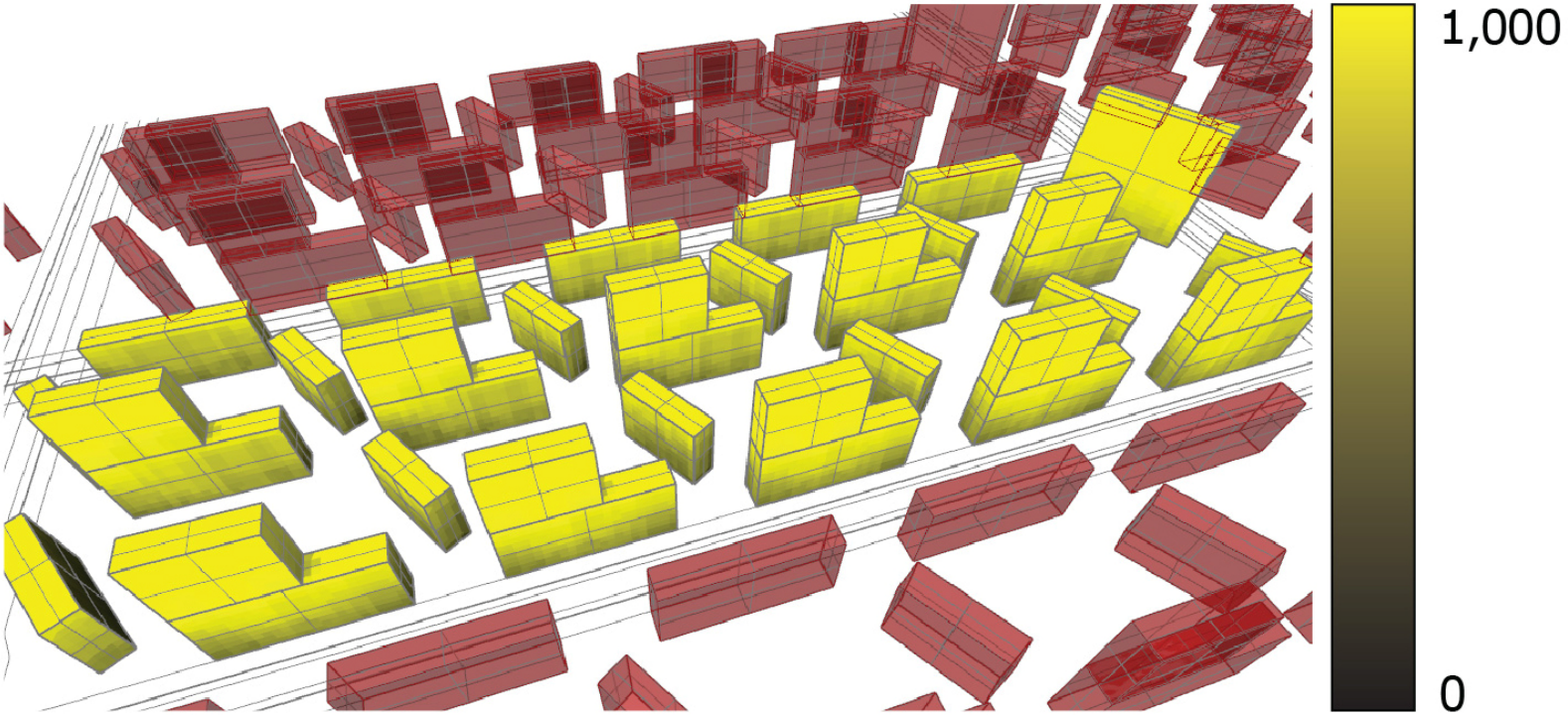
Fixed @ 8.0 m
(exceptions for commercial space)

Density: Protoblock



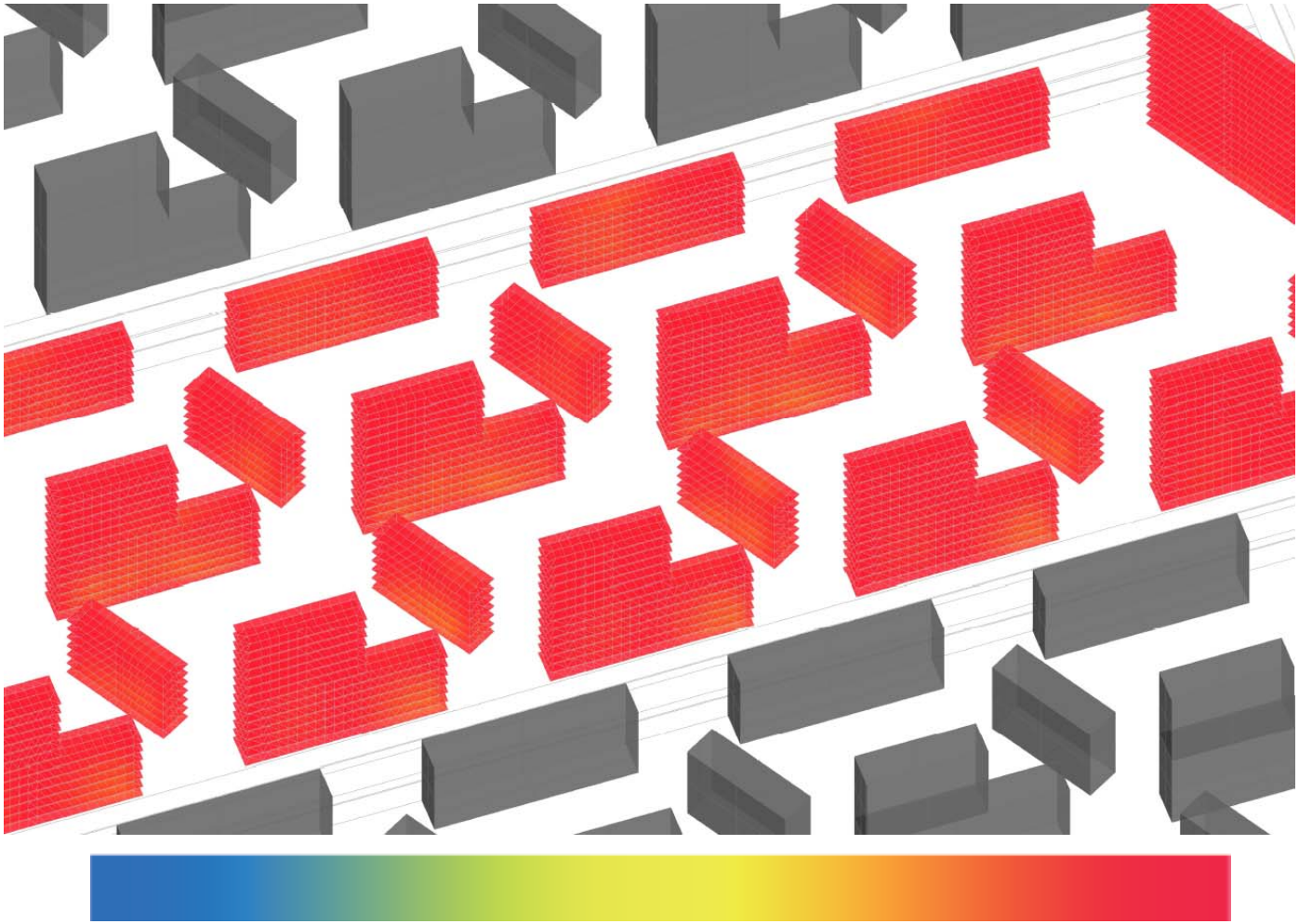
CFD:
Wind Driven Natural Ventilation Potential

Density: Protoblock



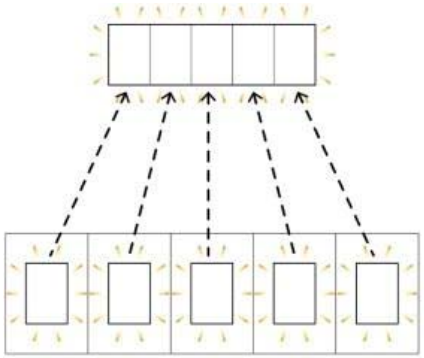
Useful Solar Radiation
Cumulative Radiation when $T_{ambient}$ < 18° C

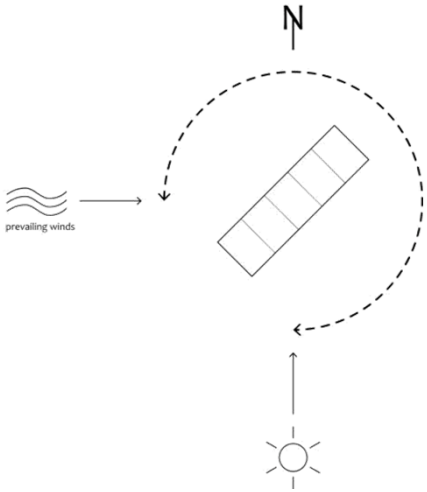
Density: Protoblock

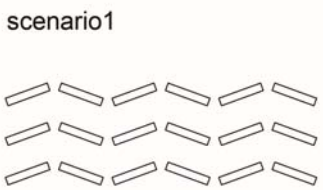


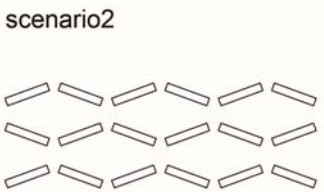
Daylight Area

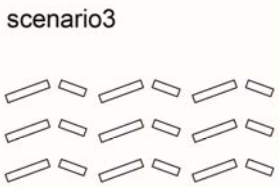
Density: Protoblock

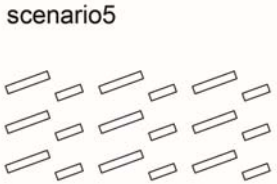


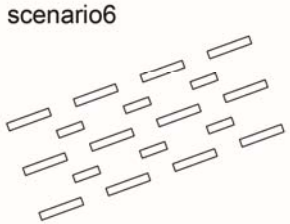


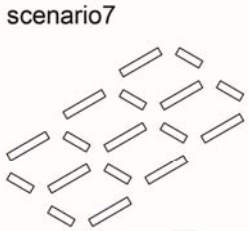






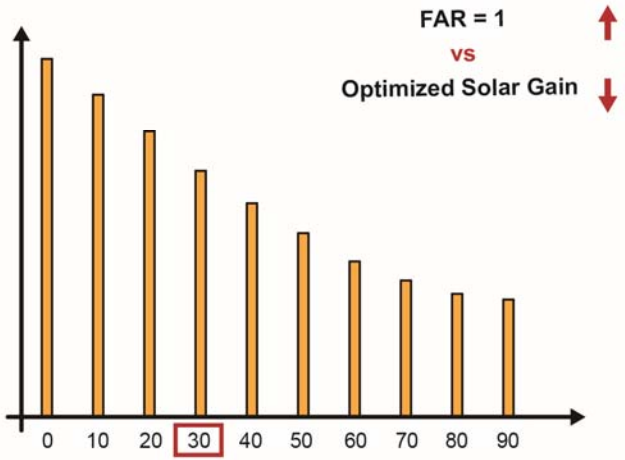


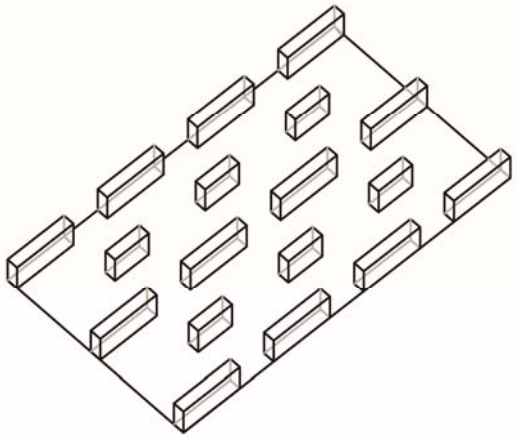




Density: Protoblock

South_0	Average Solar Gain	**700**kwh/m²
South_10	Average Solar Gain	**630**kwh/m²
South_20	Average Solar Gain	**557**kwh/m²
South_30	Average Solar Gain	**482**kwh/m²
South_40	Average Solar Gain	**417**kwh/m²
South_50	Average Solar Gain	**359**kwh/m²
South_60	Average Solar Gain	**304**kwh/m²
South_70	Average Solar Gain	**267**kwh/m²
South_80	Average Solar Gain	**241**kwh/m²
South_90	Average Solar Gain	**230**kwh/m²

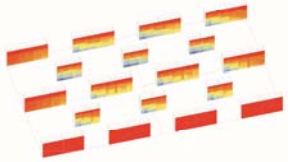




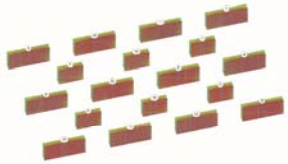
Density: Protoblock

Optimized Solar Gain Model

FAR = 1 Average **482** kwh/m²

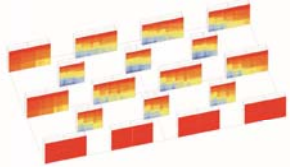


Continuous Daylight Autonomy

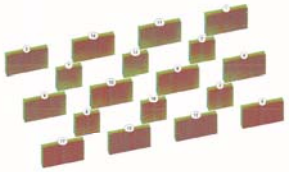


2 Ways to Raise FAR _ **Height**

FAR = 1.5 Average **454**kwh/m²

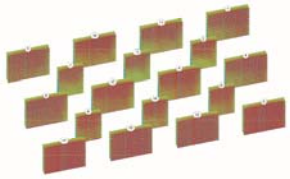


Continuous Daylight Autonomy



FAR = 2 Average **396**kwh/m²

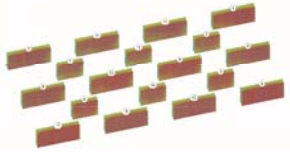
Continuous Daylight Autonomy



2 Ways to Raise FAR _ **Distance**

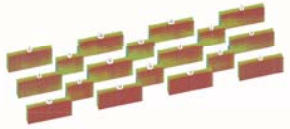
FAR = 1.5 Average **463**kwh/m²

Continuous Daylight Autonomy



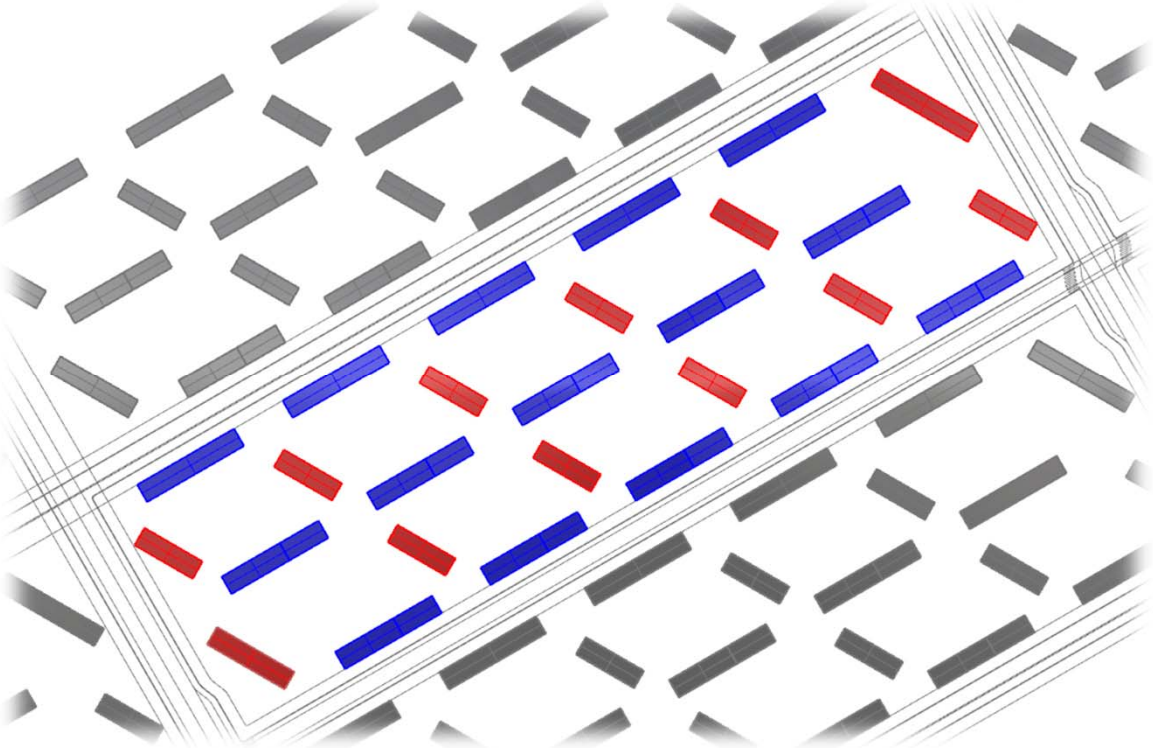
FAR = 2 Average **419**kwh/m²

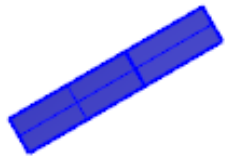
Continuous Daylight Autonomy



	FAR = 1	Distance FAR = 1.5	Height FAR = 1.5	Distance FAR = 2	Height FAR = 2
Useful Solar Gain					
Average	87.6%	84.2%	82.5%	76.2%	72.0%
Minimum	54.5%	47.6%	41.3%	25.4%	30.7%
Continuous Daylight Autonomy					
Group CDA	66.26%	64.07%	62.78%	58.10%	59.88%

Density: Protoblock





Residential

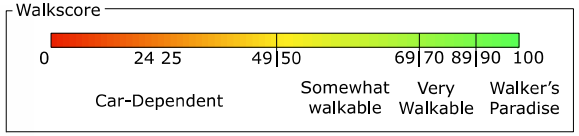
Office

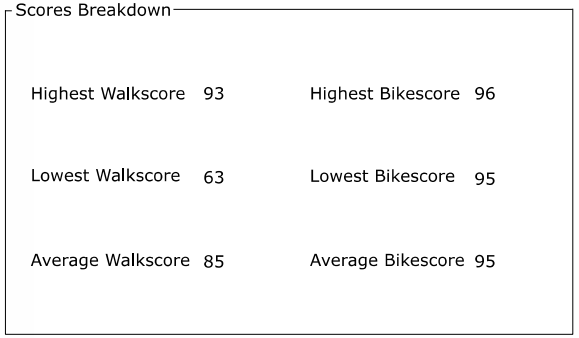
1.5
Density
[FAR]

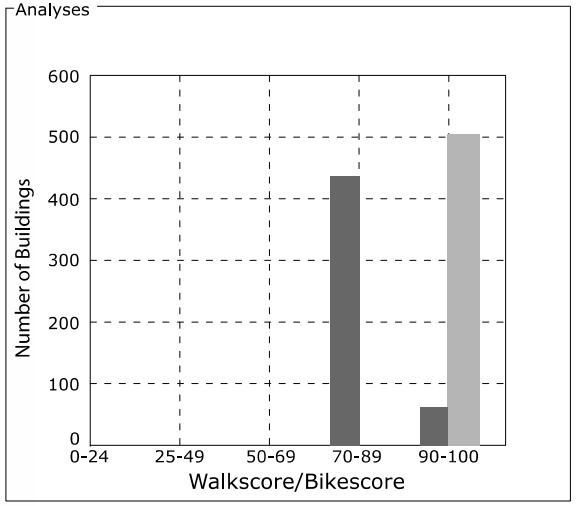
Walkability

school 1
restaurant 7
coffee 13
shopping 9
entertainment 5
Bank 7
Grocery 12
Books 4

UMI WALKSCORE RESULTS

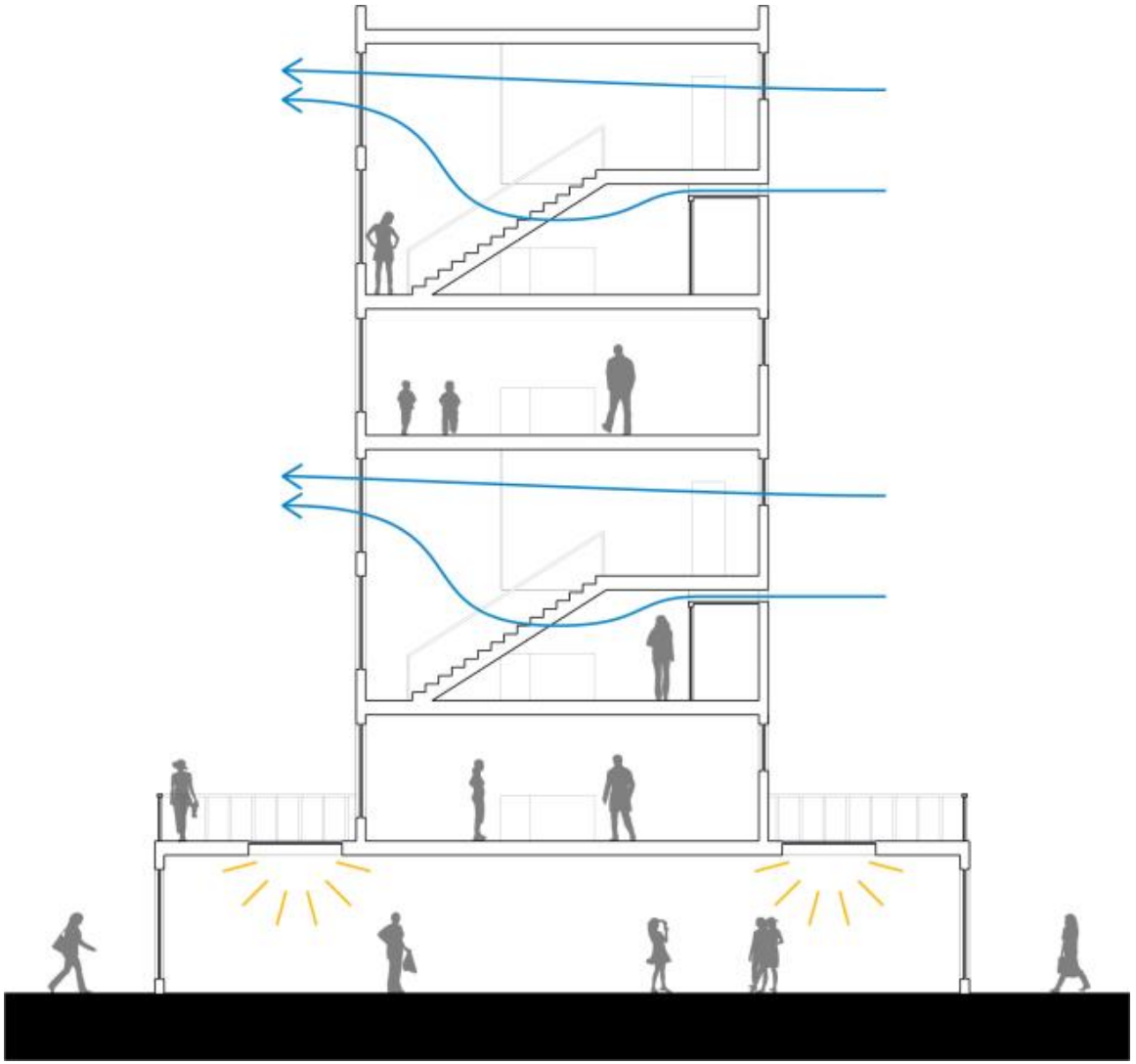






85
Accessibility
[%]

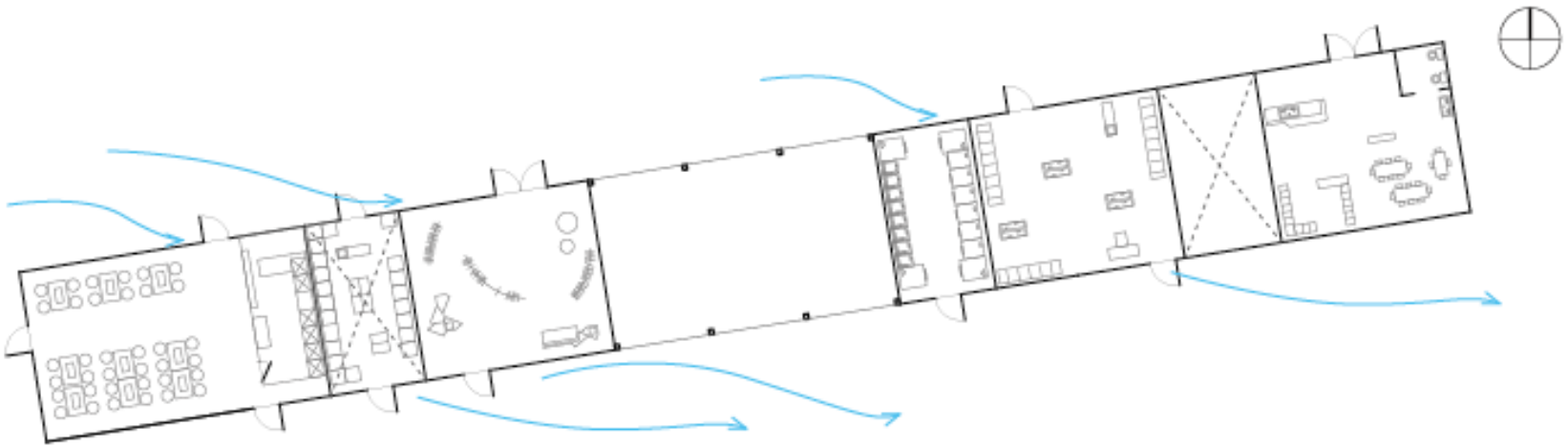
Building Design



20.4
Energy
[kWh/m² a]

100
Day-lit Area
[%]

Building Design



20.4
Energy
[kWh/m² a]

Building Design

Variation 01

Variation 02

Variation 03

20.4
Energy
[kWh/m² a]

100
Day-lit Area
[%]

Building Design

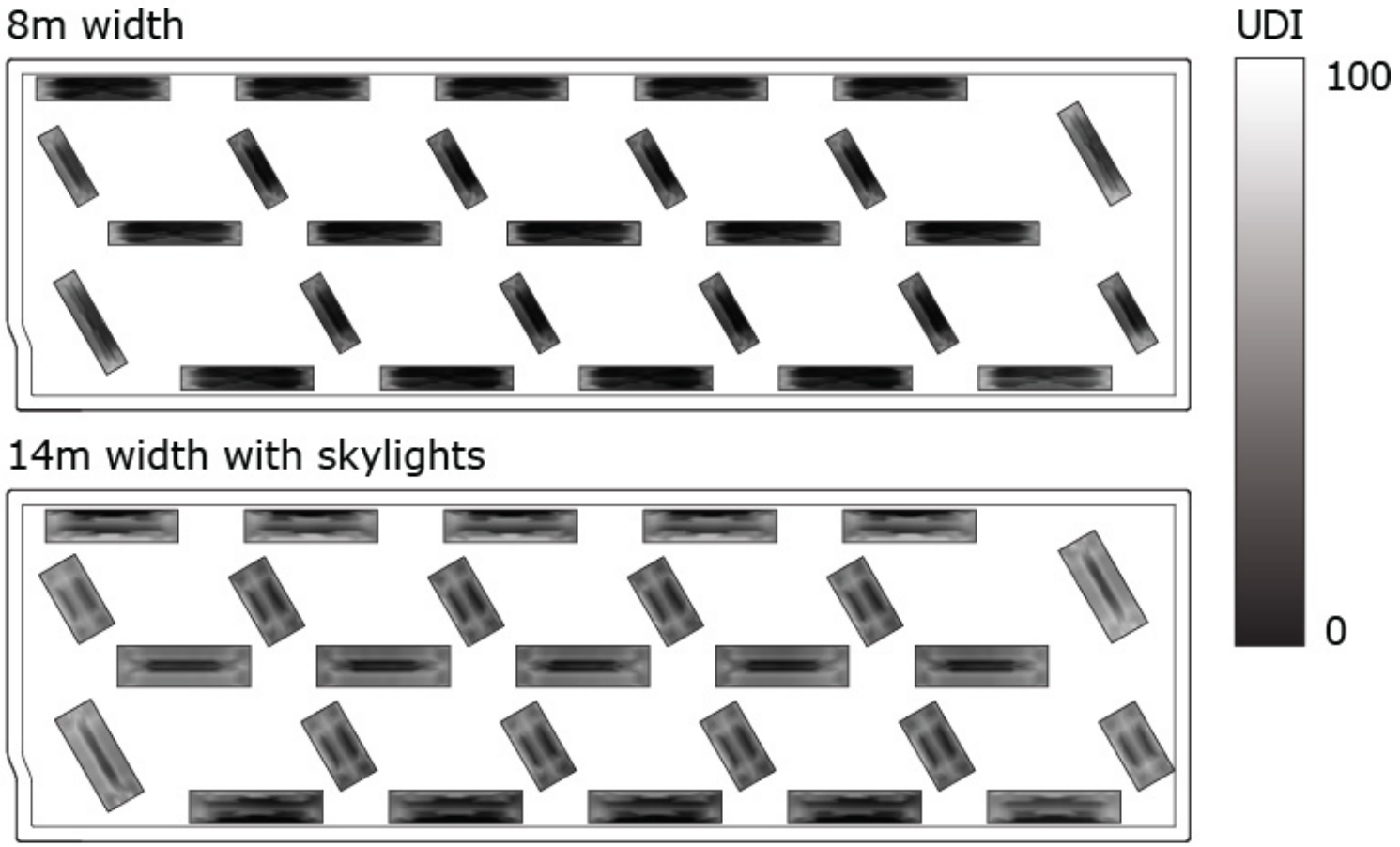
First Floor Commercial

Grocery Daycare Underpass Retail Restaurant

100
Day-lit Area
[%]

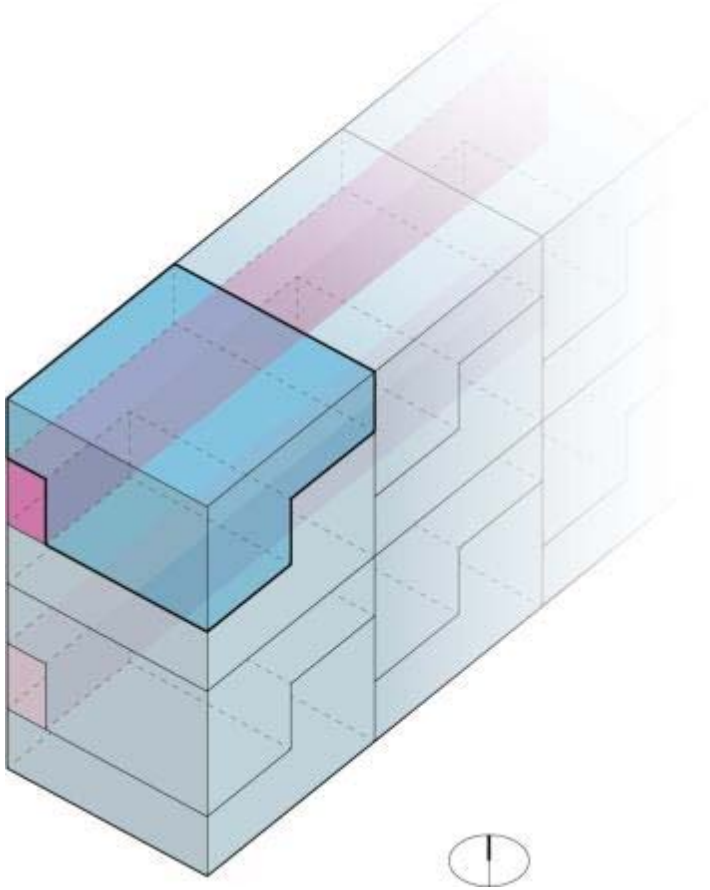
Building Design

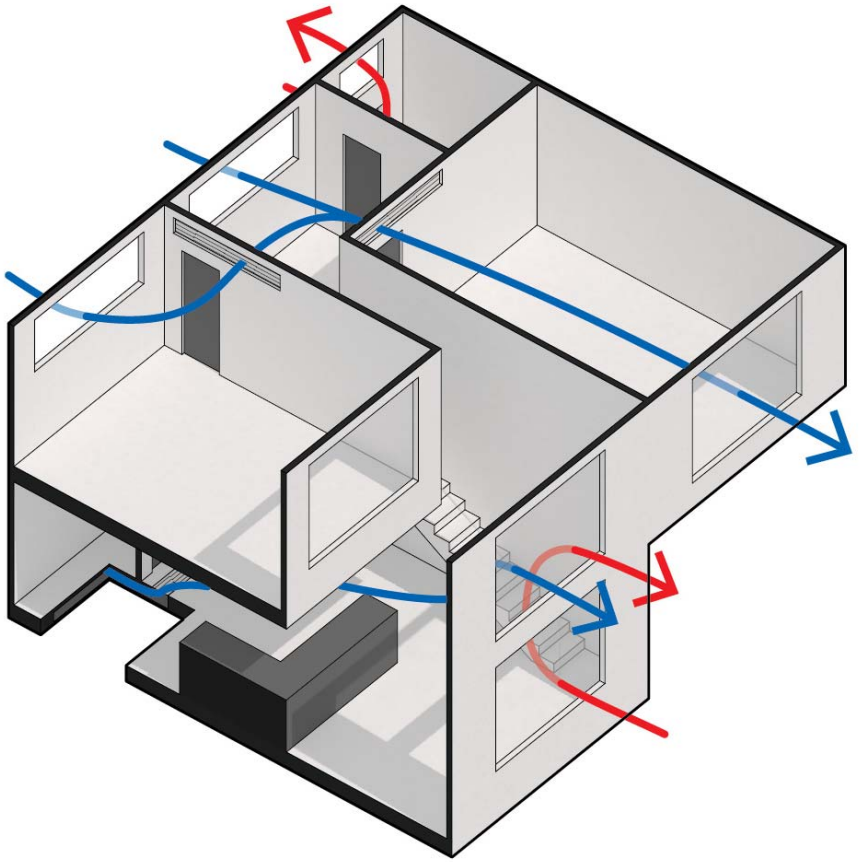
First Floor Commercial



100
Day-lit Area
[%]

Building Design



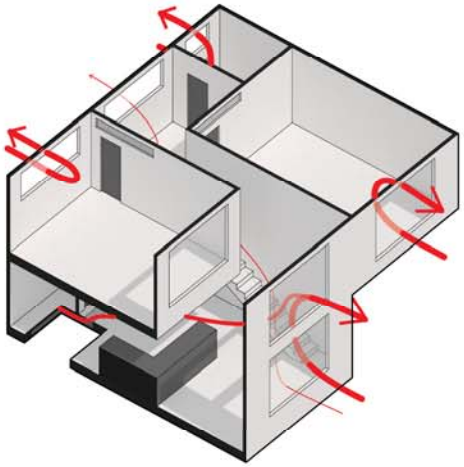


combined ventilation

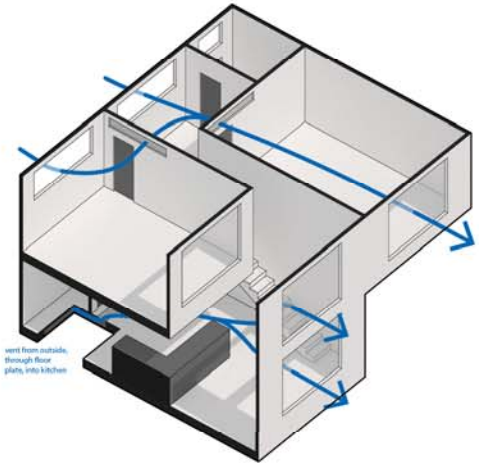
20.4
Energy
[kWh/m² a]

100
Day-lit Area
[%]

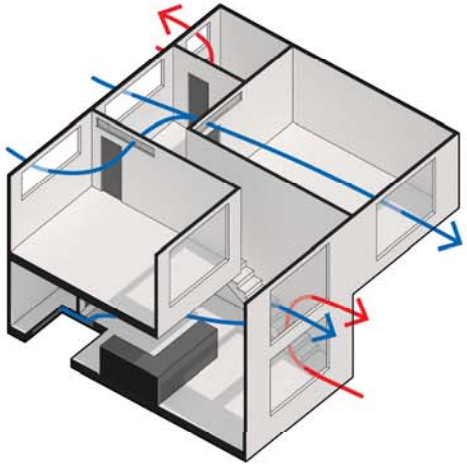
Building Design



buoyancy driven ventilation



wind driven ventilation



combined ventilation

20.4
Energy
[kWh/m² a]

Embodied carbon – Goals

- ✓ **Maintains operational energy**
- ✓ **Lower carbon than existing development**

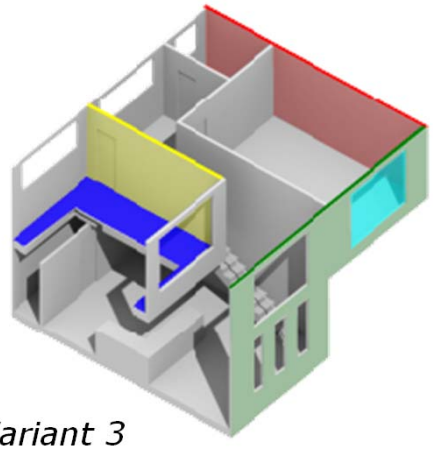
- Carbon Intensity Factors (kg CO_2/ kg material)
- Material quantities (kg/m^2)

Global Warming Potential or GWP (kg CO_2 / m^2)

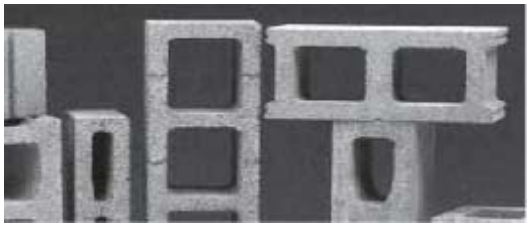
Total Residential V3	509 kg CO_2 / m^2
Total Commercial V2	265 kg CO_2 / m^2

470
Carbon
[$kgCO_2e/m^2$]

Embodied carbon – Residential

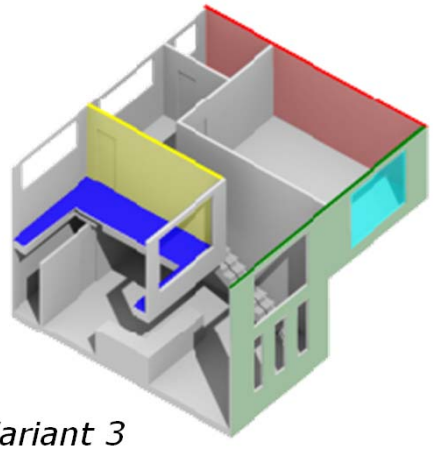


	Variant 1	*Variant 2*	*Variant 3*
Structural	Gypsum, concrete, polystyrene, brick	Reinforced concrete	Timber, wood chips, greenboard
Exterior	Gypsum, concrete, polystyrene, brick	Timber, wood chips	Timber, wood chips
Interior	Gypsum, brick	Timber	Timber frame, wood chips
Floor	Timber, screed cast concrete, urea foam	Pretensionned concrete	Linoleum, HDF, cork insulation, concrete slab
Windows	Timber framed	Timber framed	Timber framed
GWP	**1021 kg CO2 / m2**	**942 kg CO2 / m2**	**509 kg CO2 / m2**



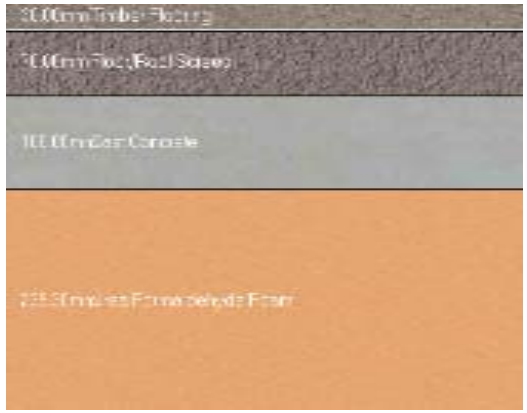
470
Carbon
[$kgCO_2e/m^2$]

Embodied carbon – Residential



✓ **Maintains operational energy**

	Variant 1	*Variant 2*	*Variant 3*
Structural	Gypsum, concrete, polystyrene, brick	Reinforced concrete	Timber, wood chips, greenboard
Exterior	Gypsum, concrete, polystyrene, brick	Timber, wood chips	Timber, wood chips
Interior	Gypsum, brick	Timber	Timber frame, wood chips
Floor	Timber, screed cast concrete, urea foam	Pretensionned concrete	Linoleum, HDF, cork insulation, concrete slab
Windows	Timber framed	Timber framed	Timber framed
GWP	**1021 kg CO2 / m2**	**942 kg CO2 / m2**	**509 kg CO2 / m2**



470
Carbon
[$kgCO_2e/m^2$]

Embodied carbon – Commercial

	Variant 1	Variant 2
Roof	Asphalt, glass wool, concrete block, gypsum	Concrete block, insulation, bitumen
Exterior	Brick, XPS, conrete block, gypsum	Timber, rockwool, plaster, brick
Interior	Gypsum, brick	Greenboards
Windows	Timber framed	Timber framed
GWP	**344 kg CO2/m2**	**265 kg CO2/m2**

470
Carbon
[$kgCO_2e/m^2$]

Embodied carbon – Commercial

✓ **Maintains operational energy**

	Variant 1	Variant 2
Roof	Asphalt, glass wool, concrete block, gypsum	Concrete block, insulation, bitumen
Exterior	Brick, XPS, conrete block, gypsum	Timber, rockwool, plaster, brick
Interior	Gypsum, brick	Greenboards
Windows	Timber framed	Timber framed
GWP	**344 kg CO2 / m2**	**265 kg CO2 / m2**

470
Carbon
[$kgCO_2e/m^2$]

Embodied carbon

- ✓ **Lower carbon than existing development**

Existing Development

Residential
930 Kg CO_2/m^2

Commercial
886 kg CO_2/m^2

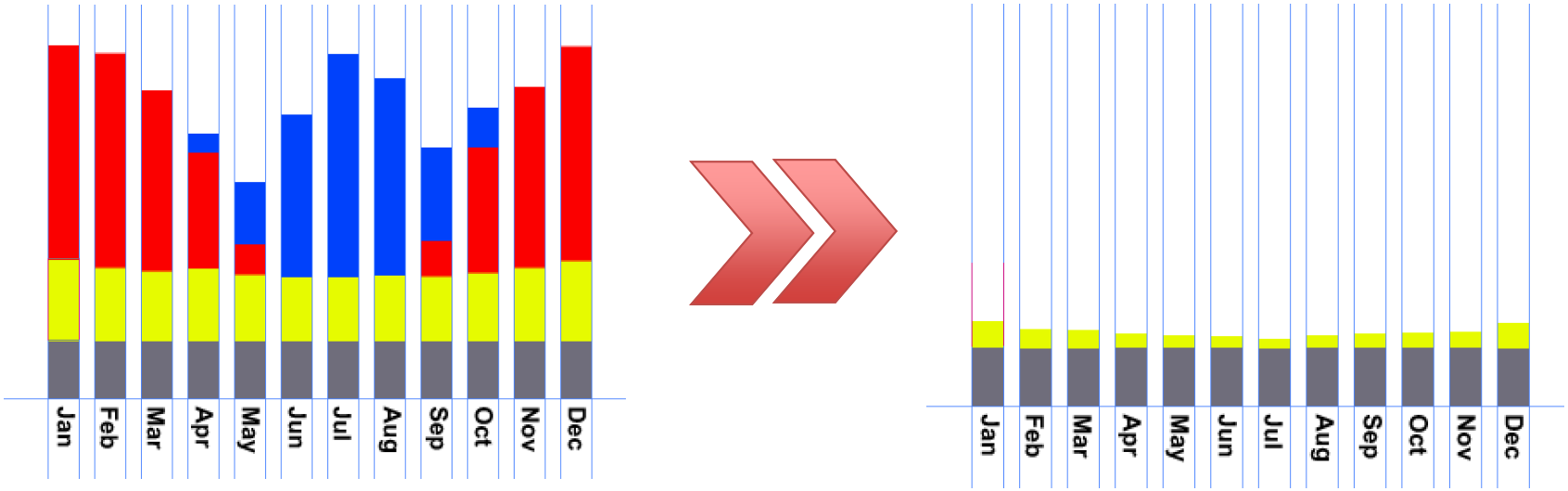
Proposed Design

Residential
509 Kg CO_2/m^2

Commercial
265 kg CO_2/m^2

470
Carbon
[$kgCO_2e/m^2$]

Energy Consumption



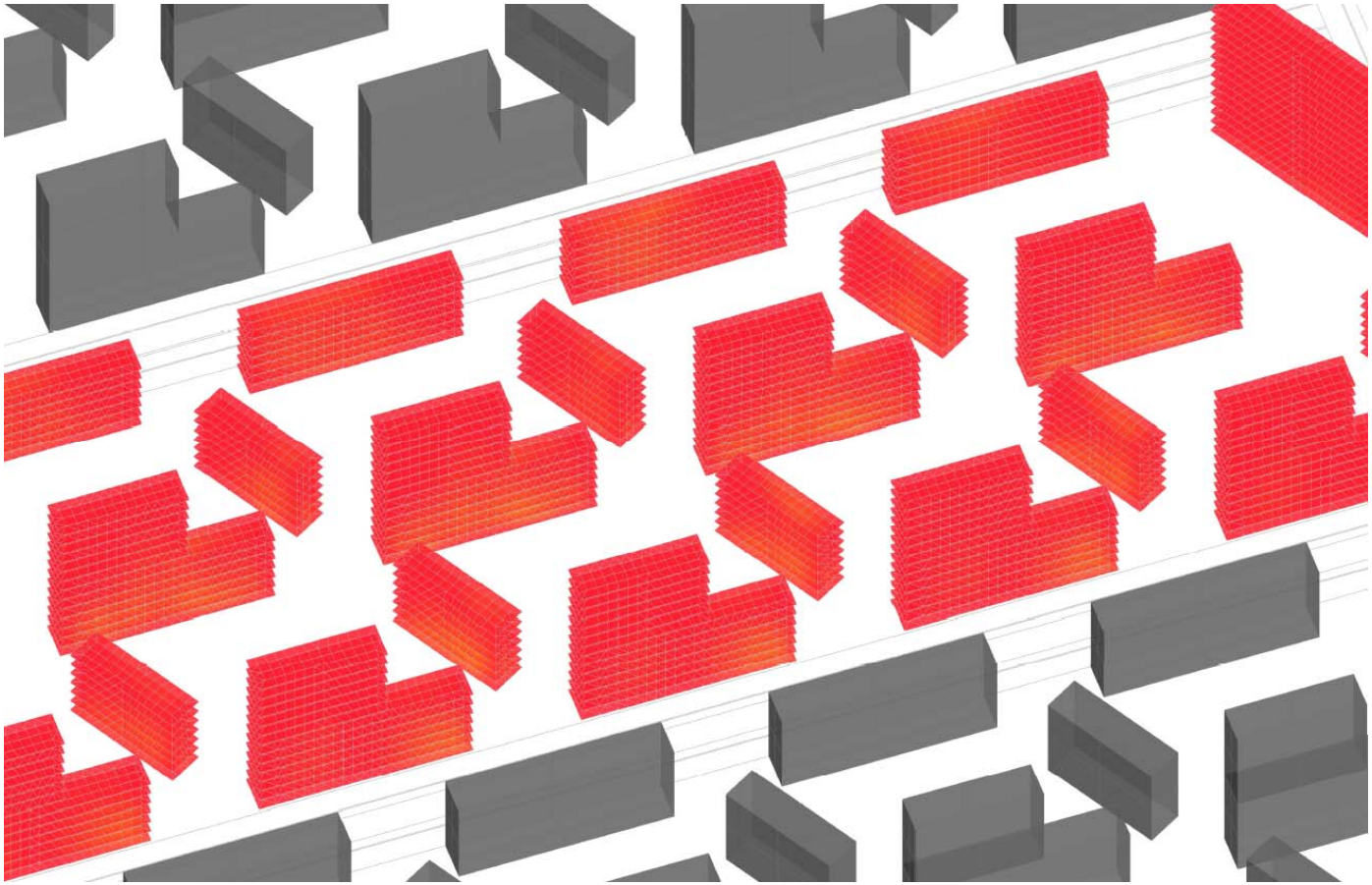
20.4
Energy
[kWh/m² a]

100
Day-lit Area
[%]

Energy Consumption - Lighting

Worst Lighting Unit?

Energy Consumption - Lighting



Daylight Area

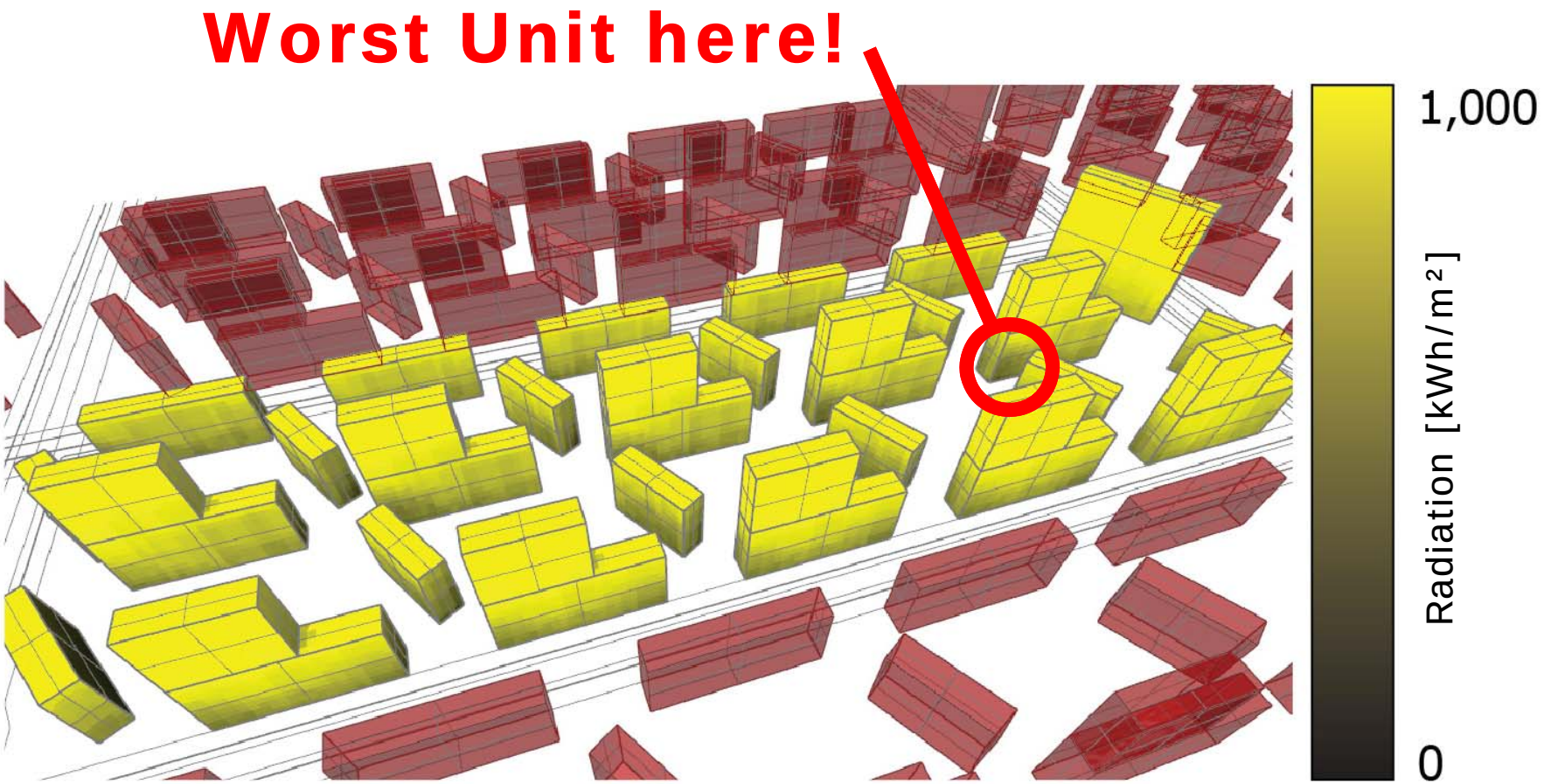
20.4
Energy
[kWh/m² a]

100
Day-lit Area
[%]

Energy Consumption - Heating

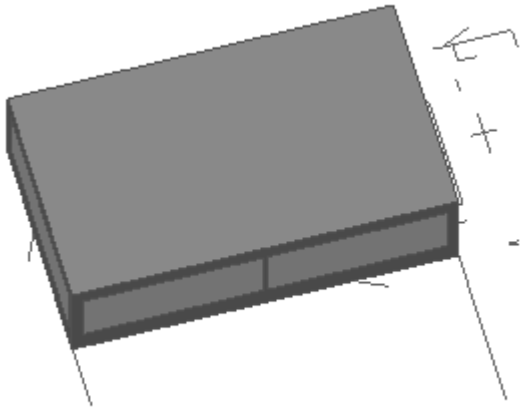
Worst Heating Unit?

Energy Consumption - Heating



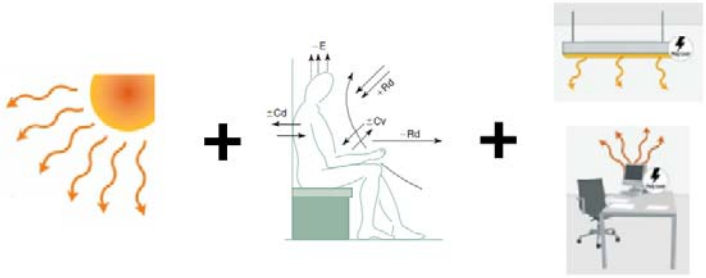
20.4
Energy
[kWh/m² a]

Energy Consumption - Heating



Commercial Space

Restaurant
Insufficient Solar Gain to maintain comfort



Insufficient Heating

$T_{operative}$ dropping to below 12°C on Jan 25th in TMY3 year

20.4
Energy
[kWh/m² a]

Energy Consumption - Heating

Parameters

Shading Schedule Files

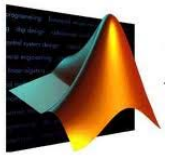
Energyplus Model

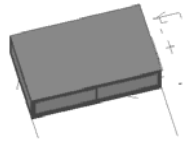
Control Optimization Attempt

20.4
Energy
[kWh/m² a]

Genetic Algorithm

Parameters

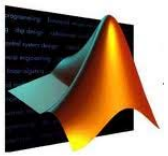


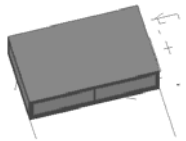


IDF

Peak Discomfort

Parameters

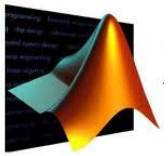


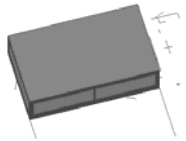


IDF

Peak Discomfort

Parameters





IDF

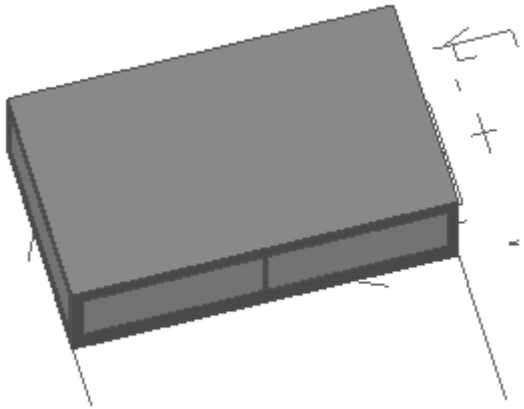
Peak Discomfort

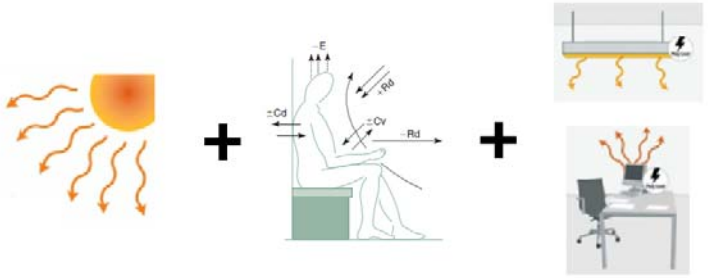
20.4

Energy

[kWh/m² a]

Energy Consumption - Heating





Commercial Space

Restaurant
Insufficient Solar Gain to maintain comfort

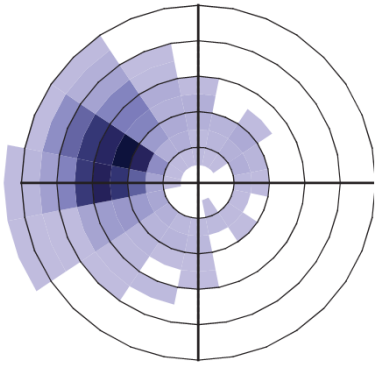
Unable to solve with Shading

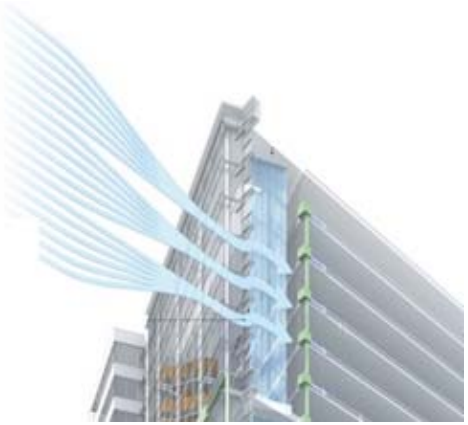
Even with Blinds Open
24/7 worst operative temperature ~ 14.5° C

But over 90% of spaces can meet heating demand…

20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling

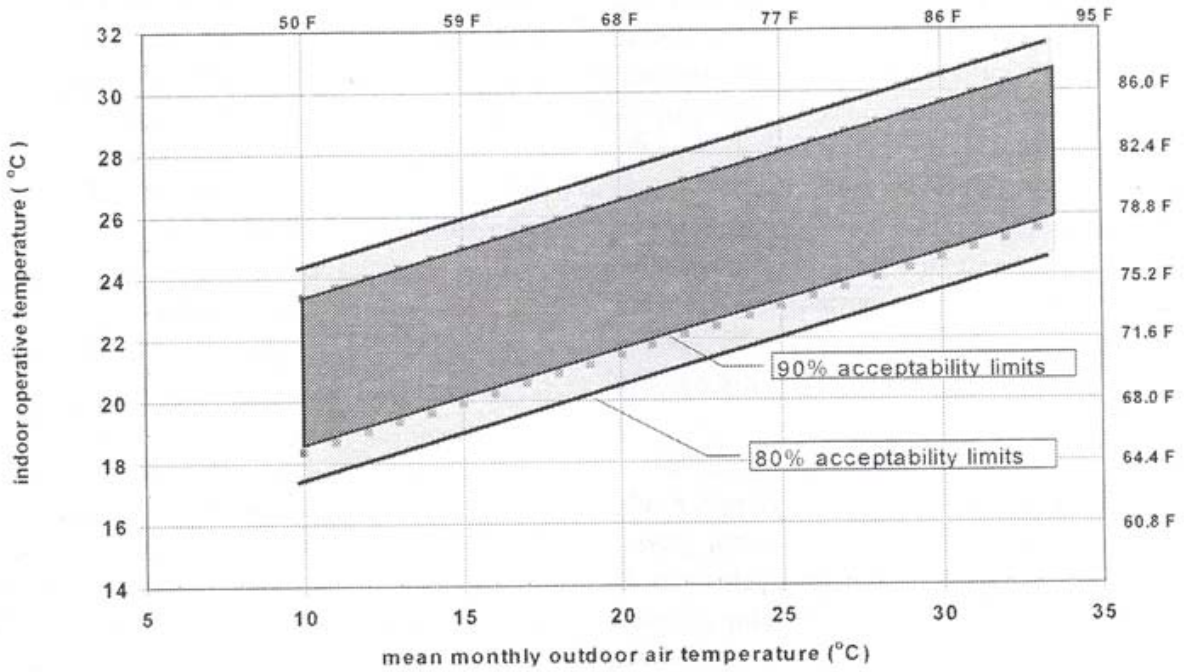




Cooling with Natural ventilation

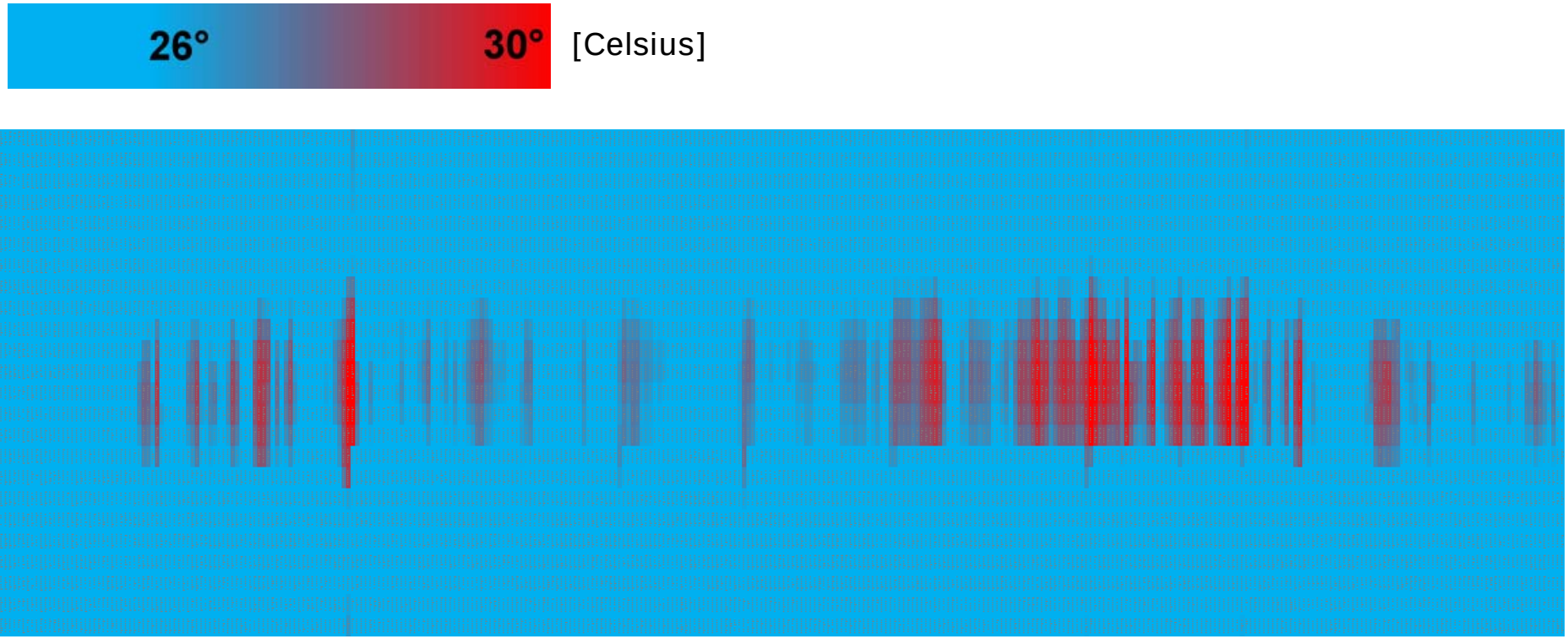
Energy Consumption - Cooling

Adaptive thermal comfort standard



20.4
Energy
[kWh/m² a]

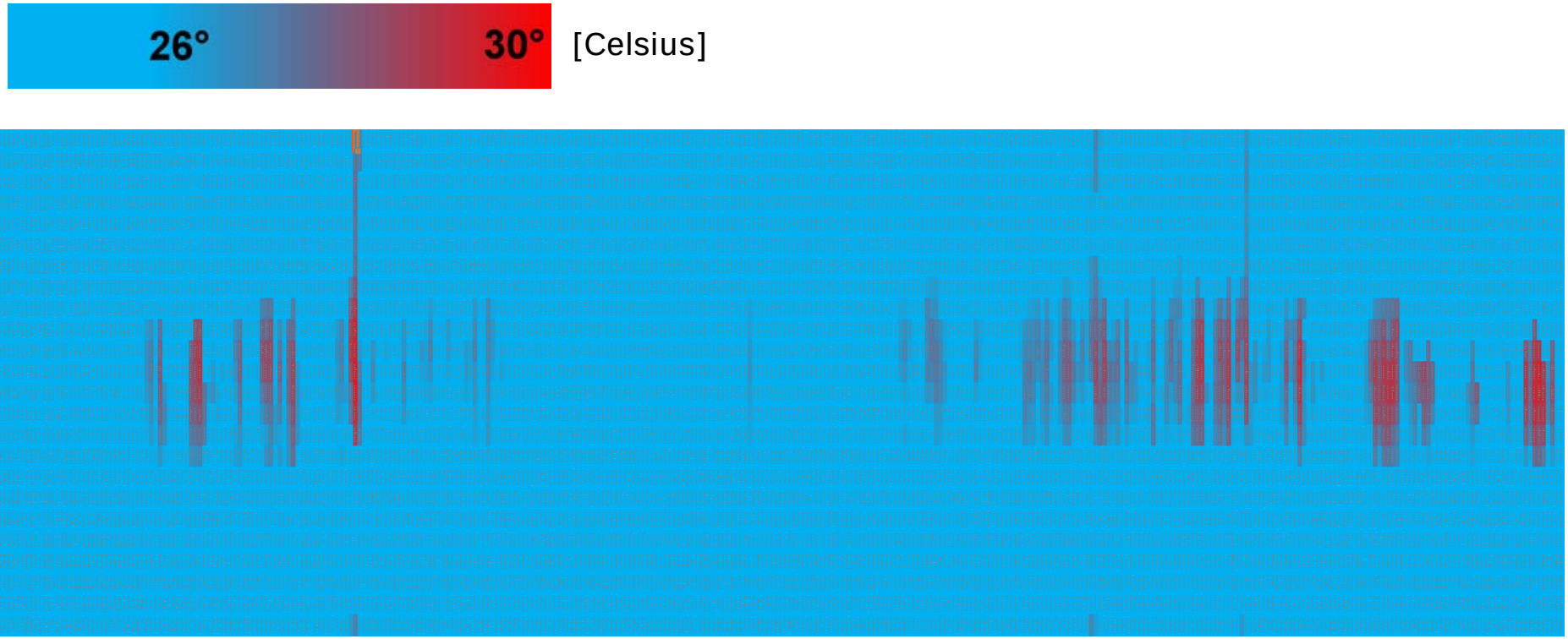
Energy Consumption - Cooling



Residential Air Temperature

20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling

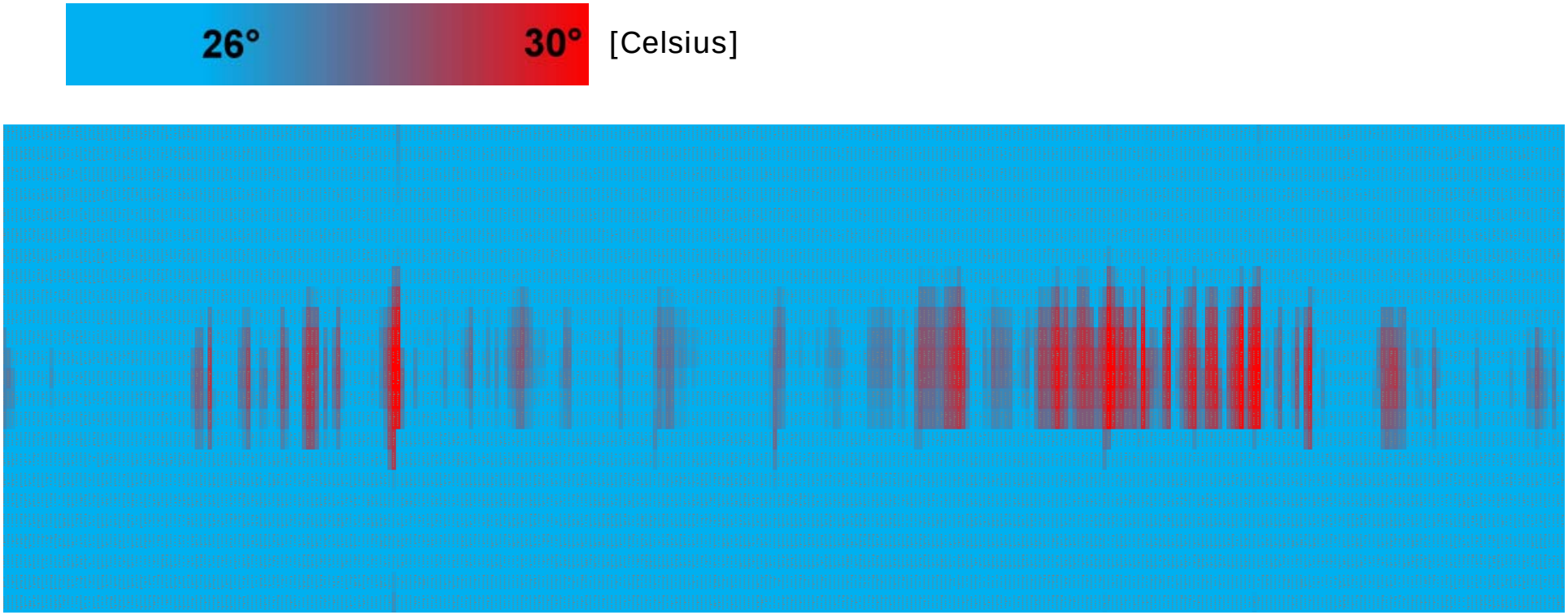


Residential Adaptive Temperature

20.4
Energy
[kWh/m² a]

What happens in 2080?

Energy Consumption - Cooling

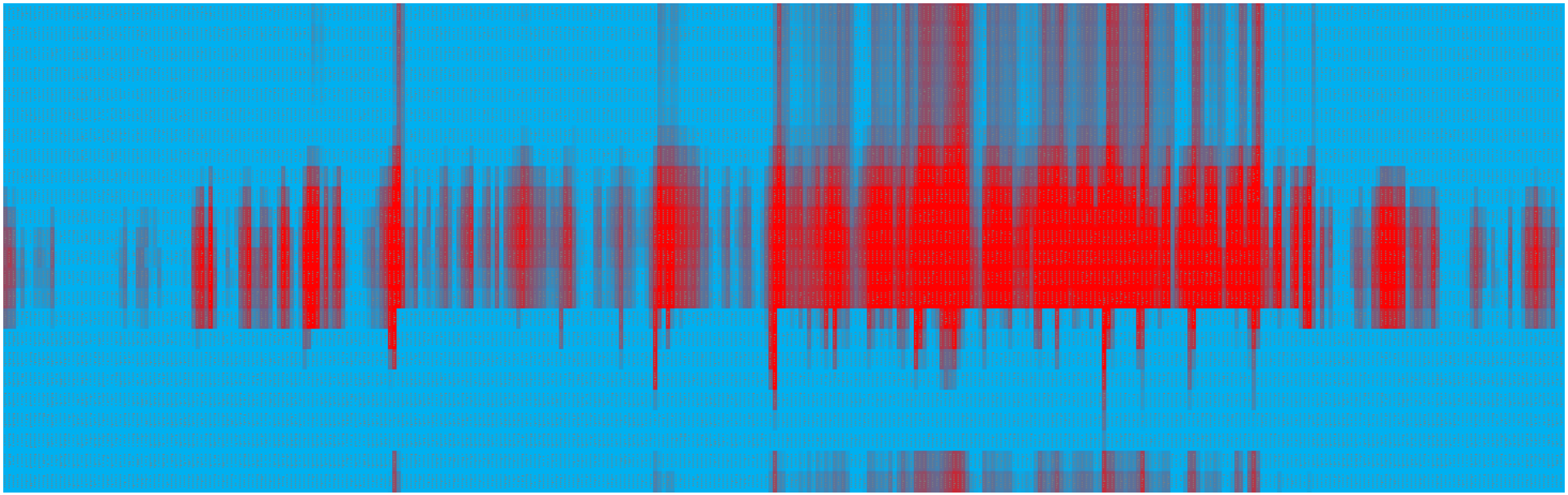


TMY3 Air Temperature

20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling

26° 30° [Celsius]

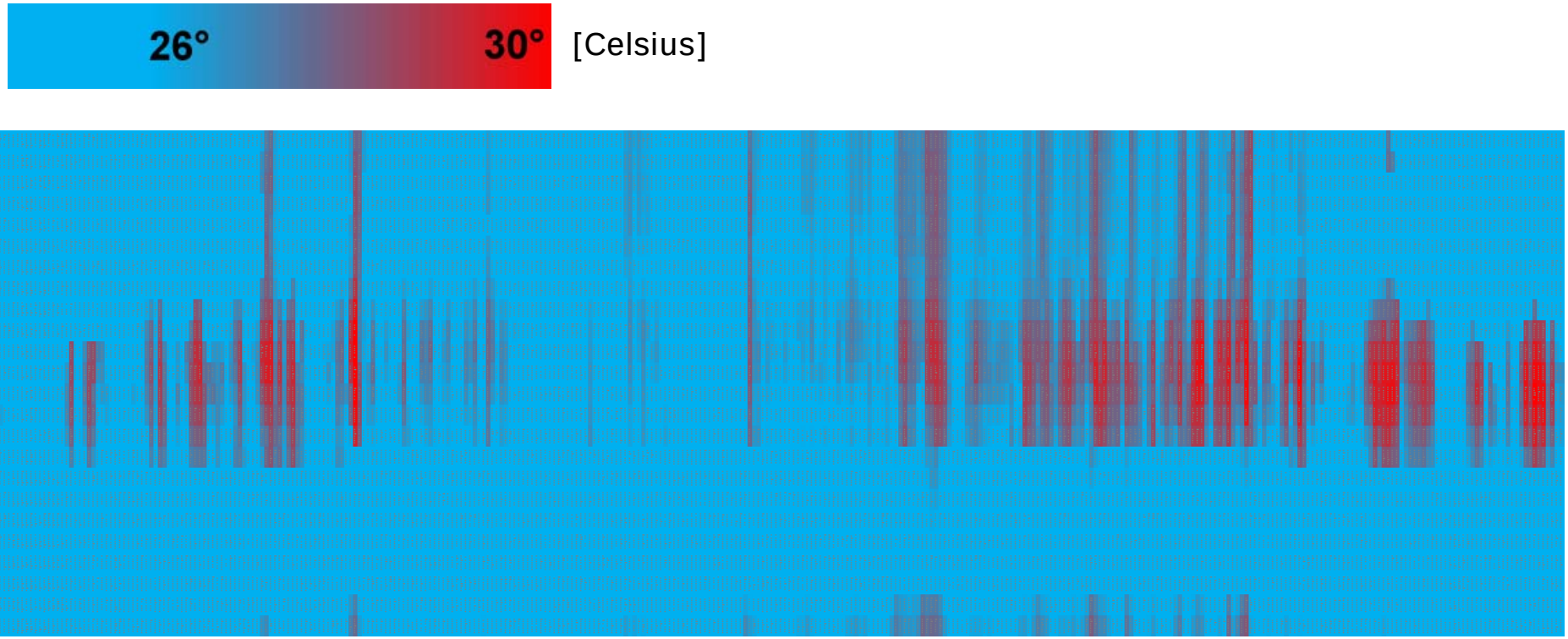


Jan Dec

2080 Air Temperature

20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling



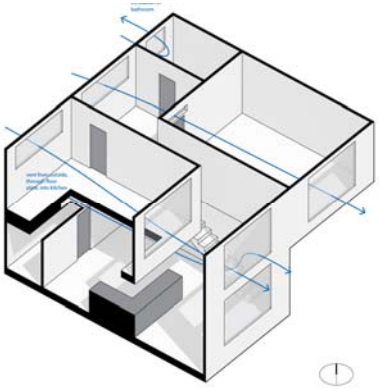
2080 Adaptive Temperature

20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling

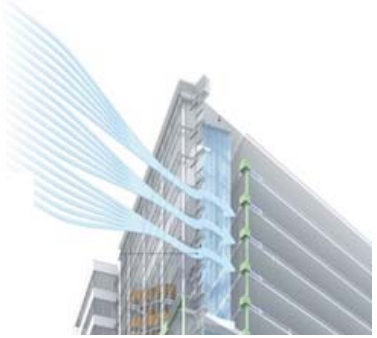
Worst Cooling Unit?
(including 2080)

Energy Consumption - Cooling



Residential Space

Restaurant
Insufficient Solar Gain to maintain comfort



Insufficient Cooling

$T_{operative}$ above 33.2°C in bedroom above stair *even with optimal N.V. operation!*

20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling

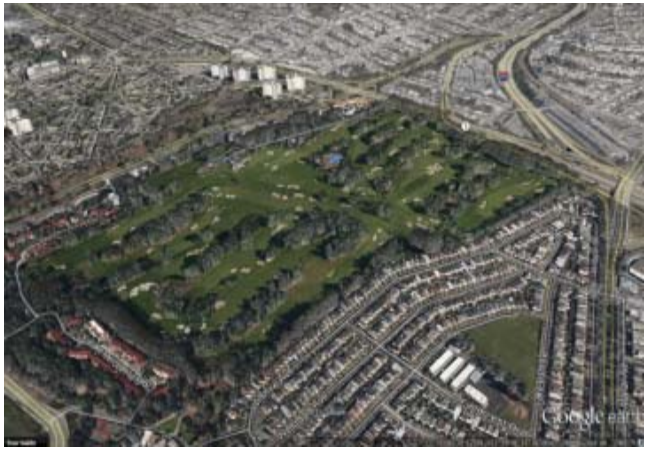
Can this be solved at an Urban Scale?

High density

>High Density: Financial District Private Station: Oregon Scientific Pro Wireless Weather Station Model # WMR100N Station ID: KCASANFR102
5 minute timestep
Started recording Jan 31, 2010

Medium density

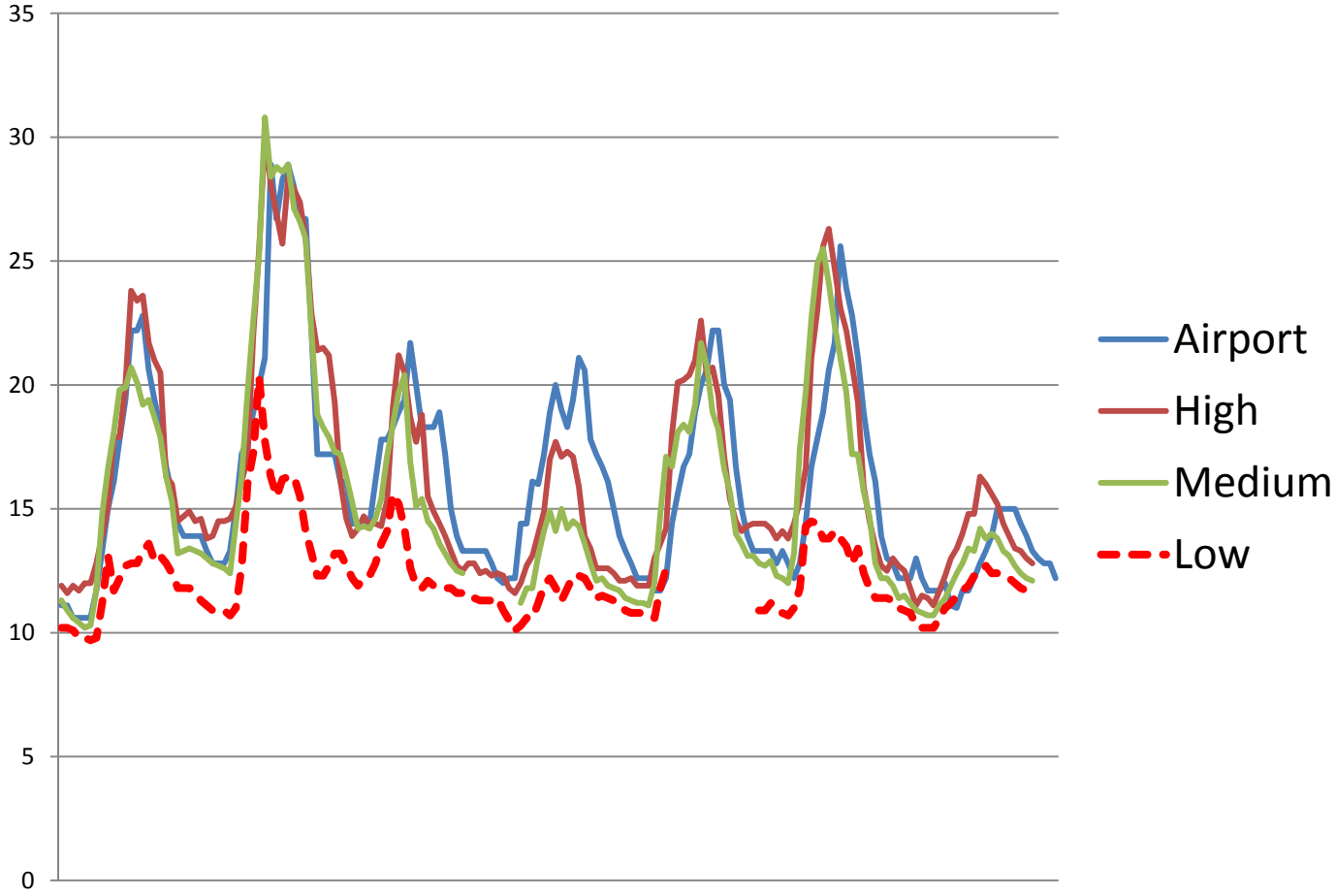
>Mid. Density: The Mission: Even the weather is hip - Station ID: KCASANFR79
5 minute timestep
Started recording Feb 7, 2008



Low density

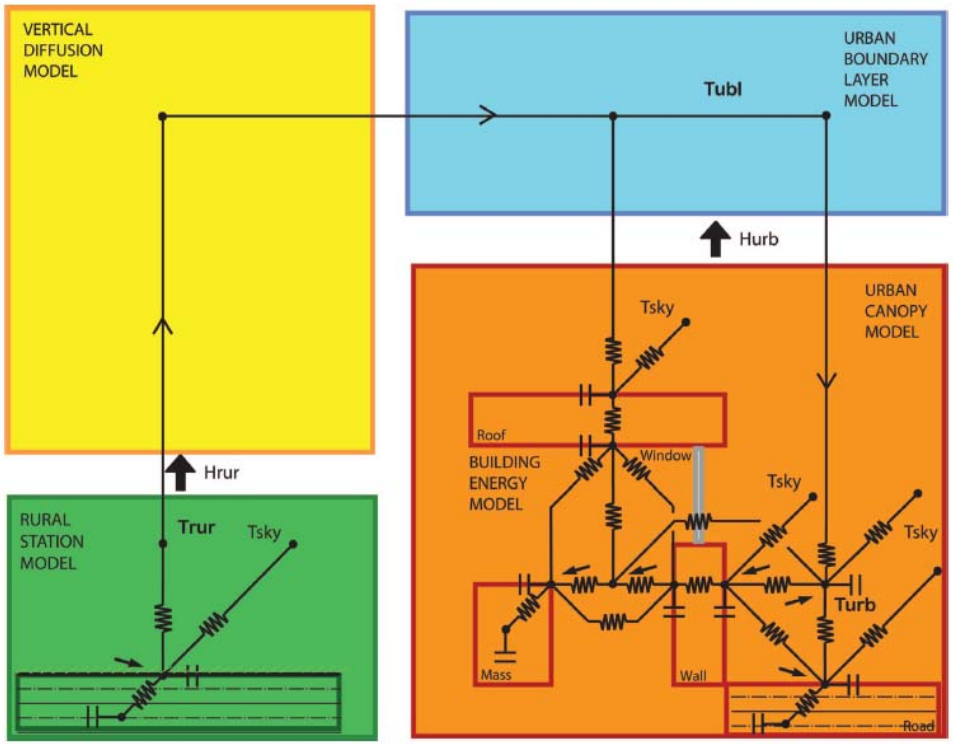
>Low Density: San Francisco Golf Club Station ID: KCASANFR100
5 minute timestep
Started recording Oct 28, 2009

Energy Consumption - Cooling



20.4
Energy
[kWh/m² a]

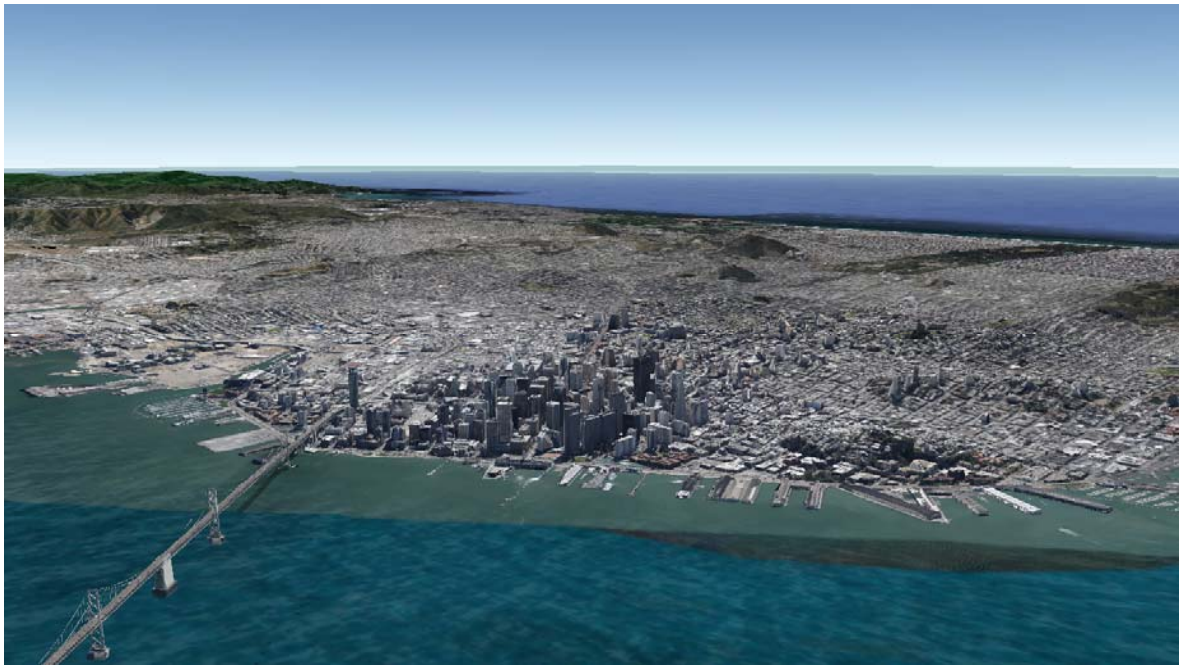
Energy Consumption - Cooling



Urban Weather Generator

20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling



Too much water / wind for current model

Energy Consumption - Cooling

Parameter	BUBBLE	CAPITOUL
City diameter	0.1	0.1
Average building height	0.1	0.1
Horizontal building density	0.4	0.4
Vertical-to-horizontal urban area ratio	0.8	0.3
Horizontal vegetation density (trees)	0.1	0.1
Wall albedo	0.1	0.1
Roof albedo	0.1	0.1
Road albedo	0.1	0.1
Volumetric heat capacity of concrete/brick in walls	0.1	0.1
Volumetric heat capacity of asphalt in road	0.2	0.1
Internal heat gains	0.1	0.1
Rural vegetation fraction	0.3	0.1
Daytime mixing height	0.1	0.1
Nighttime boundary-layer height	0.1	0.1
Reference height at which the vertical profile of potential temperature is assumed uniform	0.1	0.1
Urban-breeze scaling coefficient	0.1	0.1
Latent fraction of vegetation	0.4	0.1

Sensitive Morphological Parameters

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20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling

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Sensitive Morphological Parameters Checked vs. Low and Med Density data

Energy Consumption - Cooling

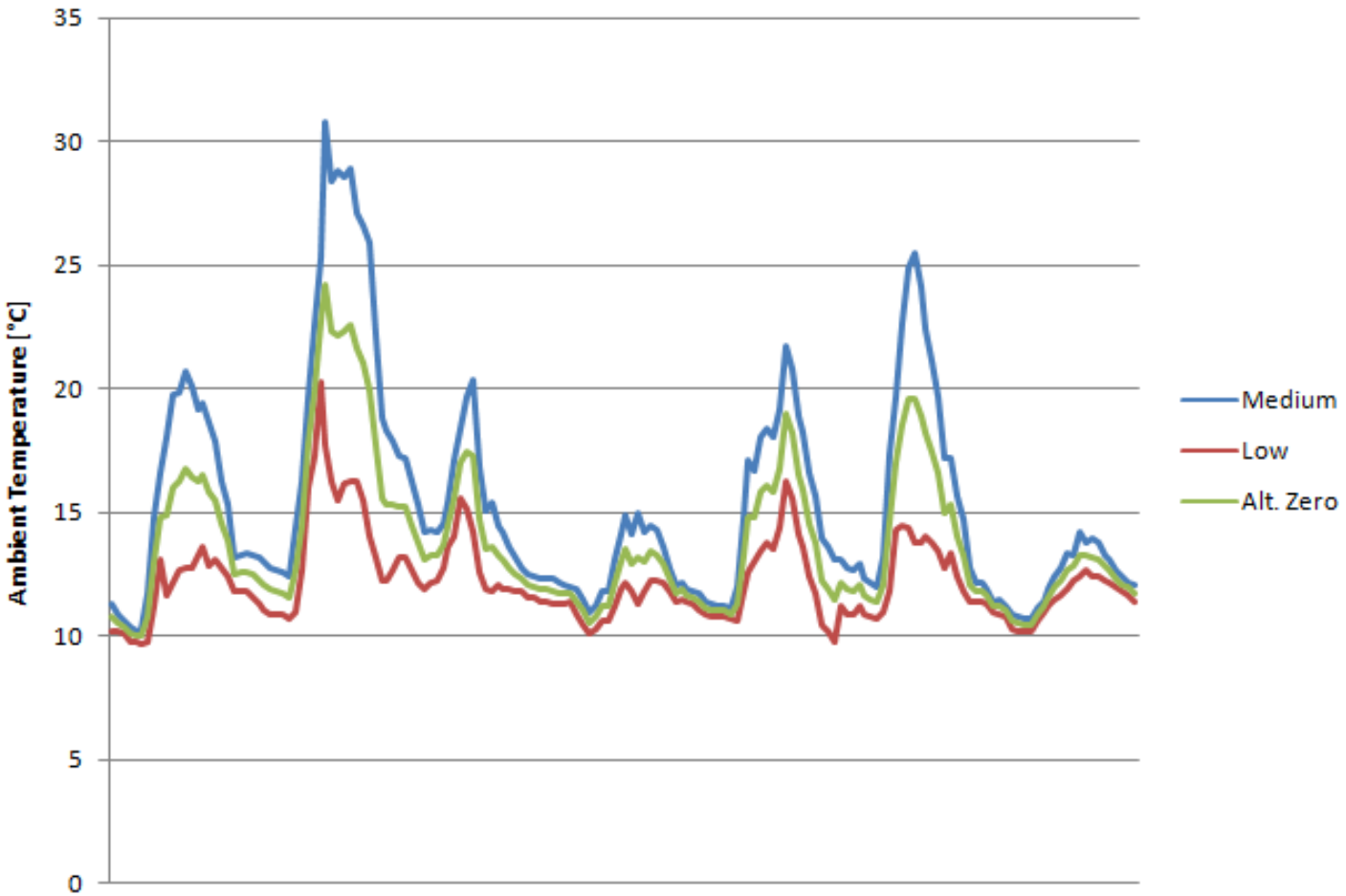
Will all Transsolar Engineers please leave the room for this part?

Low density

Medium density

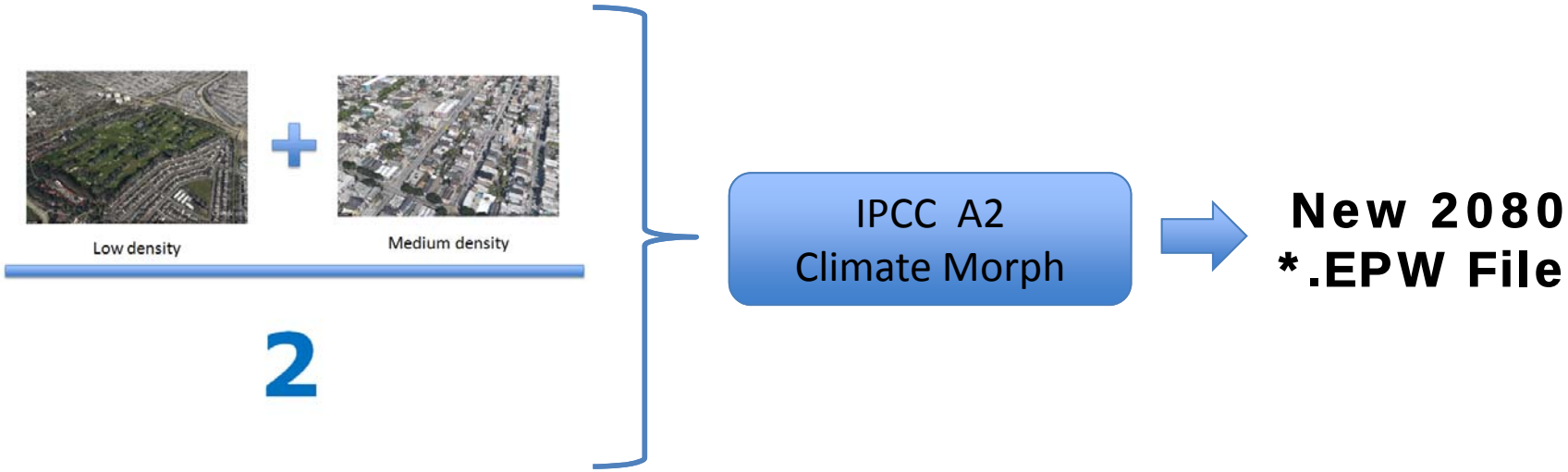
2

Energy Consumption - Cooling

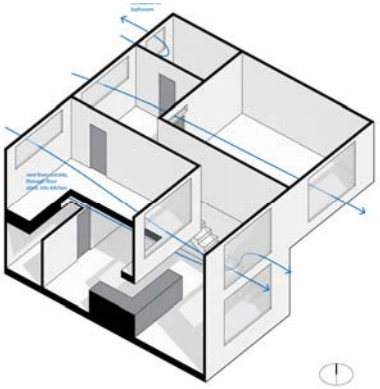


20.4
Energy
[kWh/m² a]

Energy Consumption - Cooling



Energy Consumption - Cooling



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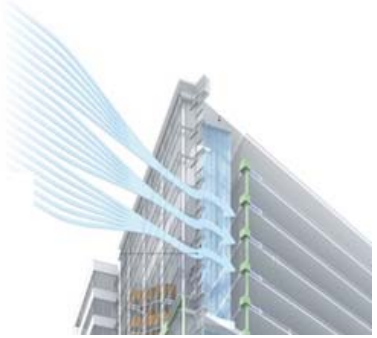


100% Potential Cooling Demand Met

$T_{operative}$ below 26°C
Adaptive Comfort in all zones in 2080 w/ extensive natural ventilation

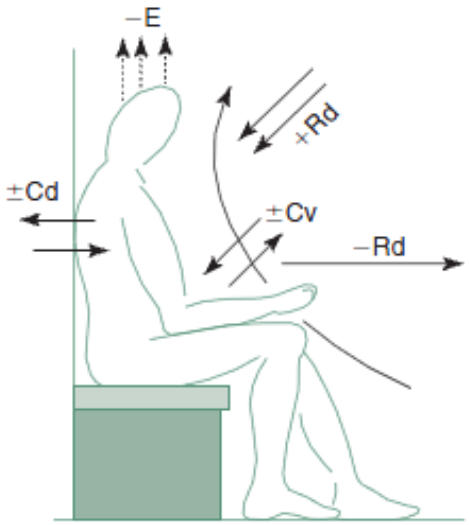
20.4
Energy
[kWh/m² a]

Finance

Construction Cost: $1,267,850,780
Annual Costs: $26,880,000
Rate of Return: 6.3%

Construction Cost: $2,915,839,080
Annual Costs: $75,683,218
Rate of Return: 9.9%
AC installed: 9.5%
with passive users: 9.0%

Conclusion



1) Lighting load can be met with thin buildings
2) Cooling load can be met by mitigating the UHI effect and using optimized natural ventilation
3) Heating load cannot be fully met in this model even with optimized schedules – but very close

**note: will be less important as global temperatures increase*

4) ...

1.5 Density [FAR]
9.5 Finance [IRR %]
25.4 Energy [kWh/m² a]
100 Day-lit Area [%]
85 Accessibility [%]
470 Carbon [$kgCO_2e/m^2$]
95 Comfort [%]

Questions?

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1.5 Density [FAR]

9.5 Finance [IRR %]

25.4 Energy [kWh/m² a]

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