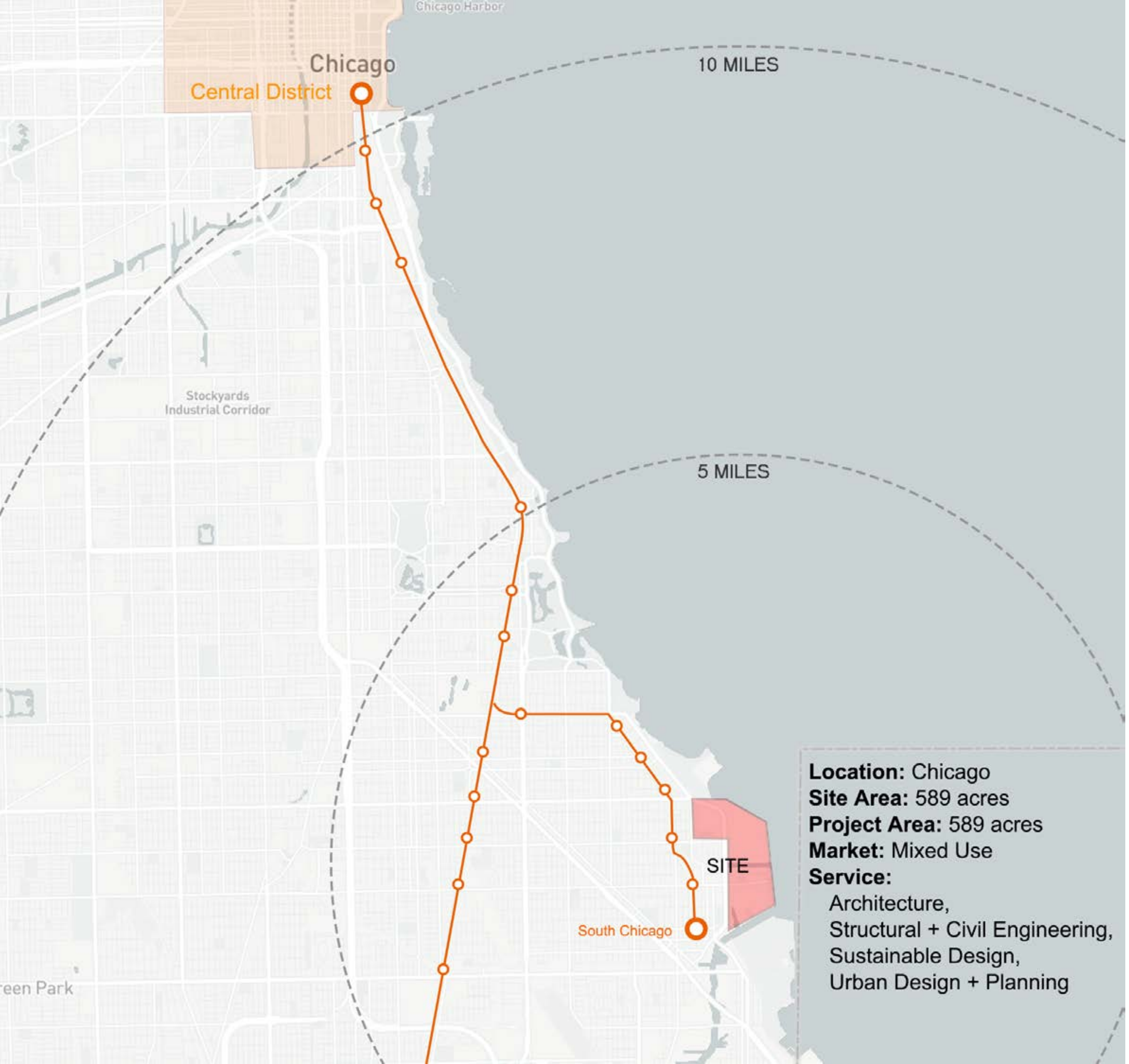
4.433 Modeling Urban Energy Flows: Neighborhood Proposal

Group: Chicago 2
Members: Benjamin Tasistro-Hart, SungHwan Lim, KuanTing Chen

Three Major Goals

Efficiency	Target net-zero operational energy consumption	Daylighting Passive ventilation Solar production
Connectivity	Create a walkable neighborhood which promotes social encounters and connects to public transport system of Chicago	Accessible public areas Bike lanes Water taxi
Resiliency	Implement strategies which allow the neighborhood to adapt to effects of climate change in Chicago.	Floodable green space Local energy production Green roof Low-carbon embedded materials



Site Analysis

Our site is 12 miles away from the central district of Chicago. According to Chicago's master plan, the site will serve as a mixed used commercial and residential district in the future.

Context

Energy supply:

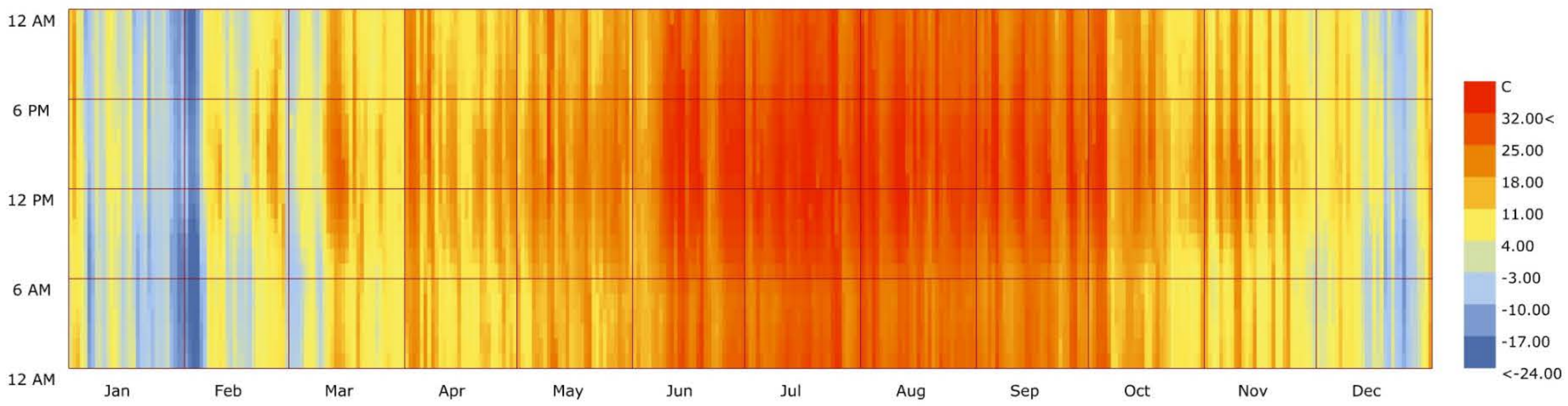
All electric NetZero community (PV and wind turbines)

Population of the new district:

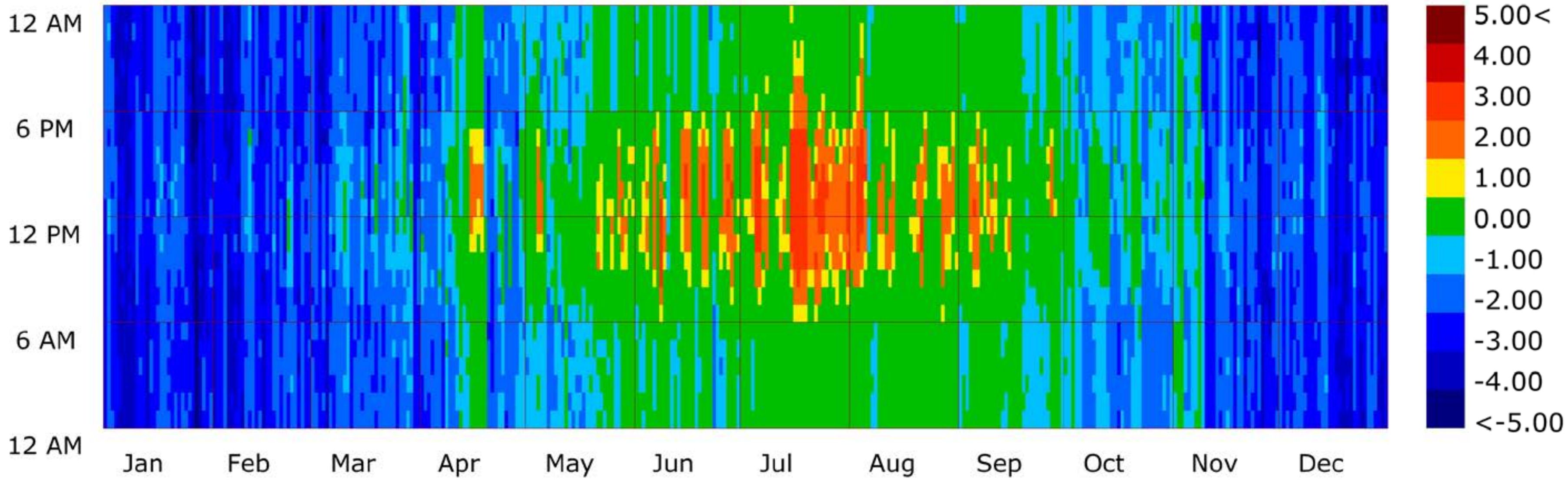
(1) Residents living at the site and commuting to downtown Chicago
(2) Onsite businesses
(3) Commercial area for local and surrounding needs

Weather data analysis – Present TMY3 (Chicago O'Hare Intl. Airport)

Dry Bulb Temperature



Outdoor Comfort (UTCI) Analysis



Annual Comfort data:

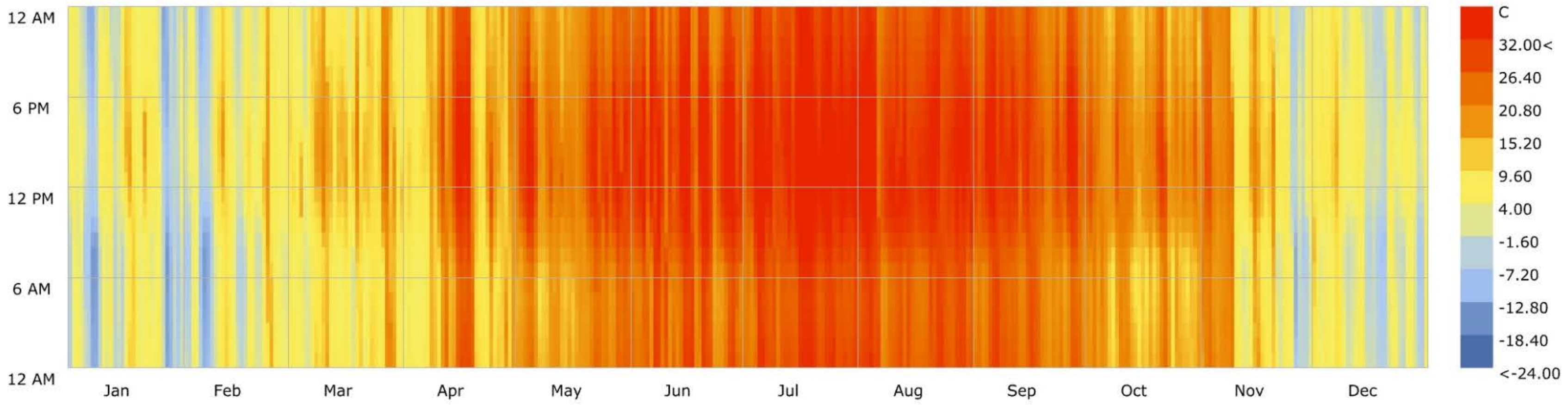
Hot (≥1): 7.1%

Comfort: 33.4%

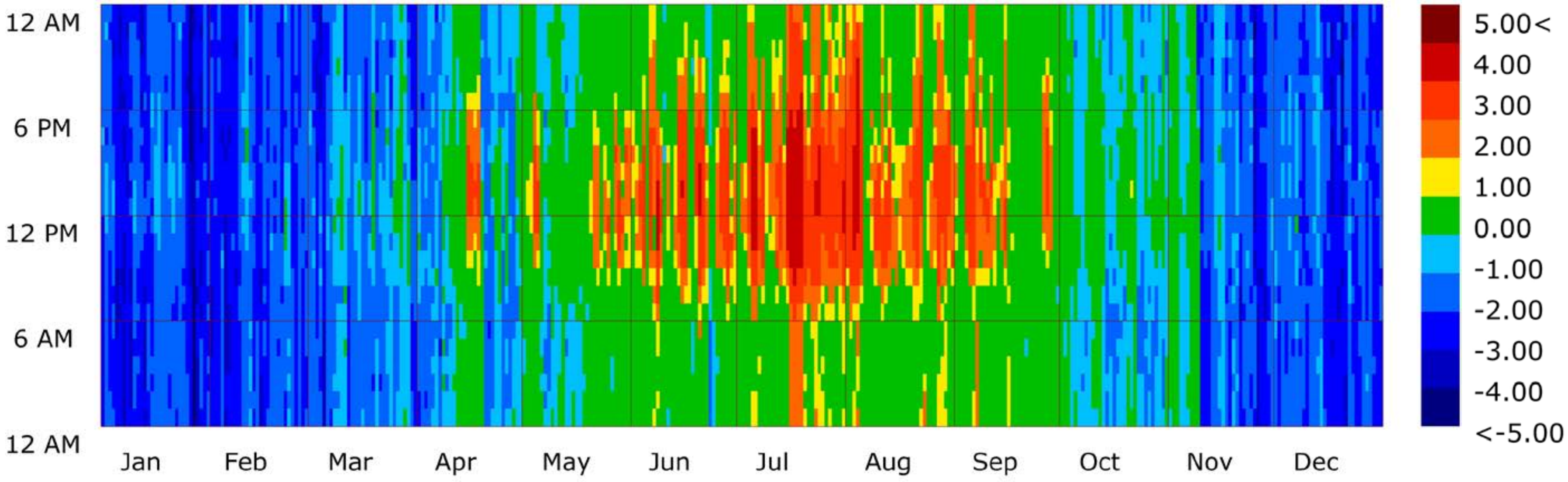
Cold (-1≤): 59.5%

Weather data analysis – Urban environment on 2050

Dry Bulb Temperature



Outdoor Comfort (UTCI) Analysis



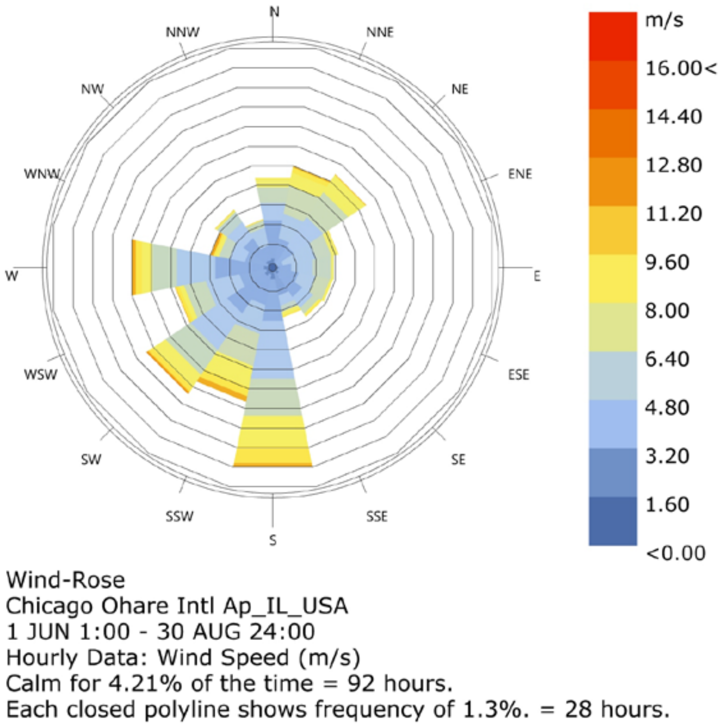
Annual Comfort data:

Hot (≥1): 15.9% **(↑ 8.8%)**

Comfort: 33.2% (↓ **0.2%)**

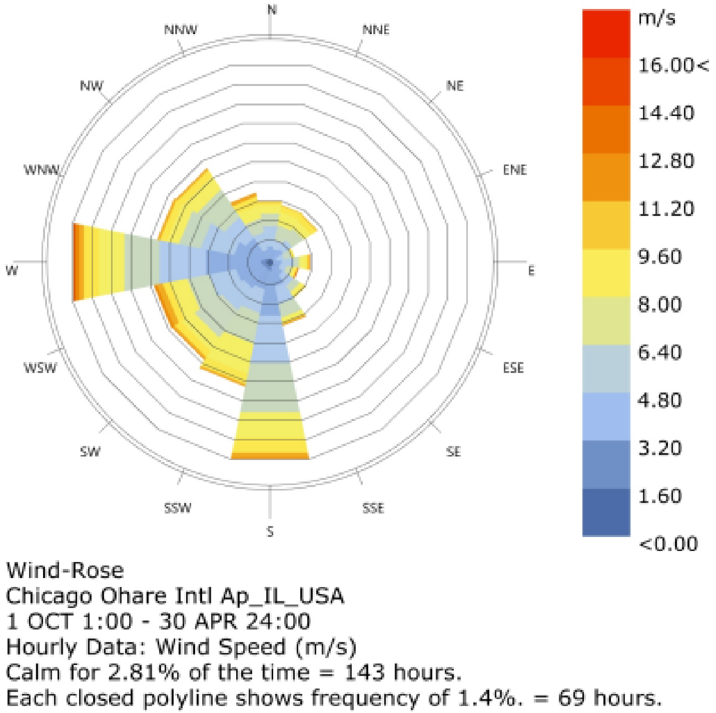
Cold (-1≤): 50.9% (**↓ 8.6%)**

Weather data analysis – Wind rose diagram



June - August

Prevailing wind directions: S, NE



October - April

Prevailing wind directions: S, W

- Hot season

(1) Utilizing natural ventilation (2) Michigan lake water as a cooling source (3) Green roof (4) Shading for pedestrians

- Cold season

(1) Allowing daylight and solar radiation into the building (2) High performance façade (3) Wind protection for pedestrians

Project Overview

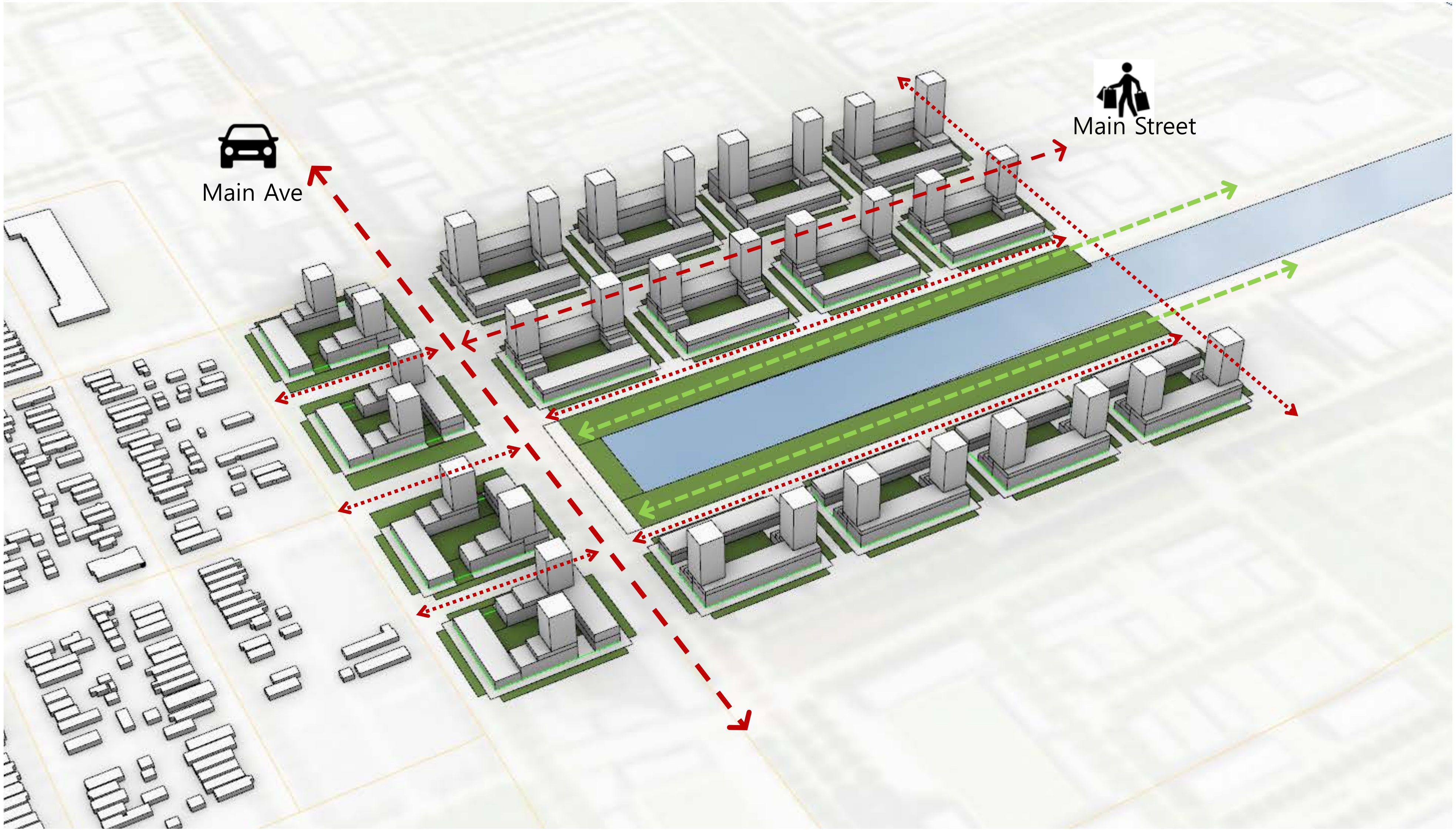
Our project aimed to create a pedestrian-friendly and convenient interface with high efficiency and resiliency that connects lake Michigan and the city.

Site Planning

We started with analyzing the master plan from SOM. We extended the original urban grid and included two main streets that forms the crossroad in the center of the new commercial district. This decision lead us to create a grid of 65 by 83 (meter) proto blocks.

Block types and design

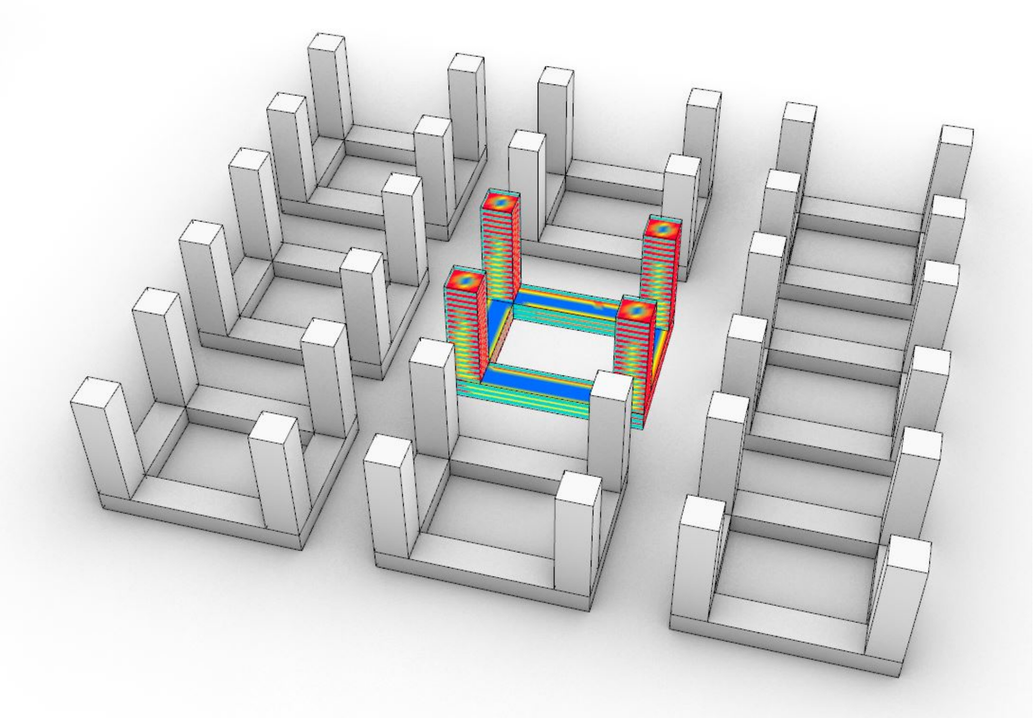
Based on our three design goals, we want to emphasis the importance of connectivity. We aim to design a pedestrian friendly environment by scaling down most of the streets in our site. Moreover, we add greenery alone side walks to enhance the connection between all the blocks.

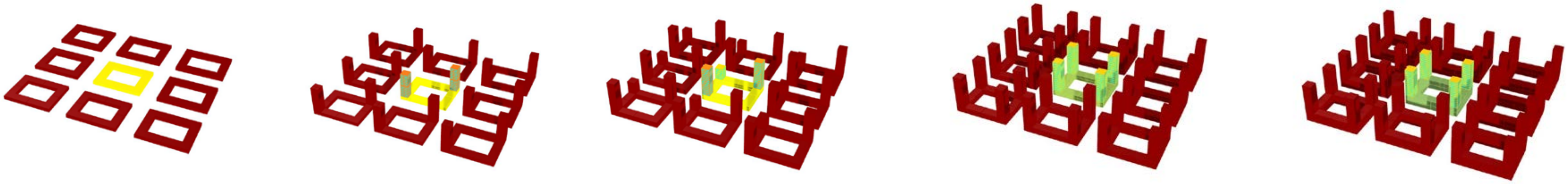


Courtyard + Tower Proto Block

By combing the courtyard and tower protoblocks, we have a block which performs well at the FAR legal limit of 5 . We controlled the distribution of floors in the tower and courtyard to prevent the towers becoming pencils which could be intruding to wards the adjacent neighborhood. The results showed that it will be better to keep FAR around 3 if we want to get a better s DA performance.

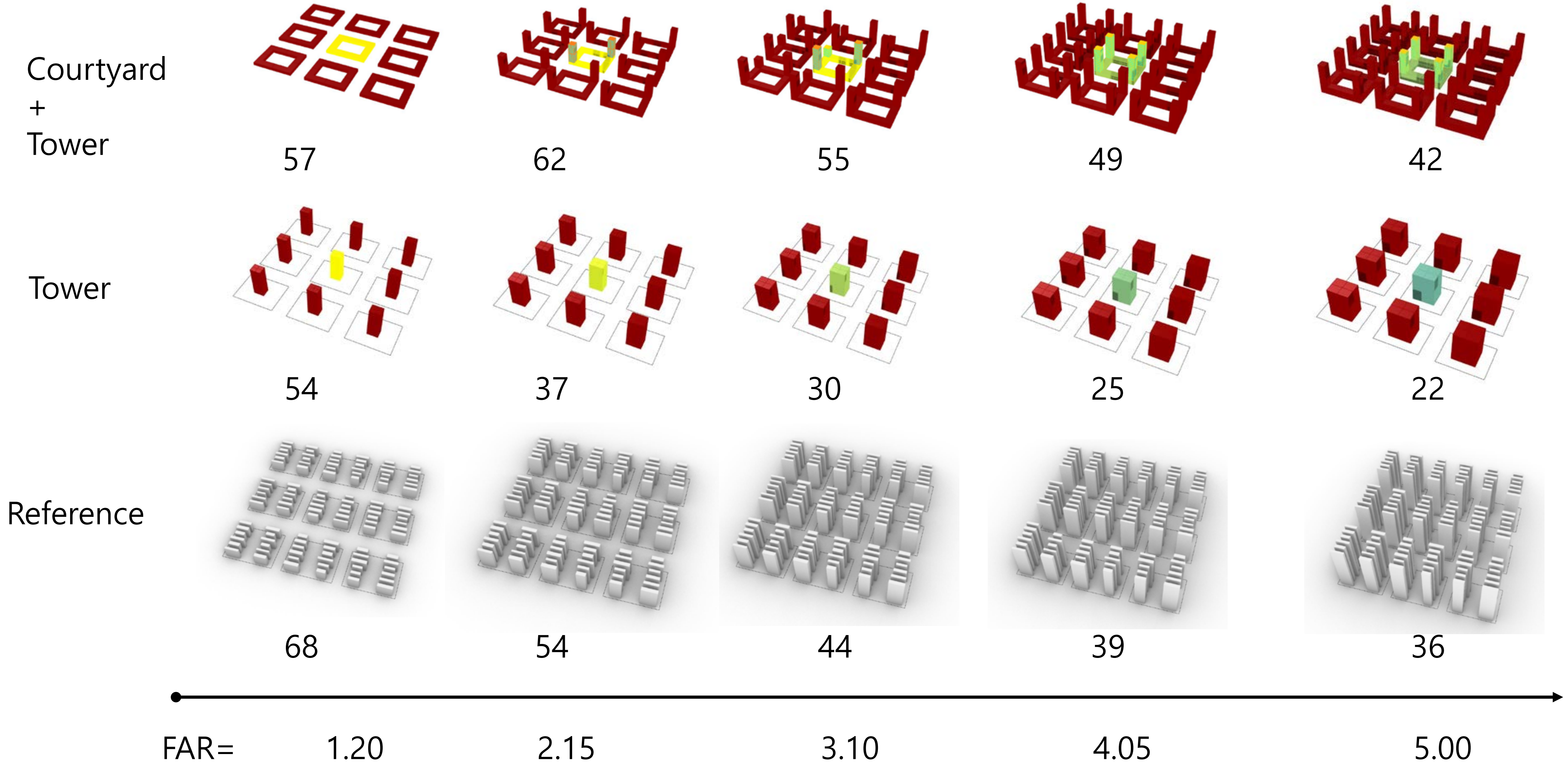
Moreover, the courtyard formed a circulation route on the ground level that suited the need of commercial spaces such as shopping malls. On the other hand, the tower is a decent space for offices or even housing based on it great view toward the city and the lake.



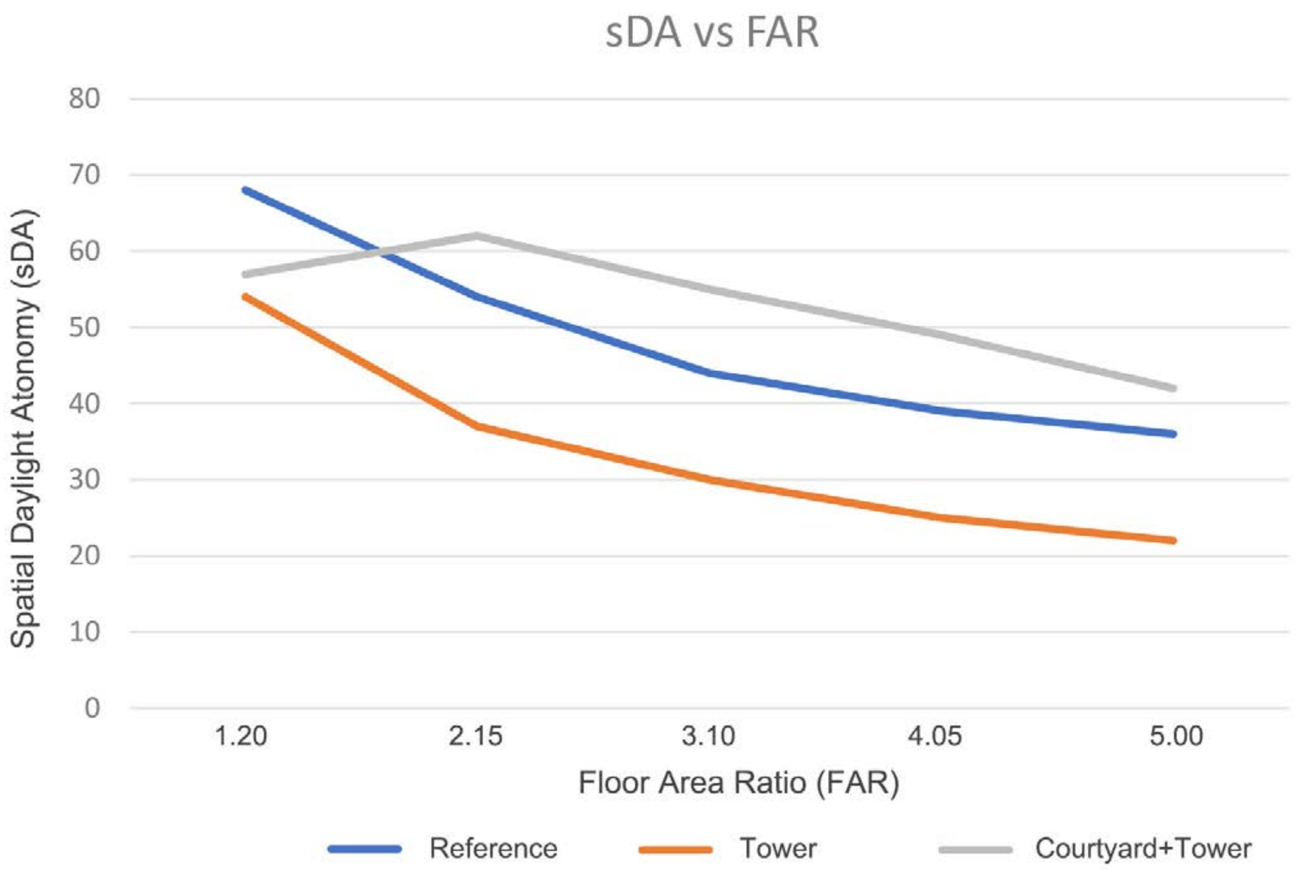


Base =	2F	2F	3F	3F	5F
Tower =	-	15/15F	17/17/7F	17F	15F
sDA =	57	62	55	49	42
FAR =	1.2	2.15	3.1	4.05	5

Comparative sDA analysis for protoblocks

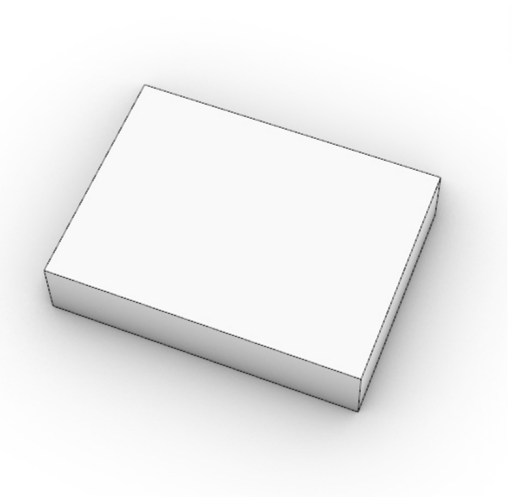


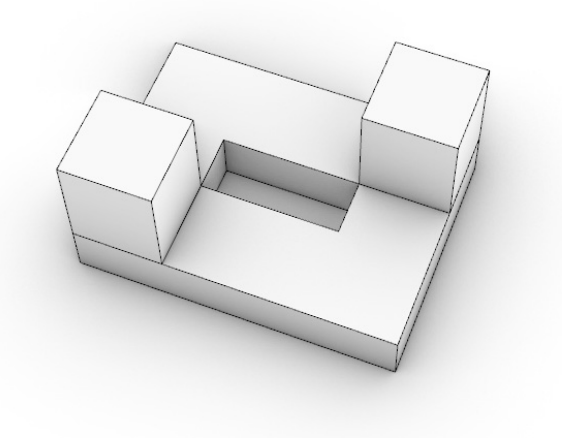
Comparative sDA analysis for protoblocks

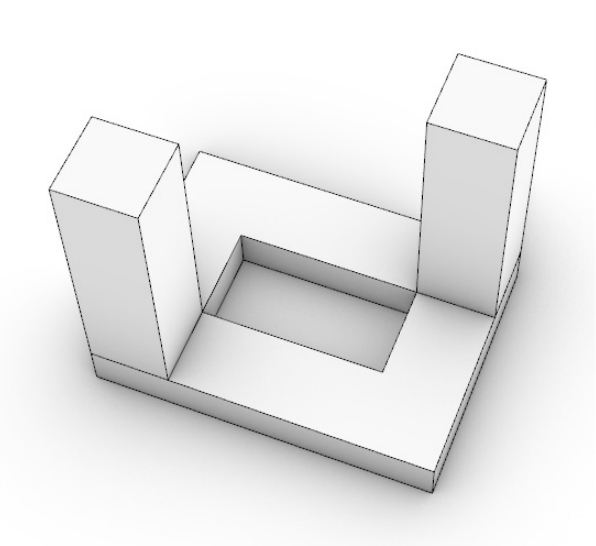


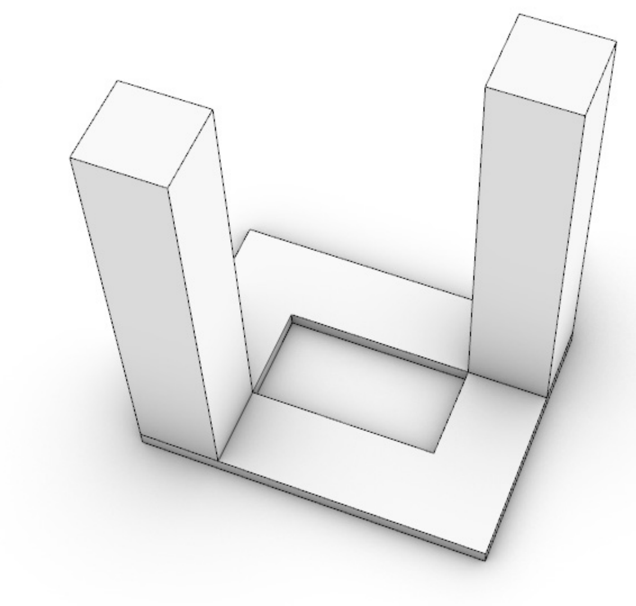
FAR	Reference	Tower	Courtyard+Tower
1.20	68	54	57
2.15	54	37	62
3.10	44	30	55
4.05	39	25	49
5.00	36	22	42

Courtyard + Tower Proto Block Variation (FAR= 3.1)









Reference block

FAR: 3.1
Floor: 5F
Surface area
Wall: 3600 m^2
Roof: 3519 m^2

Design 1

Floor
Podium: 4F
Tower: 8F
Surface area
Tower
  Wall: 3744 m^2
  Roof: 760.5 m^2
Podium
  Wall: 3888 m^2
  Roof: 2398.5 m^2

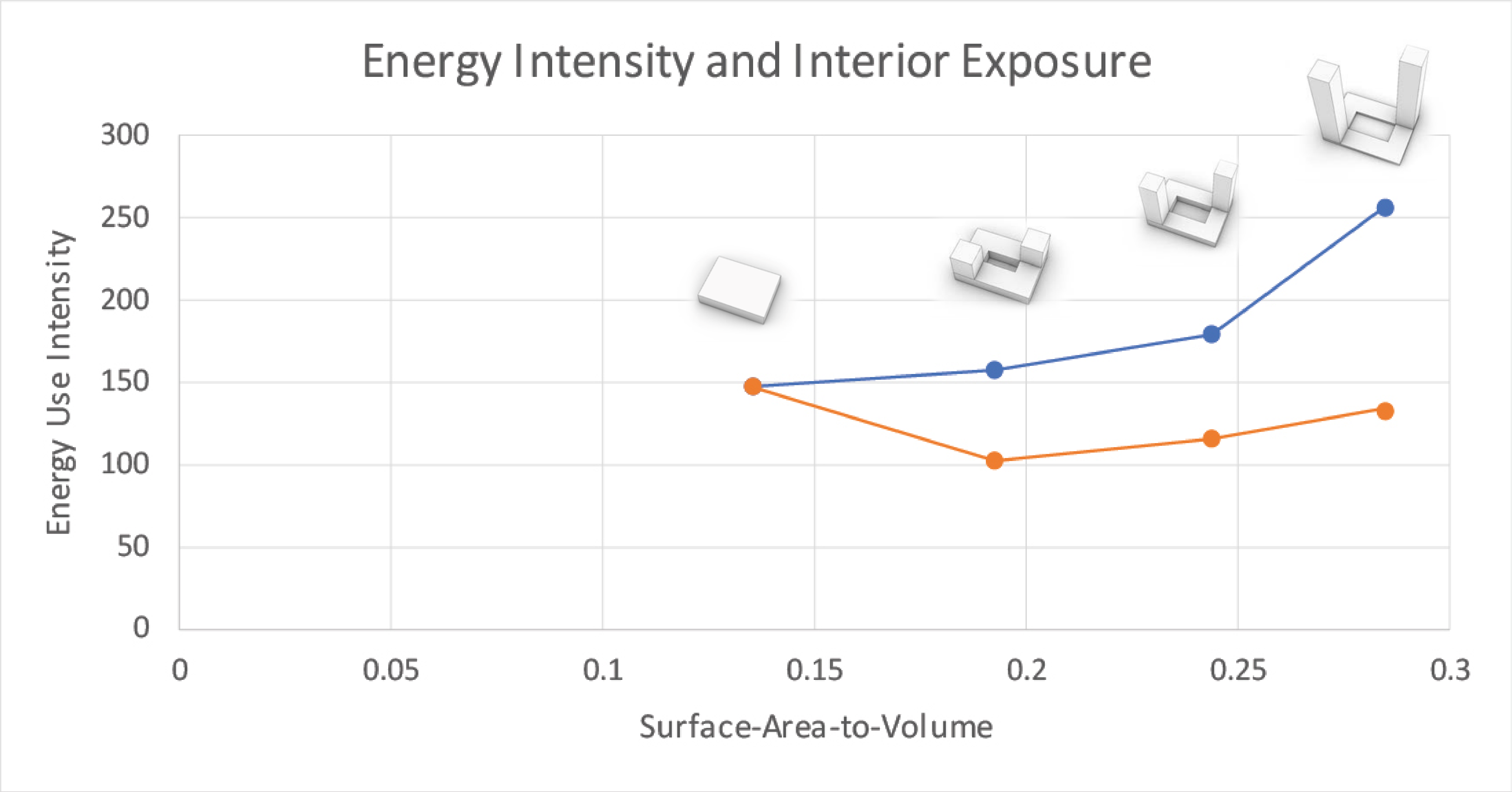
Design 2

Floor
Podium: 3F
Tower: 18F
Surface area
Tower
  Wall: 6912 m^2
  Roof: 512 m^2
Podium
  Wall: 3168 m^2
  Roof: 2304 m^2

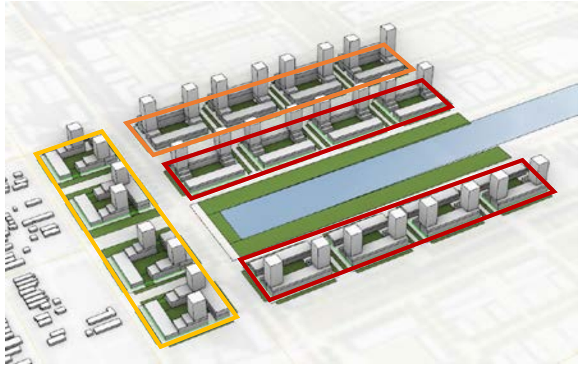
Design 3

Floor
Podium: 1F
Tower: 28F
Surface area
Tower
  Wall: 10752 m^2
  Roof: 512 m^2
Podium
  Wall: 1056 m^2
  Roof: 2304 m^2

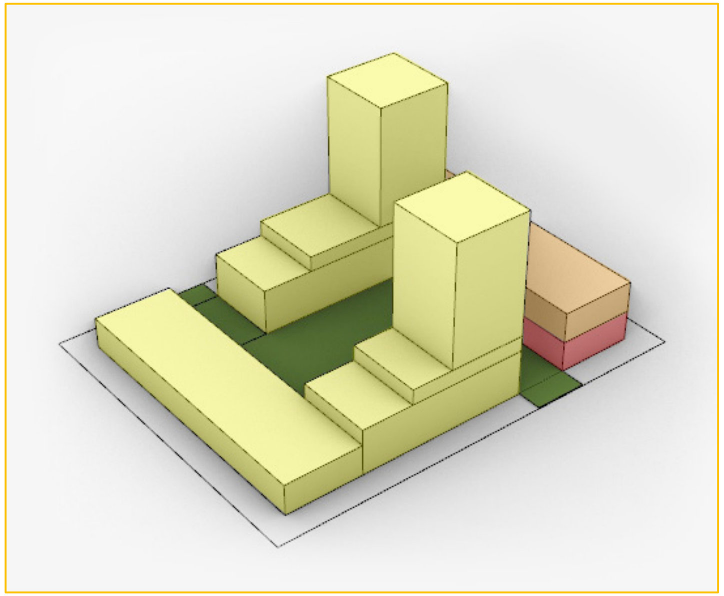
Parametric analysis – Energy intensity and interior exposure



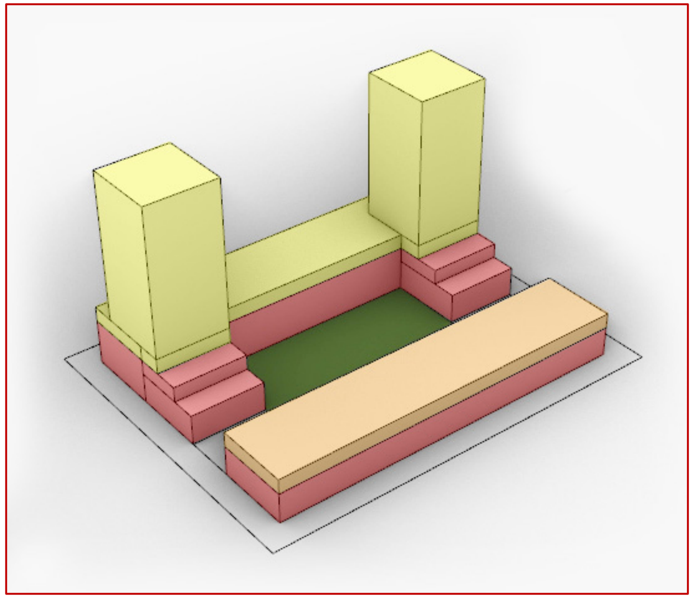
Block types and design



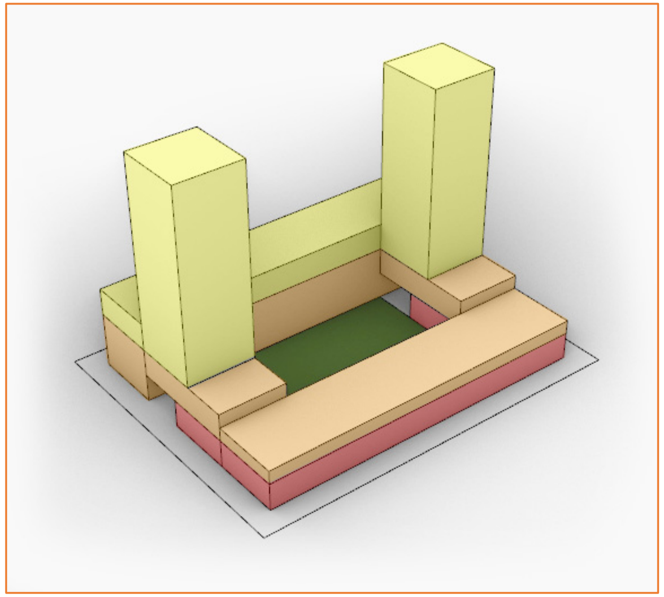
Beside from sidewalks and street greenery, we open the courtyard as a public interface that provide a inviting characteristic and better environment atmosphere. All the podium of the three block types have roof garden and leveled balcony for residents and visitors to enjoy. The tower levels and positions are also planned to avoid view blocking and functioned as a solar chimney for the large podium.



Type 1 – Residential block
FAR: 1.95
Maximum height: 12F



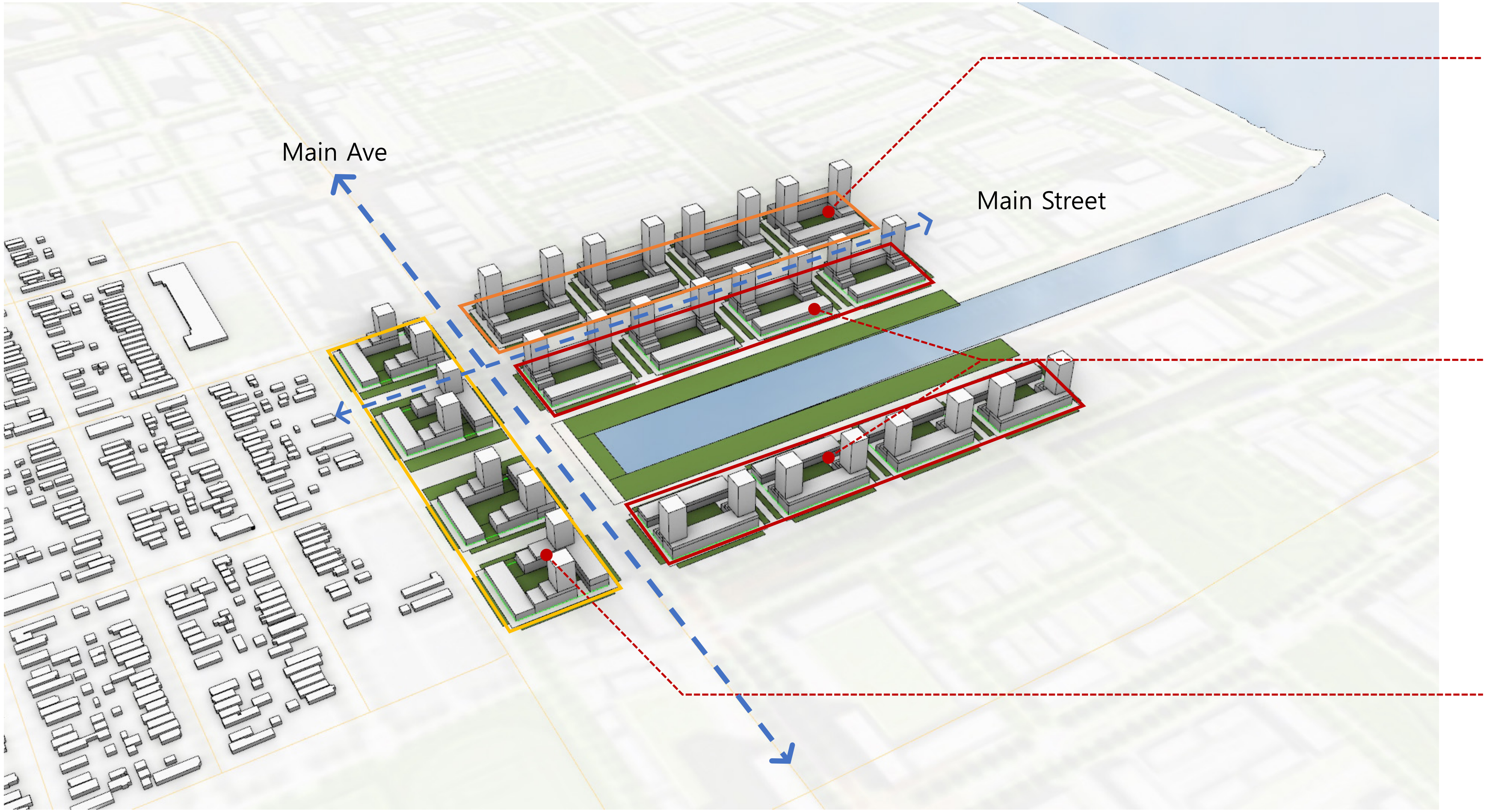
Type 2 – Commercial block
FAR: 2.3
Maximum height: 16F

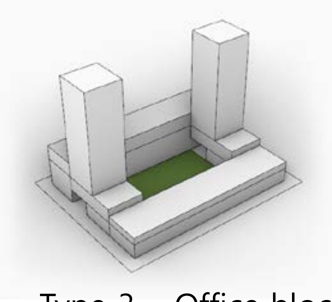


Type 3 – Office block
FAR: 3.45
Maximum height: 22F

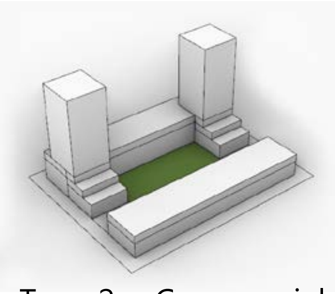
Block types and design

Based on the same geometry, we designed three different combinations with different FAR level. The main concept is to create a gradual height transformation between residential blocks and waterfront areas. Each block type has identical function proportion (residential, office, commercial) related to its location.

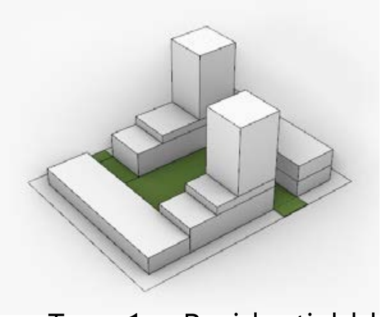




Type 3 – Office block
FAR: 3.45

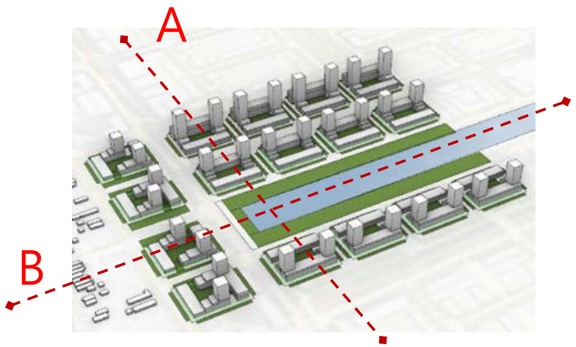


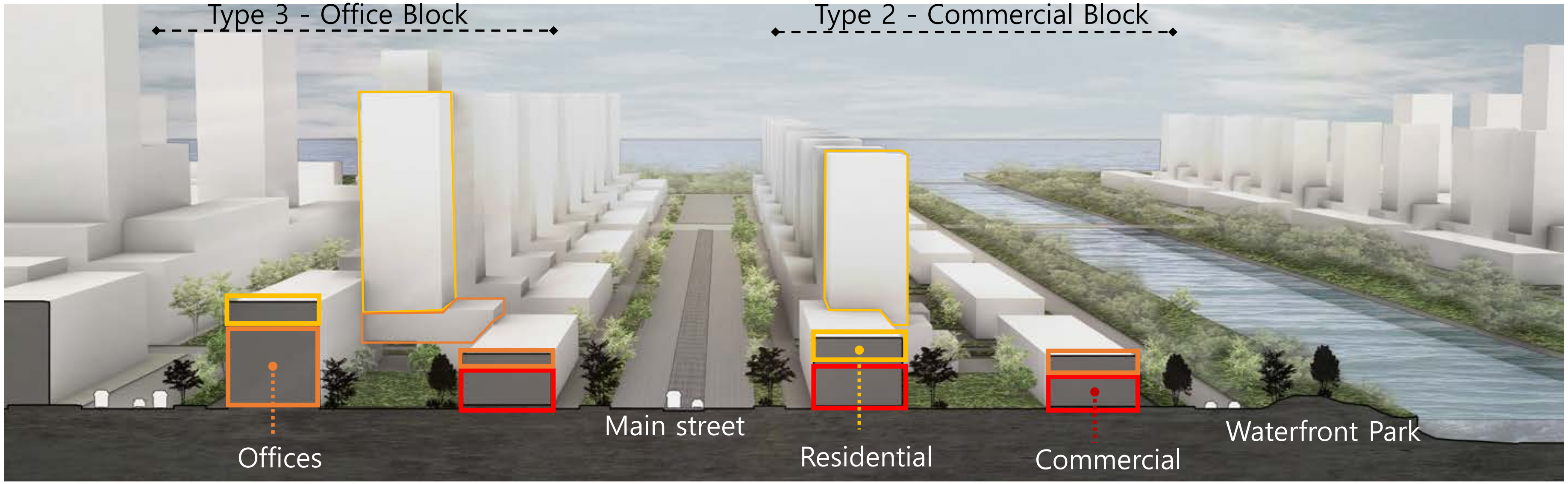
Type 2 – Commercial bl
ock
FAR: 2.3



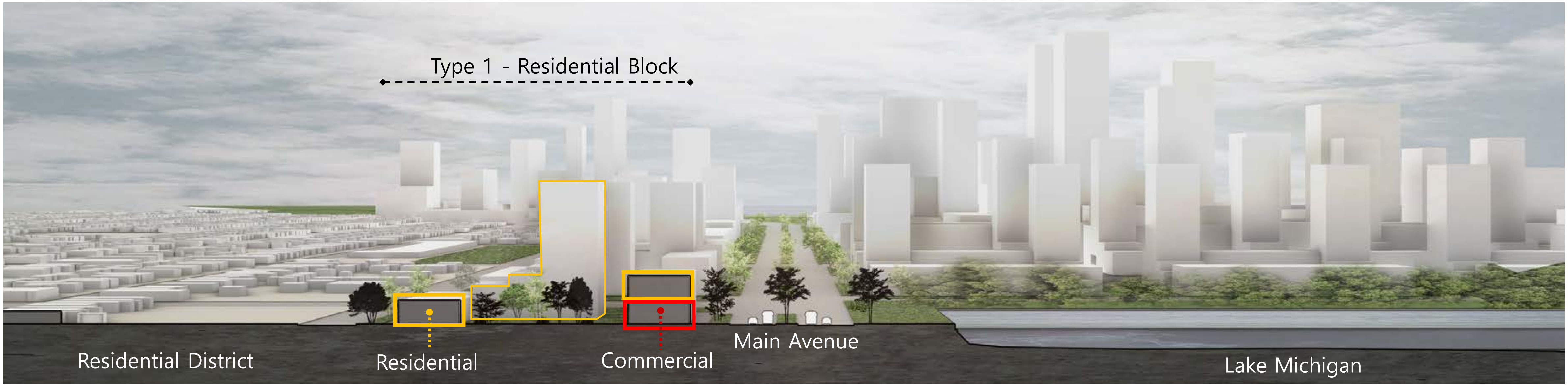
Type 1 – Residential blo
ck
FAR: 1.95

Block types and design



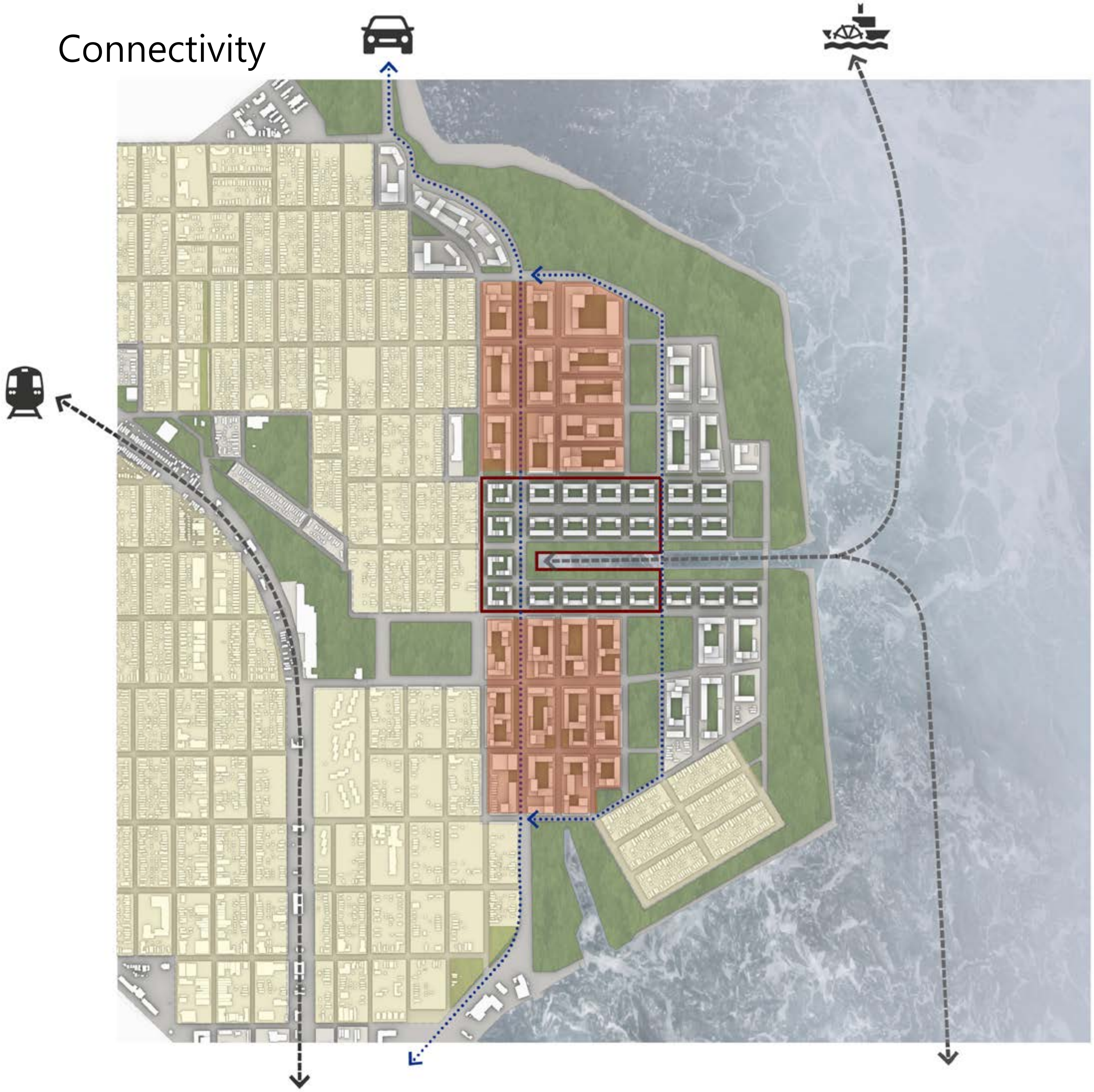


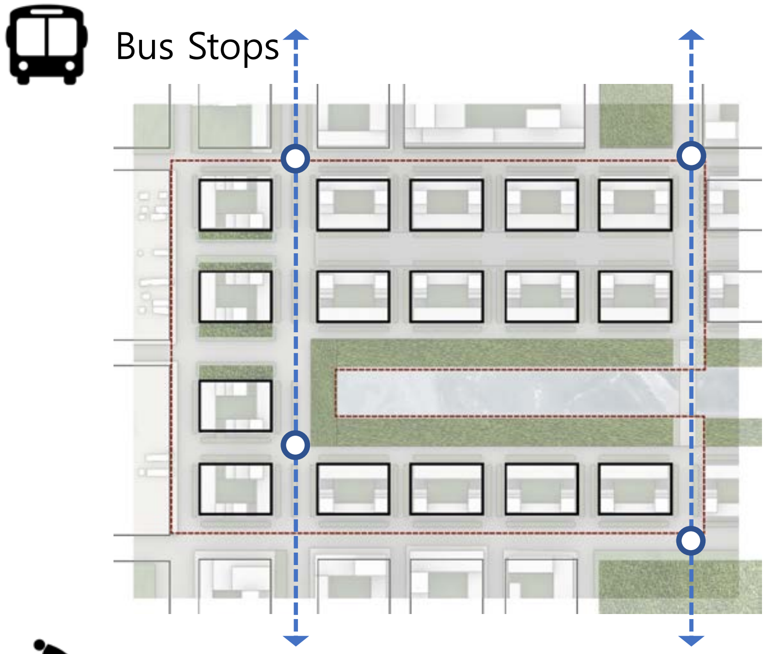
Section A

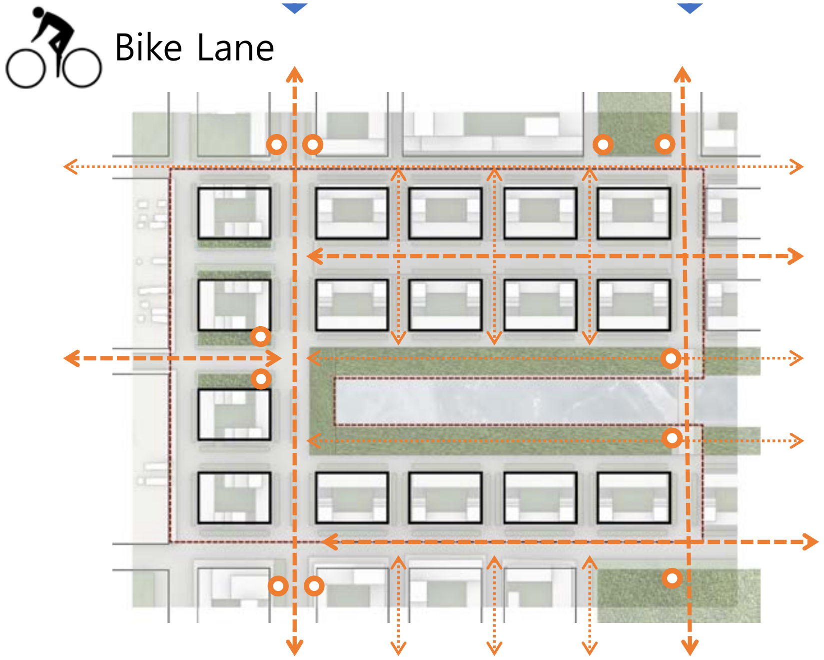


Section B

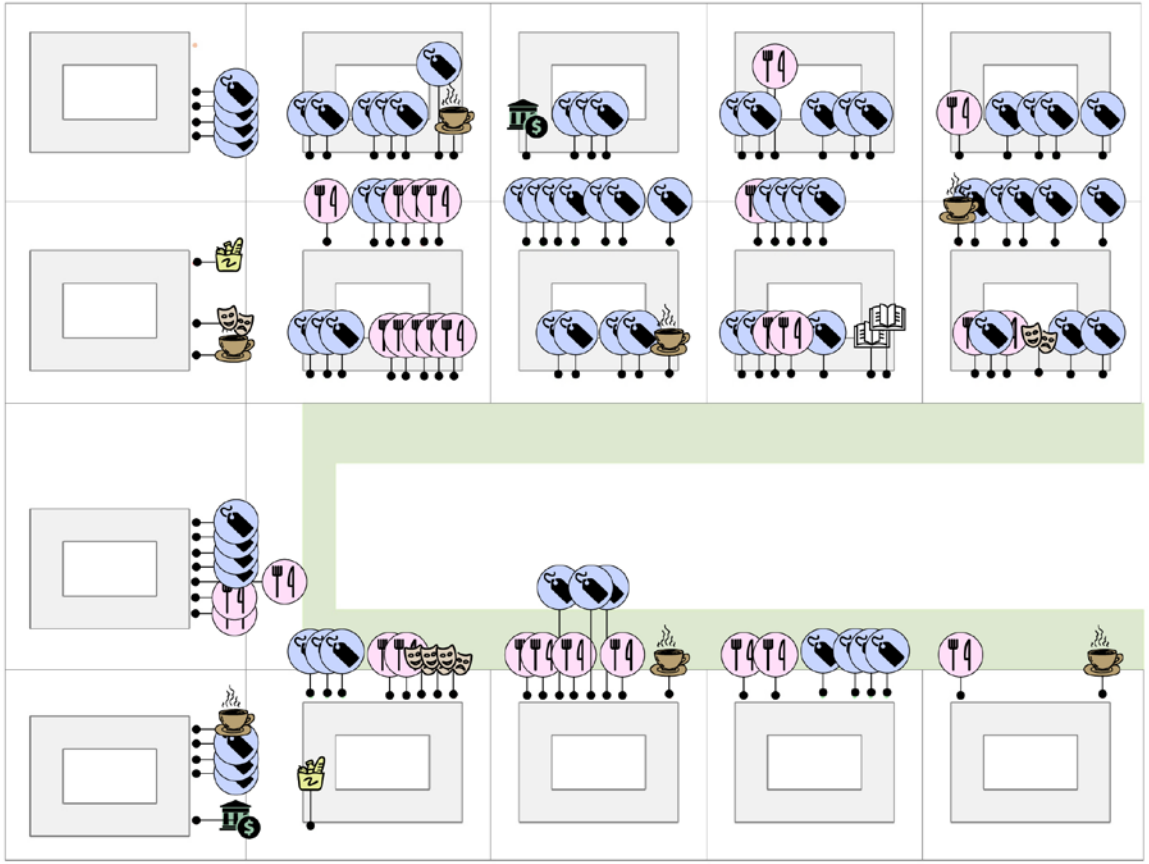
Connectivity

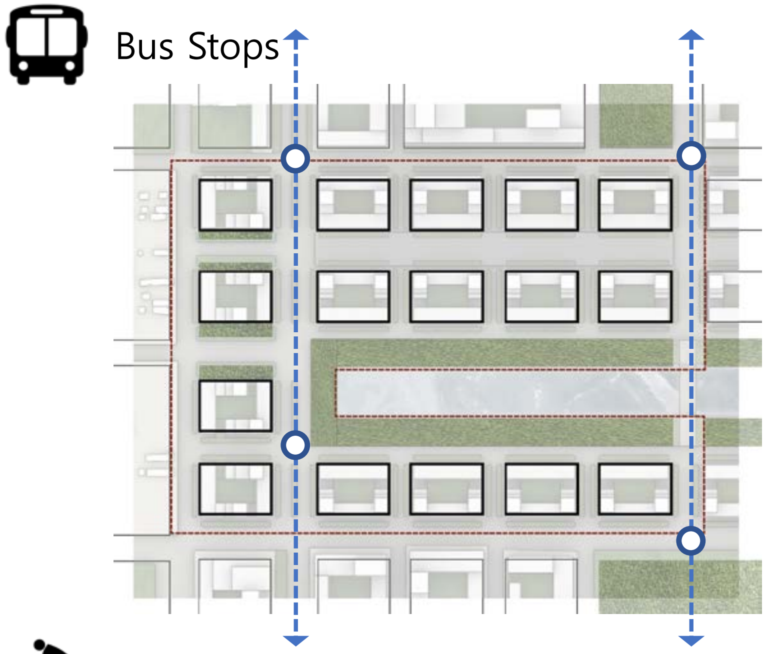


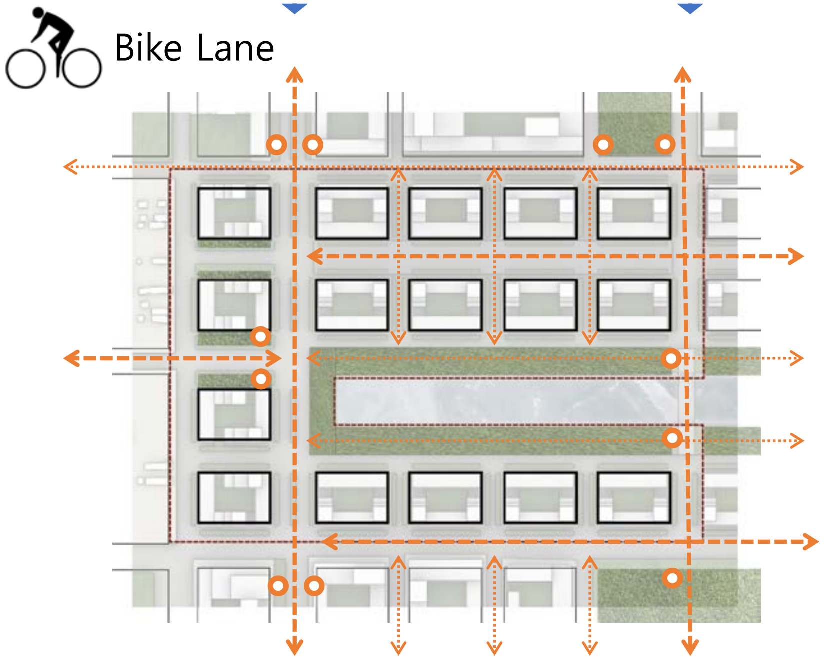




Connectivity

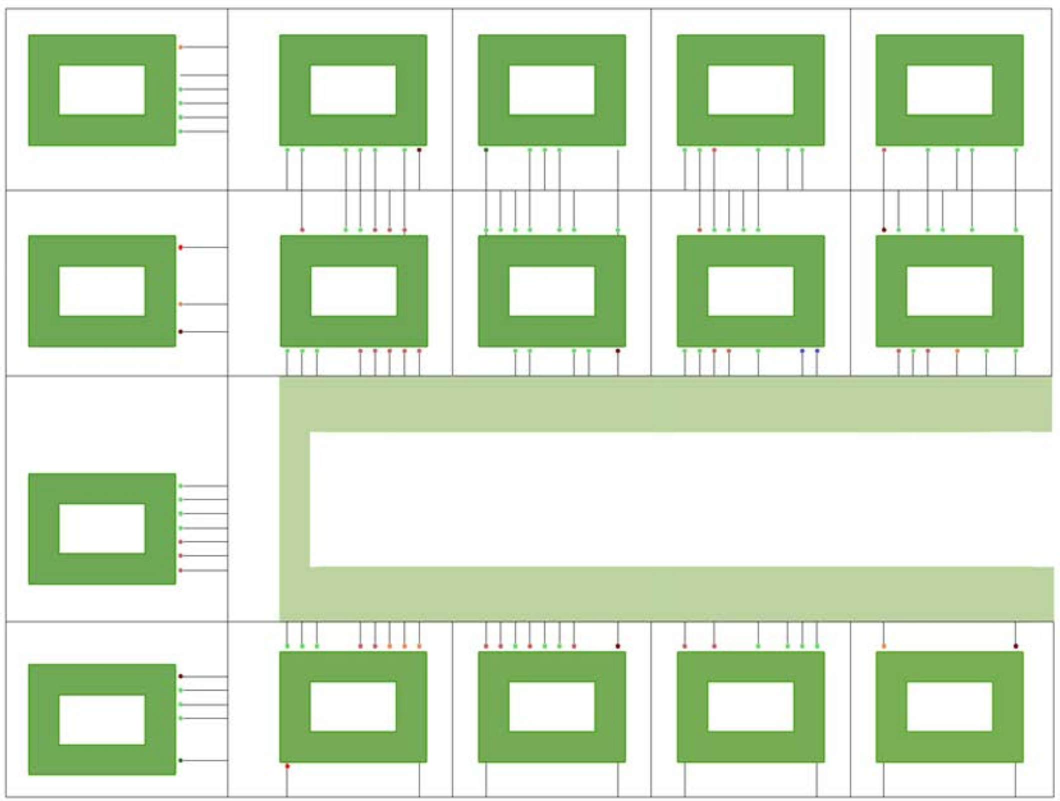


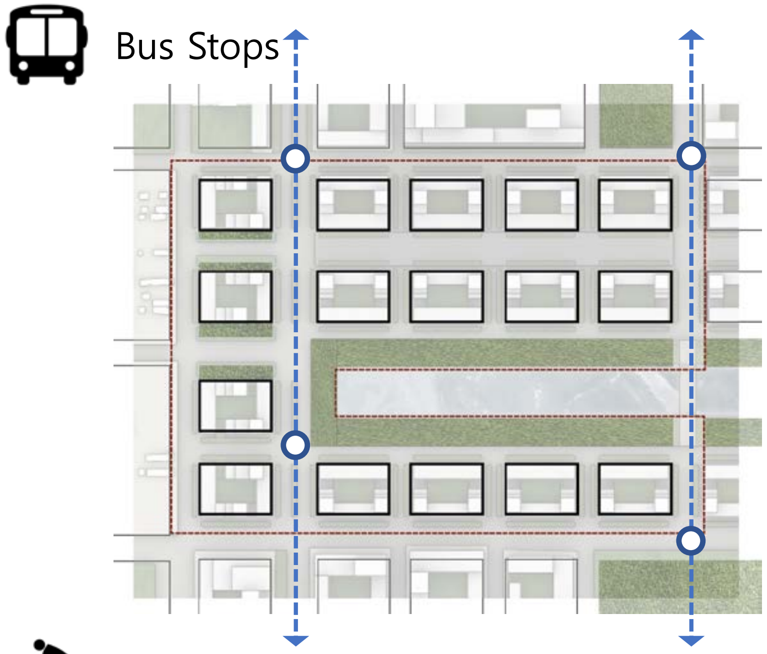


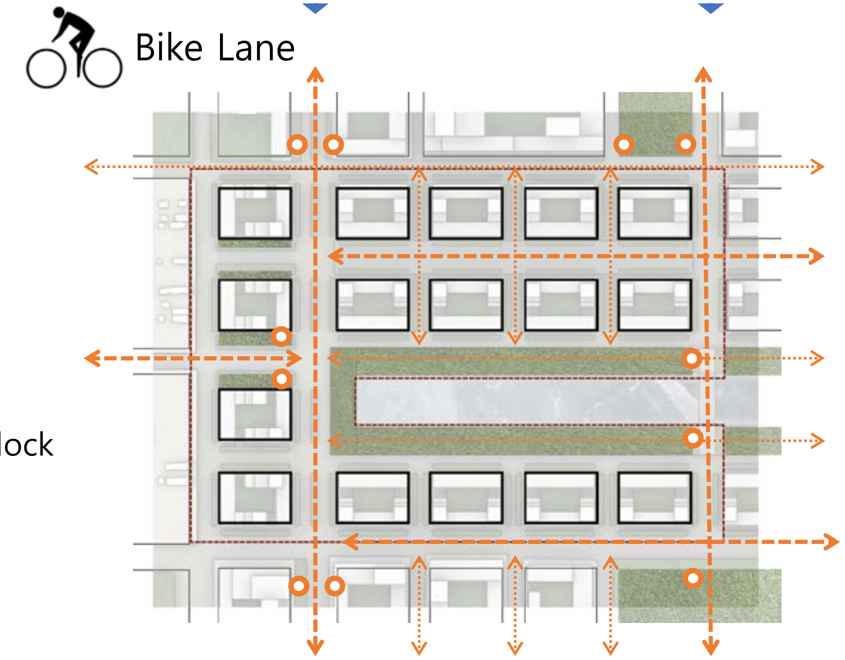


We prioritized the west-east streets of the neighborhood and those near the water as places that should be highly accessible by foot and bike. The north-south street has less walkable green space, so the amenities placed are more suited for public transport or automobile connections.

Connectivity

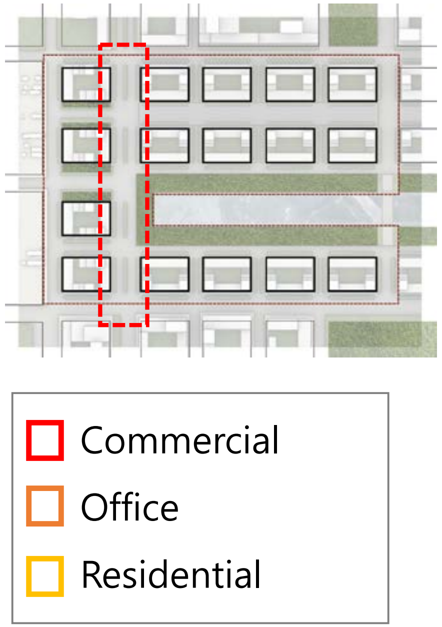




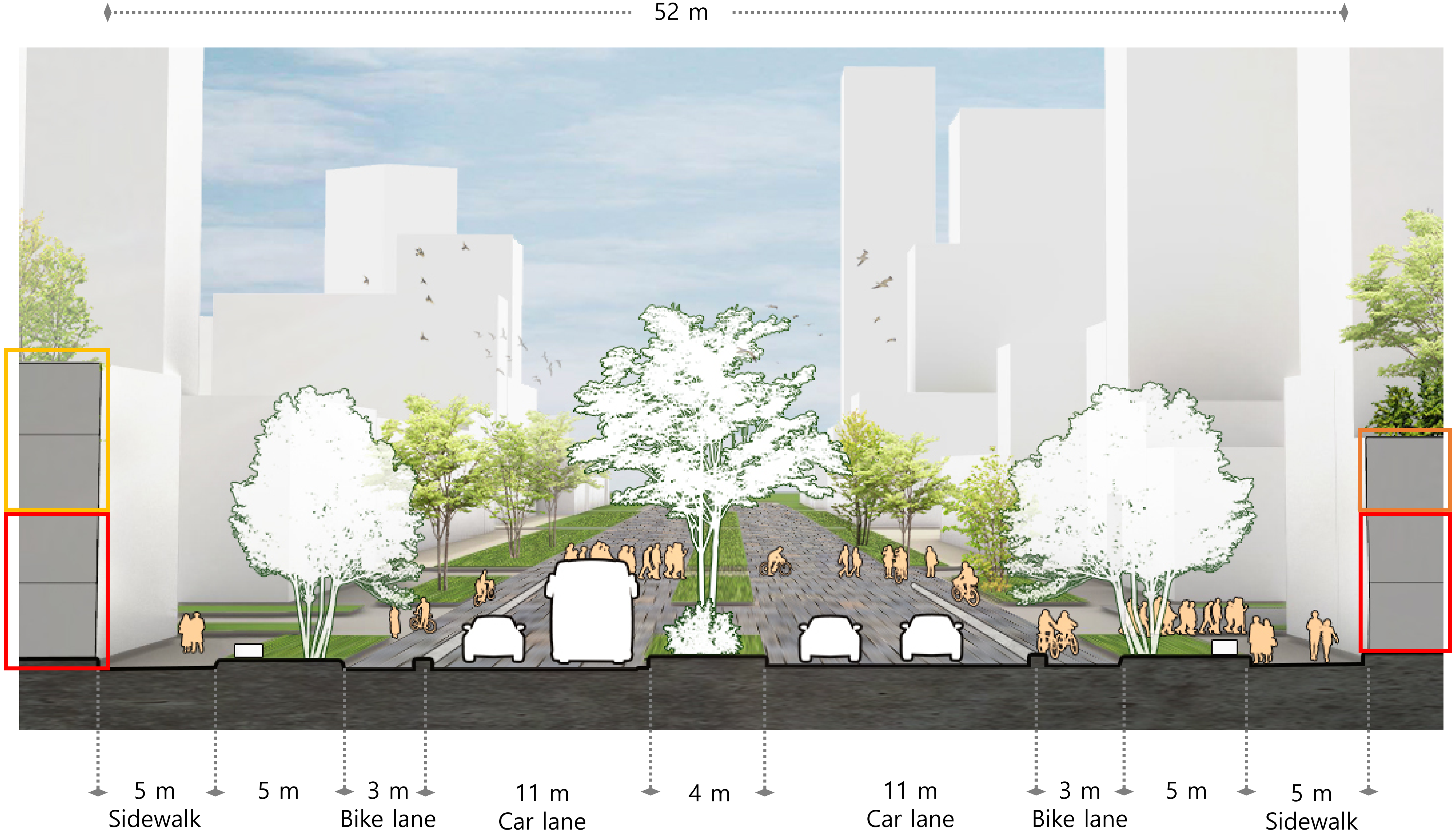


We ran the mobility simulator using the placement of the amenities and simplified geometry for each block. In our simulation, we included the green space of the esplanade as touching the central protoblock s. Each block scored over 90 for both walking and biking on the test

Main Avenue

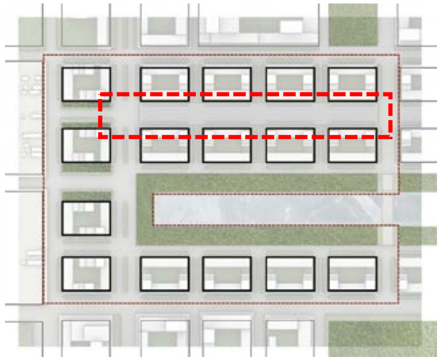


Commercial
Office
Residential

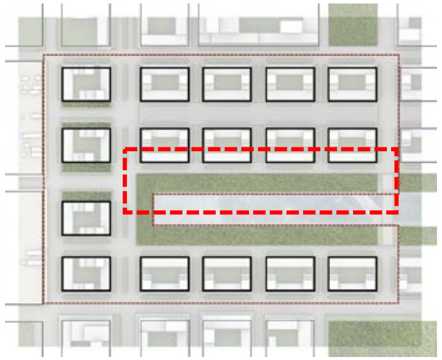


52 m
5 m
Sidewalk
5 m
3 m
Bike lane
11 m
Car lane
4 m
11 m
Car lane
3 m
Bike lane
5 m
5 m
Sidewalk

Commercial street



Water front street

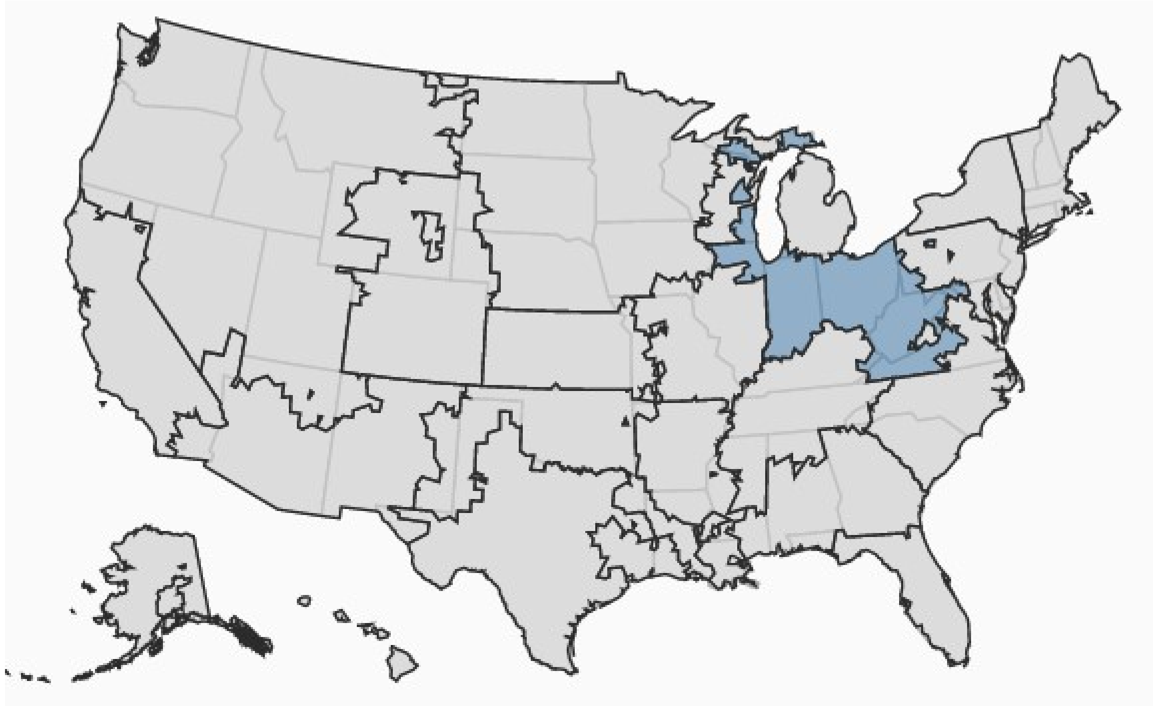


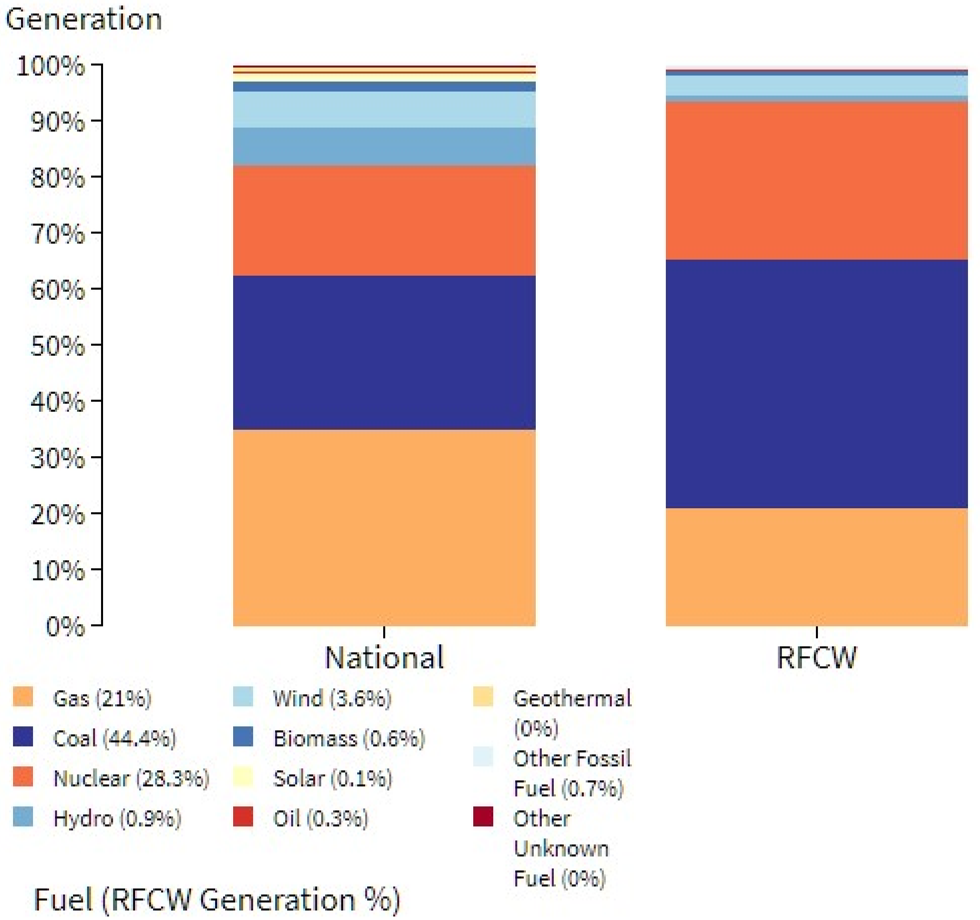
Commercial
Office
Residential

Urban Energy Supply

Carbon equivalence settings

We searched the emissions resources provided by the EPA to reflect the characteristics of the RFCW grid region where Chicago is located. Coal is the largest source in the fuel mix followed by nuclear, and natural gas.





Carbon equivalence settings

Electricity in the RFCW region is $0.15/kWh (slightly higher than the national average) while gas is the national average at $0.03/kWh.

CPI Average Price Data, U.S. city average (AP)

```
Series Id:     APUS23A72620
Series Title:  Utility (piped) gas per therm in Chicago-Naperville-Elgin, IL-IN-WI, average price, not seasonally adjusted
Area:          Chicago-Naperville-Elgin, IL-IN-WI
Item:          Utility (piped) gas per therm
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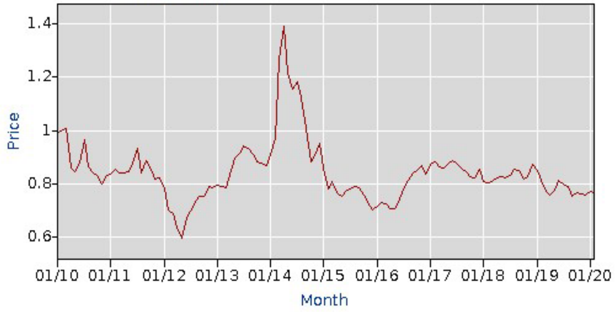

Download: xlsx

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	0.990	1.005	1.007	0.862	0.847	0.878	0.966	0.864	0.844	0.833	0.801	0.832
2011	0.835	0.857	0.843	0.844	0.846	0.877	0.935	0.844	0.886	0.855	0.818	0.822
2012	0.782	0.704	0.689	0.640	0.599	0.674	0.697	0.737	0.755	0.756	0.793	0.788
2013	0.797	0.789	0.788	0.852	0.897	0.917	0.944	0.933	0.909	0.883	0.877	0.871
2014	0.909	0.969	1.269	1.394	1.214	1.158	1.186	1.122	1.009	0.885	0.906	0.953
2015	0.862	0.781	0.811	0.766	0.756	0.774	0.783	0.793	0.786	0.760	0.733	0.702
2016	0.717	0.733	0.725	0.709	0.707	0.744	0.781	0.813	0.844	0.852	0.869	0.836
2017	0.876	0.885	0.867	0.861	0.875	0.890	0.878	0.862	0.847	0.830	0.823	0.854
2018	0.808	0.806	0.811	0.824	0.828	0.821	0.834	0.856	0.853	0.818	0.828	0.876
2019	0.852	0.816	0.772	0.760	0.778	0.812	0.799	0.792	0.756	0.767	0.764	0.760
2020	0.772	0.770										

CPI Average Price Data, U.S. city average (AP)

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Series Id:     APUS23A72610
Series Title:  Electricity per KWH in Chicago-Naperville-Elgin, IL-IN-WI, average price, not seasonally adjusted
Area:          Chicago-Naperville-Elgin, IL-IN-WI
Item:          Electricity per KWH
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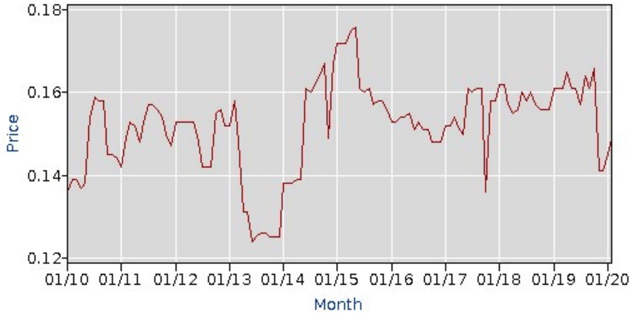


Download: xlsx

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	0.136	0.139	0.139	0.137	0.138	0.154	0.159	0.158	0.158	0.145	0.145	0.144
2011	0.142	0.149	0.153	0.152	0.148	0.153	0.157	0.157	0.156	0.154	0.150	0.147
2012	0.153	0.153	0.153	0.153	0.153	0.148	0.142	0.142	0.142	0.155	0.156	0.152
2013	0.152	0.158	0.148	0.131	0.131	0.124	0.125	0.126	0.126	0.125	0.125	0.125
2014	0.138	0.138	0.138	0.139	0.139	0.161	0.160	0.162	0.164	0.167	0.149	0.167
2015	0.172	0.172	0.172	0.175	0.176	0.161	0.160	0.161	0.157	0.158	0.158	0.156
2016	0.153	0.153	0.154	0.154	0.155	0.151	0.153	0.151	0.151	0.148	0.148	0.148
2017	0.152	0.152	0.154	0.151	0.150	0.161	0.160	0.161	0.161	0.136	0.158	0.158
2018	0.162	0.162	0.157	0.155	0.156	0.160	0.158	0.160	0.157	0.156	0.156	0.156
2019	0.161	0.161	0.161	0.165	0.161	0.161	0.157	0.164	0.161	0.166	0.141	0.141
2020	0.145	0.149										

Carbon equivalence settings

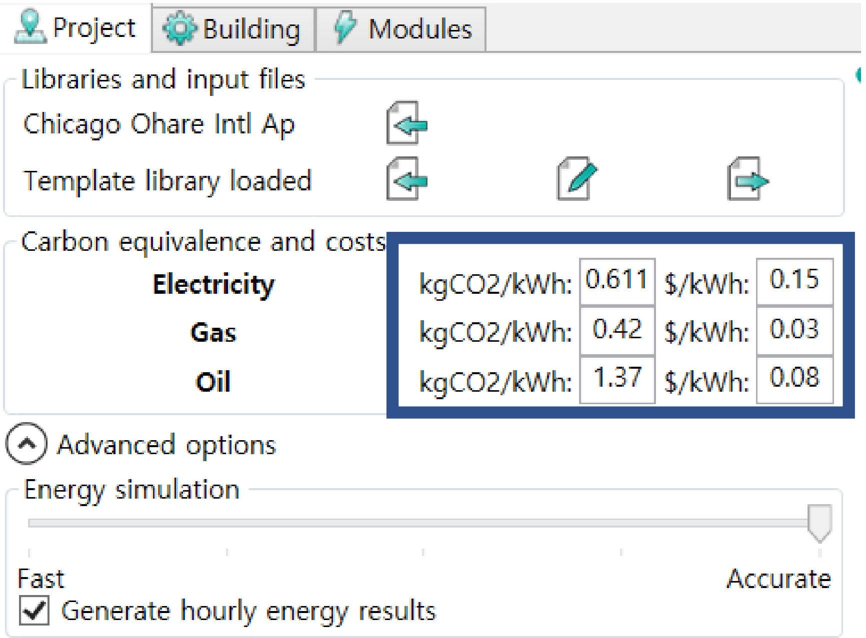
Using the eGrid database provided by the EPA we found the annual CO2 output for oil and gas for the RCFW region to update the carbon settings in UMI.

Data Year	eGRID subregion acronym	eGRID subregion name	eGRID subregion ozone season NOx coal output emission rate (lb/MWh)	eGRID subregion ozone season NOx oil output emission rate (lb/MWh)	eGRID subregion ozone season NOx gas output emission rate (lb/MWh)	eGRID subregion ozone season NOx fossil fuel output emission rate (lb/MWh)	eGRID subregion annual SO2 coal output emission rate (lb/MWh)	eGRID subregion annual SO2 oil output emission rate (lb/MWh)	eGRID subregion annual SO2 gas output emission rate (lb/MWh)	eGRID subregion annual SO2 fossil fuel output emission rate (lb/MWh)	eGRID subregion annual CO2 coal output emission rate (lb/MWh)	eGRID subregion annual CO2 oil output emission rate (lb/MWh)	eGRID subregion annual CO2 gas output emission rate (lb/MWh)
YEAR	SUBRGN	SRNAME	SRCNXORT	SRONXORT	SRGNXORT	SRFSNORT	SRCSO2RT	SROSO2RT	SRGSO2RT	SRFSS2RT	SRCCO2RT	SROCO2RT	SRGCO2RT
2018	AKGD	ASCC Alaska Grid	2.538	8.460	7.268	6.576	5.954	3.220	0.027	1.323	2,179.980	1,647.554	993.528
2018	AKMS	ASCC Miscellaneous	0.000	27.190	4.622	22.860	0.000	2.470	0.045	1.986	0.000	1,516.587	1,641.512
2018	AZNM	WECC Southwest	1.922	24.566	0.540	1.017	0.910	14.057	0.011	0.360	2,333.004	4,544.156	971.227
2018	CAMX	WECC California	2.226	8.682	0.599	0.733	0.565	0.585	0.008	0.057	1,973.587	1,934.695	857.336
2018	ERCT	ERCOT All	1.222	3.906	0.525	0.731	3.576	10.213	0.007	1.159	2,242.210	2,274.302	860.976
2018	FRCC	FRCC All	0.852	2.835	0.218	0.337	1.425	0.996	0.032	0.309	1,993.017	1,154.467	870.979
2018	HIMS	HICC Miscellaneous	0.000	11.054	0.000	11.054	0.000	5.472	0.000	5.472	0.000	1,679.396	0.000
2018	HIOA	HICC Oahu	2.361	4.127	0.000	3.768	10.580	8.371	0.000	8.837	2,338.064	1,593.114	0.000
2018	MROE	MRO East	0.865	0.751	0.864	0.864	1.040	2.583	0.325	0.880	2,218.238	1,786.522	1,050.506
2018	MROW	MRO West	1.697	3.276	0.542	1.513	2.563	0.824	0.011	2.234	2,218.292	1,084.452	978.243
2018	NEWE	NPCC New England	3.008	4.688	0.224	0.264	1.769	4.628	0.028	0.116	2,531.361	1,942.449	863.699
2018	NWPP	WECC Northwest	2.182	0.794	0.542	1.443	1.575	13.441	0.015	0.961	2,285.364	1,760.989	916.572
2018	NYCW	NPCC NYC/Westchester	0.000	12.713	0.311	0.319	0.000	1.958	0.031	0.032	0.000	3,673.333	940.601
2018	NYLI	NPCC Long Island	0.000	0.832	0.568	0.657	0.000	0.578	0.099	0.241	0.000	1,368.555	1,038.751
2018	NYUP	NPCC Upstate NY	1.608	1.720	0.248	0.318	6.669	2.436	0.043	0.319	2,043.674	1,183.795	847.601
2018	RFCE	RFC East	0.969	1.268	0.173	0.415	2.800	0.345	0.006	0.832	2,189.848	1,227.215	849.551
2018	RFCM	RFC Michigan	1.292	6.769	0.436	0.956	2.811	4.626	0.038	1.636	2,237.080	1,458.616	883.388
2018	RFCW	RFC West	1.271	1.677	0.270	0.948	1.990	5.003	0.033	1.392	2,133.760	3,028.016	926.486

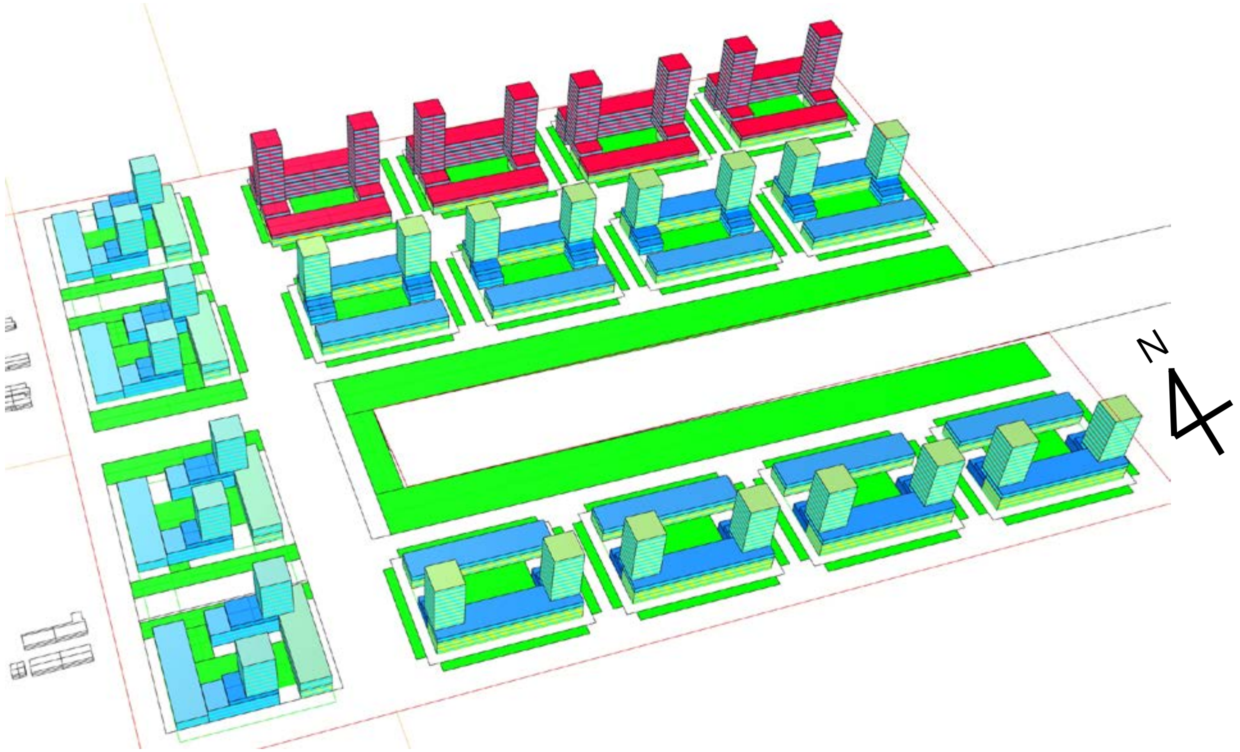
Energy supply scenarios

Before starting the simulation for cost and carbon emission of source energy, carbon equivalence settings were defined.

Next, three types of proto blocks (residential, retail, office) were distributed across the site and hourly energy simulation was done.



Carbon equivalence settings

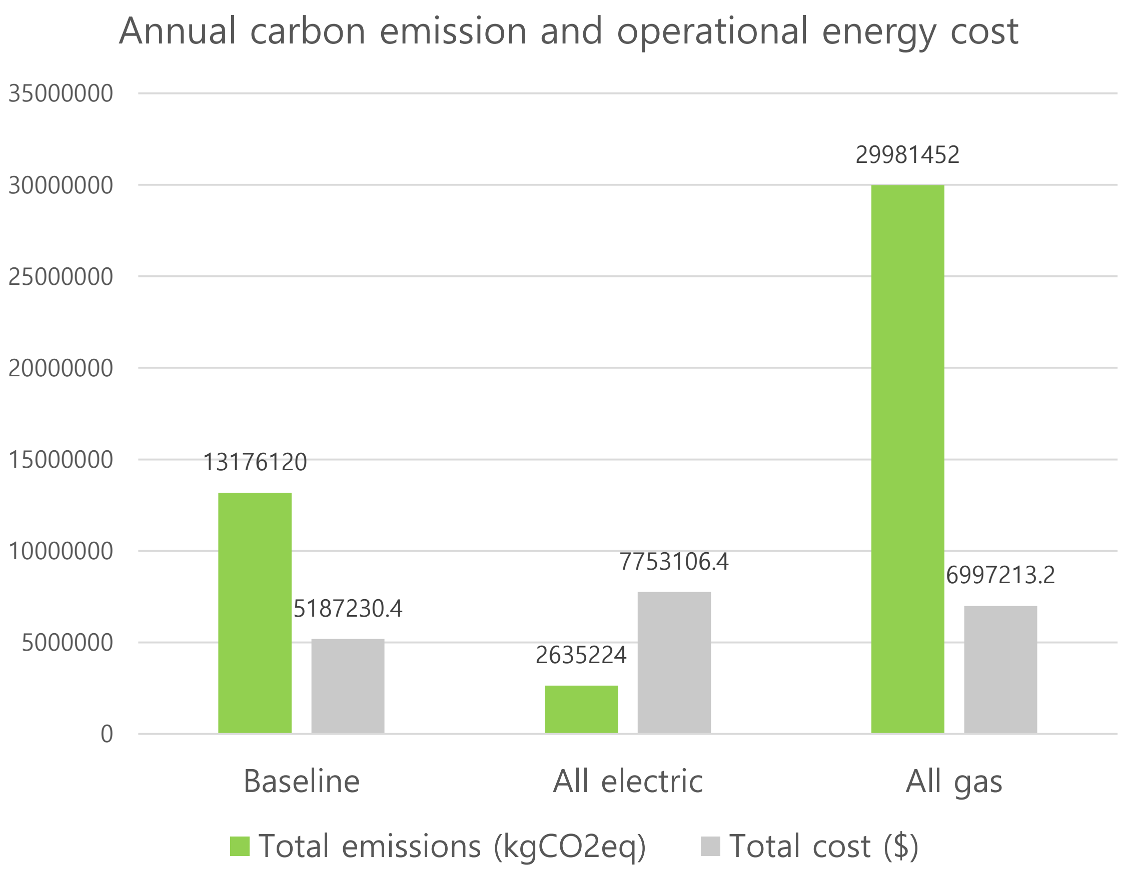


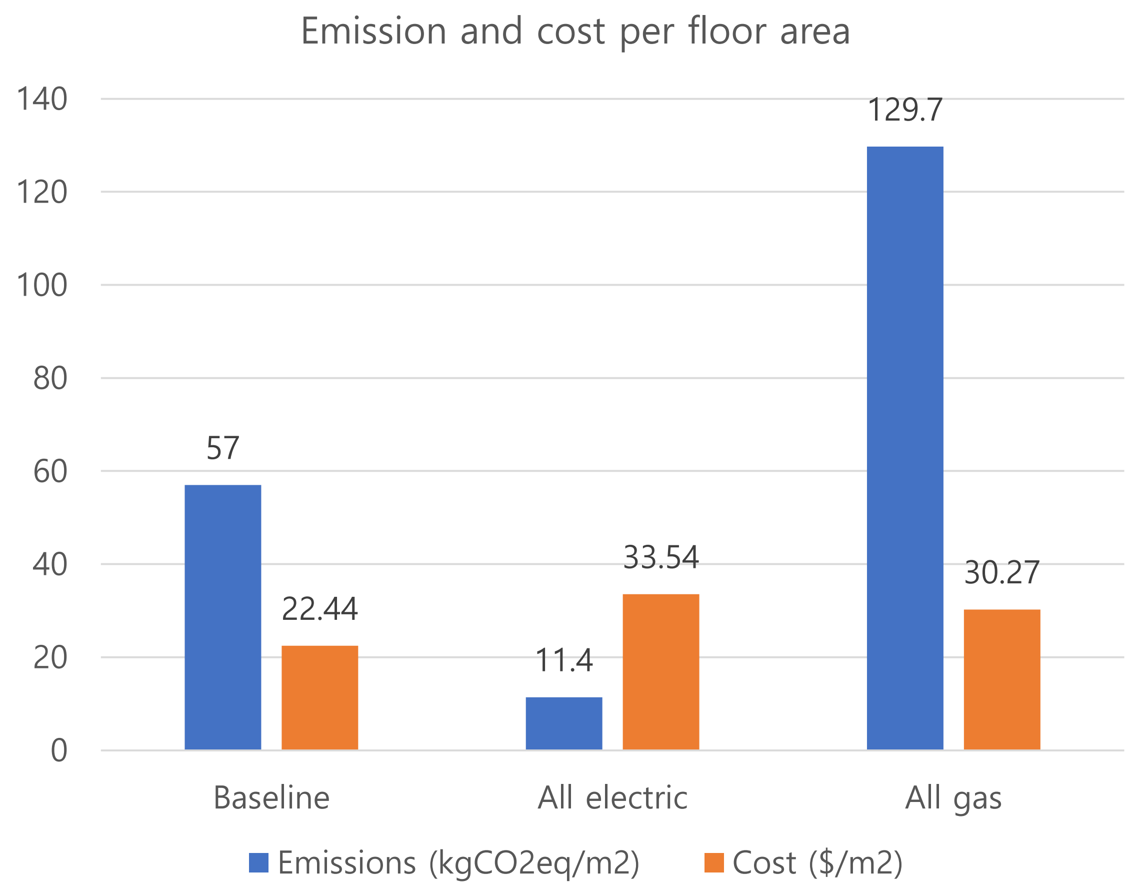
Three types of proto blocks distributed across the neighbors

Energy supply scenarios

The source energy analysis simulations were done using UMI district plugin.

Three scenarios (baseline, all electric, and all gas) were used to define different cost and carbon emission of source energies of each scenario.



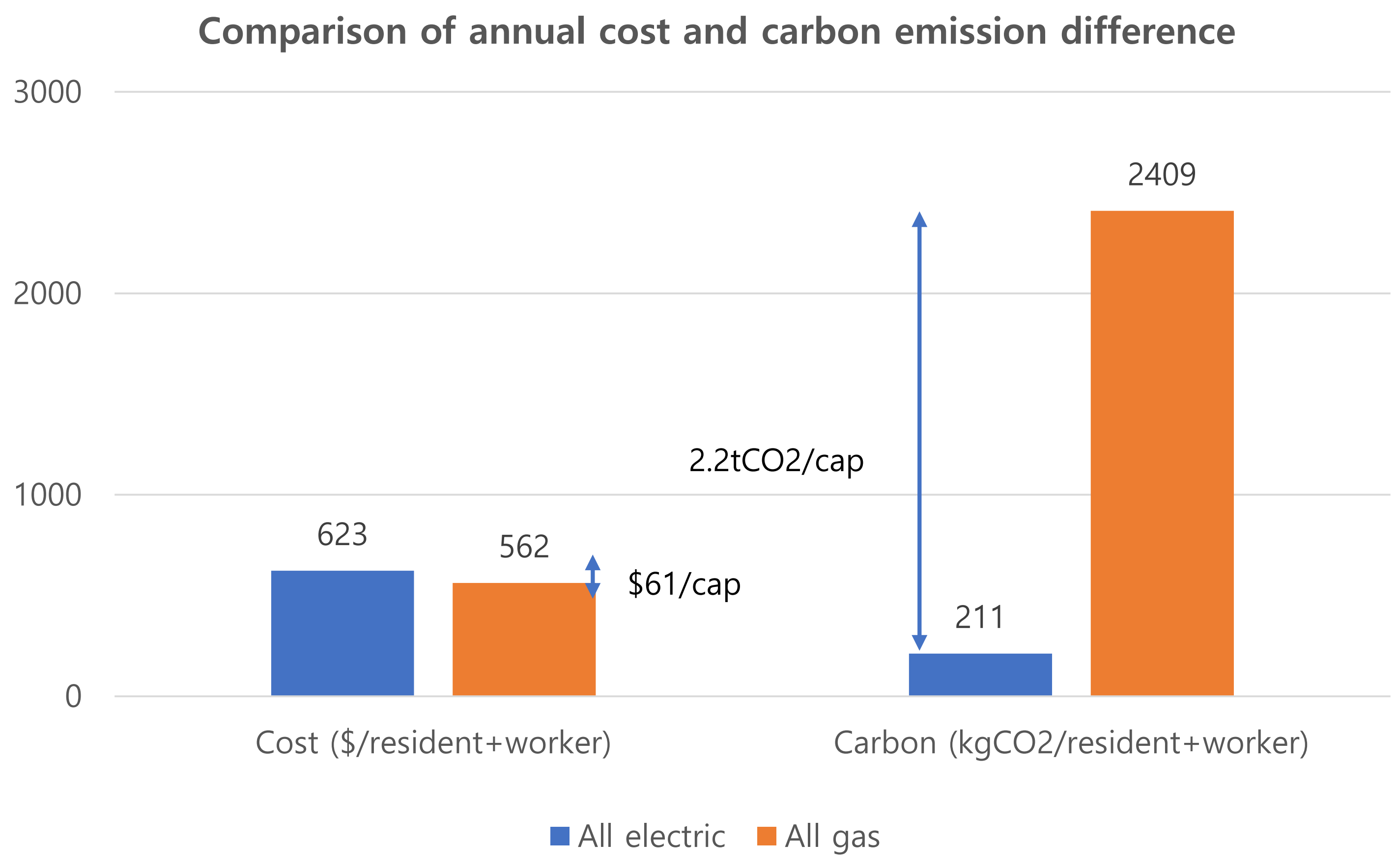


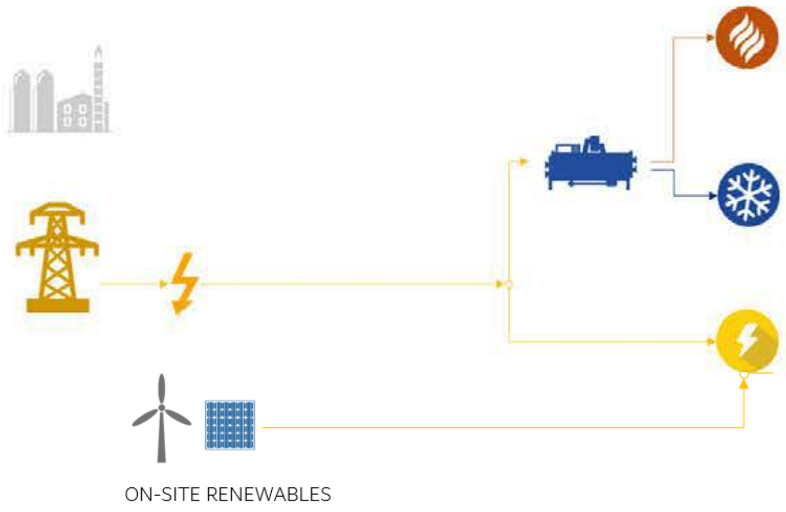
Energy supply scenarios

From the analysis, it was found that the cost difference of energy per capita on all-electric and all gas scenarios is marginal ($61/cap).

On the other hand, there is a big difference in carbon emission amount (2.2tCO2/cap).

Considering the corresponds to a carbon price of $294 per tCO2, an all-electric supply system is more favorable to our neighborhood.

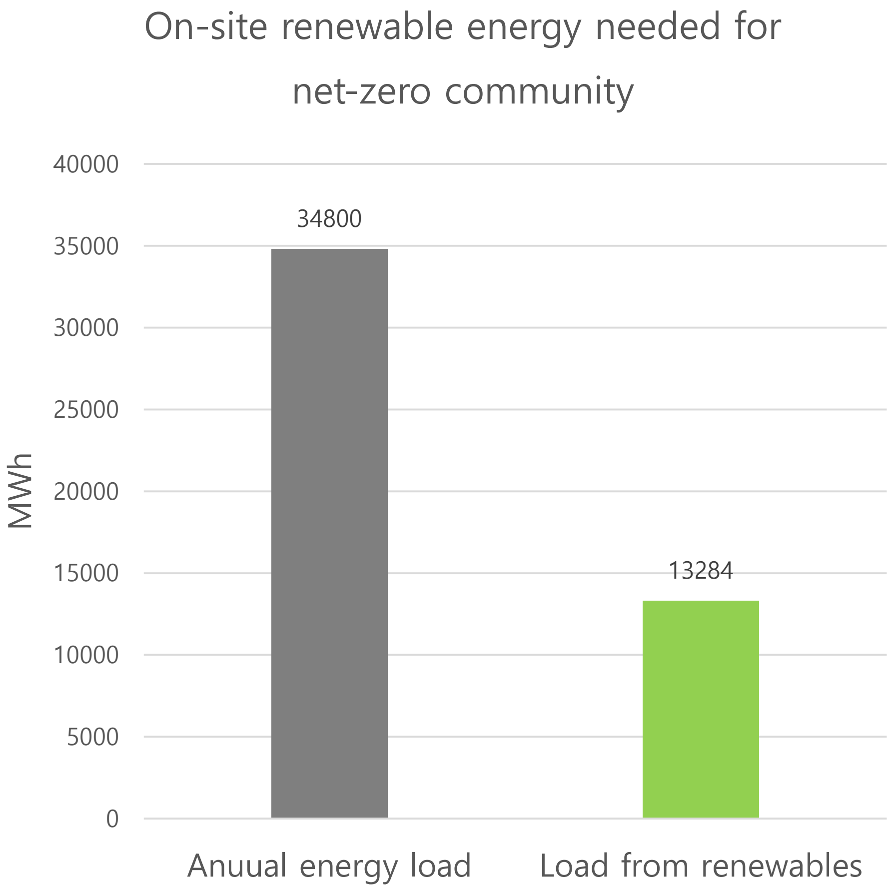


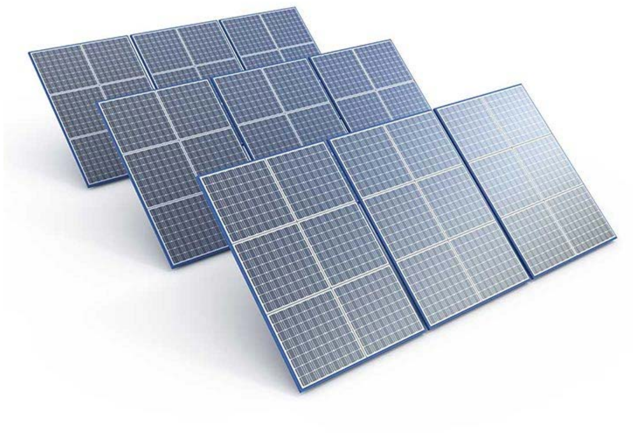


All-electric system with on-site renewables

Energy supply scenarios

On the Net Zero Community scenario, it was estimated renewable sources (PV array and wind turbines) should be responsible for 13,284MWh annual electricity need, which is about 38% of the total energy load.





PV panel

Angle: 33°

Dimension: 2m*1m (72cells)

Efficiency: 20%

Vertical axis wind turbine

Diameter: 1m

Height: 1.5m

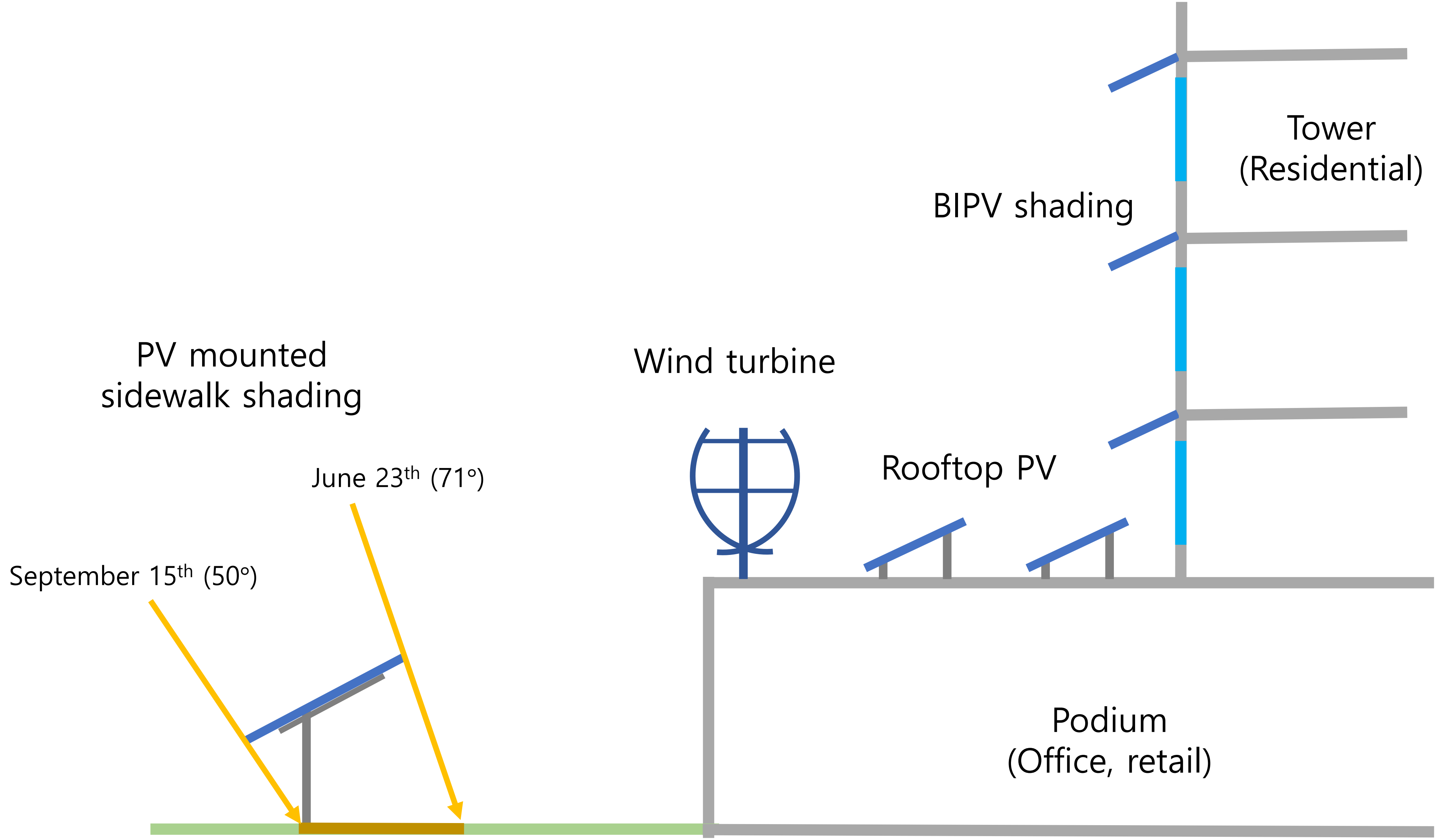
Efficiency: 30%

Average wind speed: 4.5m/s

Expected annual output: 210kWh

Energy supply scenarios

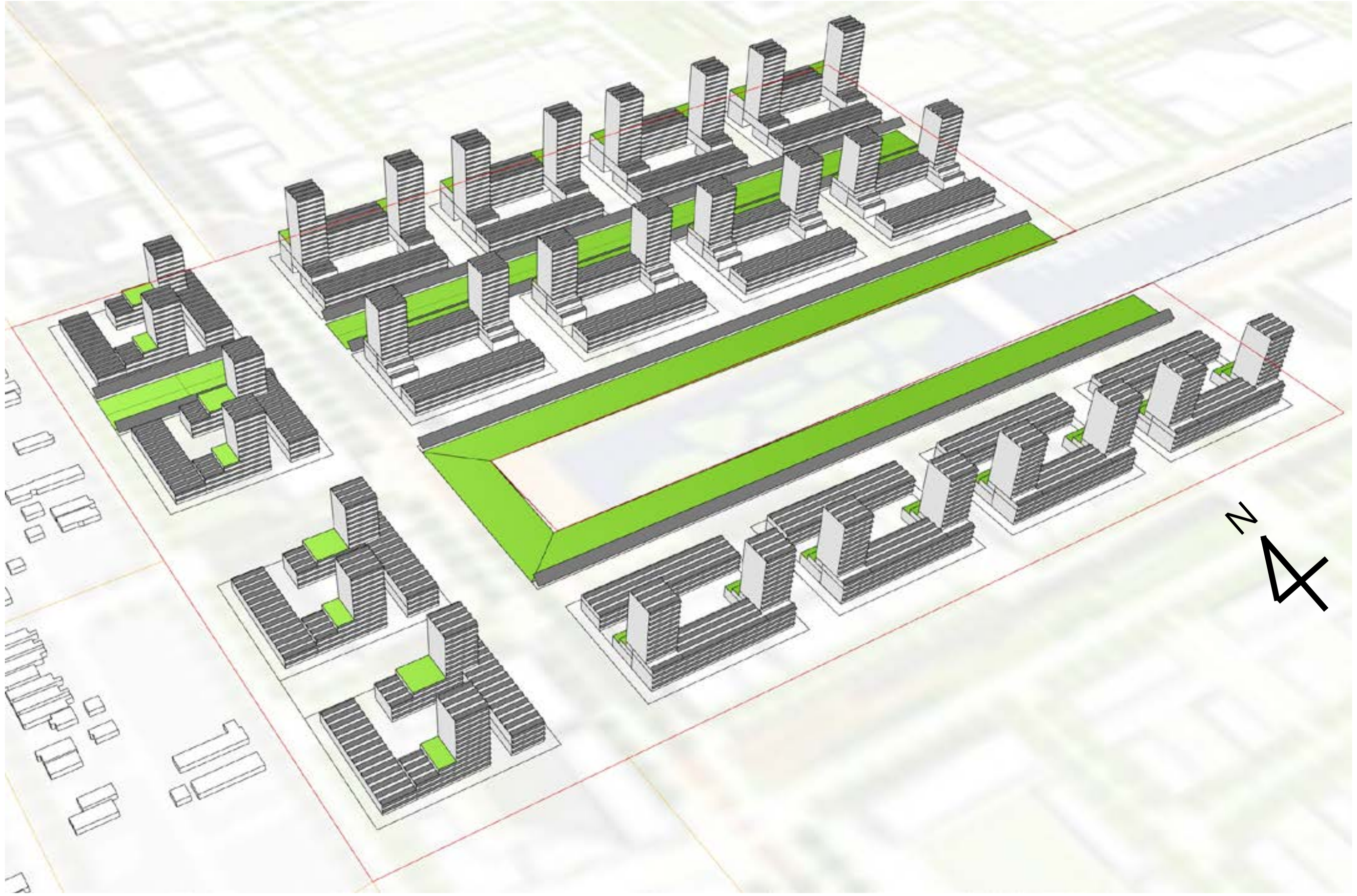
Locations of the renewable sources (PV array and wind turbines)



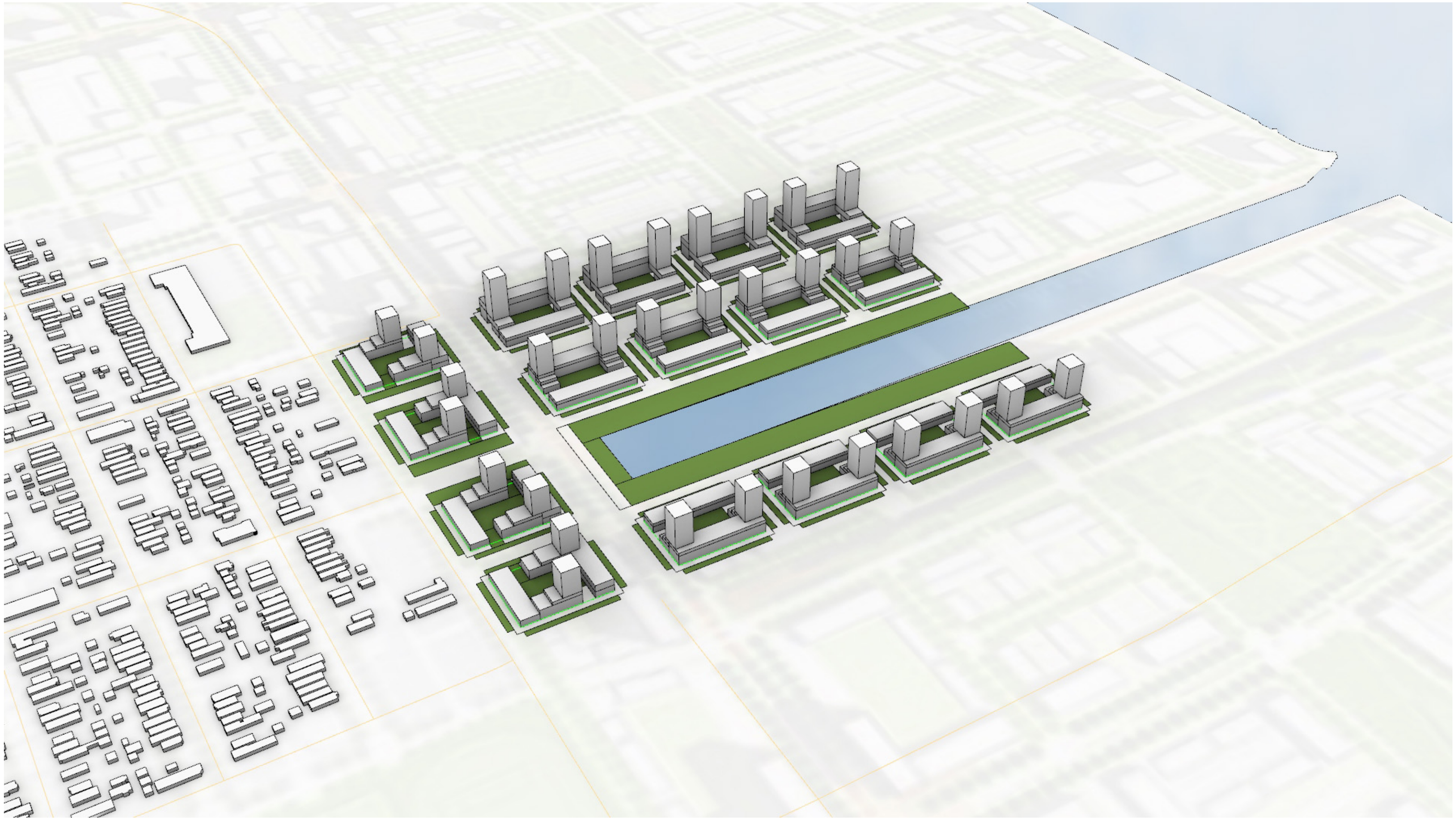
Energy supply scenarios

Yield of the renewable sources (PV array and wind turbines)

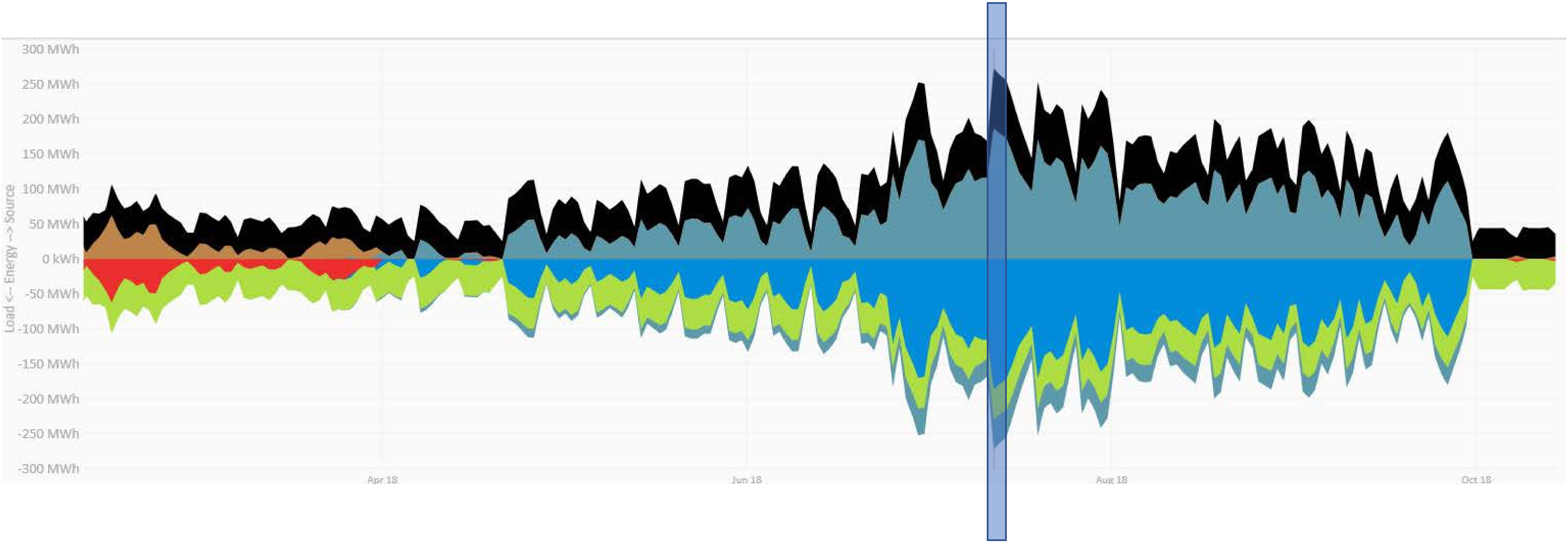
Location	Source	Area (m2)	Quantity (EA)	Annual output (MWh)
Building	BIPV shading	102,000		3,810
	Rooftop PV	19,824		6,778
	Wind turbine		320	67
Sidewalk	PV shading	10,800		2,873
Total		42,624	320	**13,528**



Lake Michigan Cooling Source



Lake Michigan Cooling Source



185 MW

Chiller peak cooling load

2,757 MWh

Annual consumption of grid-electricity

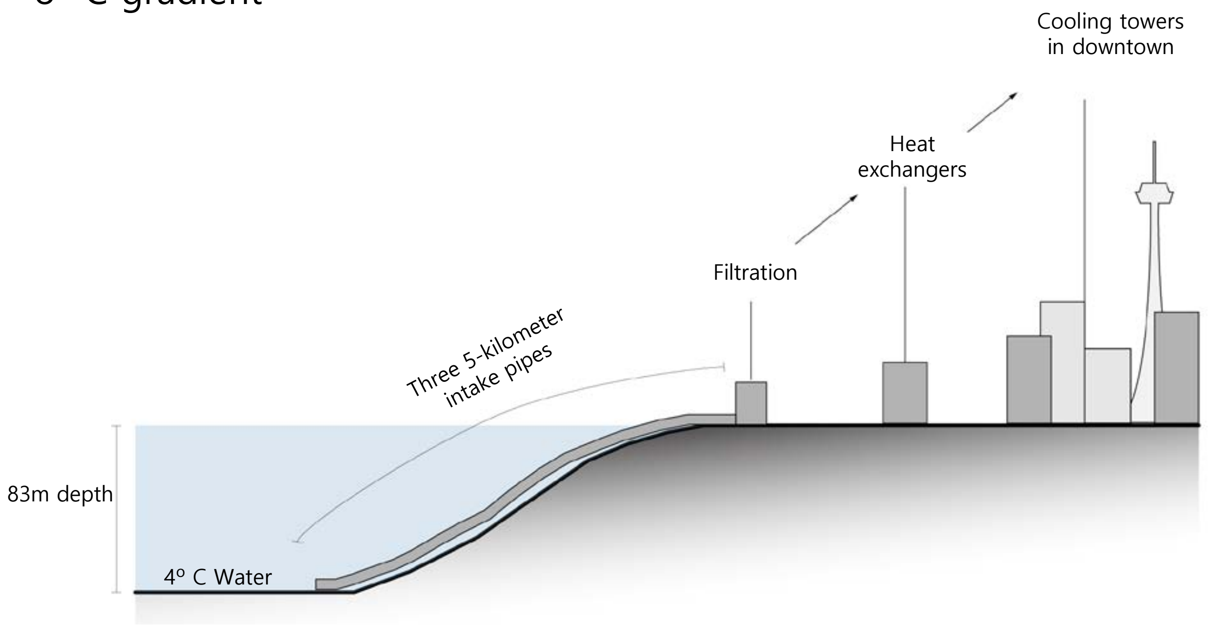
1,684 tCO2

Annual potential carbon-equivalent savings compared to absorption chiller

Lake Michigan Cooling Source

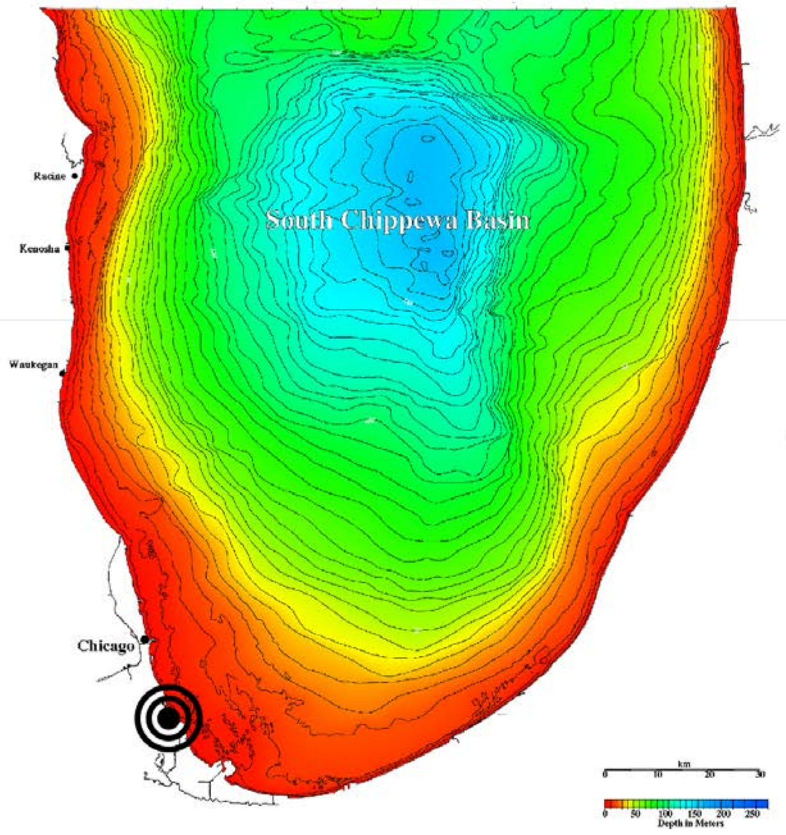
Toronto Deep Lake Water Cooling (DLWC)

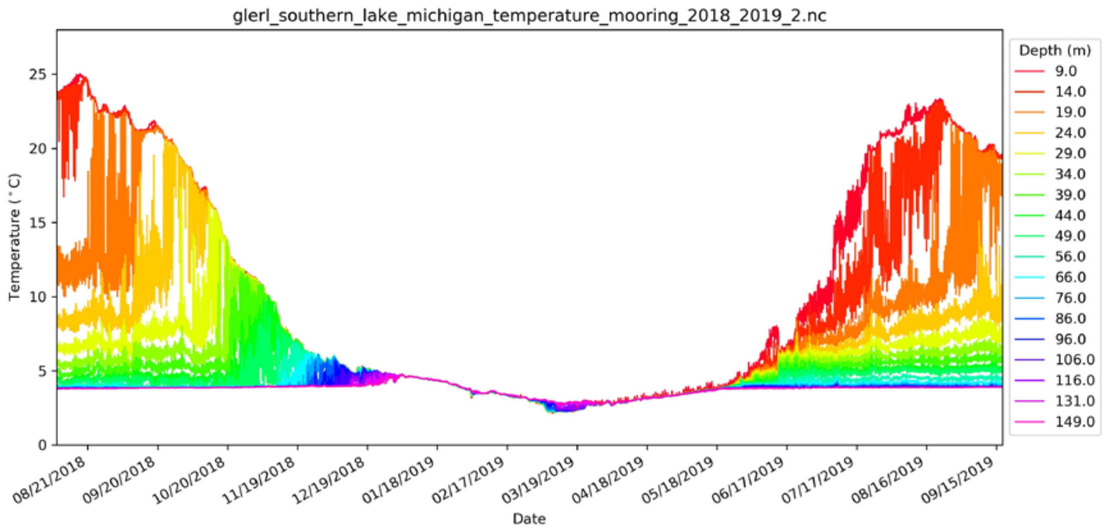
$100,000,000 project
Provides energy to 100 buildings downtown
8° C gradient



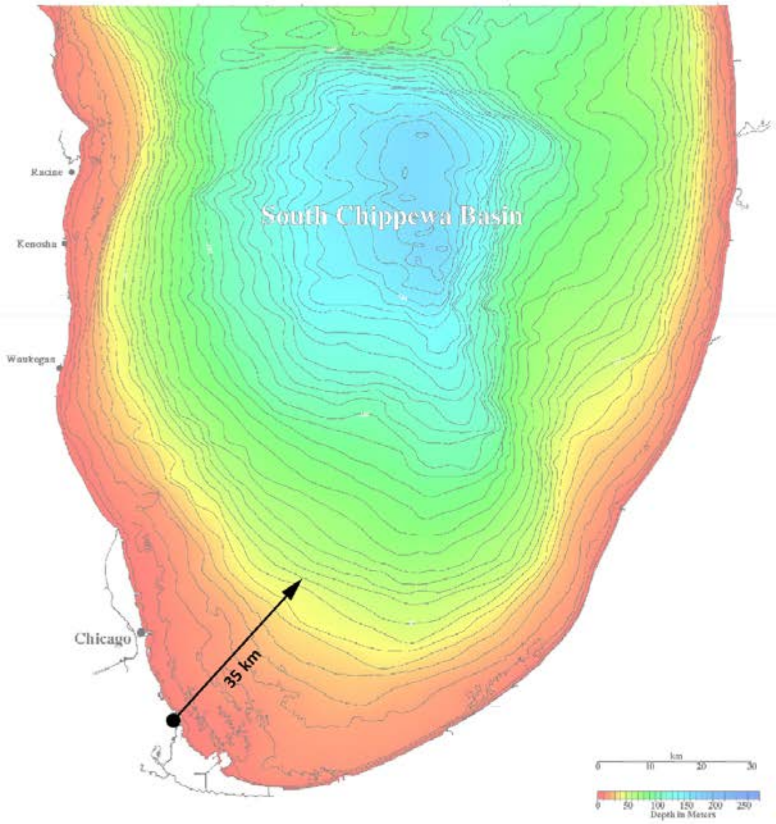
Lake Michigan Cooling Source

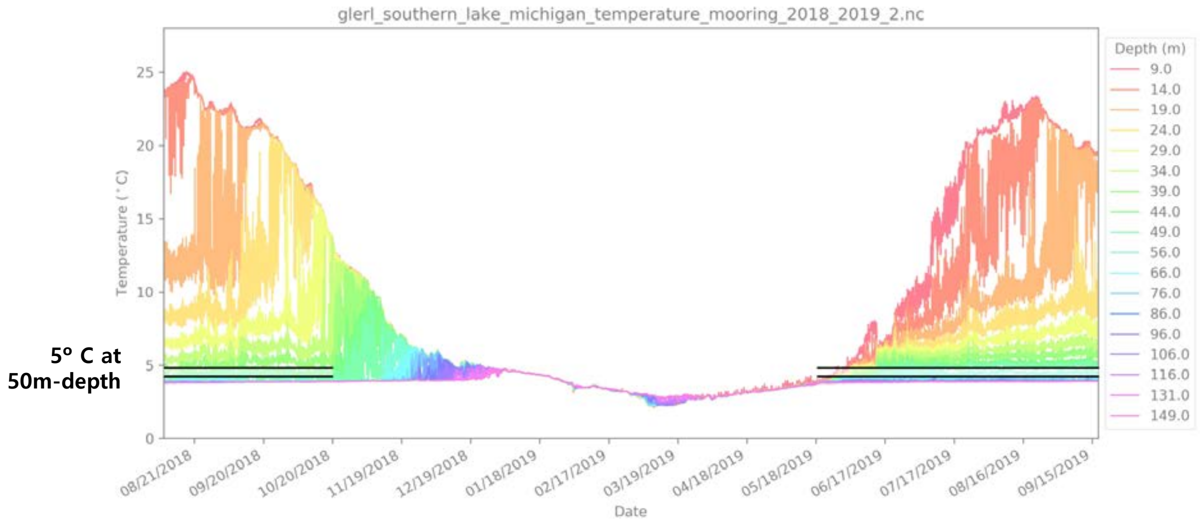
Cooling Potential in Chicago



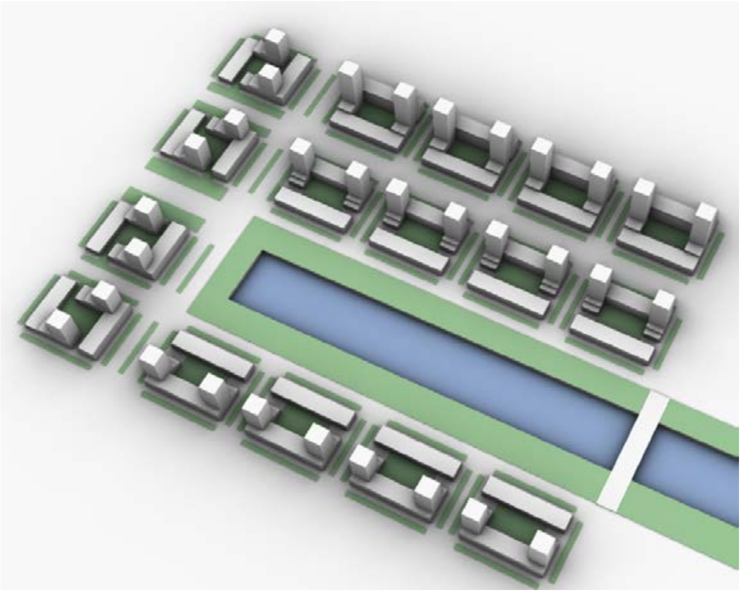


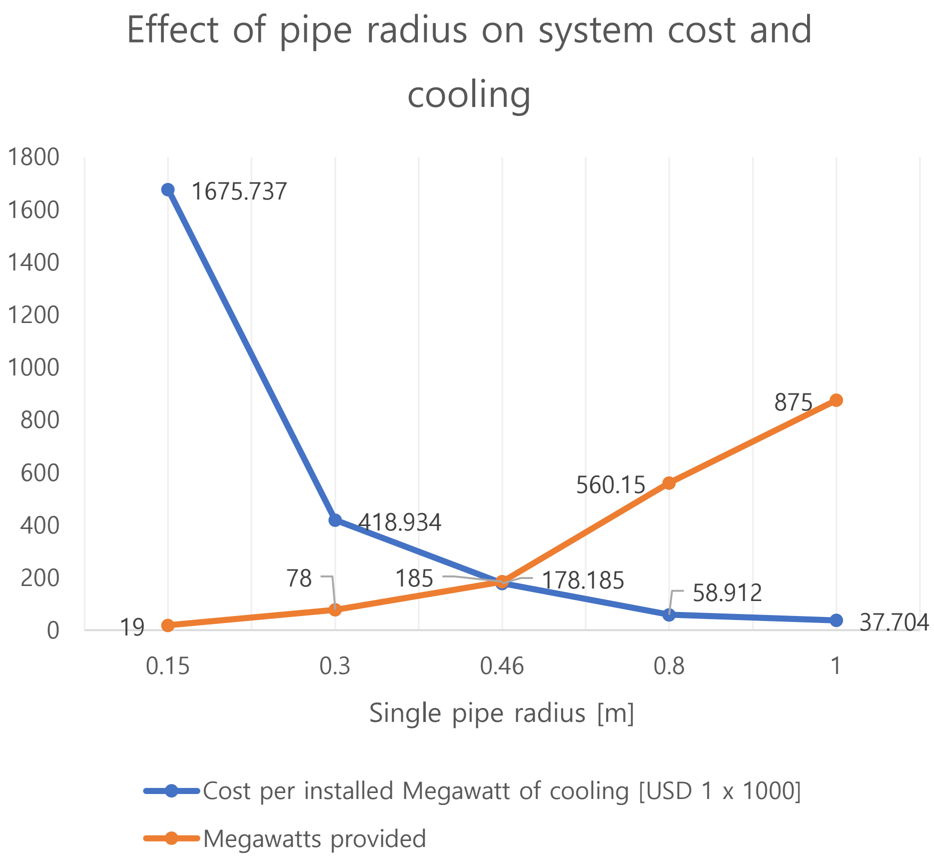
Lake Michigan Cooling Source





Lake Michigan Cooling Source





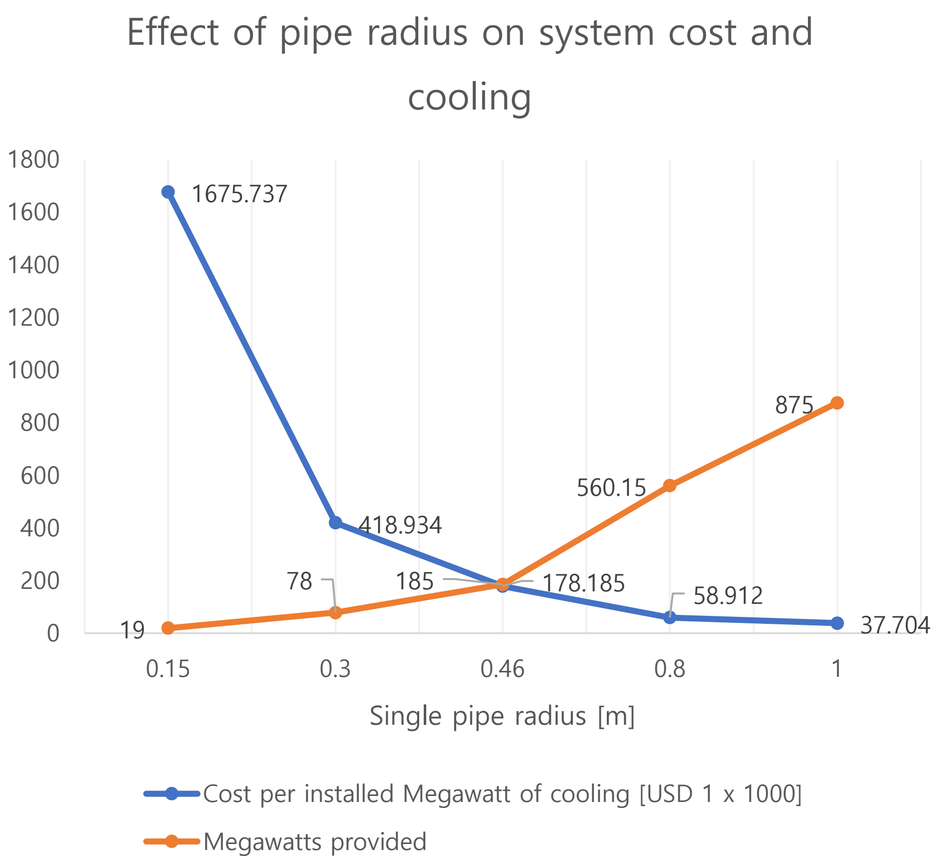
185 MW

Current Peak Cooling Demand

$178,185/MW

To meet the exact cooling demand

Lake Michigan Cooling Source



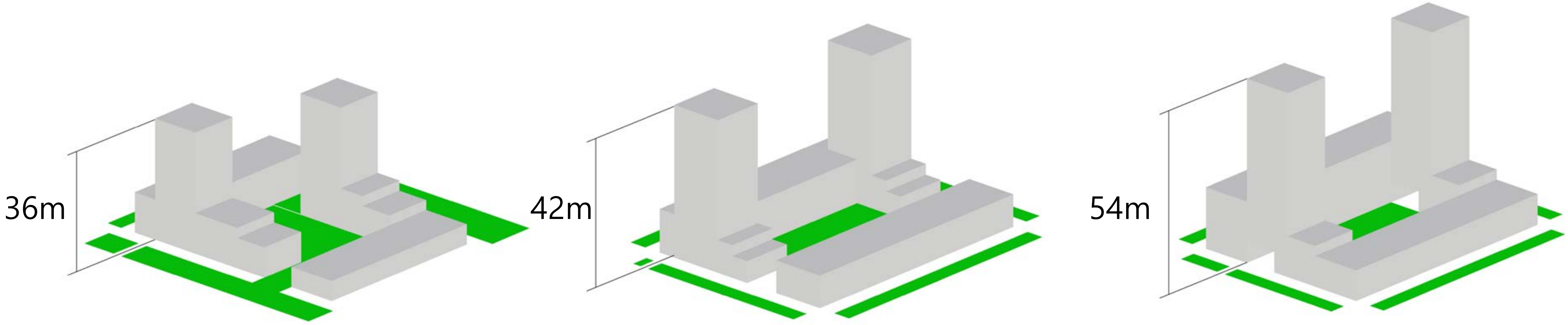
623 MW

Future Peak Cooling Demand

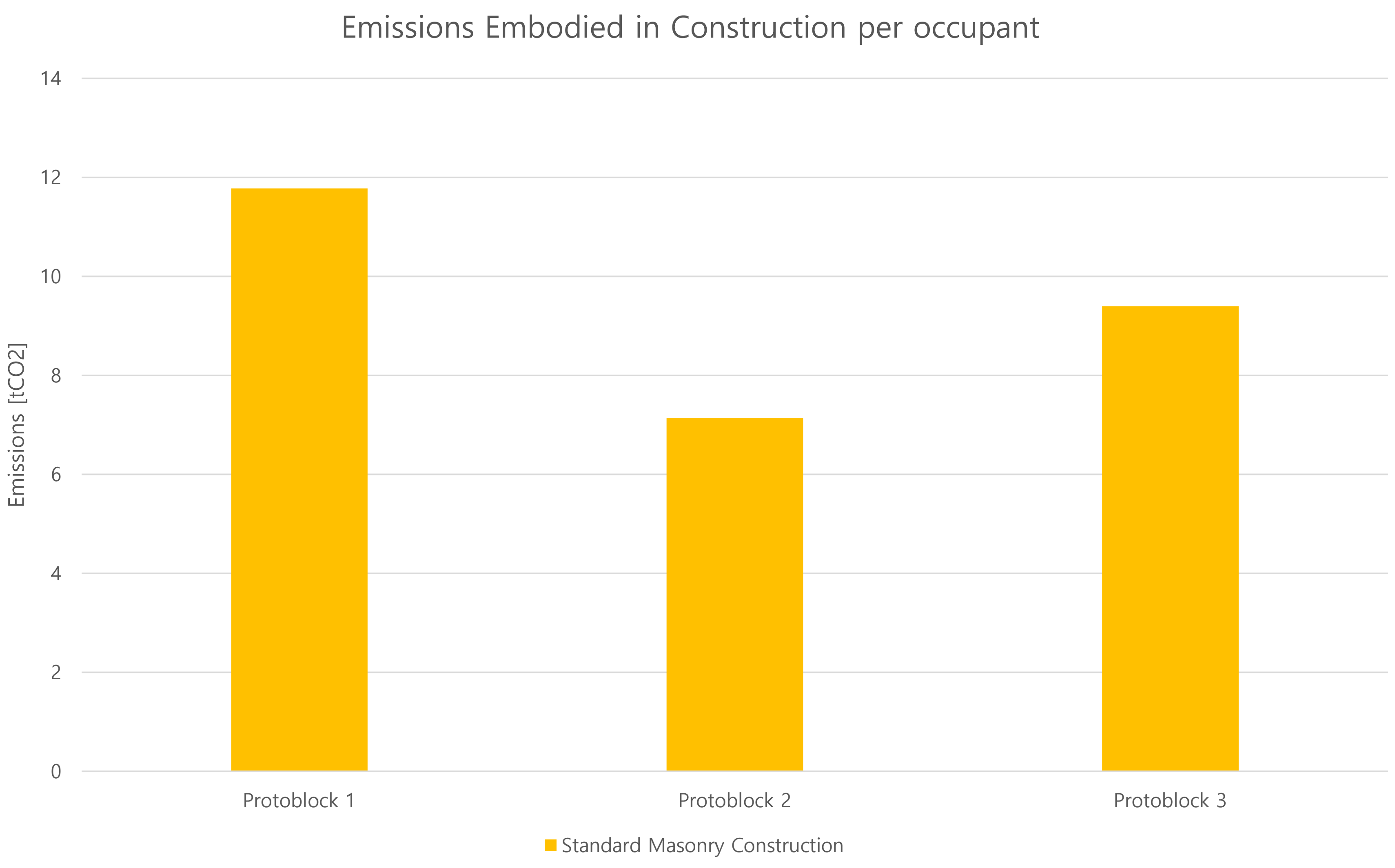
$52,185/MW

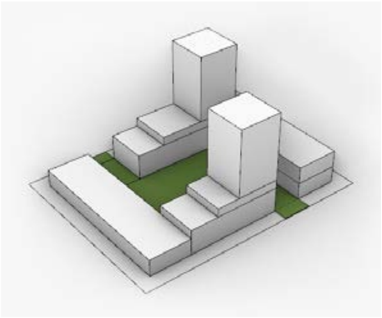
To meet future demand and climate change

Cross-Laminated Timber Analysis

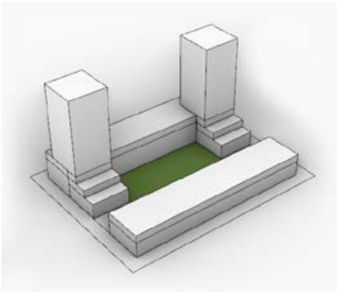


Cross-Laminated Timber Analysis

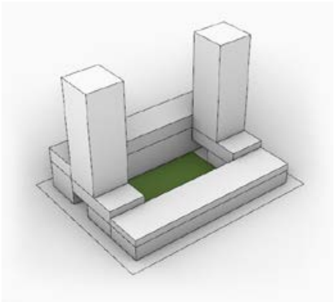




Protoblock 1

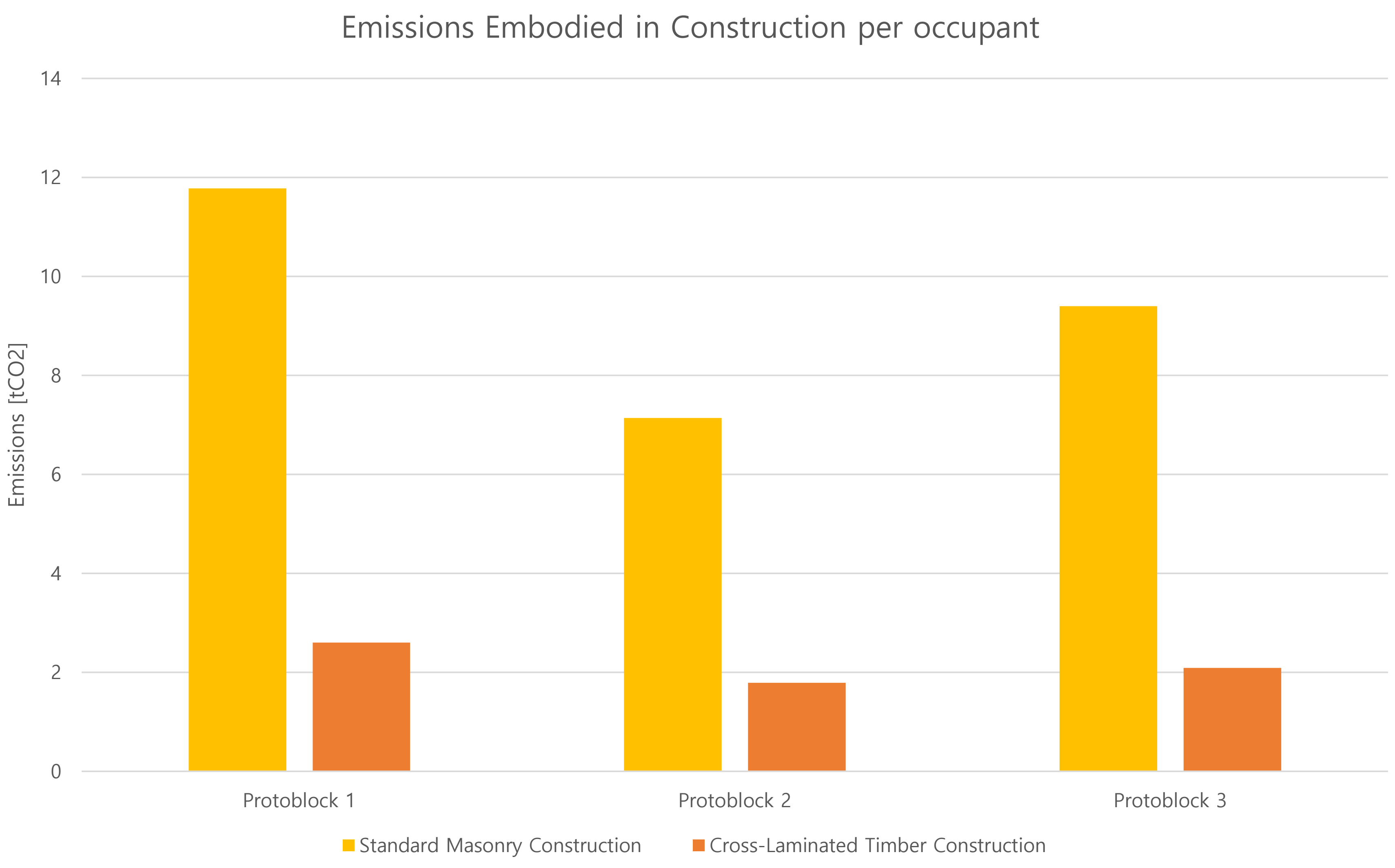


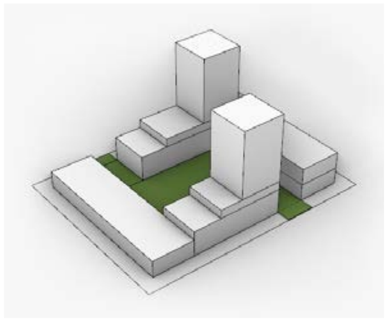
Protoblock 2



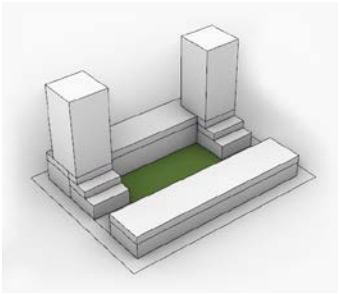
Protoblock 3

Cross-Laminated Timber Analysis

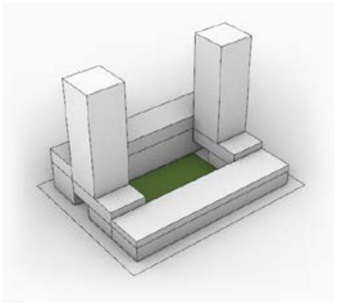




Protoblock 1: 77% reduction



Protoblock 2: 75% reduction



Protoblock 3: 77% reduction

Efficiency

38% Renewable

62% sDA

Connectivity

91/100

92/100

Resiliency

55% reduction in carbon emissions