Regenerative Design:
A Bridge between Sustainability and Resilience

Weeks after Tesla founder Elon Musk and Gov. Ricardo Rossello spoke about the tech company aiding Puerto Rico, Tesla says it has restored electricity to a children's hospital, using solar energy and batteries.

Tesla

CSBR Center for Sustainable Building Research

COLLEGE OF DESIGN
UNIVERSITY OF MINNESOTA

Richard Graves, Center for Sustainable Building Research

College of Design, University of Minnesota

Sustainable Building 2030

MINNESOTA SB 2030

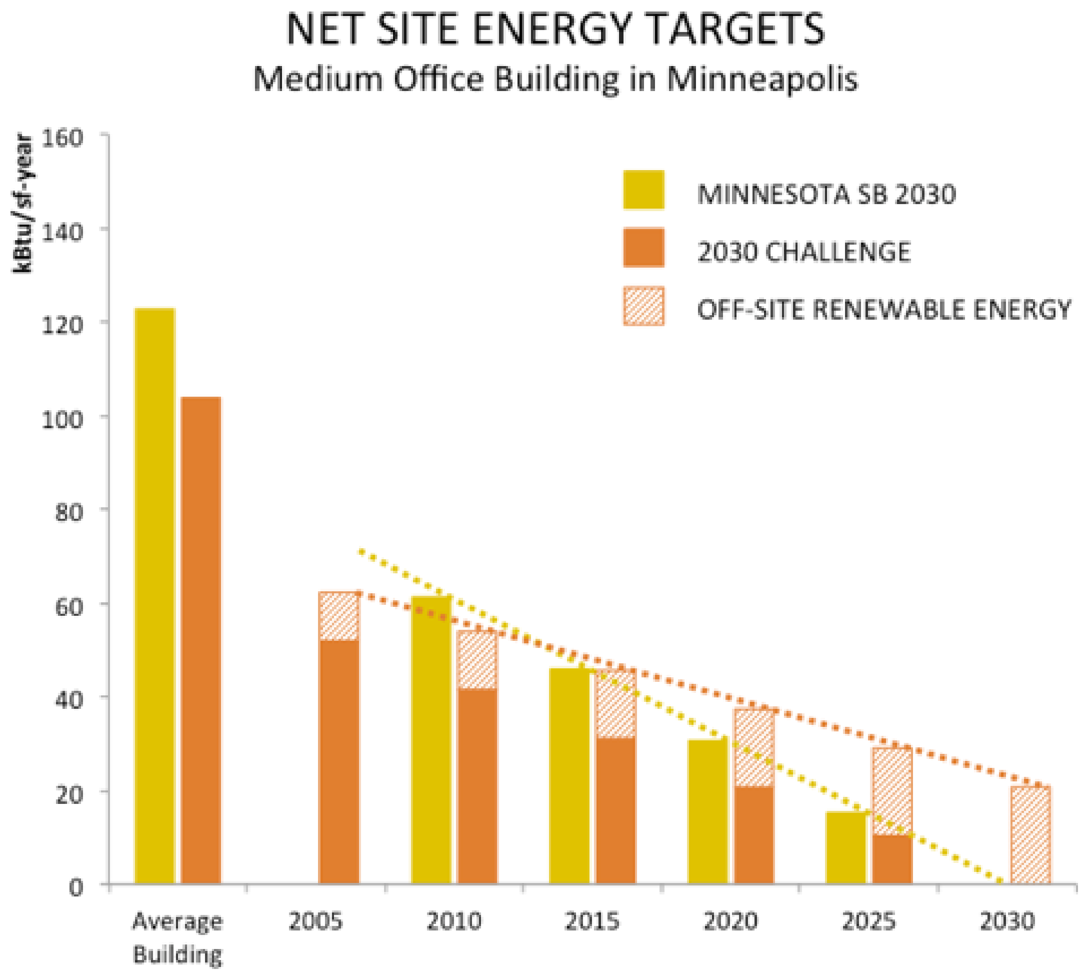
Goal of net-zero energy
Average building:

- Based on the ASHRAE 1989 90.1 Energy Code
- Calculated with the SB 2030 Energy Standard Tool

2030 CHALLENGE

Goal of carbon neutrality
Average building:

- Based on existing building energy use (CBECS 2003 data)
- Calculated with the EPA Target Finder



MINNESOTA SUSTAINABLE BUILDING 2030

CASE STUDY METRICS – www.casestudies.b3mn.org


Bear Head Lake State Park


Hennepin County 911 Facility


BSU Decker Hall Renovation


MnSCU Mankato Clinical Sciences Building


Hamline Station


Tettegouche Visitor Center and Rest Area


Western U Plaza


Kendall's Payne Avenue Hardware


Big Bog State Recreation Area


Minnesota National Guard Winona Armory Renovation


MSU Science Education Building


NHCC Biosciences and Health Careers Center


NCC Academic Partnership Center


SCC Classroom Renovation and Addition


UMM Green Living and Learning Community


BSU Memorial Hall Renovation


Camp Ripley COE Training Facility


Duluth Armory


Maplewood Mall Parking Structure


PTC Entrepreneurship Center and Business Incubator

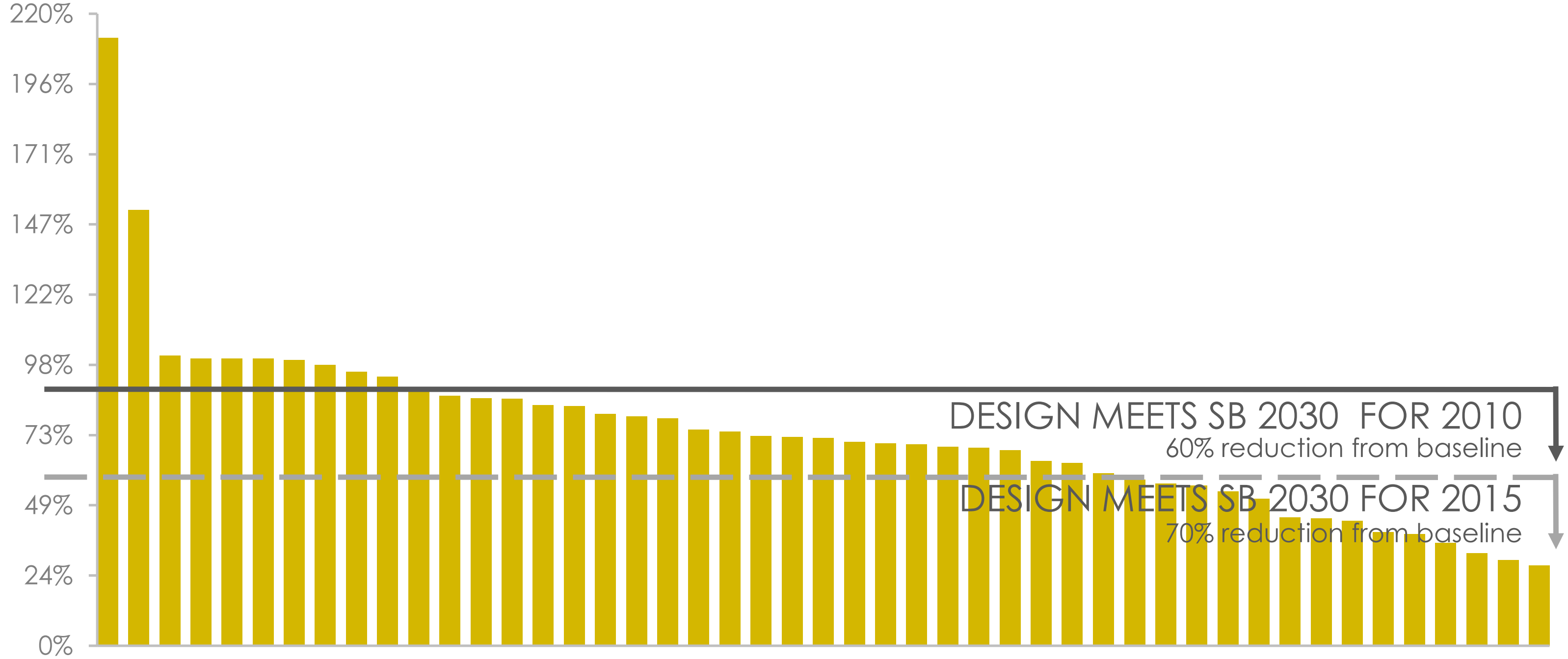

Washburn Center for Children

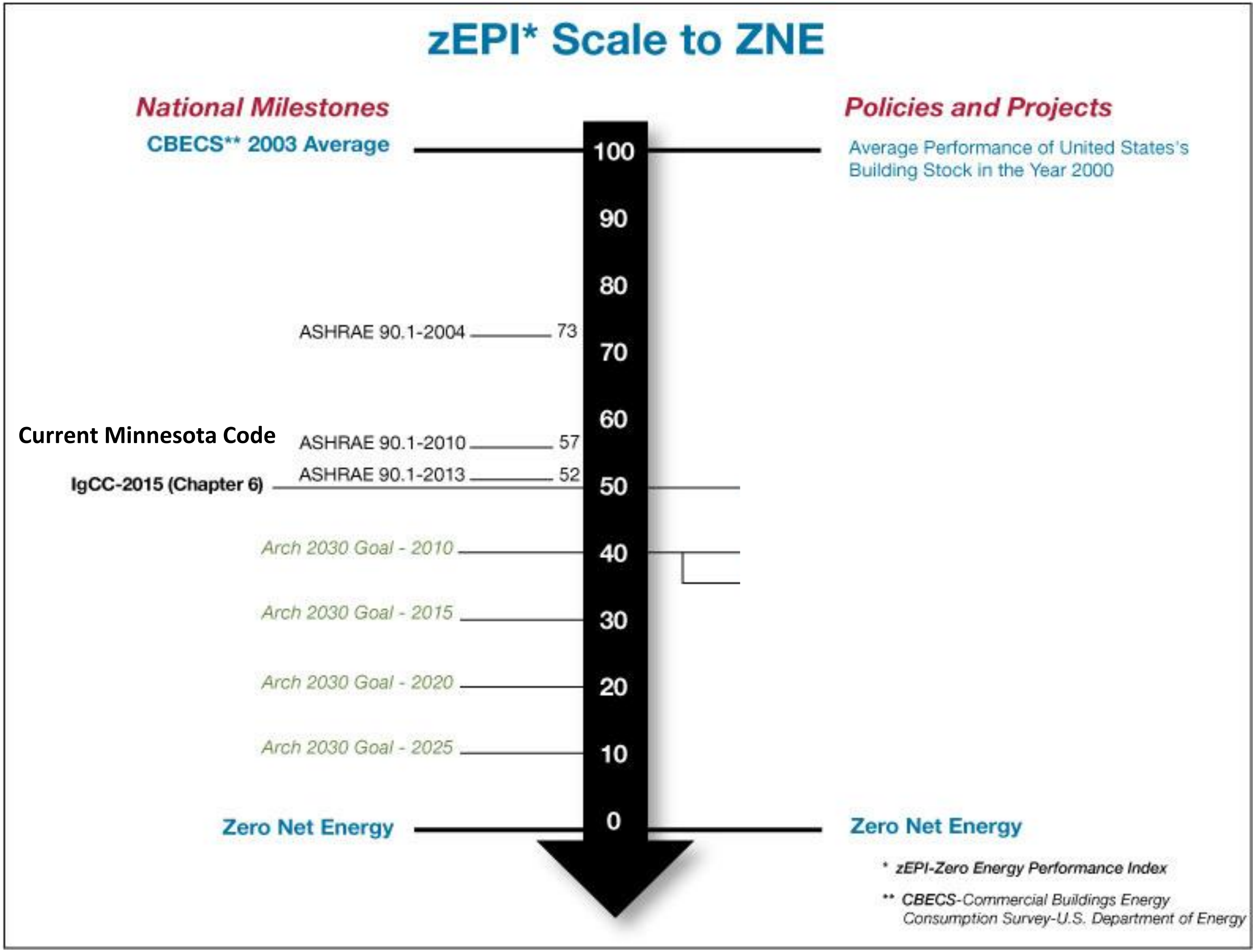

STCC Medium Heavy Truck and Auto Body


Duluth Entertainment and Convention Center


Silver Creek Corner

Results – Energy (design/SB 2030 standard)





zEPI* Scale to ZNE
National Milestones
CBECS** 2003 Average
Policies and Projects
Average Performance of United States's Building Stock in the Year 2000
100
90
80
ASHRAE 90.1-2004
73
70
60
Current Minnesota Code
ASHRAE 90.1-2010
57
ASHRAE 90.1-2013
52
IgCC-2015 (Chapter 6)
50
Arch 2030 Goal - 2010
40
Arch 2030 Goal - 2015
30
Arch 2030 Goal - 2020
20
Arch 2030 Goal - 2025
10
Zero Net Energy
0
Zero Net Energy
* zEPI-Zero Energy Performance Index
** CBECS-Commercial Buildings Energy Consumption Survey-U.S. Department of Energy

IGCC

TABLE 612.1 REFERENCE ANNUAL ENERGY USE INDEX (EUI_r)

CLIMATE ZONE	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
Use and Occupancy[a]	Reference EUI_r skBtu/sf/yr														
Business (B)															
Office	154	159	154	151	140	137	167	144	152	179	155	190	176	208	282
Bank	154	159	154	151	140	137	167	144	152	179	155	190	176	208	282
Medical office (non-diagnostic)	115	118	115	113	104	102	125	108	114	134	116	148	131	156	210
Storage (S-2)															
Distribution/Shipping Center	105	67	69	66	64	55	75	70	66	87	81	104	95	119	186
Mercantile (M)															
Grocery/Food Store	448	476	452	484	450	473	522	479	514	554	511	592	561	633	758
Assembly (A)															
Library (A-3)	234	232	224	230	217	209	254	228	235	275	246	304	277	327	434
Educational (E)															
Elementary/Middle School	140	139	134	134	128	124	149	132	132	160	141	182	161	193	274
Institutional (I-2)															
Hospital/Inpatient Health	417	422	397	408	388	407	425	366	398	425	374	439	394	446	532

a. Use and occupancy as determined by Chapter 3 of the *International Building Code*.

Figure 4 – EUI Reference Table from IGCC 2015

First, define the building's parameters

Building Definition

Unlock

Building Type: Office

Gross Building SF: 176,865 ft²

Location: Minneapolis

Space Asset Areas

+ Add Area | Scale All To Fit | Summary

Retail 1

Type: **Retail**

Area: **26,865 ft²** (15%)

Floors: **1**

Arrangement: **Stacked**

Construction Type: **New**

Edit

Office

Type: **Office**

Area: **150,000 ft²** (85%)

Floors: **5**

Arrangement: **Stacked**

Construction Type: **New**

Edit

Exterior Lighting

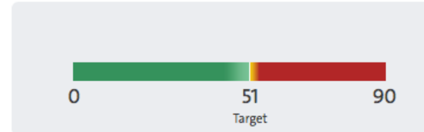
Parking Area Illuminated: 0 ft²

Number of Main Entrances: 1

Number of Secondary Entrances: 1

Exterior Wall Area Illuminated: 0 %

Annual SB 2030



Energy Standard (kBtu/ft²/yr)

Target (based on 70% reduction) **51**

Carbon Dioxide (lbs CO2/ft²/yr)

Target (based on 70% reduction) **15**

Building

Project Name .... **DLI**

Building Type .... **Office**

Gross Building SF **176,865**

Organization .... **CSBR**

Location .... **Minneapolis**

Space Asset Areas

Retail 1

Type: **Retail**

Area: **26,865 ft²** (15%)

Floors: **1**

Arrangement: **Hosted**

Construction Type: **New**

Cooling: **Not District**

Heating: **Not District**

Office

Type: **Office**

Area: **150,000 ft²** (85%)

Floors: **4**

Arrangement: **Adjacent**

Construction Type: **Renovated**

Cooling: **Not District**

Heating: **Not District**

Exterior Lighting

Parking Area Illuminated **0**

Number of Secondary Entrances **0**

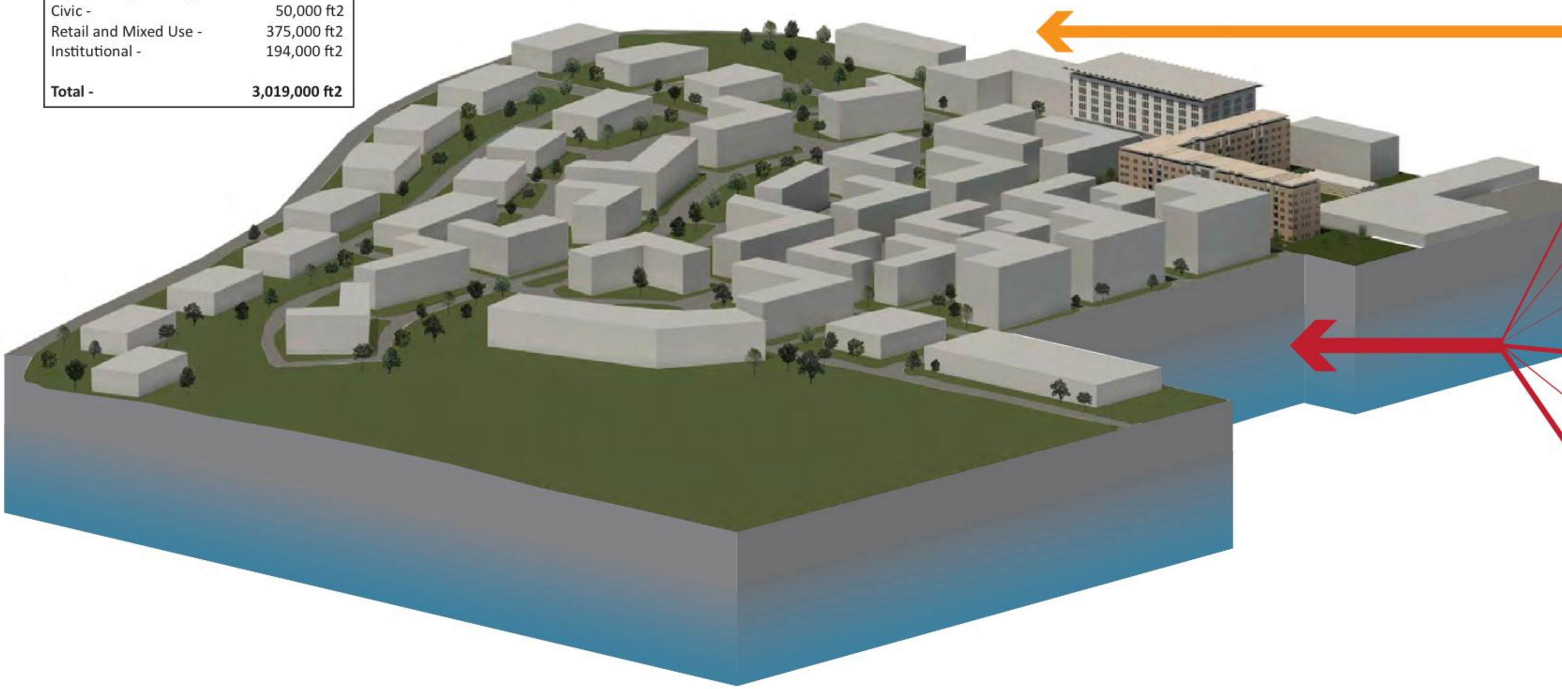
Number of Main Entrances **0**

Exterior Wall Area Illuminated **0**

Code-Based Buildings - ASHRAE 90.1 2010
2015 Energy Grid

Built Up Area:	
Low Density Housing -	534,000 ft2
Med Density Housing -	1,296,000 ft2
High Density Housing -	570,000 ft2
Civic -	50,000 ft2
Retail and Mixed Use -	375,000 ft2
Institutional -	194,000 ft2
Total -	**3,019,000 ft2**

Total Energy Use:
60,984 MWh / year



Natural Gas Imported
21,344,682,557 kWh / year
35% of Total Energy

Electricity Imported
39,640,124,749 kWh / year
65% of Total Energy
Wind Generated - 15%
Hydro Generated - 6%
Biomass Generated - 4%
Nuclear Generated - 30%
Natural Gas Generated - 8%
Coal Generated - 37%

Code-Based Buildings - ASHRAE 90.1 2010
2030 Energy Grid

Total Energy Use:
60,984 MWh / year

Built Up Area:	
Low Density Housing -	534,000 ft2
Med Density Housing -	1,296,000 ft2
High Density Housing -	570,000 ft2
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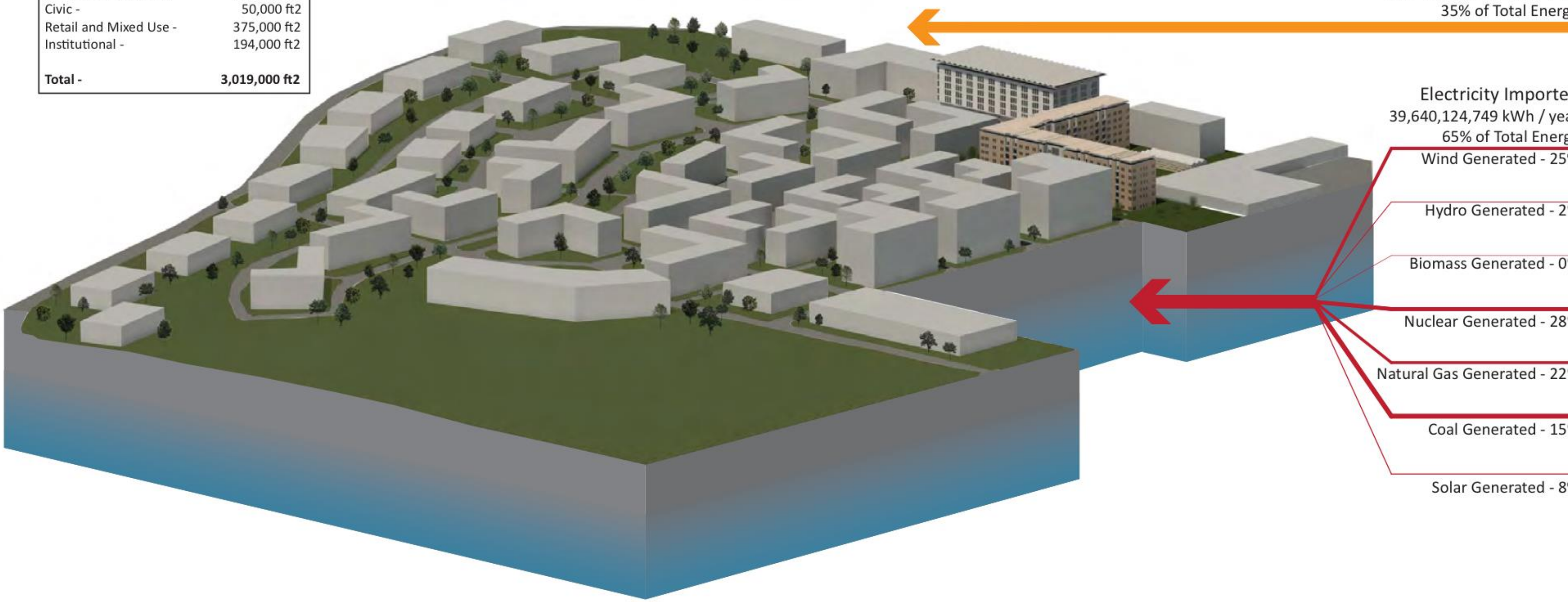


Estimated Site Energy Utilization Intensity (EUI) for different new building types in climate zone 6A (St. Paul) using different energ codes or certification systems.

Krifcon
Sustainable Consulting

COMPARATIVE SITE EUI

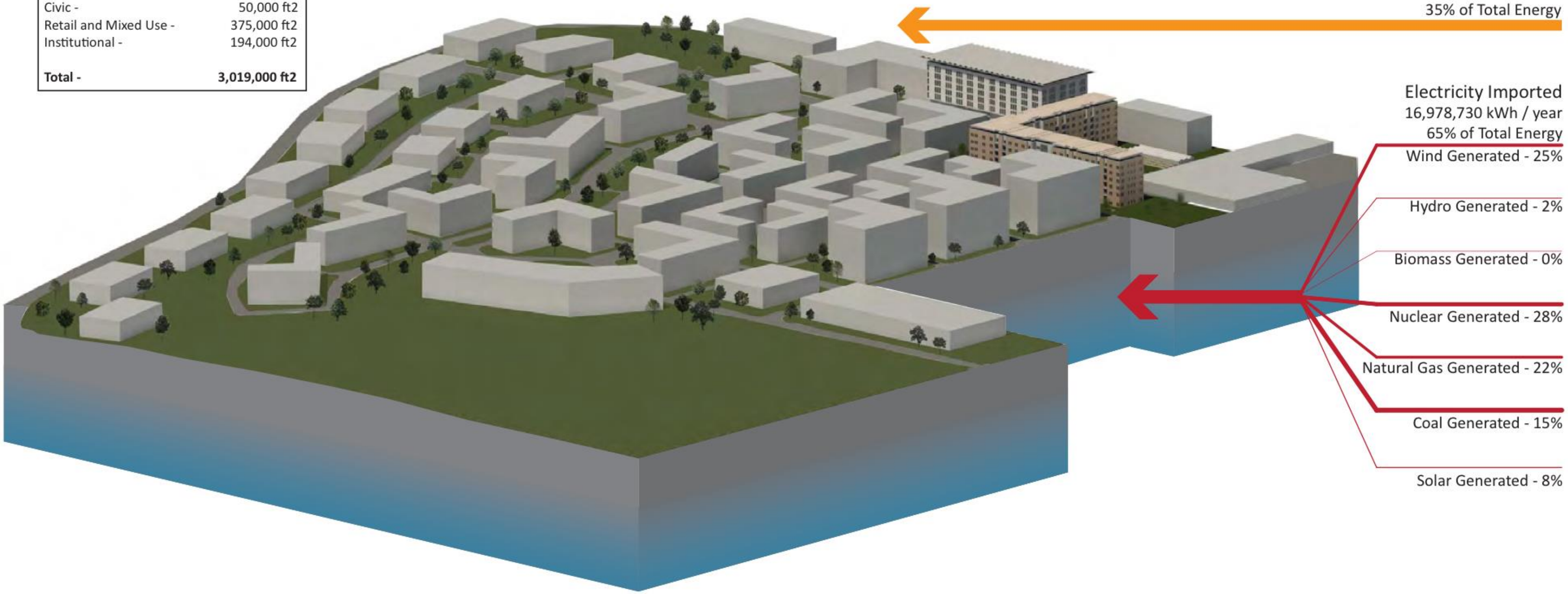
kBtu/ft²/yr

Code / Building Type	Prototype Floor Area (sf)	~ Current MN Energy Code ASHRAE 90.1-2004	2012 IECC / ASHRAE 90.1-2010	2015 IECC / ASHRAE 90.1-2013	SB 2030 (2010) -60%	SB 2030 (2015) -70%	SB 2030 (2020) -80%	SB 2030 (2025) -90%	German Passive House System	Danish Building Code BR 2010	Danish Building Code Class 2015	Danish Building Code Class 2020
Small office	5,502	53.7	41.8	37.2	63.0	47.3	31.5	15.8	14.3	37.1	25.8	18.7
Medium office	53,628	62.2	46.2	42.8	62.0	46.5	31.0	15.5	14.3	36.1	25.2	18.7
Large office	498,588	99.7	84.8	83.5	60.0	45.0	30.0	15.0	14.3	36.1	25.1	18.7
Stand-alone retail	24,692	107.2	71.9	61.9	59.0	44.3	29.5	14.8	14.3	36.3	25.2	18.7
Strip mall retail	22,500	118.3	85.4	77.9	60.0	45.0	30.0	15.0	14.3	36.3	25.3	18.7
Supermarket	n/a	208.0	145.0	128.7	119.0	89.3	59.5	29.8	14.3	36.0	25.1	18.7
Primary school	73,959	100.1	75.1	67.8	70.0	52.5	35.0	17.5	14.3	36.1	25.1	18.7
Secondary school	210,887	98.4	64.7	56.2	60.0	45.0	30.0	15.0	14.3	36.1	25.1	18.7
Hospital	241,501	179.9	138.5	130.5	79.0	59.3	39.5	19.8	14.3	36.1	25.1	18.7
Outpatient health care	40,946	161.5	123.3	118.8	52.0	39.0	26.0	13.0	14.3	36.2	25.2	18.7
Full-service restaurant	5,502	570.2	470.9	450.8	90.0	67.5	45.0	22.5	14.3	37.1	25.8	18.7
Quick-service restaurant	2,501	781.9	723.0	689.6	98.0	73.5	49.0	24.5	14.3	38.3	26.6	18.7
Small hotel	43,202	87.4	75.8	71.5	50.0	37.5	25.0	12.5	14.3	28.5	19.6	15.0
Large hotel	122,120	151.8	119.1	109.4	63.0	47.3	31.5	15.8	14.3	28.5	19.5	15.0
Warehouse	52,045	35.3	25.2	23.6	42.0	31.5	21.0	10.5	14.3	36.2	25.2	18.7
Mid-rise apartment	33,741	68.0	60.4	57.3	82.0	61.5	41.0	20.5	14.3	28.6	19.6	15.0
High-rise apartment	84,360	72.1	65.8	61.2	88.0	66.0	44.0	22.0	14.3	28.5	19.5	15.0

SB2030 80% Better Buildings
2030 Energy Grid

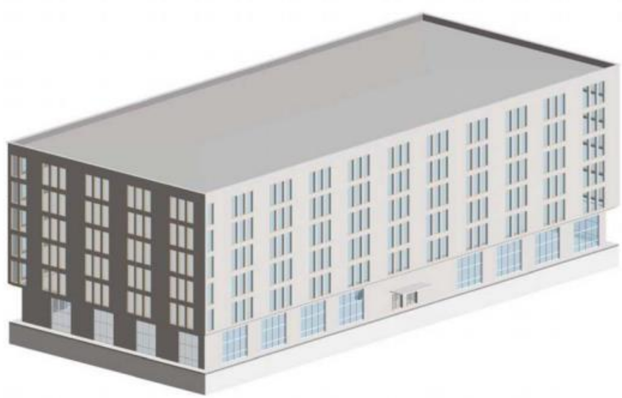
Built Up Area:	
Low Density Housing -	534,000 ft2
Med Density Housing -	1,296,000 ft2
High Density Housing -	570,000 ft2
Civic -	50,000 ft2
Retail and Mixed Use -	375,000 ft2
Institutional -	194,000 ft2
Total -	**3,019,000 ft2**

Total Energy Use:
26,121 MWh / year
57% Reduction



OFFICE PROTOTYPE

IMPROVED CASE - BY THE NUMBERS
Office and Retail



BUILDING DETAILS
176,865 Total SF
26,865 Retail SF on 1st Floor
30,000 Office SF on 2nd-6th Floor
30,000 Roof SF

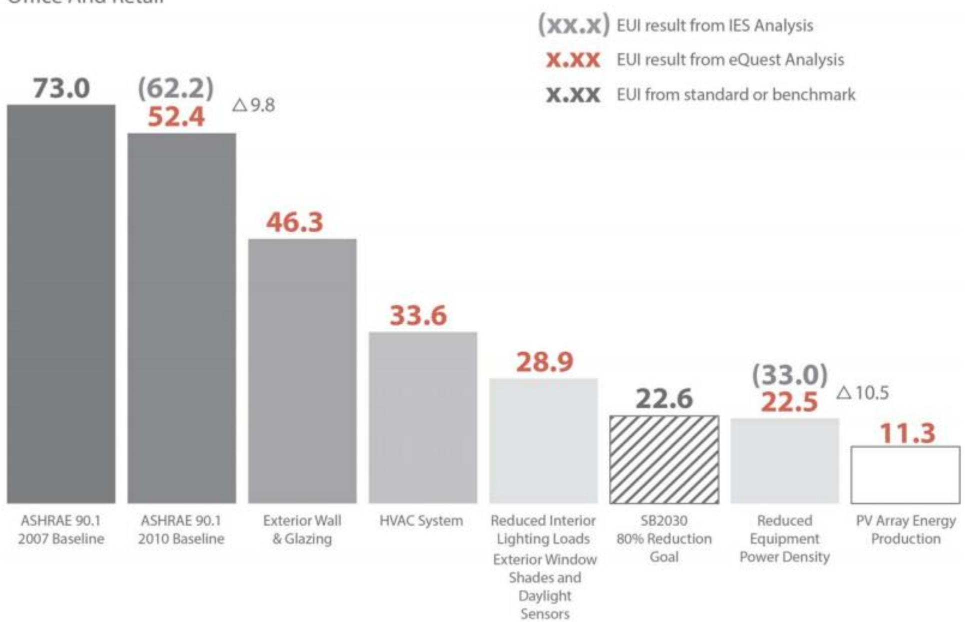
ENERGY PERFORMANCE
22.5 kBtu/sf/yr EUI
610,837 kW Photovoltaic Array

WATER USE
72% of Potable Water Demand met by Rainfall
6.3 Gallon Demand per Person per Day

VALUE
$000 / SF Baseline
$000 / SF Net Zero Energy
$000 / SF Net Zero Water
$000 / SF Living Building Challenge

MAJOR DESIGN STRATEGIES
88% Potable Water Demand Reduction
Rainwater capture & Greywater reuse
Increased R Values for Walls & Roof
Improved Glazing Performance
Improved HVAC system and efficiency
Lighting Power Densities reduced 50%
Equipment Power Density Reduced 40%

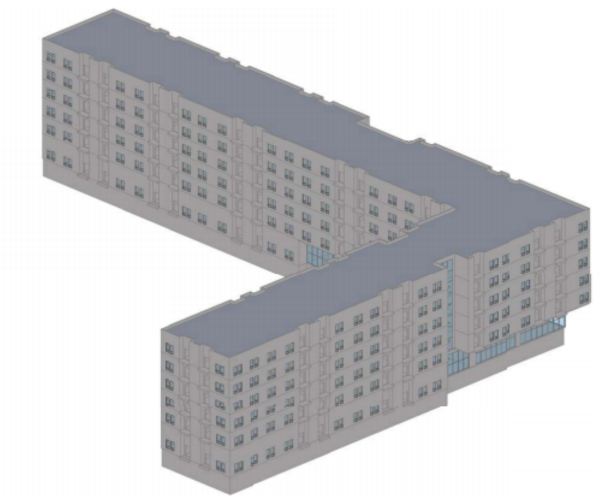
IMPROVED CASE - ENERGY USE
Office And Retail



EUI = Energy Use Intensity measured in kBtu/sf/yr

RESIDENTIAL PROTOTYPE

IMPROVED CASE - BY THE NUMBERS
Multi Family and Retail



BUILDING DETAILS
219,096 Total SF
7,658 Retail SF on 1st Floor
187 Units on 1st-6th Floor
37,073 Roof SF

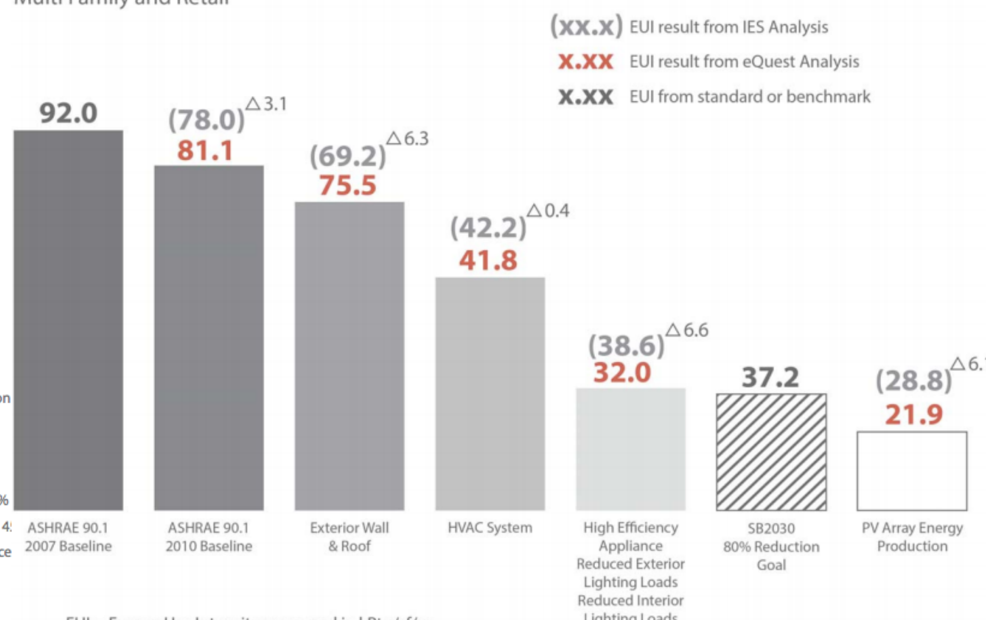
ENERGY PERFORMANCE
38.2 kBtu/sf/yr EUI
511,870 kW Photovoltaic Array

WATER USE
35% of Potable Water Demand met by Rainfall
18.13 Gallon Demand per Person per Day

VALUE
$000 / SF Baseline
$000 / SF Net Zero Energy
$000 / SF Net Zero Water
$000 / SF Living Building Challenge

MAJOR DESIGN STRATEGIES
53% Potable Water Demand Reduction
Rainwater capture & Greywater reuse
Increased R Values for Walls & Roof
Improved Glazing Performance
Lighting Power Densities reduced 20%
Lights dim when daylighting reaches 4
Orientation optimized for performance

IMPROVED CASE - ENERGY USE
Multi Family and Retail



EUI = Energy Use Intensity measured in kBtu/sf/yr

MID-RISE APARTMENT BUILDING PROTOTYPE | PHIUS - WUFI PASSIVE

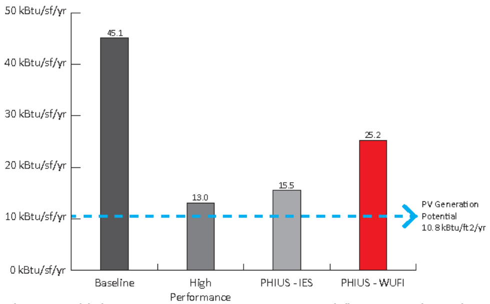


Figure 1: Mid-rise Apartment Prototype Energy Modeling Comparison. The prototype was modeled in IES (in grey) and PHIUS - WUFI Passive (red) software. WUFI Passive outcomes show a more conservative estimate of energy use intensity 25.2 compared to 15.5.

PASSIVEHOUSE REQUIREMENTS

Certificate criteria: **PHIUS+ 2015 Standard**

Heating demand			
specific:	**3.86**	kBtu/ft²yr	✓
target:	**6.9**	kBtu/ft²yr	
total:	206119.88	kBtu/yr	
Cooling demand			
specific:	**2.74**	kBtu/ft²yr	✓
target:	**3.1**	kBtu/ft²yr	
total:	146114.39	kBtu/yr	
latent:	0.65	kBtu/ft²yr	
Heating load			
specific:	**4.46**	Btu/hr ft²	✓
target:	**5.6**	Btu/hr ft²	
total:	237962.1	Btu/hr	
Cooling load			
specific:	**2.45**	Btu/hr ft²	✓
target:	**4.3**	Btu/hr ft²	
total:	130709.33	Btu/hr	
Primary energy			
specific:	**6751**	kWh/Person yr	✗
target:	**6200**	kWh/Person yr	
total:	3109264.18	kBtu/yr	
Site energy			
total:	25.2	kBtu/ft²yr	
building systems:	44.09	kBtu/yr	
photovoltaic savings:	0	kBtu/ft²yr	
Air tightness			
ACH50:	**0.3**	1/hr	✓
target:	**0.3**	1/hr	
CFM50 per envelope area:	**0.05**	cfm/ft²	
target:	**0.05**	cfm/ft²	

Figure 2: Passive House Performance Requirements. The project as modeled meets six of the seven WUFI Passive house performance thresholds. The exception being Primary Energy, which the project exceeds by 8%. However, the project does very well on space conditioning on both the load and demand criteria. Onsite renewables generate 10.8 kBtu/sf/yr (Figure 5) compared to the WUFI Passive modeling predicted EUI is 25.2 kBtu/sf/yr a 60% shortfall.

PROJECT INFORMATION

Mid-Rise Prototype
41 Units: 2, 3 BR
135 Residents
11.7 DHW gpd/person@140F
19.9 cfm/person continuous ventilation (0.3 ACH)

Area

Conditioned Floor Area (iCFA)
53,340 ft2
Roof: 14,093 ft2
Exterior Wall: 18,507 ft2
Window & glass doors: 6,741 ft2
Opaque Doors: 0 ft2
Window to Wall ratio: 36.4%
Surface area/volume ratio: 0.09

Location and Climate

Minneapolis, Minnesota
Climate Zone 6
HDD: 8217
CDD: 831

SPECIFICATIONS

Passive House Equipment

Variable Refrigerant Flow (VRF)
Heating COP: 2.5
Cooling COP: 5
Ventilation:
80% SRE heat recovery and 0.7 W/cfm
Lighting Power Density:
0.05 - 0.6 W/ft2
Equipment Power Density:
0.0 - 1.11 W/ft2
Nat. Gas Storage Water Heater:
480g, 0.95EF

Passive House Envelope

Roof: R-96
Wall: R-45
Floor slab: R-16
Whole-window U-0.21, SHGC-0.25
Curtainwall U-0.33
SHGC-0.25
Infiltration: 0.05 cfm50/sf
(0.30 ACH50)

MID-RISE APARTMENT BUILDING PROTOTYPE | PHIUS- IES

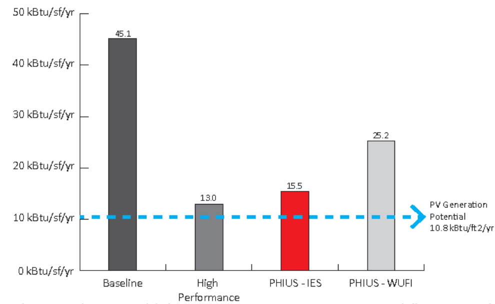


Figure 3: Figure 1: Mid-rise Apartment Prototype Energy Modeling Comparison. The prototype was modeled in IES and PHIUS - WUFI Passive software. This was done by adapting the WUFI Passive model inputs for IES. The PHUIS compliant IES model show above in red has a predicted EUI of 15.5 kBtu/sf/yr, compared to 25.2 kBtu/sf/yr from the WUFI Passive model. The discrepancy between modeling is likely due in part, to how each project calculates equipment efficiencies. In addition, IES does not estimate air-tightness and ACH in a readily verifiable manner.

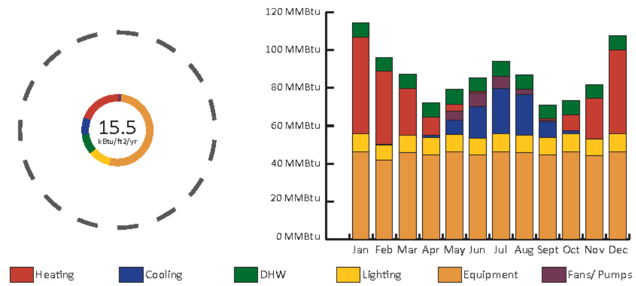


Figure 4: EUI and Energy Load Distribution. Major reduction in heating and cooling loads result in the primary loads of the high performance building shifting to equipment and plug loads associated with in unit end uses.

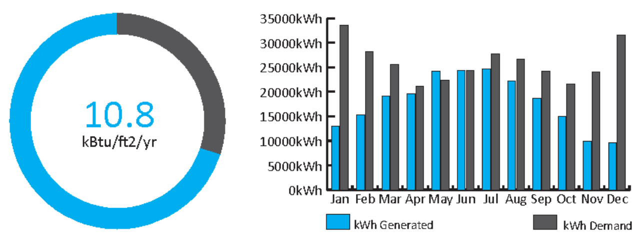


Figure 5: Renewable Energy Generation. Onsite renewables generate 10.8 kBtu/sf/yr compared to the IES modeled energy use intensity of 15.5 kBtu/sf/yr, resulting in an energy deficit of 30% (IES).

PROJECT INFORMATION

Mid-Rise Prototype
52 Units, 2, 3BR
170 Residents
11.7 DHW gpd/person@140F
17.5 cfm/person, continuous ventilation

Area

Floor: 67,845 ft2
Roof: 13,673 ft2
Exterior Wall: 27,637 ft2
Opening: 7,698 ft2
WWR: 27.8
Surface Area / Volume Ratio: 0.07

Location and Climate

Minneapolis, Minnesota
Climate Zone 6
HDD: 8217
CDD: 831

SPECIFICATIONS

Passive House Equipment

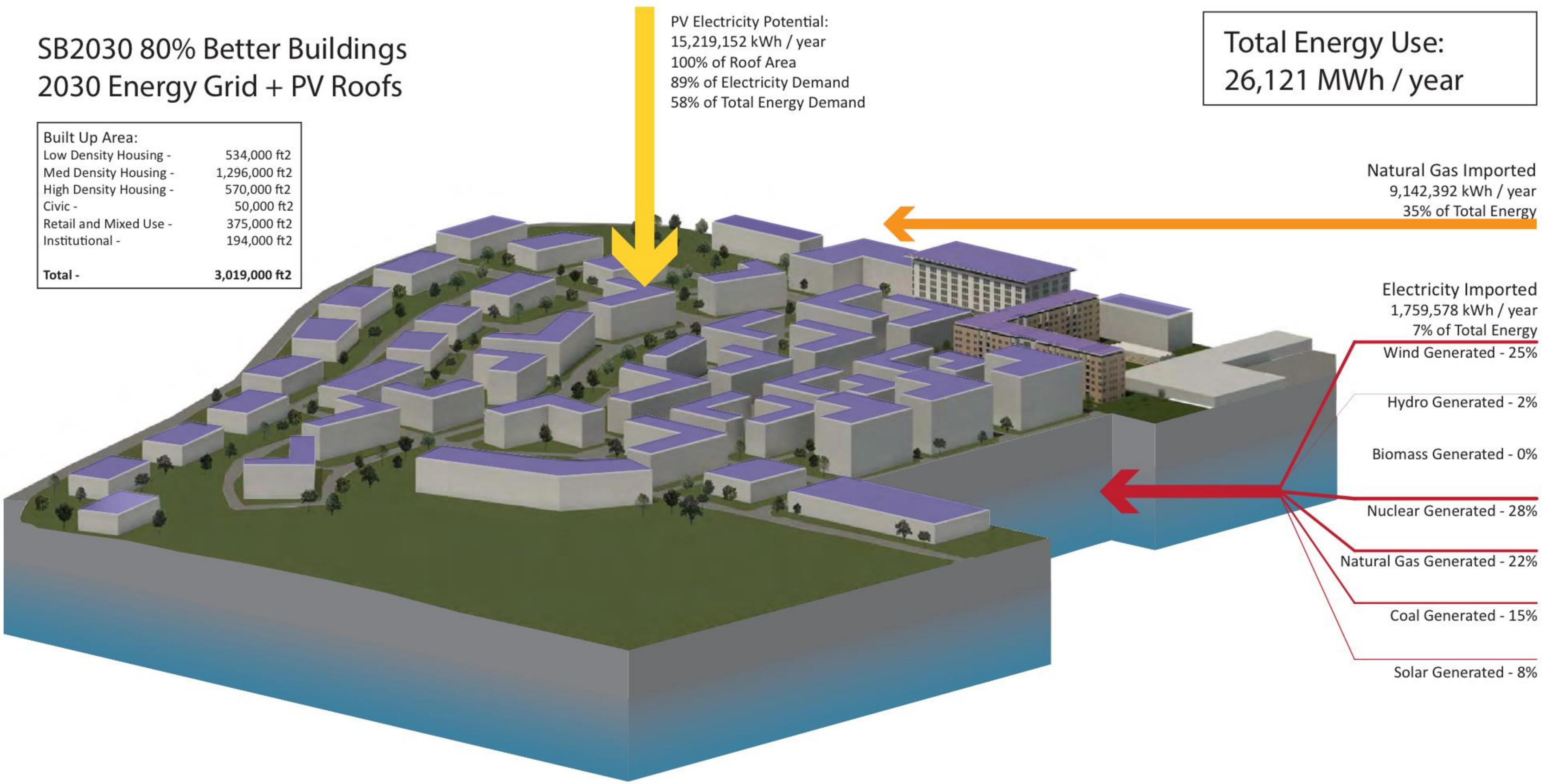
VRF System
Heating CoP: 2.5
Cooling CoP: 5
Natural Gas Hot Water Heater, 0.95 EF, 480.0 Gal Storage
80% Efficient Energy Recovery
Lighting Power Density:
0.05 - 0.60 w/ft2
Equipment Power Density:
0.0 - 1.11 w/ft2

Passive House Envelope

Roof: R-96
Wall: R-46
Glazing:
Whole Window U-0.241, SHGC 0.4
Slab: R-16
Infiltration: 0.3 ACH50

SB2030 80% Better Buildings
2030 Energy Grid + PV Roofs

Built Up Area:	
Low Density Housing -	534,000 ft2
Med Density Housing -	1,296,000 ft2
High Density Housing -	570,000 ft2
Civic -	50,000 ft2
Retail and Mixed Use -	375,000 ft2
Institutional -	194,000 ft2
Total -	**3,019,000 ft2**



SB2030 80% Better Buildings
Renewable Energy Grid + PV Roofs

Total Energy Use:
26,121 MWh / year

Built Up Area:	
Low Density Housing -	534,000 ft2
Med Density Housing -	1,296,000 ft2
High Density Housing -	570,000 ft2
Civic -	50,000 ft2
Retail and Mixed Use -	375,000 ft2
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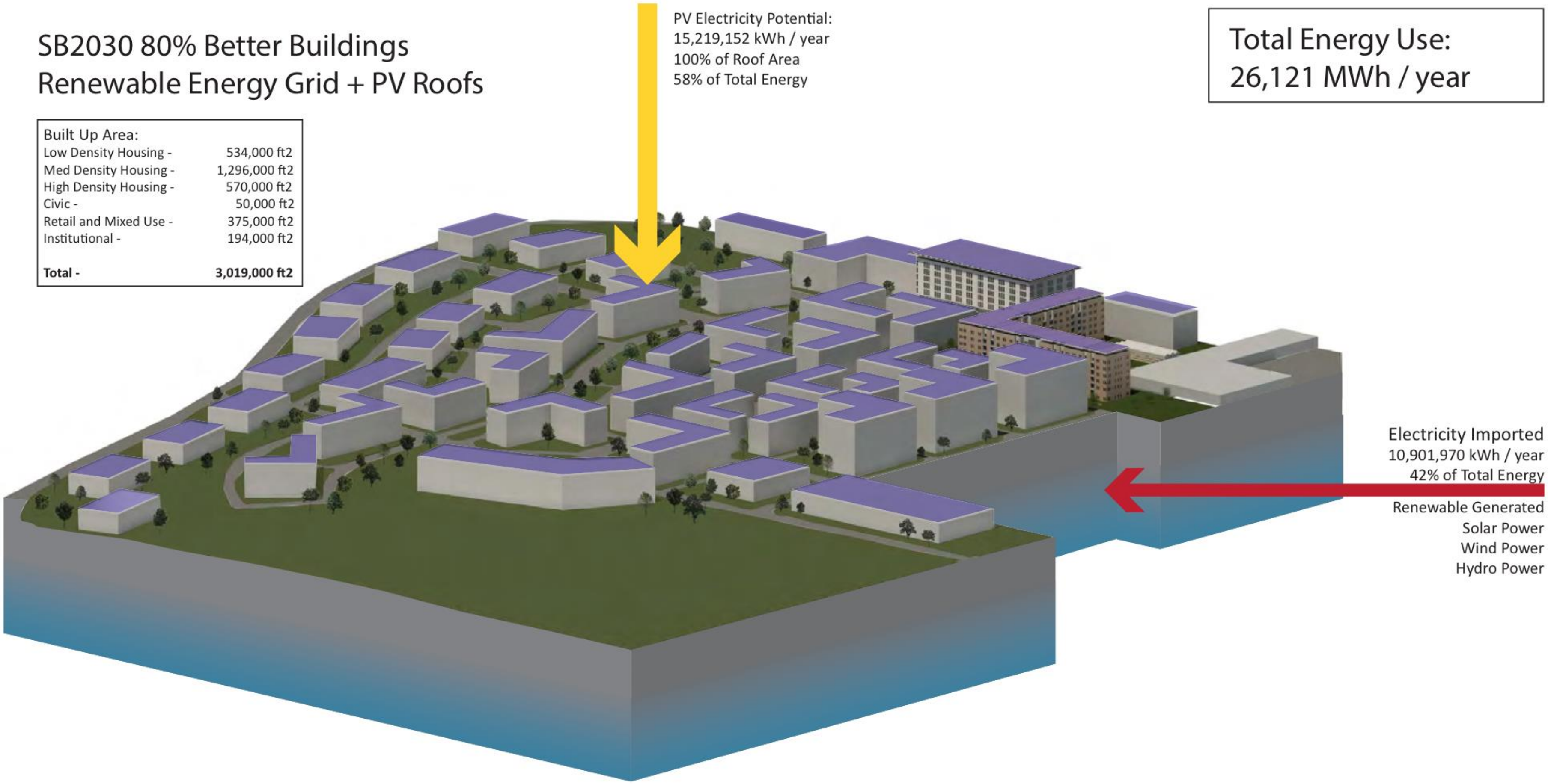


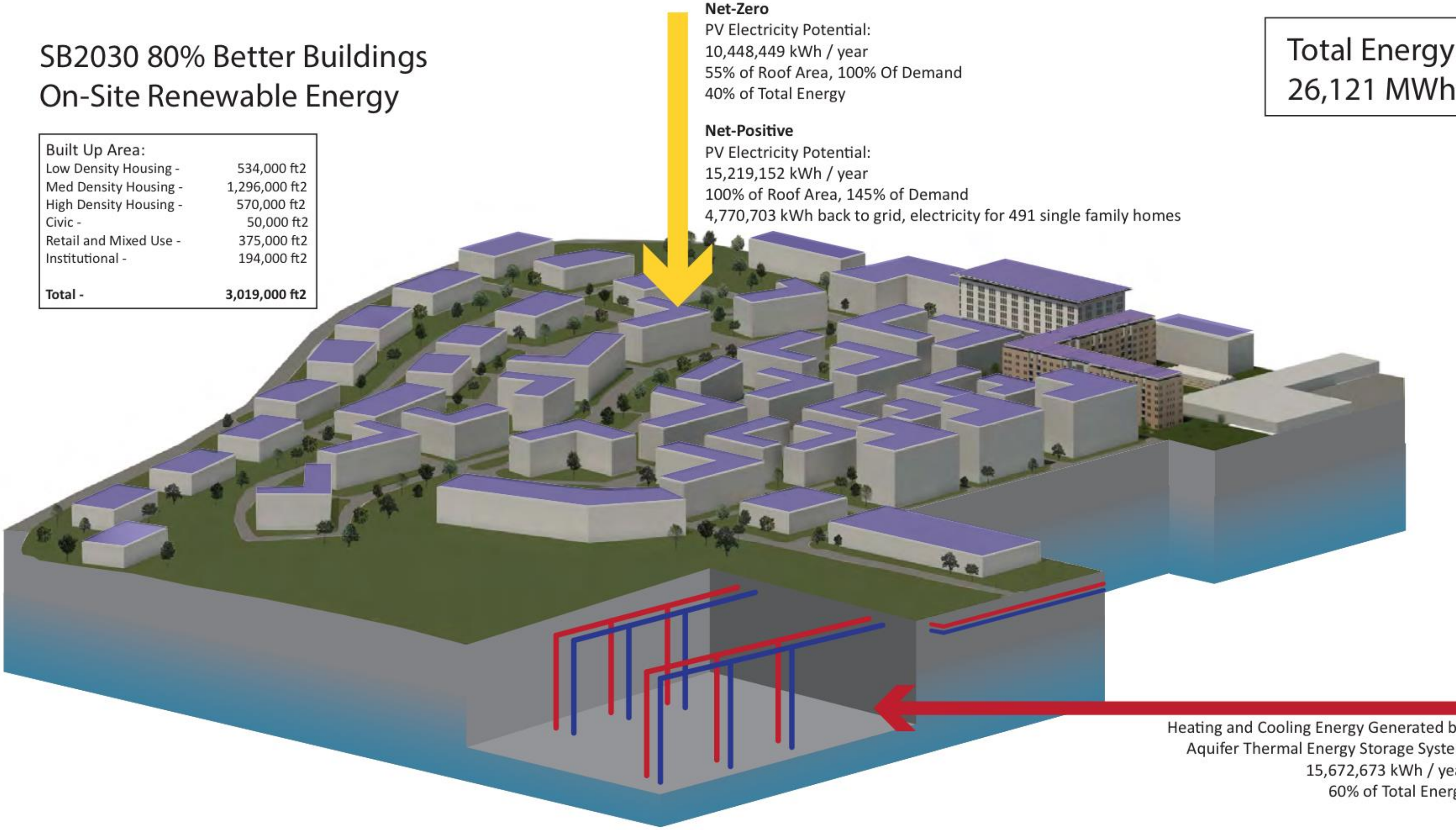
SB2030 80% Better Buildings
On-Site Renewable Energy

Built Up Area:	
Low Density Housing -	534,000 ft2
Med Density Housing -	1,296,000 ft2
High Density Housing -	570,000 ft2
Civic -	50,000 ft2
Retail and Mixed Use -	375,000 ft2
Institutional -	194,000 ft2
Total -	**3,019,000 ft2**

Net-Zero
PV Electricity Potential:
10,448,449 kWh / year
55% of Roof Area, 100% Of Demand
40% of Total Energy

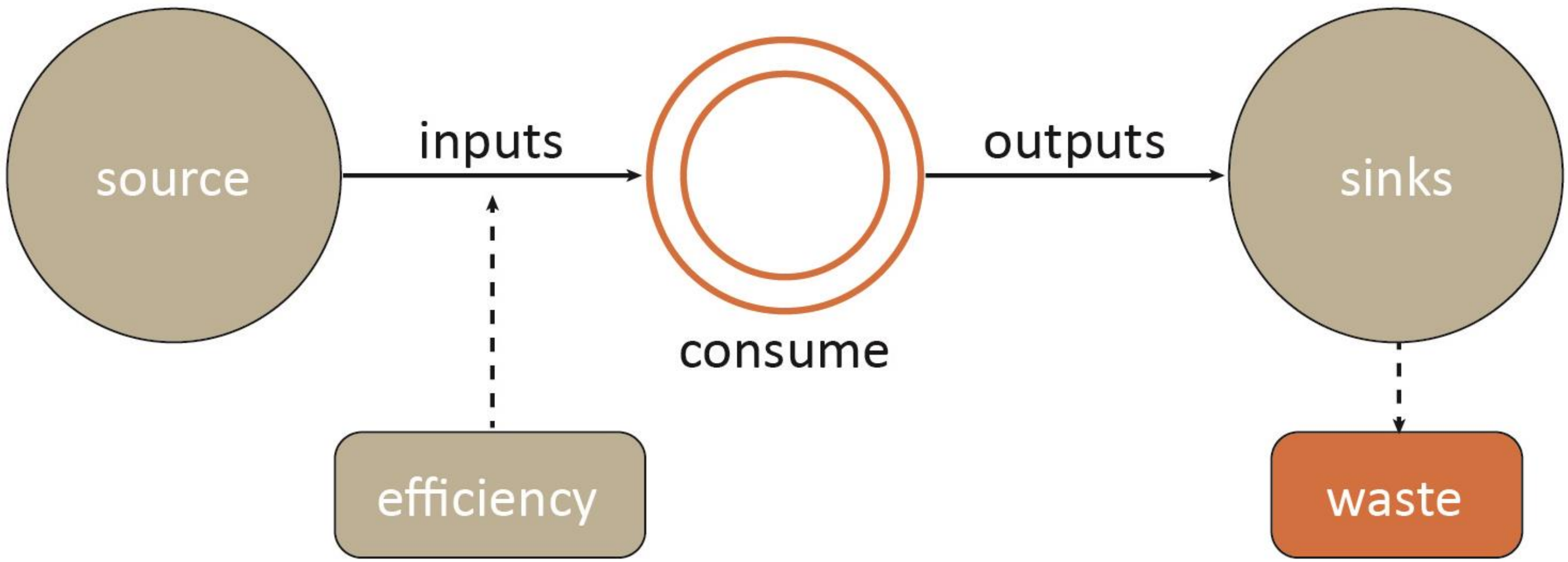
Net-Positive
PV Electricity Potential:
15,219,152 kWh / year
100% of Roof Area, 145% of Demand
4,770,703 kWh back to grid, electricity for 491 single family homes

Total Energy Use:
26,121 MWh / year



Heating and Cooling Energy Generated by
Aquifer Thermal Energy Storage System
15,672,673 kWh / year
60% of Total Energy

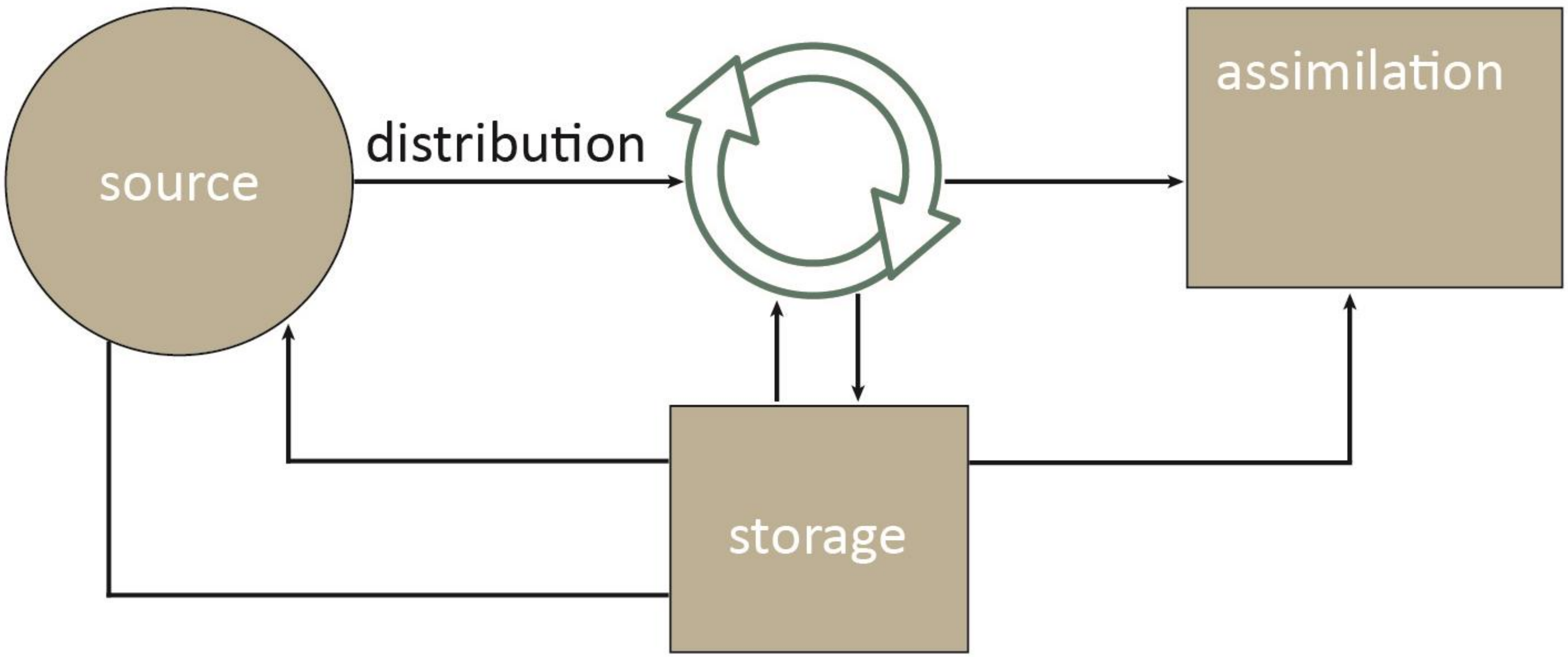
Existing Throughput Systems



- Efficiency as end goal
- Degenerative linear flows

John Tillman Lyle, Regenerative Design for Sustainable Development, 1994

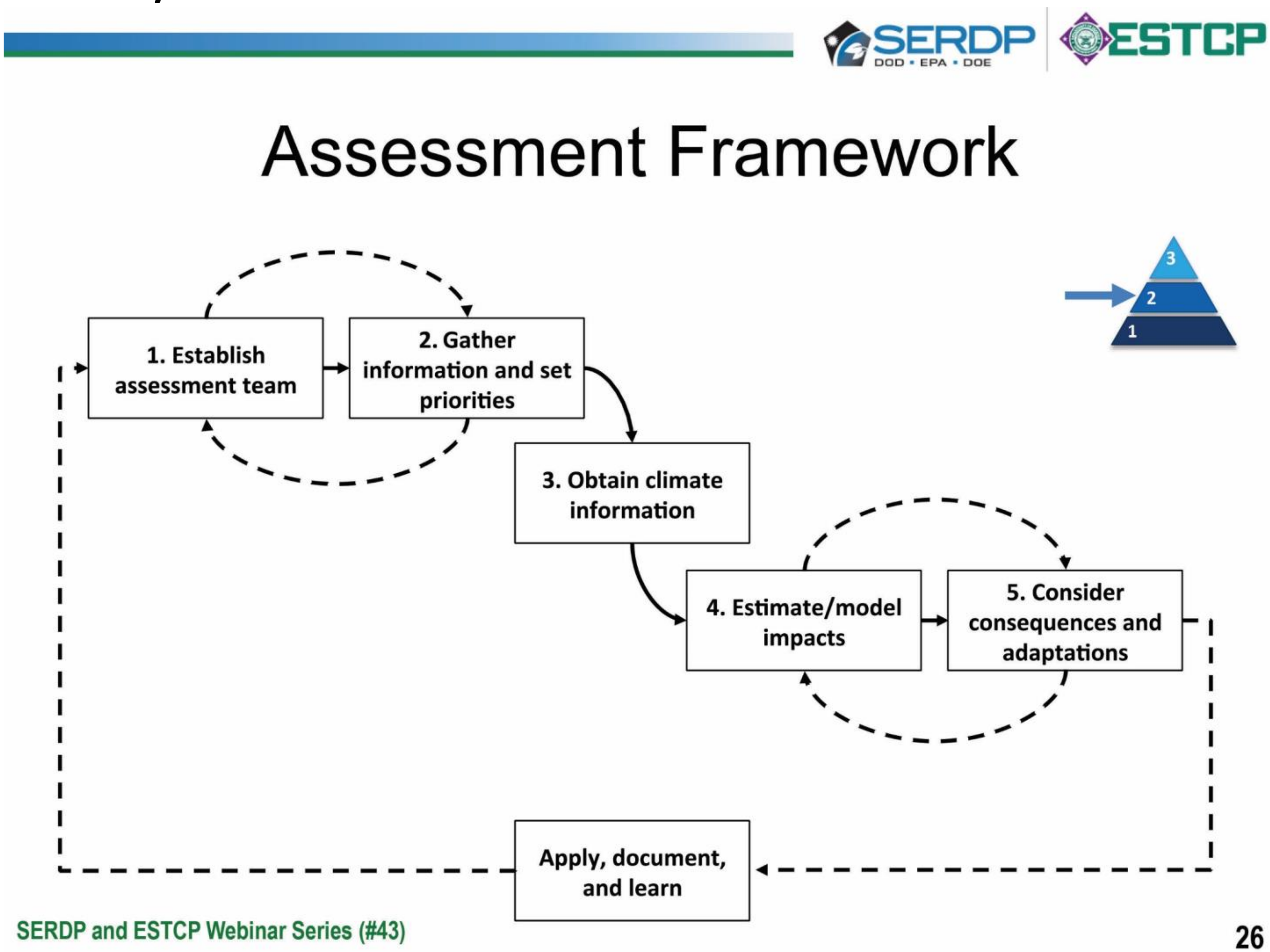
Regenerative Systems



- Effectiveness as end goal
- Within renewal capacity
- Integrate with natural processes
- Symbiosis
- Closed-loop system
- Multiple pathways

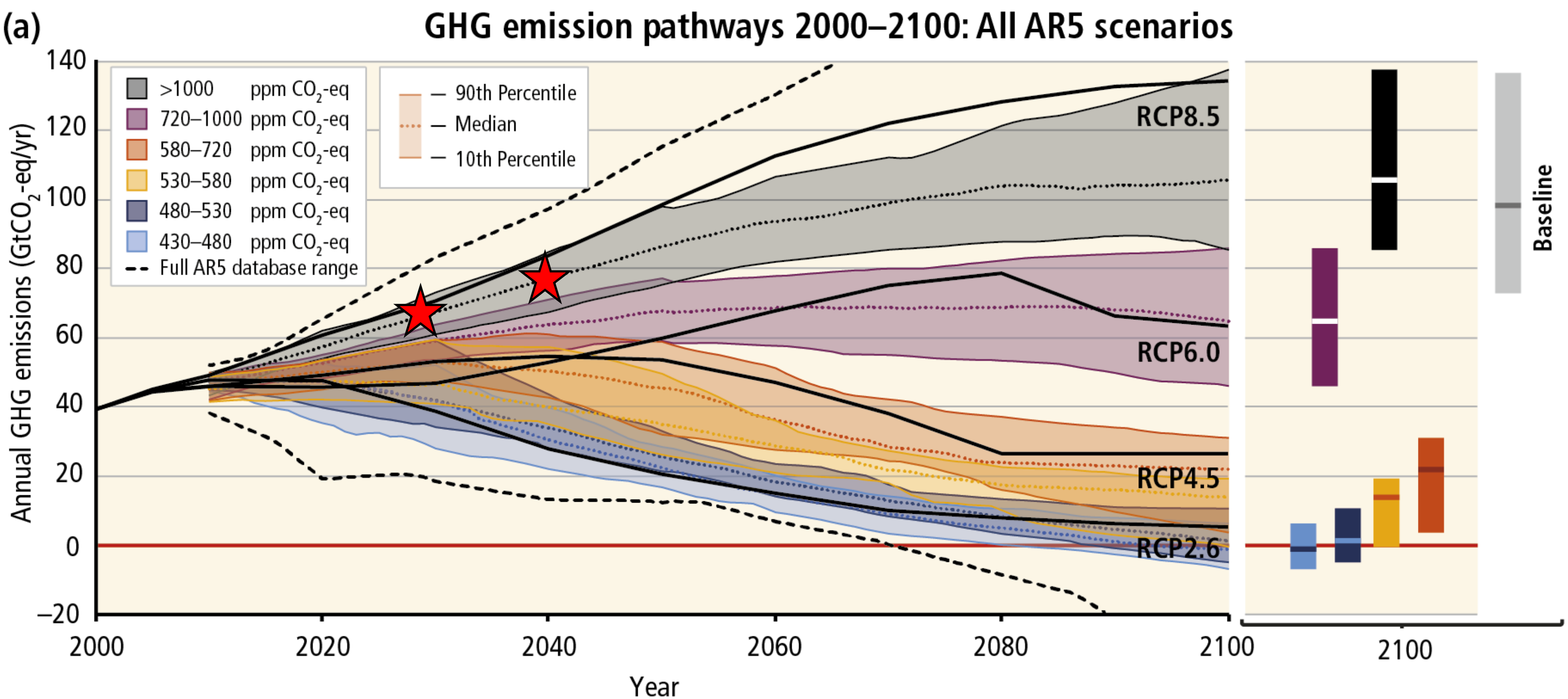
John Tillman Lyle, Regenerative Design for Sustainable Development, 1994

Vulnerability Assessment Framework



SERDP and ESTCP Webinar Series, Vulnerability Assessments and Resilience Planning at Federal Sites, 2016
Strategic Environmental Research and Development Program (SERDP)
Environmental Security Technology Certification Program (ESTCP)

Future Weather Files



Intergovernmental Panel on Climate Change, Fifth Assessment Report. 2014

- Morphed weather files for the Minneapolis / Saint Paul Area
- Future performance analyzed using RCP 8.5, 50th percentile

CSBR
Center for Sustainable Building Research

Future Weather Files

Strategy	Hours: Actual and Percentage					
	Now		2030		2040	
Comfort	942	11%	885	10%	936	11%
Sun Shading of Windows	586	7%	778	9%	817	9%
High Thermal Mass	154	2%	217	2%	240	3%
High Thermal Mass Night Flushed	154	2%	228	3%	256	3%
Direct Evaporative Cooling	109	1%	179	2%	198	2%
Two-Stage Evaporative Cooling	111	1%	192	2%	216	2%
Natural Ventilation Cooling	104	1%	162	2%	170	2%
Fan-Forced Ventilation Cooling	72	1%	104	1%	106	1%
Internal Heat Gain	1589	18%	1353	15%	1361	16%
Passive Solar Direct Gain Low Mass	899	10%	826	9%	796	9%
Passive Solar Direct Gain High Mass	624	7%	559	6%	539	6%
Wind Protection of Outdoor Spaces	259	3%	254	3%	249	3%
Humidification Only	0	0%	0	0%	0	0%
Dehumidification Only	491	6%	659	8%	692	8%
Cooling, add dehumidification if needed	305	3%	549	6%	604	7%
Heating, add humidification if needed	4791	55%	4545	52%	4436	51%

Predicted Effectiveness of Comfort Strategies for Minneapolis / Saint Paul – Climate Consultant, UCLA Energy Design Tools Group

Future Weather Files

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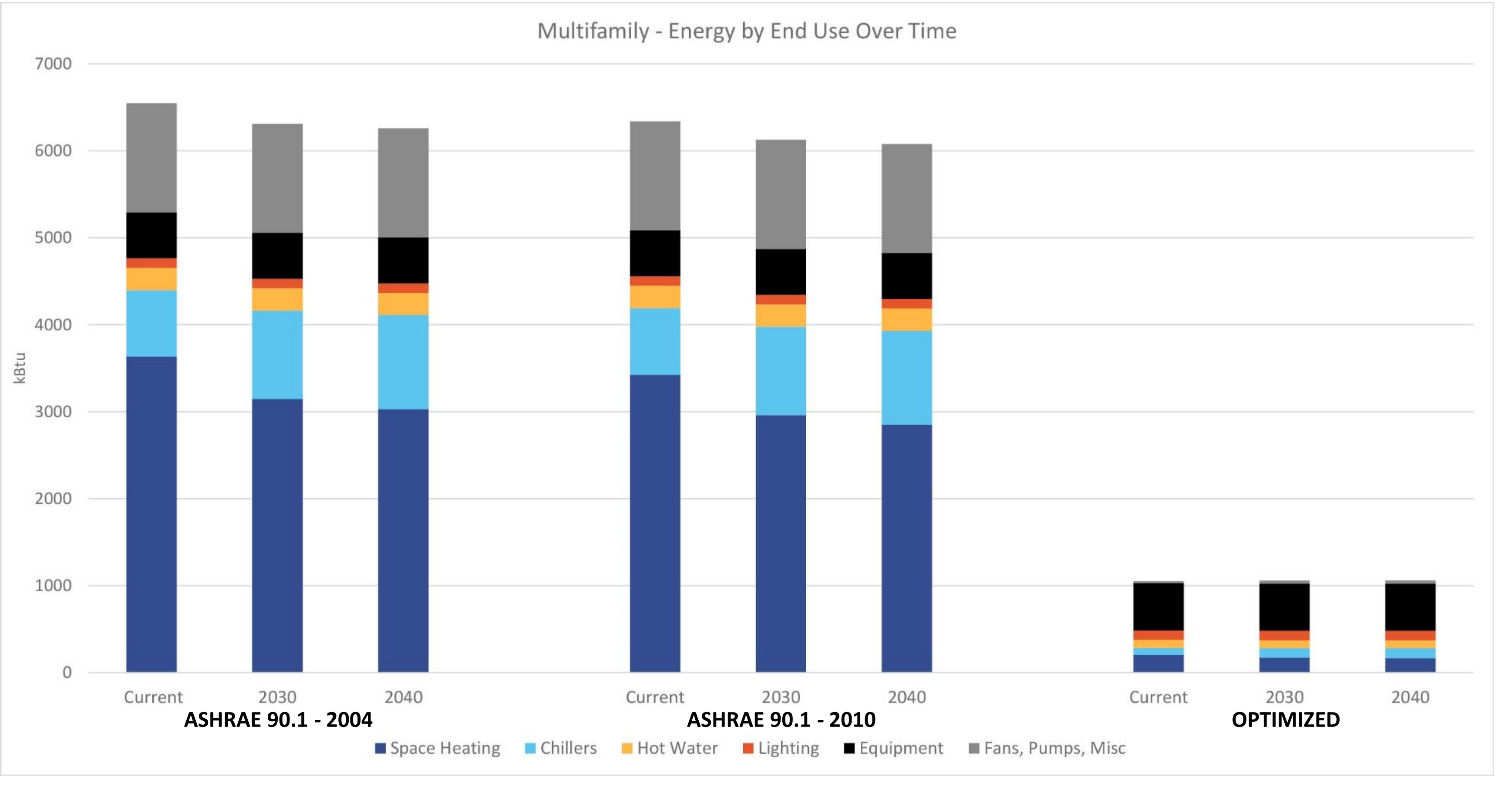
Predicted Effectiveness of Comfort Strategies for Minneapolis / Saint Paul – Climate Consultant, UCLA Energy Design Tools Group

Future Weather Files

- Energy use in code buildings decreases over time
- Increase in cooling load is outweighed by decrease in heating loads
- Energy use in high performing buildings stable over time



Future Weather Files

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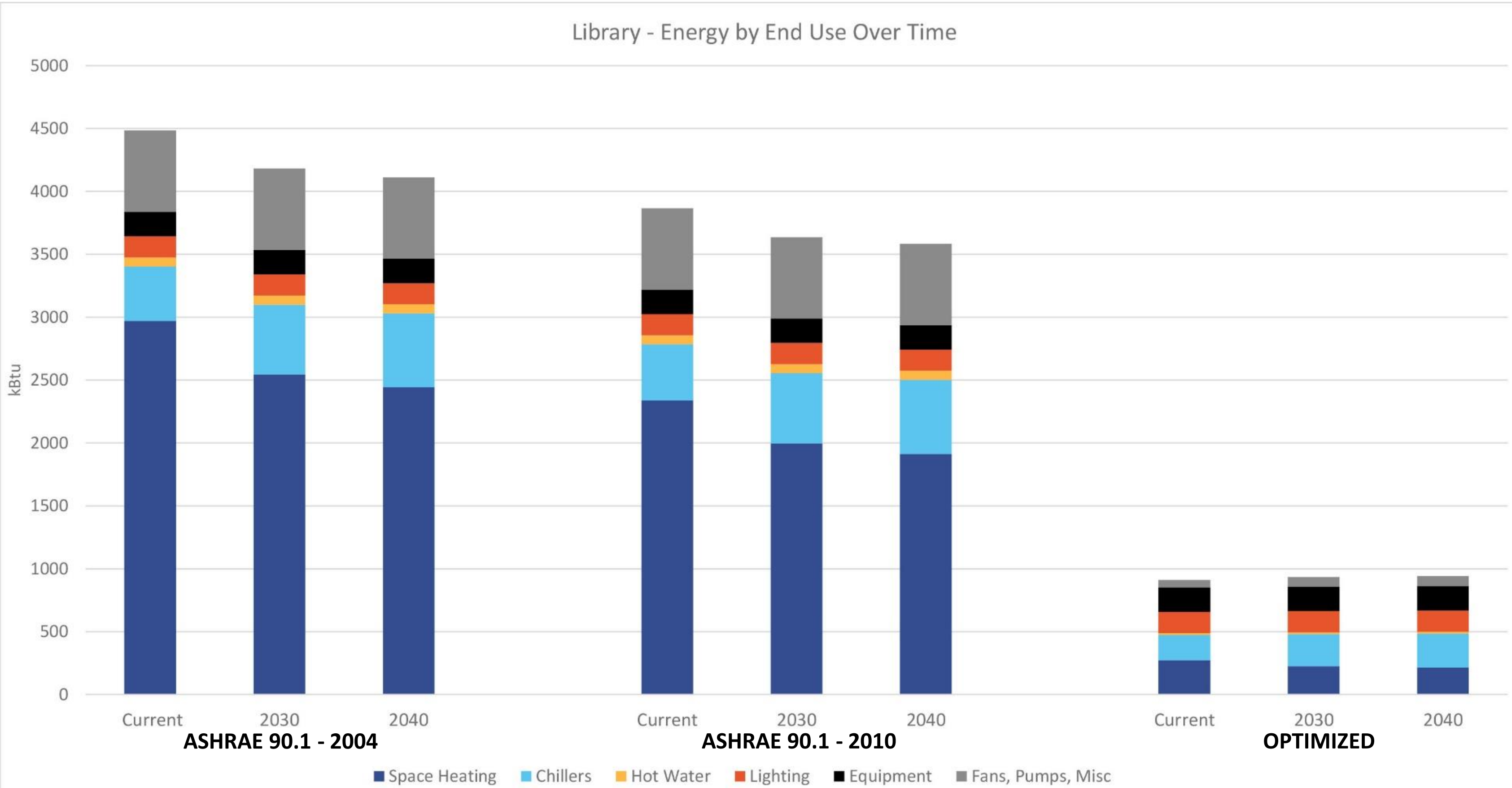

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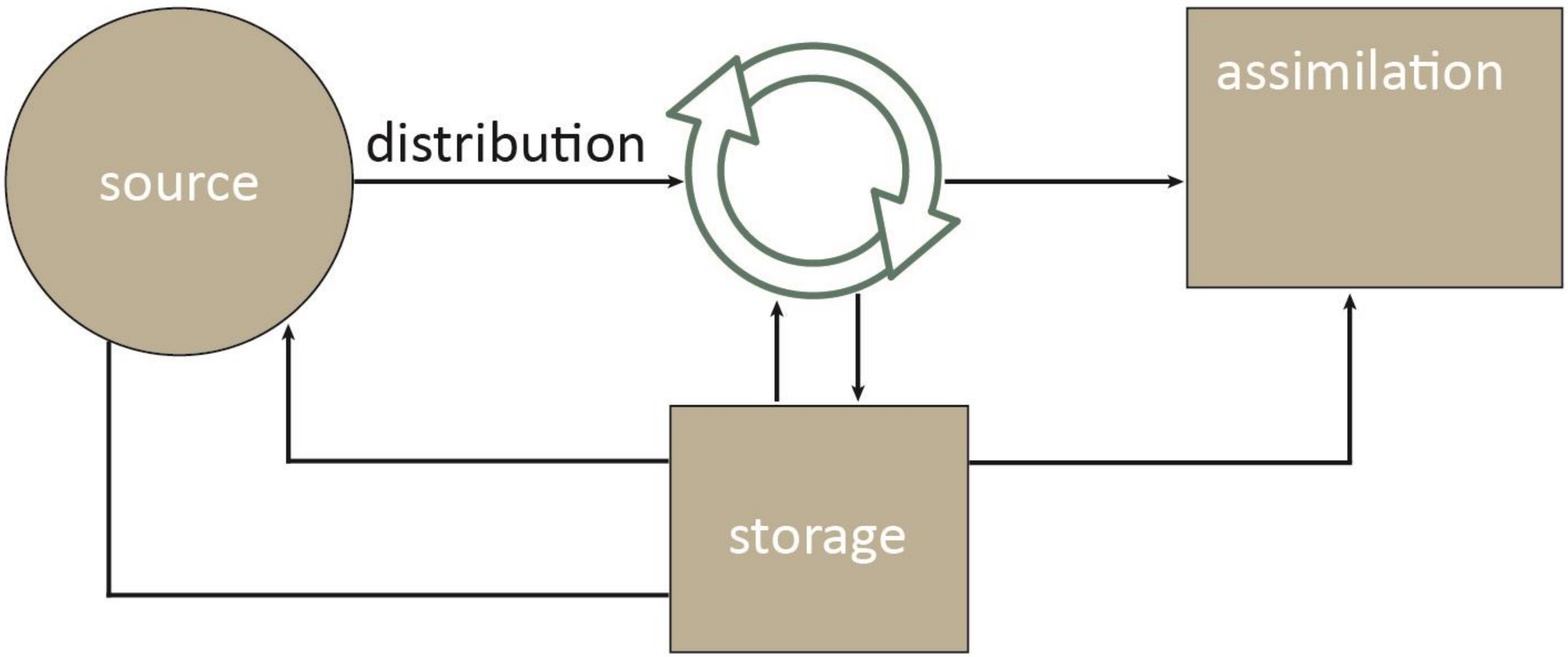
Regenerative Systems



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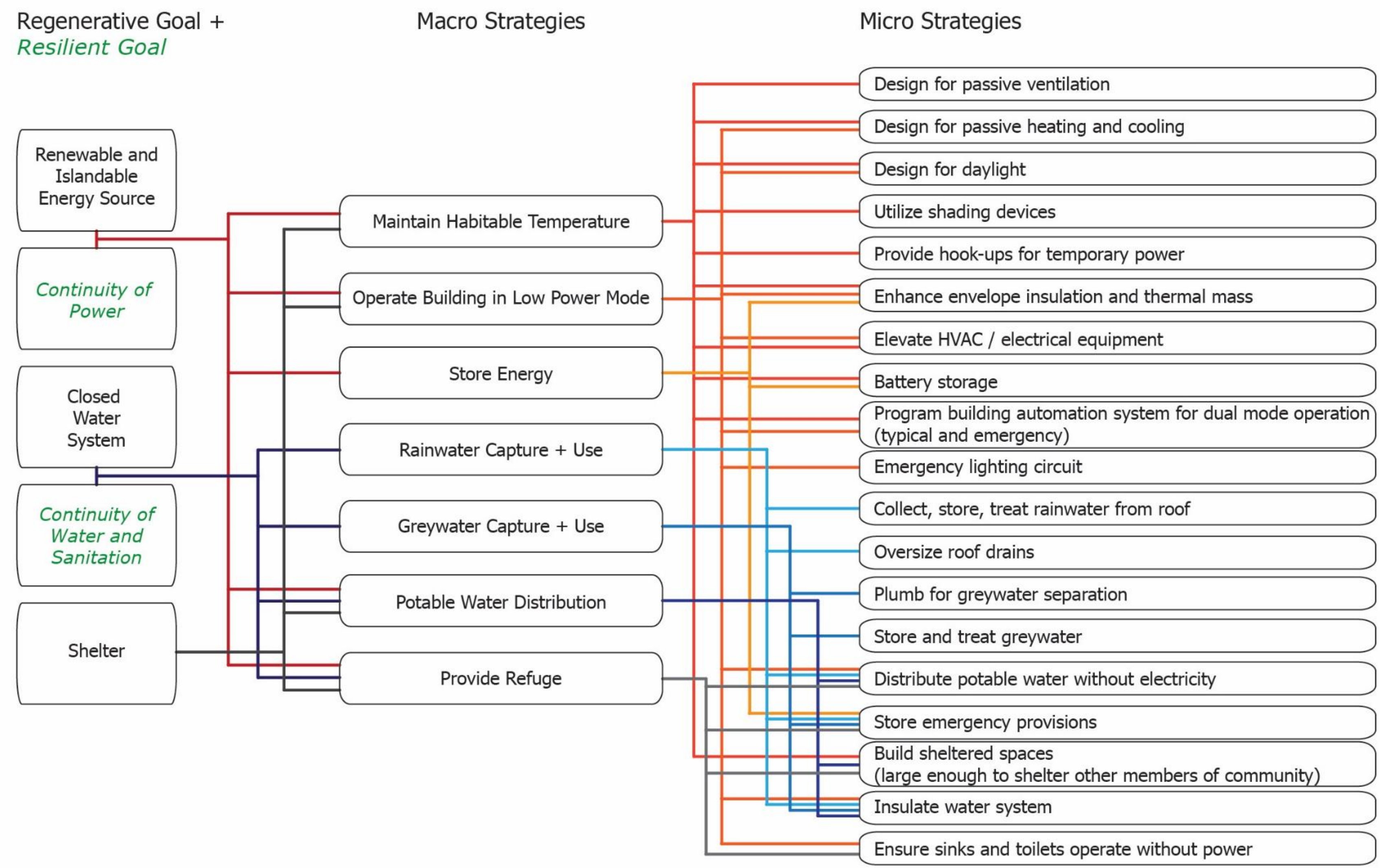
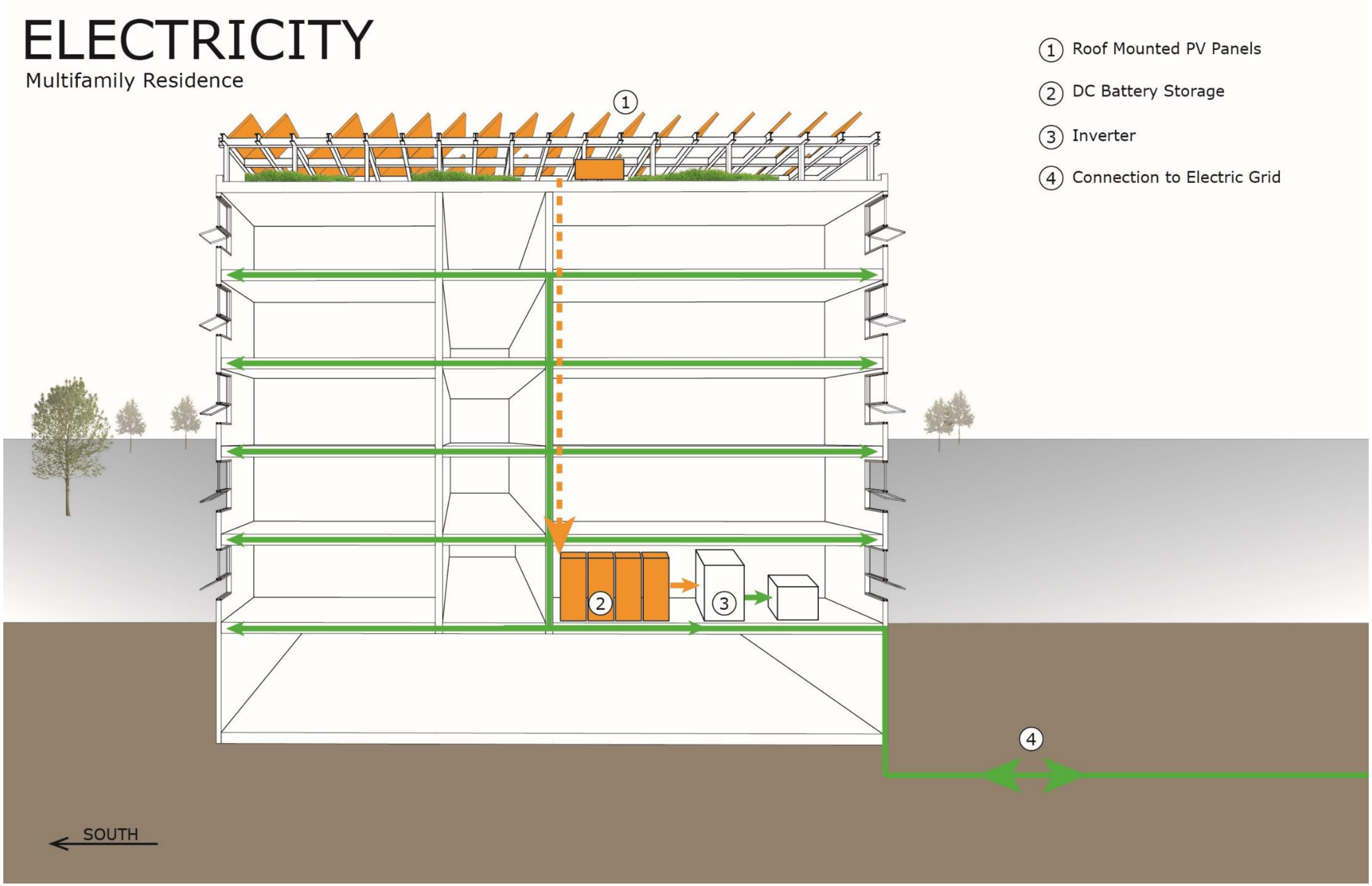
John Tillman Lyle, Regenerative Design for Sustainable Development, 1994

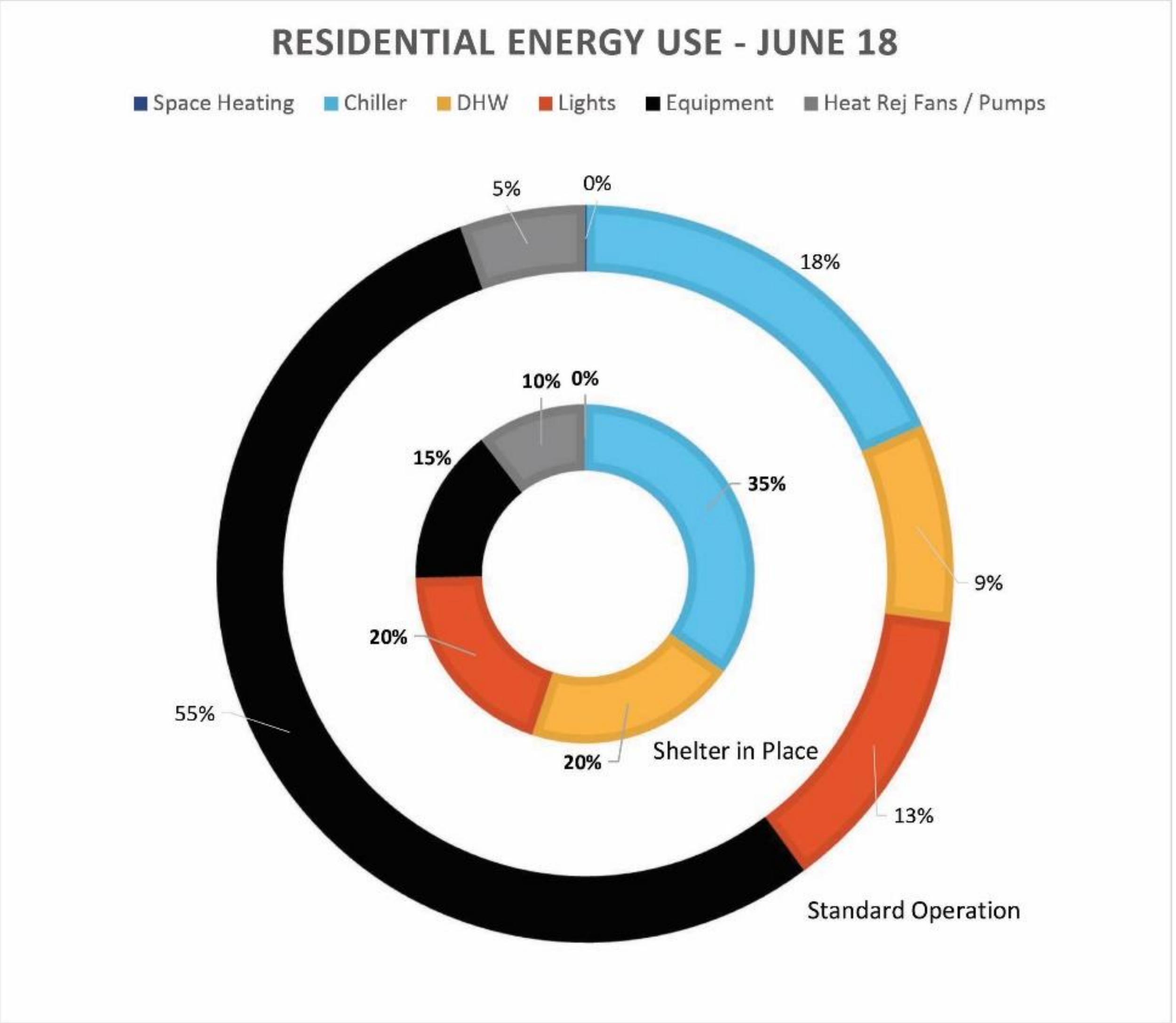
Regenerative and Resilient Design Strategies



Prototype: Multi-Family Residential

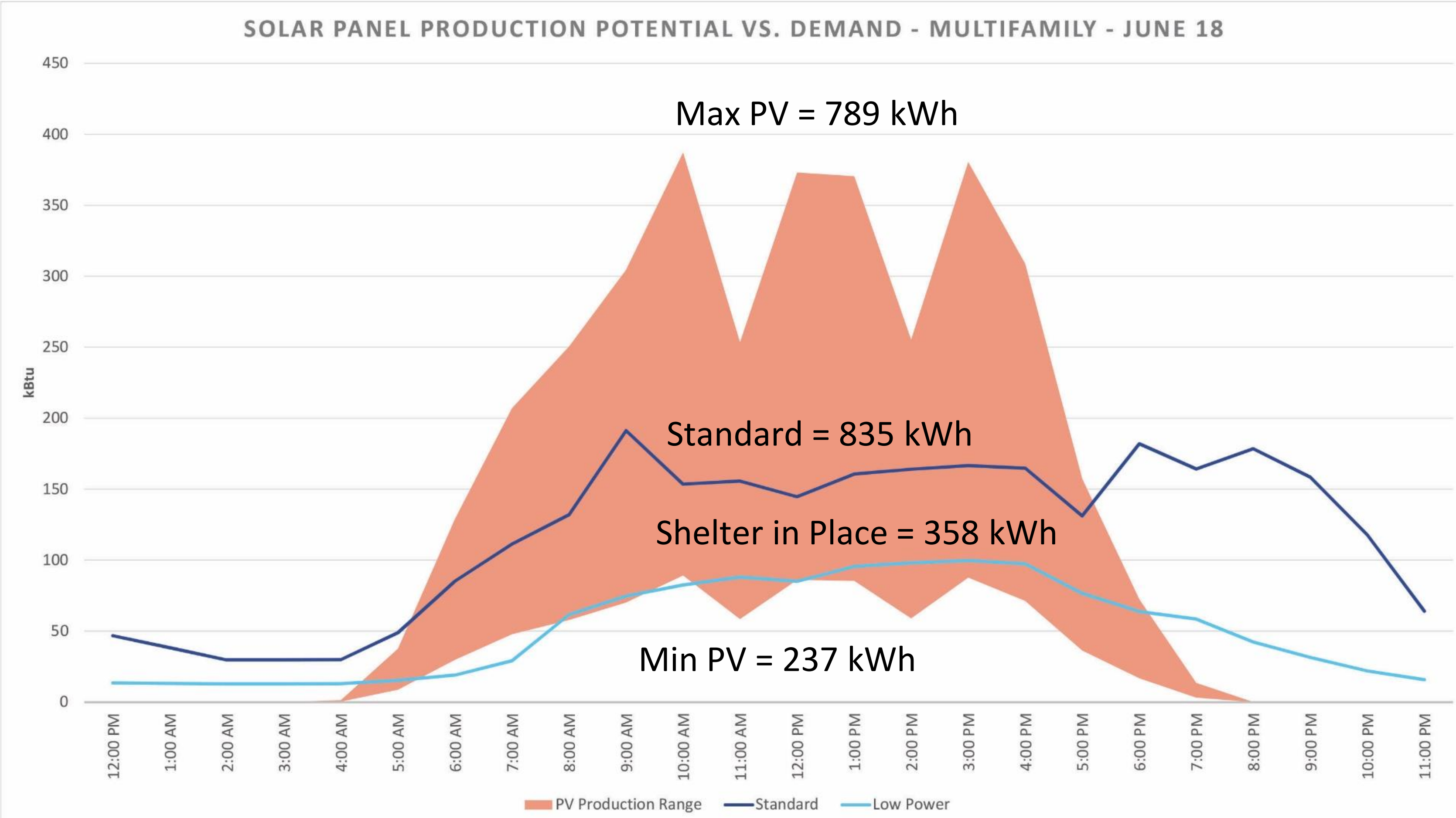


Prototype: Multi-Family Residential



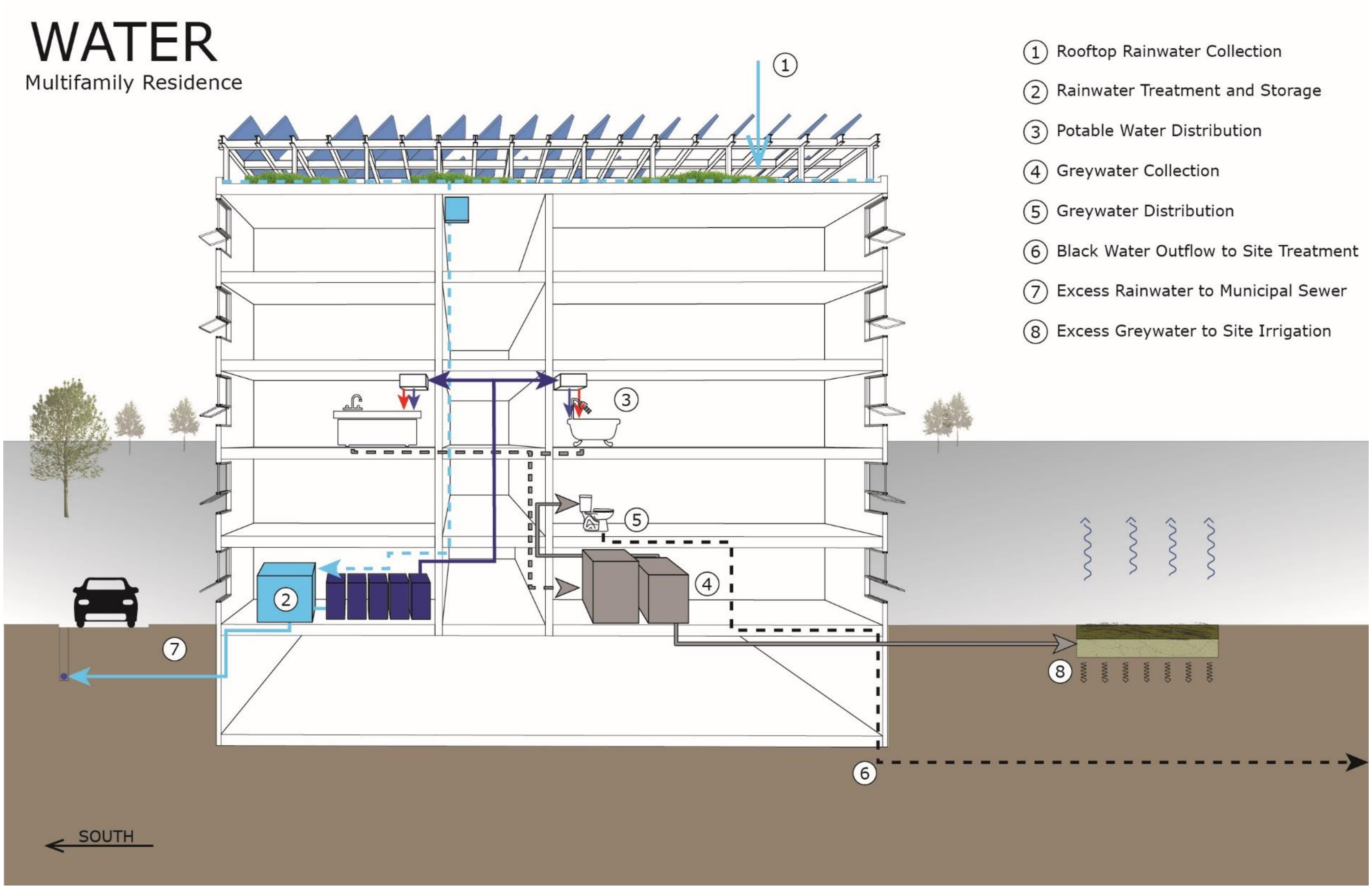
Simulated Energy Use during Standard Operation and Shelter in Place Operation. Energy Modeled in IES-VE 2015

Prototype: Multi-Family Residential

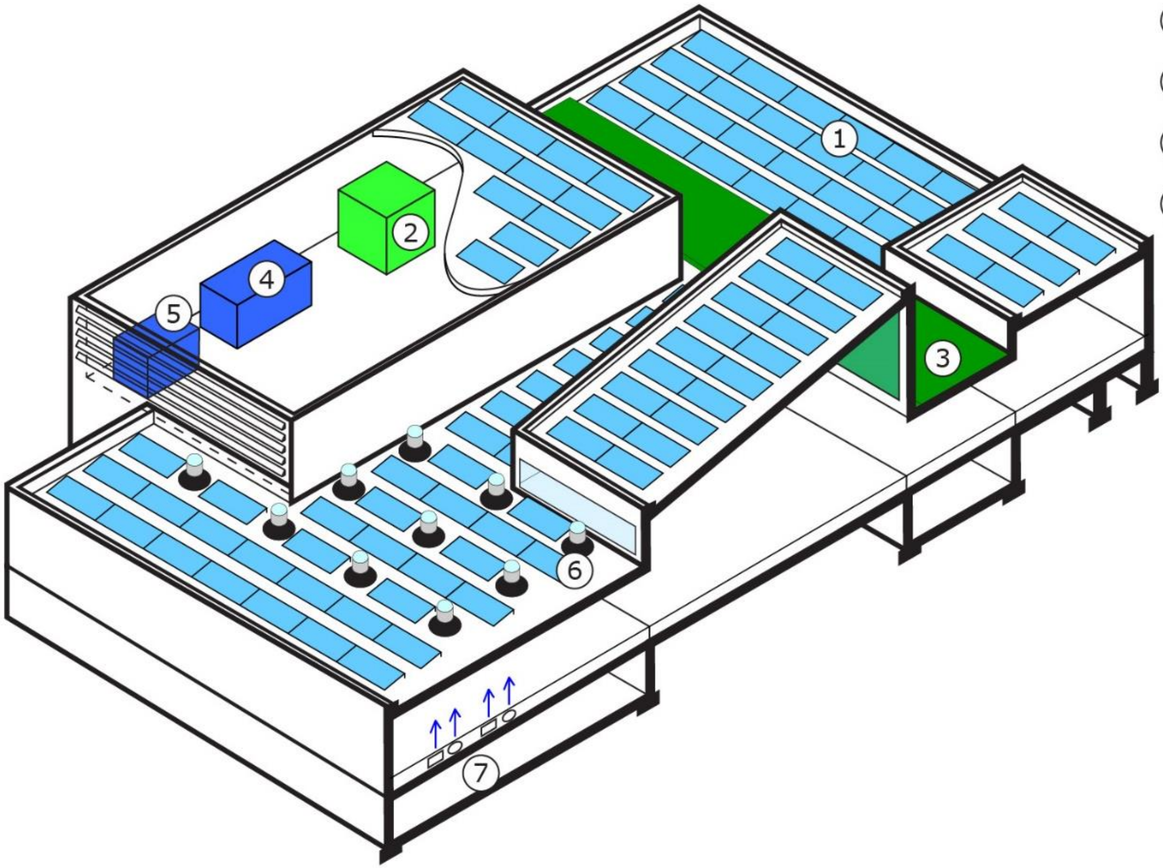


Predicted PV Production and Predicted Energy Use. Energy Modeled in IES-VE 2015, PV data from NREL PVWatts

Prototype: Multi-Family Residential

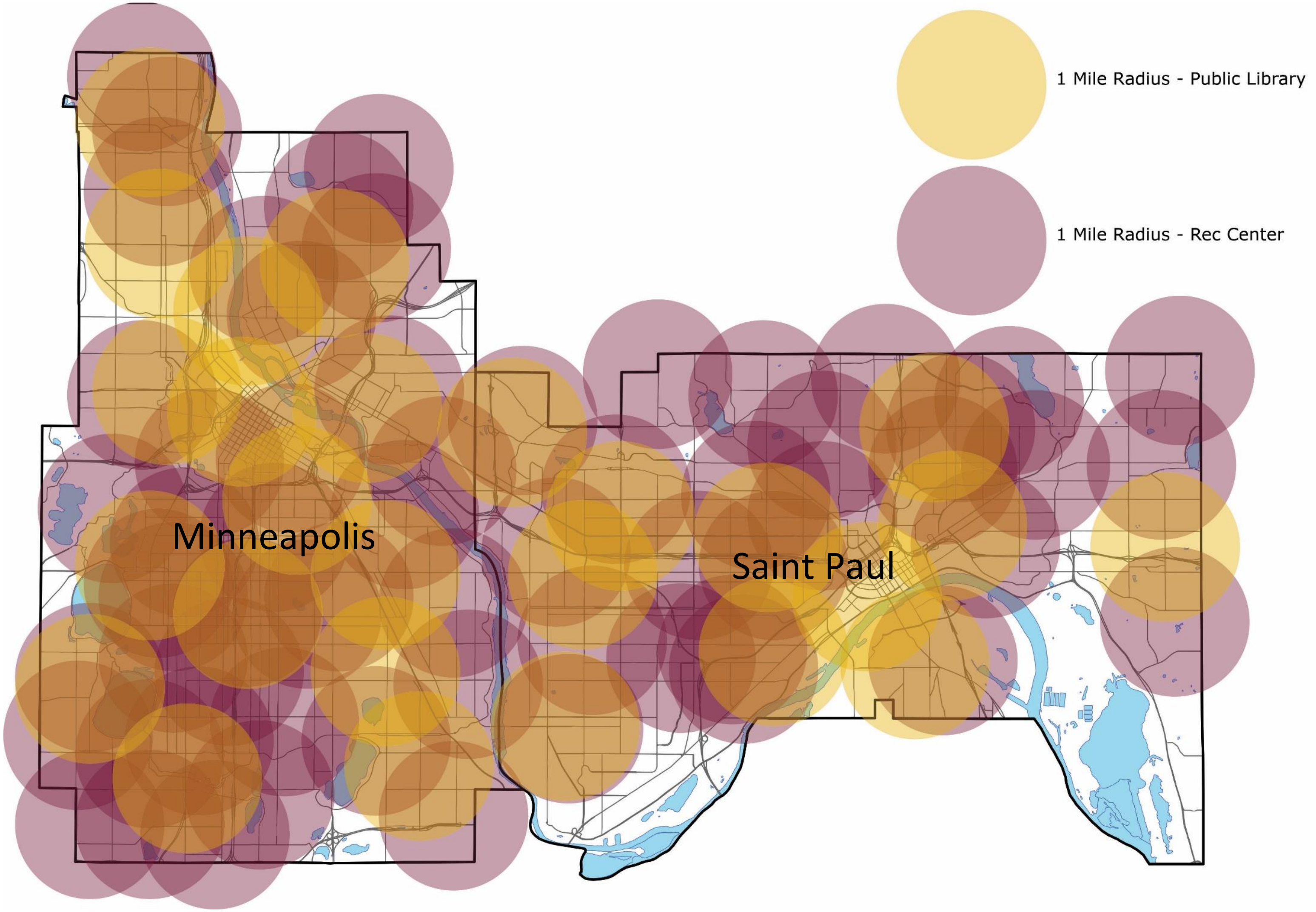


Prototype: Library



1. Solar Panels
2. DC Battery Storage and Inverter
3. Green Roof
4. Air Exchanger with Heat Recovery
5. Condensor
6. Light Tubes
7. In-Floor Ventilation and Evaporator

Prototype: Library



Potential Areas Served by Disaster Hubs

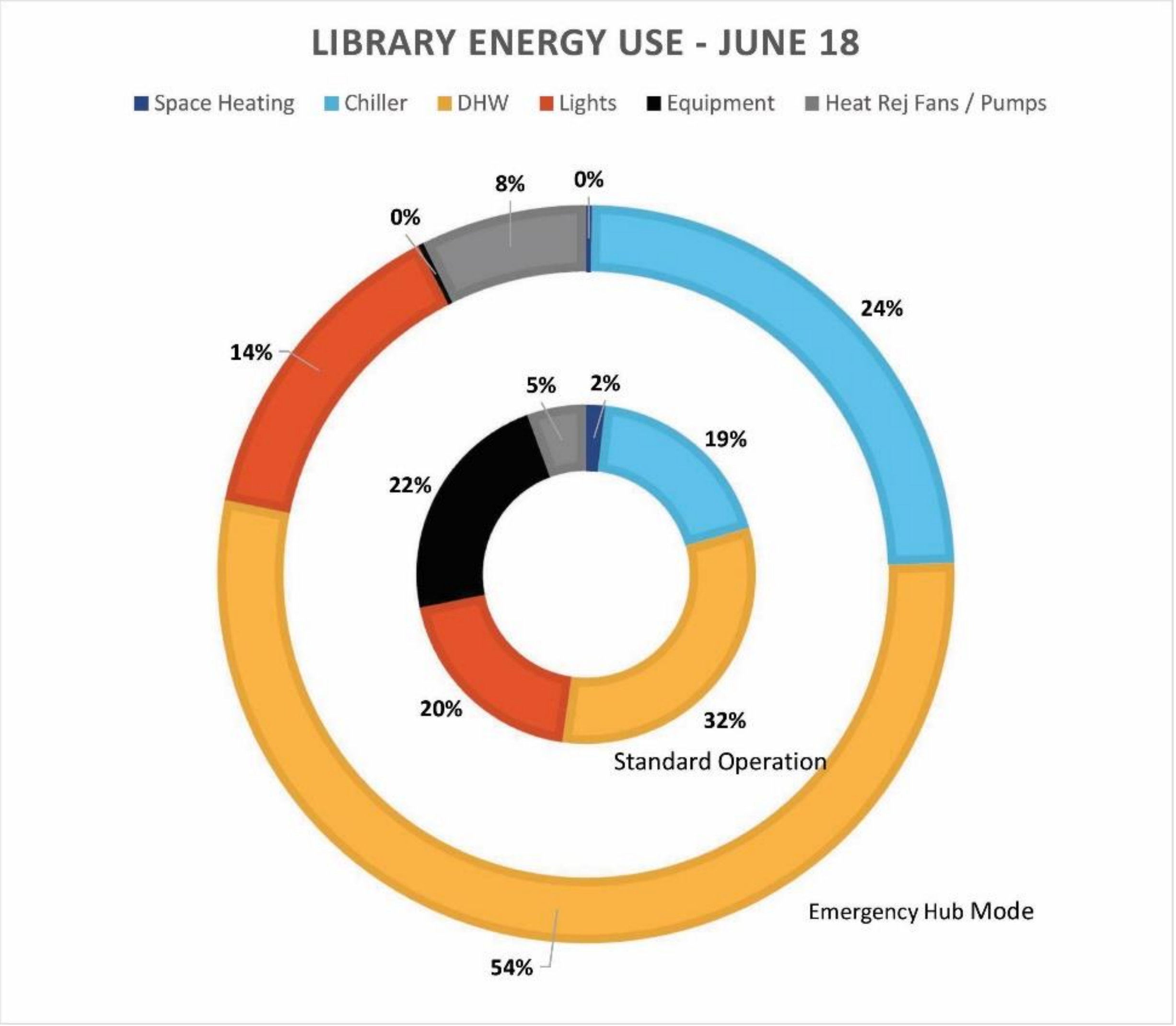
Prototype: Library

Library can support approximately 550 people in 'hub mode'

- Roughly 10% of population living within ½ mile
- Statistically will include:
  - 64 people with a disability
  - 125 people living within 150% of poverty line
  - 42 children under age 5
  - 52 people over age 65

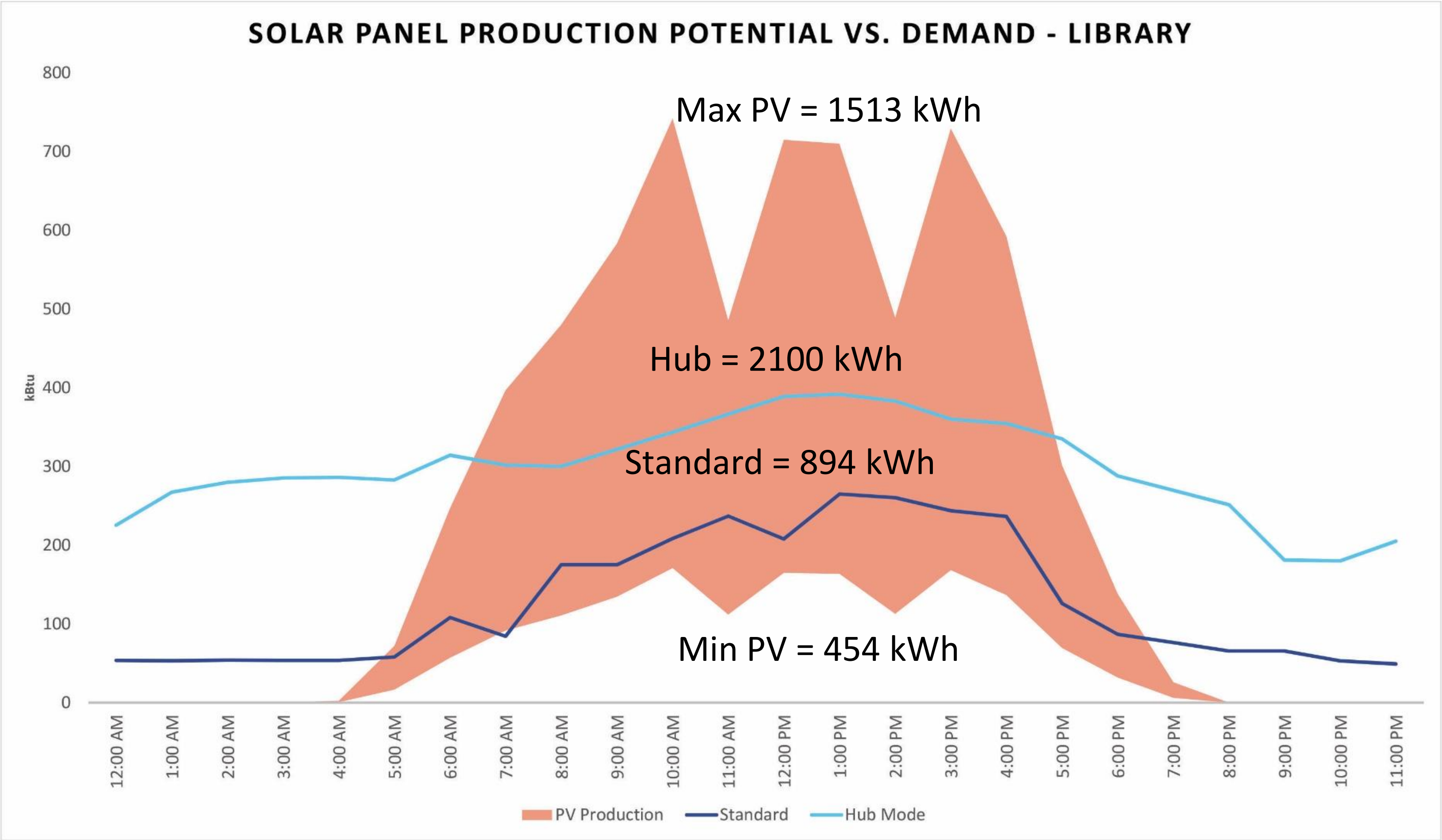
Potential Population Served by Disaster Hubs
American Community Survey, 2015

Prototype: Library



Simulated Energy Use during Standard Operation and Disaster Hub Operation. Energy Modeled in IES-VE 2015

Prototype: Library



Predicted PV Production and Predicted Energy Use. Energy Modeled in IES-VE 2015, PV data from NREL PVWatts

Next Steps

BUILDINGS, BENCHMARKS & BEYOND

Tools and Programs for Sustainable Buildings in Minnesota


Resilient Adaptation of Sustainable Buildings
Center for Sustainable Building Research
University of Minnesota
May 2018

View the full report at www.CSBR.umn