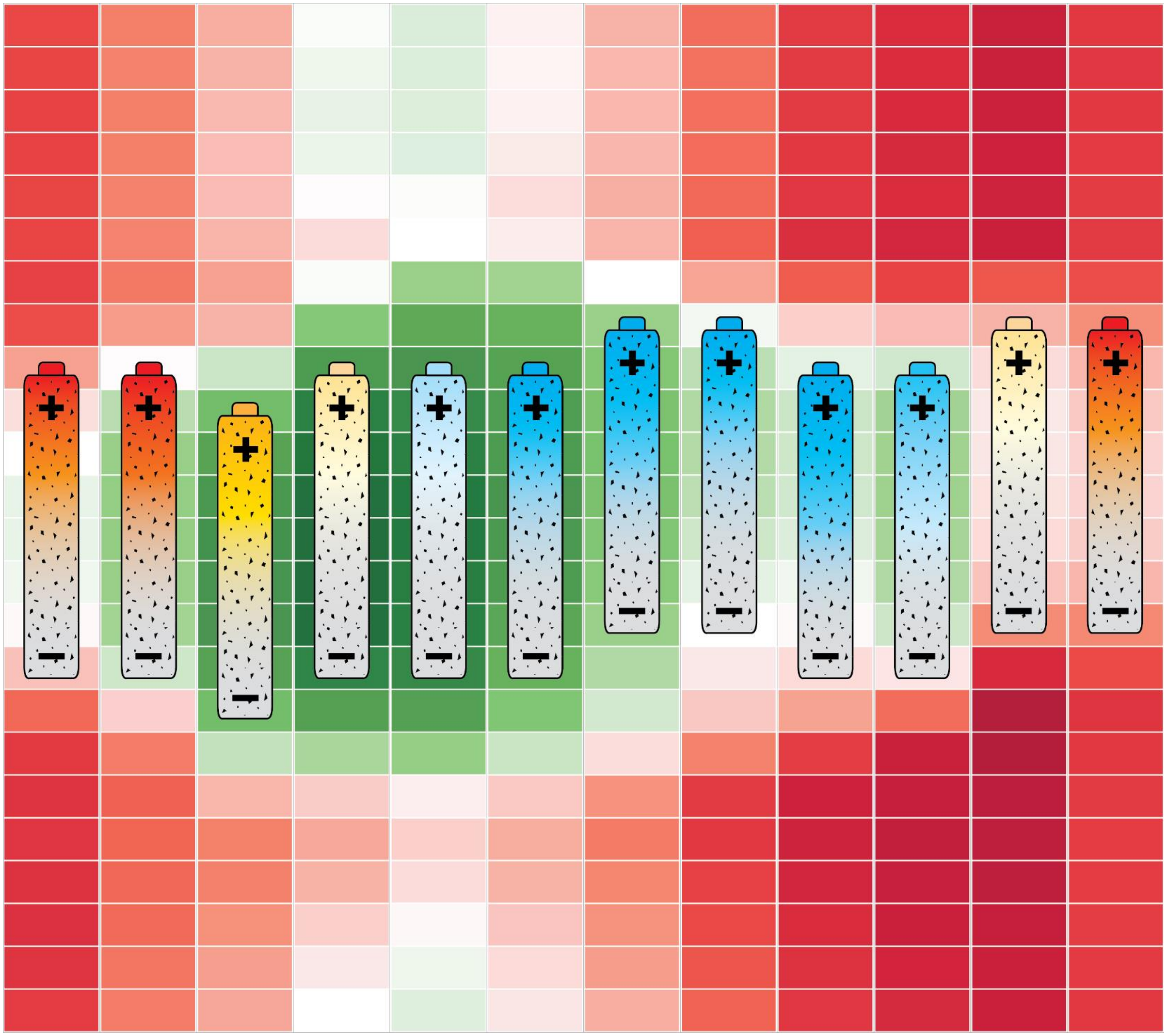
The Radiant Whole Life Carbon Study

ALL-ELECTRIC BUSINESS AS USUAL (STEEL + VRF) VS. CLARK PACIFIC (PRECAST + RADIANT)

April 2021



INTEGRAL

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Main Authors

Noah Zallen – Principal and Radiant Design Practice Lead at Integral Group (Oakland, USA)

Louise Hamot – Global Lead of Life Cycle Research at Integral Group (Lille, France)

John Nelson – Associate Senior Building Performance Analyst at Integral Group (Denver, USA)

Contact

Noah Zallen

nzallen@integralgroup.com

Contributors

Megan White – Chief Sustainability Officer at Integral Group (Oakland)

John Gautrey – Senior Principal and US West Mechanical Department Lead at Integral Group (Los Angeles)

Jeremy Field – Senior Sustainability Advisor at Integral Group (Vancouver)

Ransom Hamrick – Associate Mechanical Engineer at Integral Group (San Diego)

Breffni O'Rourke – Sustainability Consultant at Integral Group (Oakland)

Clara Bagenal George – Associate Mechanical Engineer at Elementa Consulting (London)

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www.integralgroup.com

1 Executive Summary

The Clark Pacific Precast Radiant Building System has, conservatively, at least 40% less Whole Life Carbon emissions than a Business as Usual All-Electric Building.

Noah Zallen

Noah is Integral Group's Global Radiant Practice Lead, based in Berkeley, CA

The Radiant Whole Life Carbon Study will spark change. Change expectations for what it means to actionably assess carbon. Change markets by creating something fundamentally sound, yet truly new. And, change minds on just how powerful a climate asset an unleashed radiant slab building can be.

A New Benchmark. This Study is a pioneeringly comprehensive comparison of the whole life carbon emissions of a Business as Usual All-Electric Building vs. the Clark Pacific Radiant Building System. Integral assembled a world-leading team of practicing engineers and subject matter experts to create a profoundly better carbon study, including not just Structure & Envelope, but also the full complexity of Mechanical Systems, Refrigerant Leakage, and Electrical Grid Dynamics.

It's an Invention. This Study canonizes the Clark Pacific Radiant Building System – a new total building solution that leverages radiant slabs, prefabrication, and intentional design to both minimize whole life carbon and be highly affordable, mass producible, and robust in application throughout the entire United States.

Radiant Slabs Unleashed. Performing new primary research, Integral tested the limits of concrete as a thermal battery to find an enormously untapped potential. Using an extraordinarily simple and robust configuration, radiant slabs can easily provide all heating and cooling, operating in just any daily 8 hours you choose, making the building an immensely powerful and flexible carbon asset to the grid. The Radiant Building System's central plant size and HVAC emissions are also both 50% smaller than even a best-in-class building. The possibilities are endless.

Space Heating & Cooling Emissions in the Radiant Building System are 65% smaller than a Business as Usual All-Electric Building.

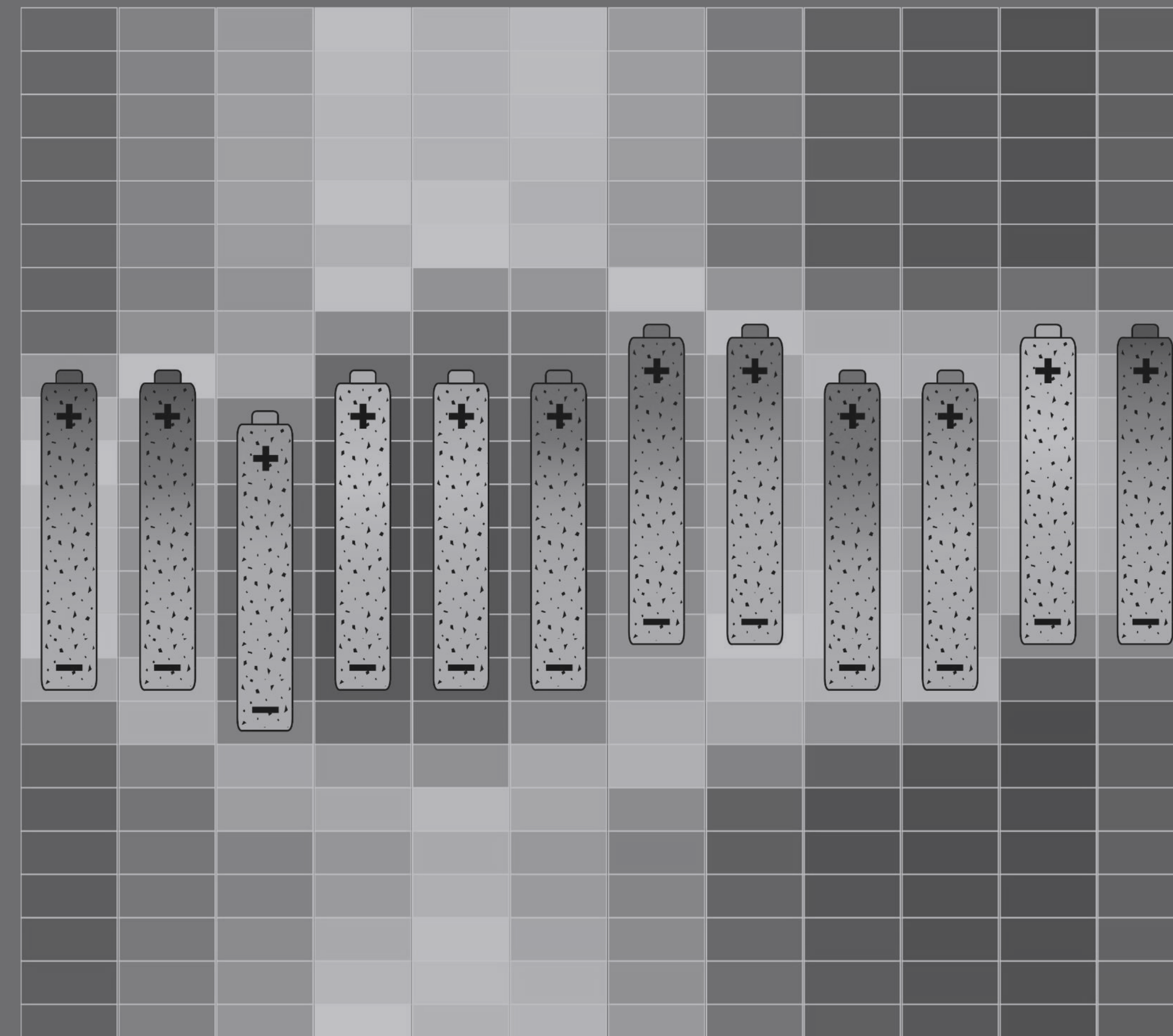
The Lightweight Concrete Topping Slabs in the Business as Usual Building have more embodied carbon than All Concrete Above Ground in the Clark Pacific Building.

During its 60-year use, a Clark Pacific Radiant Building emits so much less carbon than a Business as Usual All-Electric Building that it could offset the entire structure, envelope, and mechanical carbon embodied in making another new Business as Usual building.

"This is real. This is exciting. We would love to talk to you."

A wholehearted thank you to Clark Pacific for the opportunity.

THE RADIANT WHOLE LIFE CARBON STUDY



INTEGRAL

2 Study Context, Aim, and Scope

We need today's new buildings to be low carbon now, yet we've only recently started assessing the whole life carbon of what we've been building.

2.1 Carbon Context

Low-carbon designs

To mitigate climate change, low-carbon design must become our guiding light in developing the built environment. The IPCC's climate target of global warming no more than 1.5°C requires building emissions reduce 80–90% by 2050[1]. Low carbon buildings generate less emissions from not only their operational electricity, but also the embodied carbon of their material creation, construction, maintenance & replacement, and end of life processes. The barrier to low carbon buildings, frankly, has been that as an industry, we've been pretty bad at actionably assessing these things.

In assessing climate impact, the industry has long focused solely on building annual energy use (kWh). This original paradigm is significantly inaccurate and significantly incomplete. Electrical grid emission rates vary enormously within a day and over the year, so a building with higher total electricity use can easily have significantly lower electrical carbon emissions if it's use was at a cleaner time (think Duck Curve). This also ignores the climate impact of all physical elements of a building (e.g. structure, envelope, mechanical, electrical) and other elements linked to its operation (e.g. refrigerant leakage). This original paradigm is dead.

A recent paradigm has emerged that includes an attempt at carbon emissions from electricity use along with now the embodied carbon emissions of structural and envelope systems. This recent paradigm, while a positive step, is still fundamentally inaccurate and significantly incomplete. Electrical grid emissions are still based on a single average number for the year, leaving all the issues of grid variance and timing unresolved. Life cycle embodied carbon of mechanical and refrigeration systems is still left unknown and unguided. The vast majority of a building's emissions that we can control are being ignored or woefully inaccurately assessed. Simply put, we as an industry must and can do better.

The Radiant Whole Life Carbon Study aims to create a new better paradigm. One that says these gaps in data and tools are not unsolvable, and that by working together, we can leverage our industry's ample talent and knowledge to close these gaps with the vigor and urgency the moment needs.

Mechanical Systems

Very few whole life carbon studies include embodied carbon impact of the MEP systems within their carbon assessment. However, Integral Group has done preliminary research studies which show MEP design could represent up to 50% of the embodied carbon impact of a new office building and up to 75% for an office retrofit[2]. The Radiant Whole Life Carbon Study attempts an intentionally rigorous assessment of the mechanical systems' entire life cycle.

Refrigerant Leakage

With the adoption of all-electric building codes, combined with their own organic popularity, there has been a substantial uptick in VRF systems built in the United States. These systems, fundamentally, require high pressure class refrigerants, all of which have extremely high global warming potentials (GWP). One of the most common refrigerants, R410a, has a GWP of 2088, meaning the release of 1kg of R410a into the air is equivalent to more than 2,000 kg of carbon dioxide into the atmosphere. VRF systems use extremely large volumes of refrigerant, in highly pressurized bespoke mazes of field fabricated copper pipe, making refrigerant leakage fundamentally unavoidable. This creates the potential for an enormous overall negative impact on the fight against climate change. In fact, mitigating refrigerant leakage has been identified as the number one thing we can do to cool down our planet[3]. The Radiant Whole Life Carbon Study attempts both to accurately quantify the impact of refrigerant leakage in a business as usual all-electric building, and to present a robust mechanical system alternative to VRF.

Real Operational Grid Emissions

Electrical grids are at an inflection point. The increasing adoption of all-electric building and transportation systems is rapidly changing the grid's demand-side shape (time of use) and magnitude (size of use). At the same time, increasing use of time-variant renewables (such as solar PV and wind) is also rapidly changing the grid's supply-side dynamics, both in terms of composition (type of power plants) and hourly shape (when and how much they are in use). In California this is currently solar driven. In other states this may be wind driven. The resulting phenomenon is the same - electrical grid carbon emission intensity varies significantly over the day, month, and year, and will continue to change. Failure to capture the time-variance of this dynamic risks not only being substantially wrong on a building's commonly largest single source of life cycle carbon emissions, but also mistakenly concluding one mechanical system is better when, in reality, it is meaningfully worse. The Radiant Whole Life Carbon Study seeks to use research-grade analysis and understanding to maximally capture the interaction of electricity time of use and grid carbon emission, and provide ideas with the resiliency to adapt as it all changes.

Radiant Slabs as a Concrete Thermal Battery

People have known from our earliest days that buildings can store "warmth" or "coolth" in their mass. Adobe structures in the American southwest and rammed earth buildings from across most of the globe were used for millennia to even out daily temperature variations. In more recent history, before the invention and widespread adoption of air-conditioning, stone structures were also common across the globe to store night cooling for use the following day. Over the past half century, most buildings in the United States have been operated and conceived in spite of their mass, completely sealed off, and relying instead entirely on cold or hot air to provide space conditioning. A niche trend in the past couple decades, in contrast to the industry at large, has been thermally active building systems (TABS) – typically PEX tubing embedded in concrete circulates warm/cool water to mechanically change mass temperature. Just like their passive cousins, active thermal mass can store cooling/heating from earlier for use later to shift load and reduce load. However, until recently, a broad lack of motivation to care or means of quantifying this phenomenon, has left this approach vastly under explored and underutilized. No longer. The Radiant Whole Life Carbon Study investigates just how much concrete can serve as a thermal battery, and in doing so reduce cooling plant equipment (save construction costs), improve grid carbon emissions (help the climate), and shift/reduce electrical loads (save operational costs).

[1] Intergovernmental Panel on Climate Change (2018) https://www.ipcc.ch/site/assets/uploads/sites/2/2018/11/SR15_Chapter4_Low_Res.pdf

[2] https://www.cibsejournal.com/general/getting-to-grips-with-whole-life-carbon/

[3] Project Drawdown, https://www.drawdown.org/solutions/refrigerant-management

2.2 Whole Life Cycle Carbon Assessment

In the context of this study, the term carbon impact refers to the sum of greenhouse gas (GHG) emissions in an associated asset, expressed as kg of CO_2 equivalent (kgCO2e). The carbon impact of a building can be evaluated by a life cycle assessment quantifying Global Warming Potential (GWP) at each life cycle stage. A life cycle assessment is a standardized methodology to evaluate total life environmental impacts.

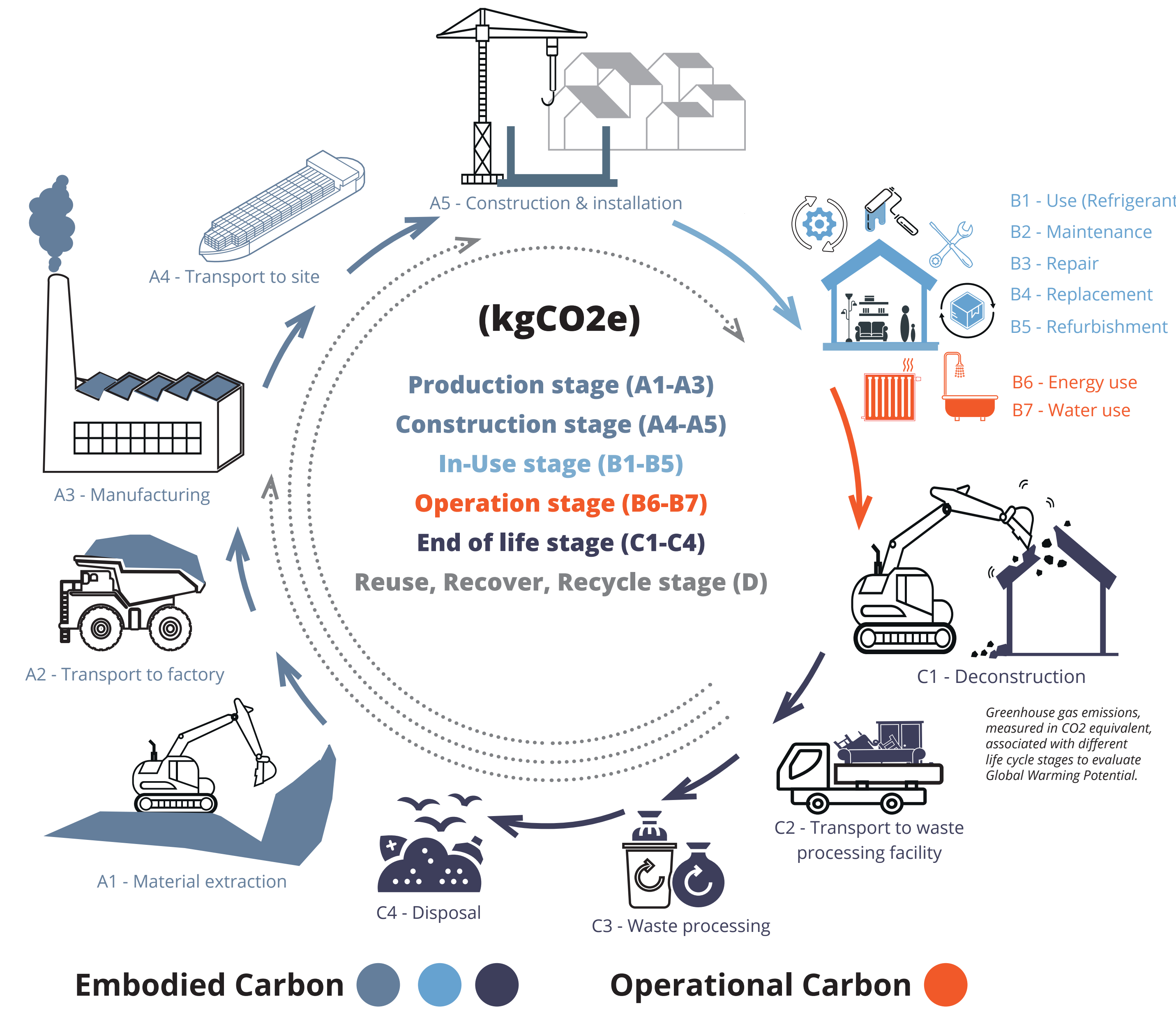
The following table provides the nomenclature and definitions of each life cycle stage according to industry standard EN15804 and indicates which stages were included or excluded.

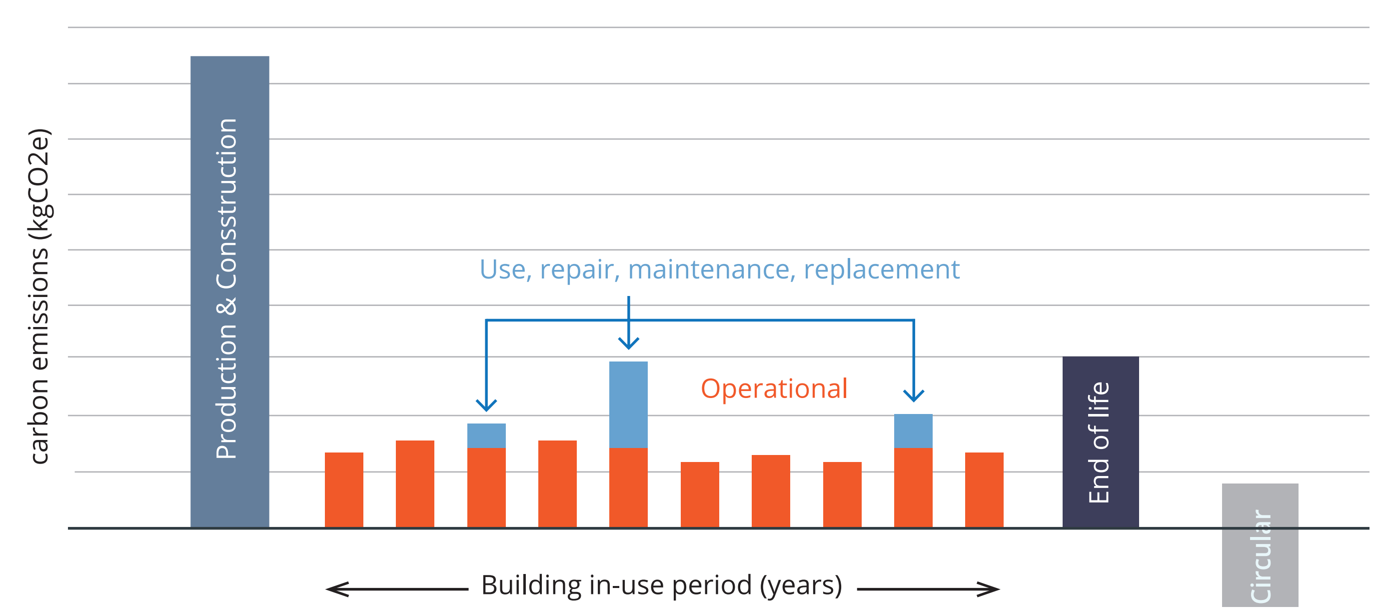
Life Cycle Stage	Life Cycle Stage Module	Study Scope
Product Stage	A1: Material extraction	Included
	A2: Transport (Extraction > Manufacturing)	Included
	A3: Manufacturing	Included
Construction Stage	A4: Transportation (Manufacturing > Construction site)	Included
	~~A5: Construction + Installation process~~	Excluded
Use Stage	B1: Use (Refrigerant Leakage)	Included
	~~B2: Maintenance~~	Excluded
	B3: Repair	Included
	B4: Replacement	Included
	~~B5: Refurbishment~~	Excluded
	B6: Operational Energy Use (Electricity)	Included
	~~B7: Operational Water Use~~	Excluded
End of life Stage	C1: Deconstruction / Demolition / Decommissioning Refrigerant	Included
	C2: Transportation (Deconstruction site > waste processing facility)	Included
	C3: Waste Processing	Included
	C4: Disposal	Included
Beyond system boundary	~~D: Reuse, Recover, Recycling~~	Excluded

Embodied carbon emissions are the carbon impact associated with A1 to A3 (Product Stage), A4 to A5 (Construction Stage), B1 (Use Stage Refrigerant Leakage), B2 to B5 (Servicing and Replacement), and C1 to C4 (end of life stage). This is sometimes referred to as scope 3 emissions.

Operational carbon emissions are the carbon impact associated with B6 (Operational Energy Use) and B7 (Operational Water use). This is sometimes referred to as scope 1 & 2 emissions

Whole life carbon emissions therefore, is the sum of embodied carbon plus operational carbon, as well as emissions resulting from reuse, recovery, and recycling. In the case of The Radiant Whole Life Carbon Study, this includes the A, B, and C Stages.





Whole Life Cycle Carbon Assessment

2.3 Aims of the study

The Radiant Whole Life Carbon Study aimed to accomplish the following

1. **Baseline Scenario: Business as Usual**: define and design complete structural, envelope, and mechanical systems for a market typical all-electric building in the California Bay Area.
2. **Clark Pacific Scenario: Precast + Radiant**: develop and engineer an integrated building solution that leverages radiant slabs, prefabrication, and intentional design in a package that both minimizes whole life carbon and is highly affordable, mass producible, and robust in application throughout the entire United States.
3. **Whole Life Carbon Assessment**: compare the whole life carbon emissions of a Business as Usual All-Electric Building against a Clark Pacific Precast Concrete Radiant Building.
4. **Precast Concrete Embodied Carbon**: quantify the embodied carbon of Clark Pacific Scenario's precast concrete using the specific mix designs employed by Clark Pacific.
5. **Mechanical System Embodied Carbon**: quantify the embodied carbon impact of the mechanical systems' physical elements, including replacement from future tenant improvements and reaching end of service life.
6. **Refrigerant Leakage**: quantify the amount and carbon impact of refrigerant leakage during both building use and decommissioning at end of life.
7. **Actual Electrical Grid Carbon Emissions**: evaluate electricity use using real historical weather and carbon using real historic hourly grid emission intensities to accurately assess operational electricity carbon impact in both scenarios and inform radiant building solution.
8. **Concrete as a Thermal Battery**: perform research grade analysis investigating and actionably quantifying the ability of radiant slabs to reduce building cooling & heating equipment size and shift electrical demand.
9. **Professional Engineers, Builders, and Subject Matter Experts**: perform a pioneeringly pragmatic and comprehensive study by combining Integral Group's global leadership in life cycle carbon assessment and experience in radiant slab buildings with Clark Pacific's expertise in concrete mix design and prefabrication.
10. **Document "everything" and share with extreme transparency**: publish with sufficient completeness and rigor to allow an independent, thorough, and ultimately successful peer review. Better empower industry's ability to assess whole life carbon emissions.

2.4 Scope of the Study

The following provides a summary description of the study period, included & excluded building categories, and included & excluded life cycle stages. Additional information provided throughout report, particularly in Scenario Quantities, Methodology, and Appendix sections.

Study Period

The whole life carbon assessment is carried out over a building lifetime period of 60 years. This influences the carbon impact associated with B4 – replacement. This is aligned with international standards, especially the RICS Guidance[4].

Building categories included in study

The Radiant Whole Life Carbon Study evaluates carbon emissions for the following five categories in both scenarios. A full list of products included in the study can be found in Summary Table A in the Appendix.

- Structural Systems
- Envelope Systems
- Mechanical Systems
- Refrigerant Leakage
- Electricity Use

Building categories excluded from study

Other parts of the office building were not included because they are the same in both study scenarios (such as):

- Plumbing Systems
- Technology Systems
- Landscape Systems
- Interior Walls & Finishes
- Furniture, Fixtures, and Equipment

Electrical Systems were not included in the study due to funding limitations to do a full electrical engineering design and the understanding that the quantity of electrical systems would be close in both scenarios, but greater in the baseline VRF scenario, and thus exclusion of electrical systems is conservative in favor of the baseline.

Life cycle stages included in study

As detailed in section 2.3, carbon emissions associated with the following stages are included in the study.

- Product Stage (A1 to A3), Transportation to Site (A4)
- Refrigerant Leakage (B1), Repair (B3), Replacement (B4), Electricity Use (B6)
- Deconstruction/Decommissioning (C1), Transportation to Facility (C2), Waste Processing (C3), Disposal (C4)

The carbon impact associated with Maintenance (B2) was not included separately, but any maintenance needed is included in the calculations of the carbon impact associated with Repair (B3).

The carbon impact associated with Refurbishment (B5) was not included separately, but any refurbishment needed is included in the calculations of the carbon impact associated with Replacement (B4).

Life cycle stages excluded from study

The carbon emissions associated with Construction (A5) were not included because of lack of consistent available data. Omitting construction emissions is conservative in favor of the baseline, as the Clark Pacific Scenario precast building system is assembled faster, and thus uses less fuel, than the Baseline Scenario fully field fabricated building.

Module D, associated with reuse, recovery and recycling was not included in this version of the study due to funding prioritization and the understanding that Stage D impacts are not expected to be consequentially different between the two scenarios.

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[4] Whole Life Carbon Assessment for the Built Environment, https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf

3 Study Scenarios

The Radiant Whole Life Carbon Study assessed the following two scenarios. Descriptions, drawings, and detailed quantities are provided in this section. See Appendix for more information.

3.1 Baseline: Steel + VRF

The Baseline Scenario is intended to be a business as usual all-electric office building in the California Bay Area. Accordingly, the Baseline Scenario was defined as a structural steel building, with panelized curtain wall facade, and an air-source VRF + DOAS mechanical system. The Baseline Scenario is abbreviated as "Baseline Steel + VRF".

3.2 Clark Pacific: Precast + Radiant

The Clark Pacific Scenario is an alternative all-electric building that uses precast concrete and radiant slabs. Accordingly, the Clark Pacific Scenario is a precast concrete structure, with sun shading on panelized facade, and a precast radiant + ASHP + DOAS mechanical system. The Clark Pacific Scenario is abbreviated "Clark Precast + Radiant".

3.3 Building Type, Area, and Location

The Radiant Whole Life Carbon Study, at Clark Pacific's instruction, assessed both scenarios for a building of the following size, use type, and location. *These choices serve to quantify impact for a larger office building in the California bay area. This is in no way meant to imply any limitations of feasibility to this specific size and location. The precast radiant building scheme presented in The Radiant Whole Life Carbon Study is intentionally applicable throughout the United States in a range of sizes, shapes, and heights.* See Results for more information.

Building Type	Office
Number of Levels	8 floors
Area	240,000 SF total
Location	Mountain View, CA

3.4 Scenario Description Summary

The table below is a high-level overview of the components and intention for both scenarios. Further details provided in subsequent pages.

BASELINE SCENARIO: STEEL + VRF

Structure

- Steel Structure with cast-in-place lightweight topping slab on metal deck, slab on grade, and foundation
- Mix designs and structural design choices to minimize steel quantity

Envelope

- Aluminum Curtain Wall Panels with typical performance vision glass and insulated spandrel for non-vision glass.
- No sunshades as it has minimal impact on overall annual electricity use, and is not common practice
- Area of vision glass equal in both scenarios
- 15ft floor-to-floor (standard)

Mechanical

- VRF Fan Coils provide all space heating & cooling (including DCV meeting rooms)
- DOAS heat recovery provides ventilation & exhaust
- VRF condenser units (heat recovery) serve fan coils
- VRF condenser units (reversible) serve DOAS
- VAV box for each demand control ventilation space
- Fan coils throughout all spaces
- Field fabrication of fan coil assembly (pipe, duct, diffusers)
- Field fabrication of floor level refrigerant piping distribution
- Larger central plant cannot downsize from thermal mass
- Larger pipe length cannot reduce via prefabricated beam openings

CLARK PACIFIC SCENARIO: PRECAST + RADIANT

Structure

- Clark Pacific Precast Concrete Structure with cast-in-place topping slab/closure, slab on grade, and foundation
- Mix designs and structural design choices work backwards to minimize carbon

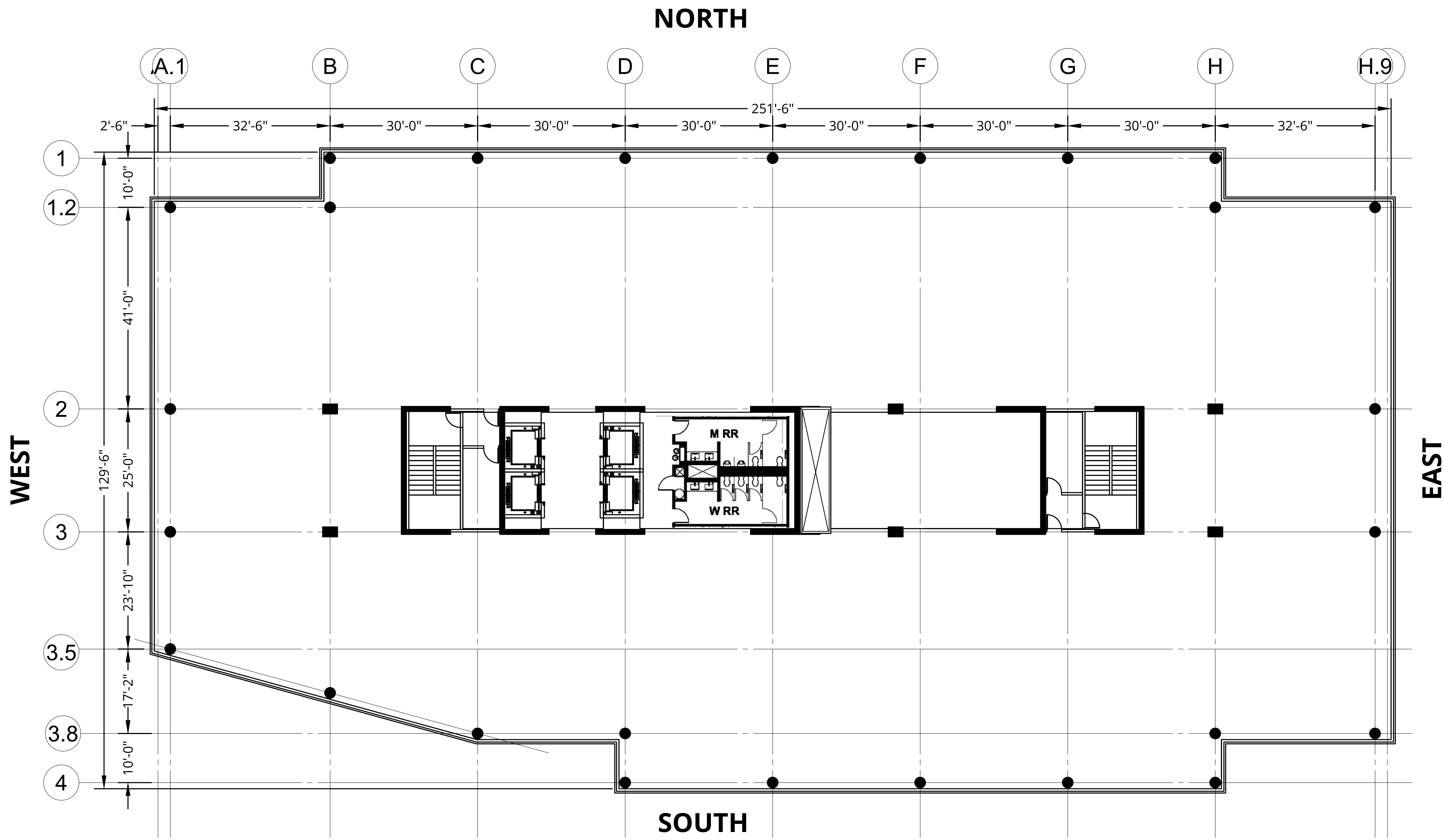
Envelope

- Combination of same type Aluminum Curtain Wall Panels and Precast Infinite Façade Panels (to show design flexibility)
- Sunshades on south & west to even out rapid swings in solar load to allow radiant system the chance to succeed without assistance
- 13ft floor-to-floor (reduced by prefabrication and structural/mechanical integration)

Mechanical

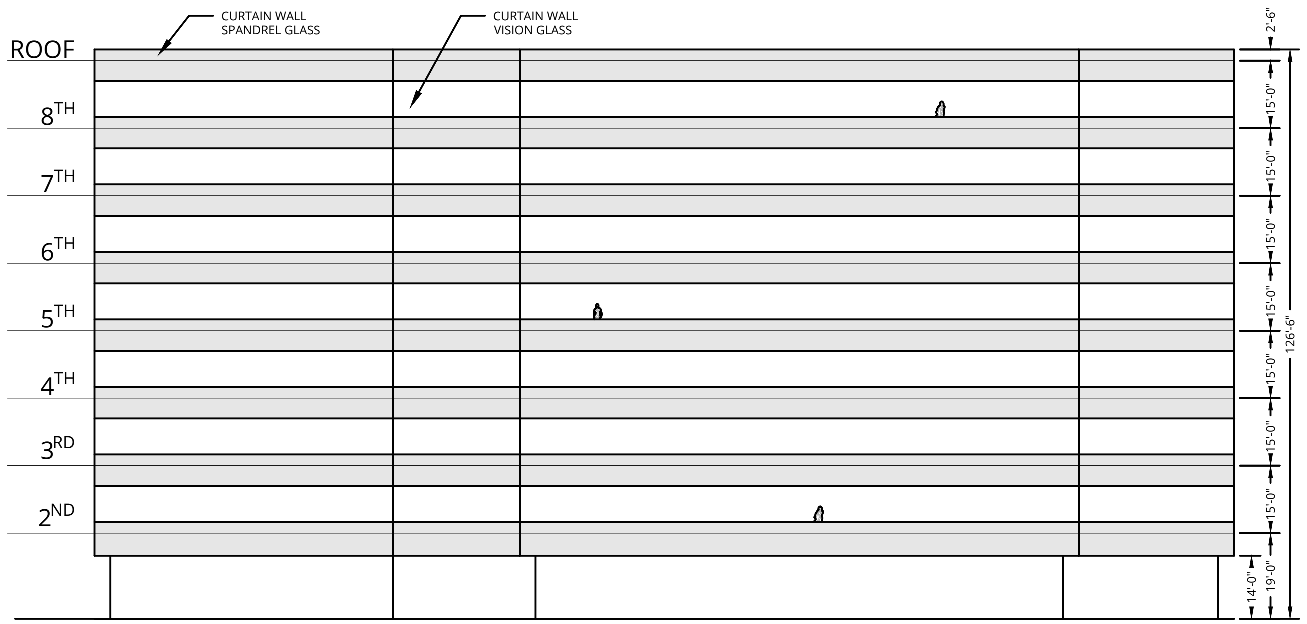
- Precast radiant slabs provide all space heating & cooling (with support only in DCV meeting rooms)
- DOAS heat recovery provides ventilation & exhaust
- ASHP (4-pipe heat recovery) serves radiant zones
- ASHP (reversible) serves DOAS
- VAV box for each demand control ventilation space
- Ceiling Fans in workspace (not in meeting rooms)
- Maximized prefabrication of radiant assembly tight under slab
- Maximized prefabrication of floor level hydronic distribution
- Minimized central plant size via slab as thermal battery
- Minimized pipe length via mains run in continuous prefabricated beam openings next to manifolds

3.5 Plans, Elevations, and Sections

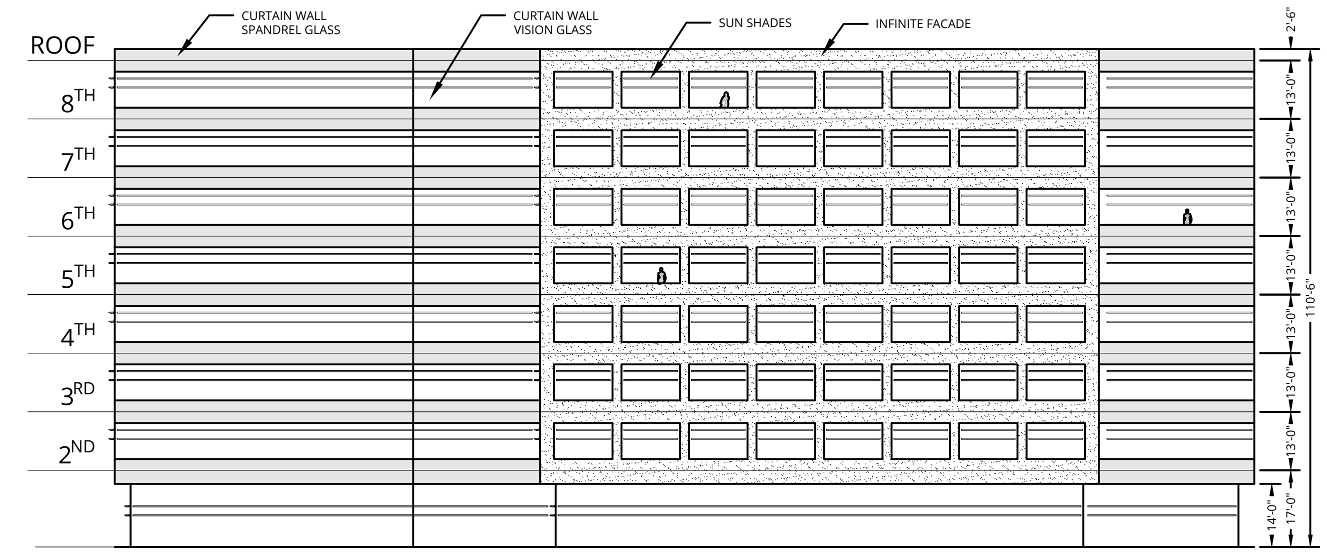


BUILDING FLOOR PLAN

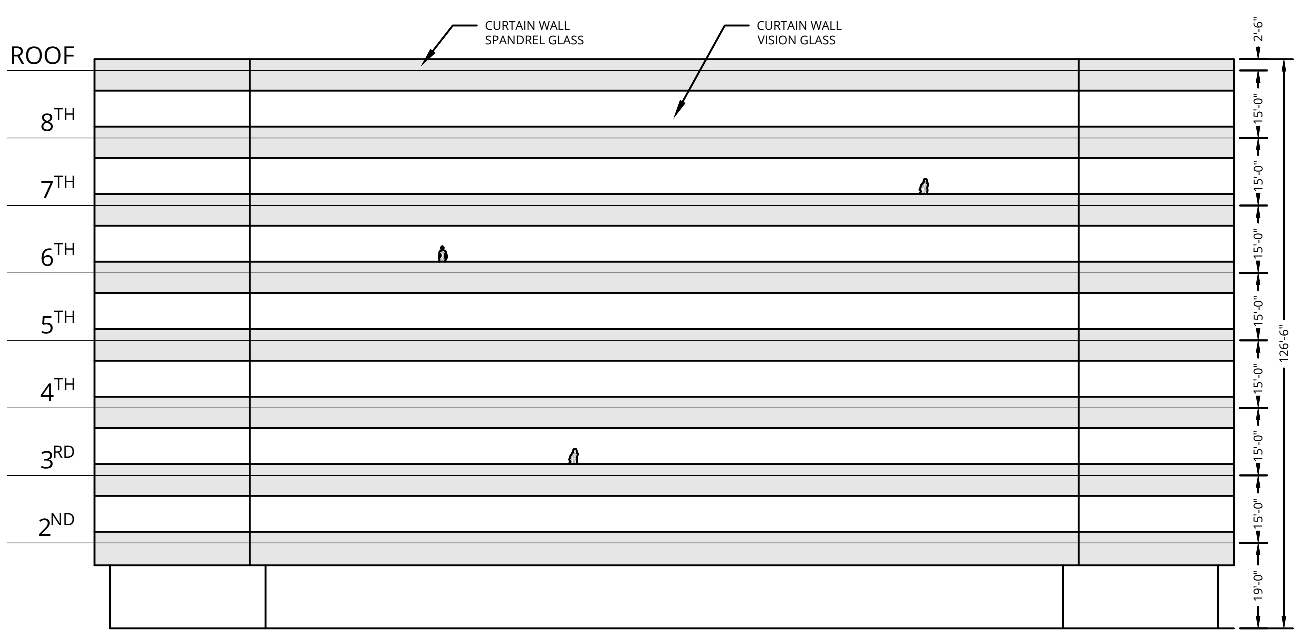
3.5 Plans, Elevations, and Sections



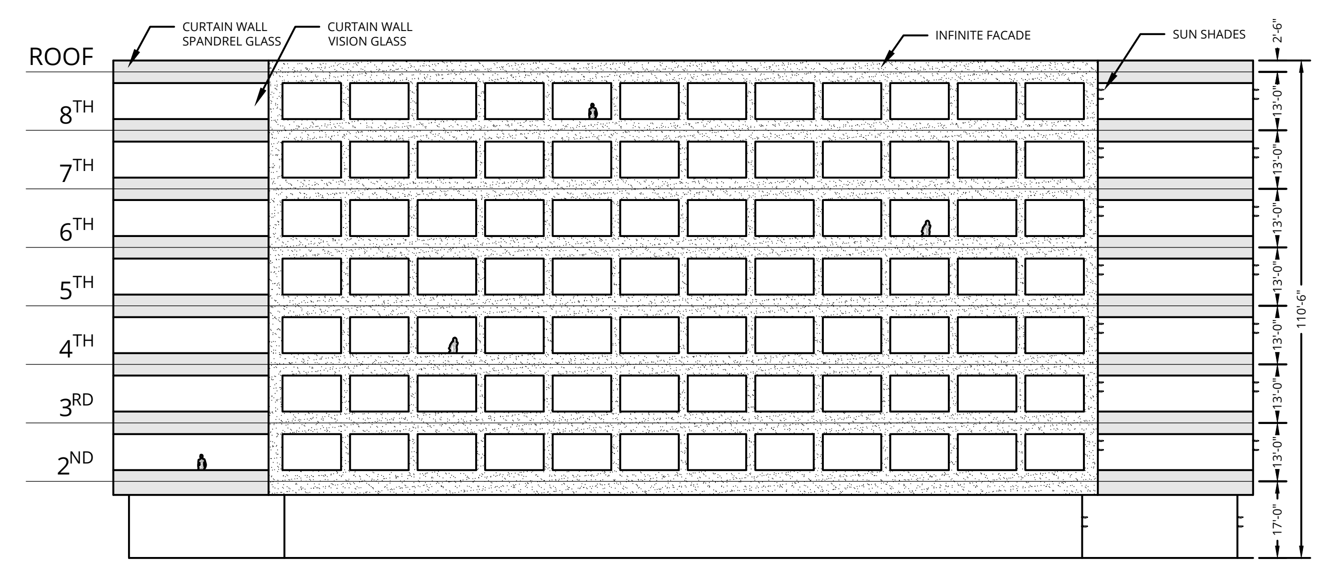
SOUTH ELEVATION
Baseline Steel Scenario



SOUTH ELEVATION
Clark Pacific Precast Scenario

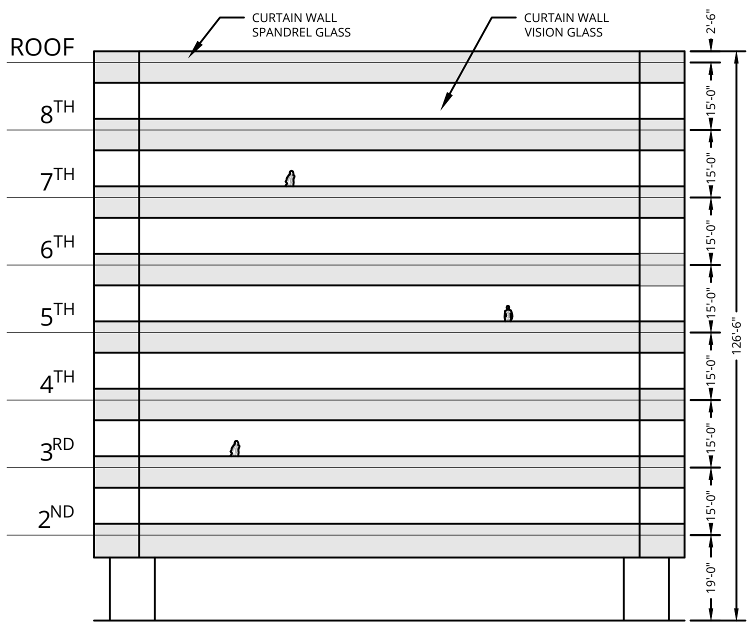


NORTH ELEVATION
Baseline Steel Scenario

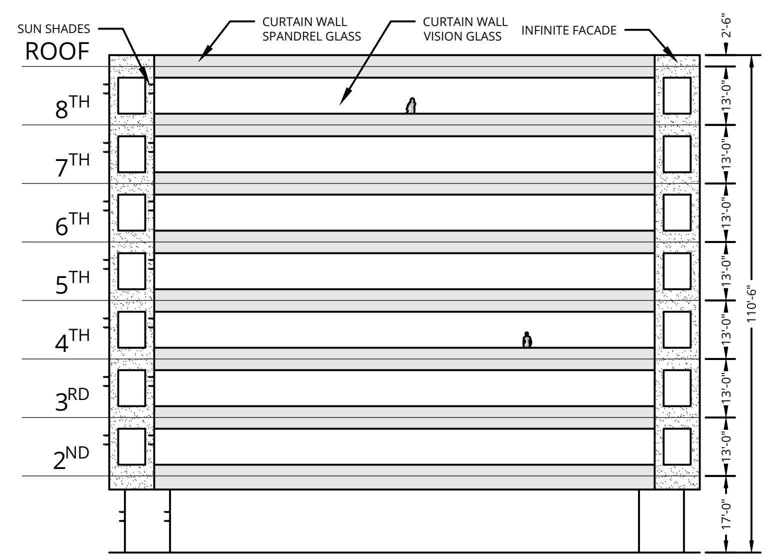


NORTH ELEVATION
Clark Pacific Precast Scenario

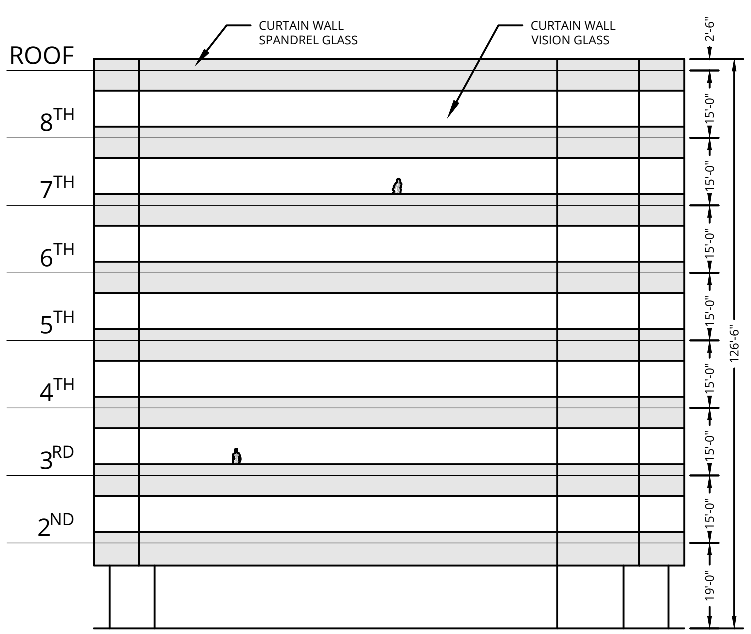
3.5 Plans, Elevations, and Sections



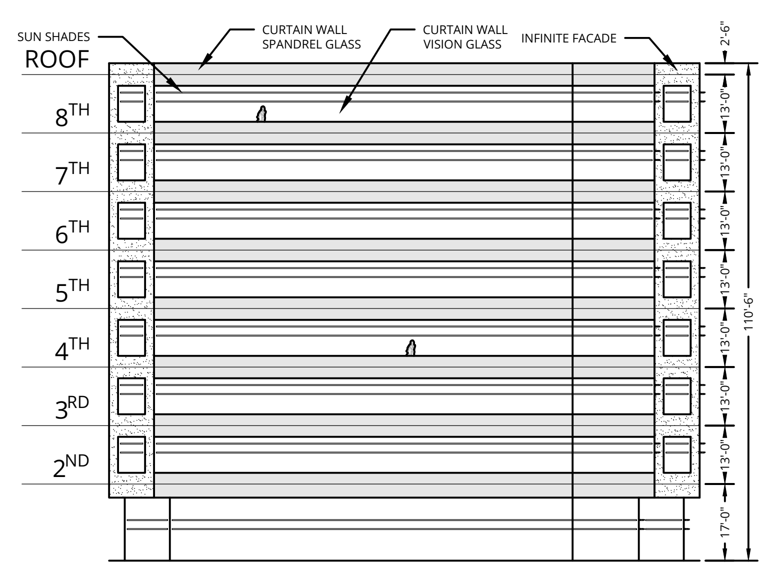
EAST ELEVATION
Baseline Steel Scenario



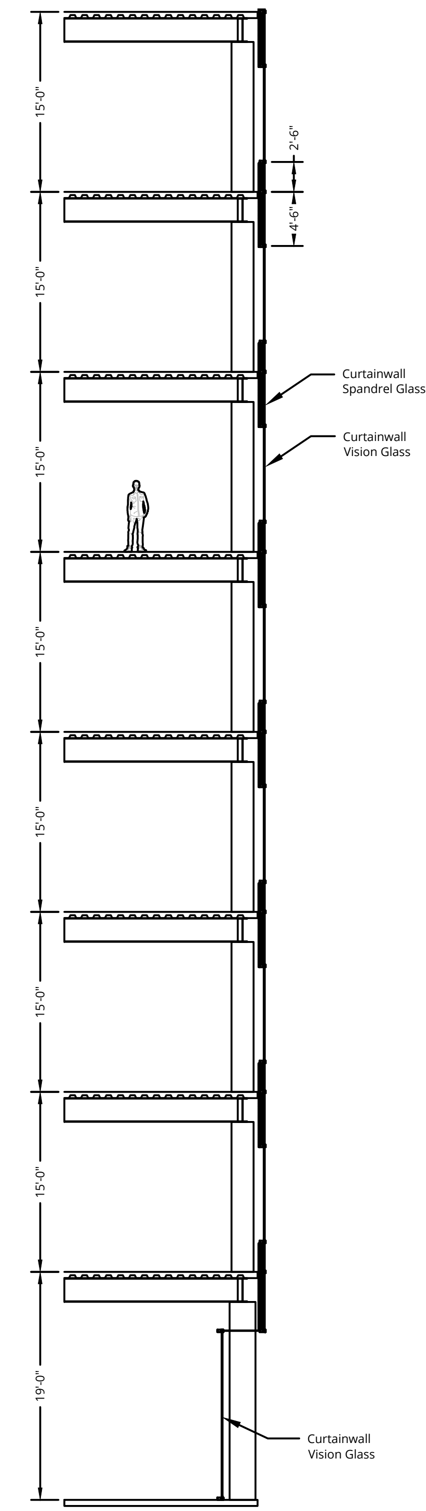
EAST ELEVATION
Clark Pacific Precast Scenario



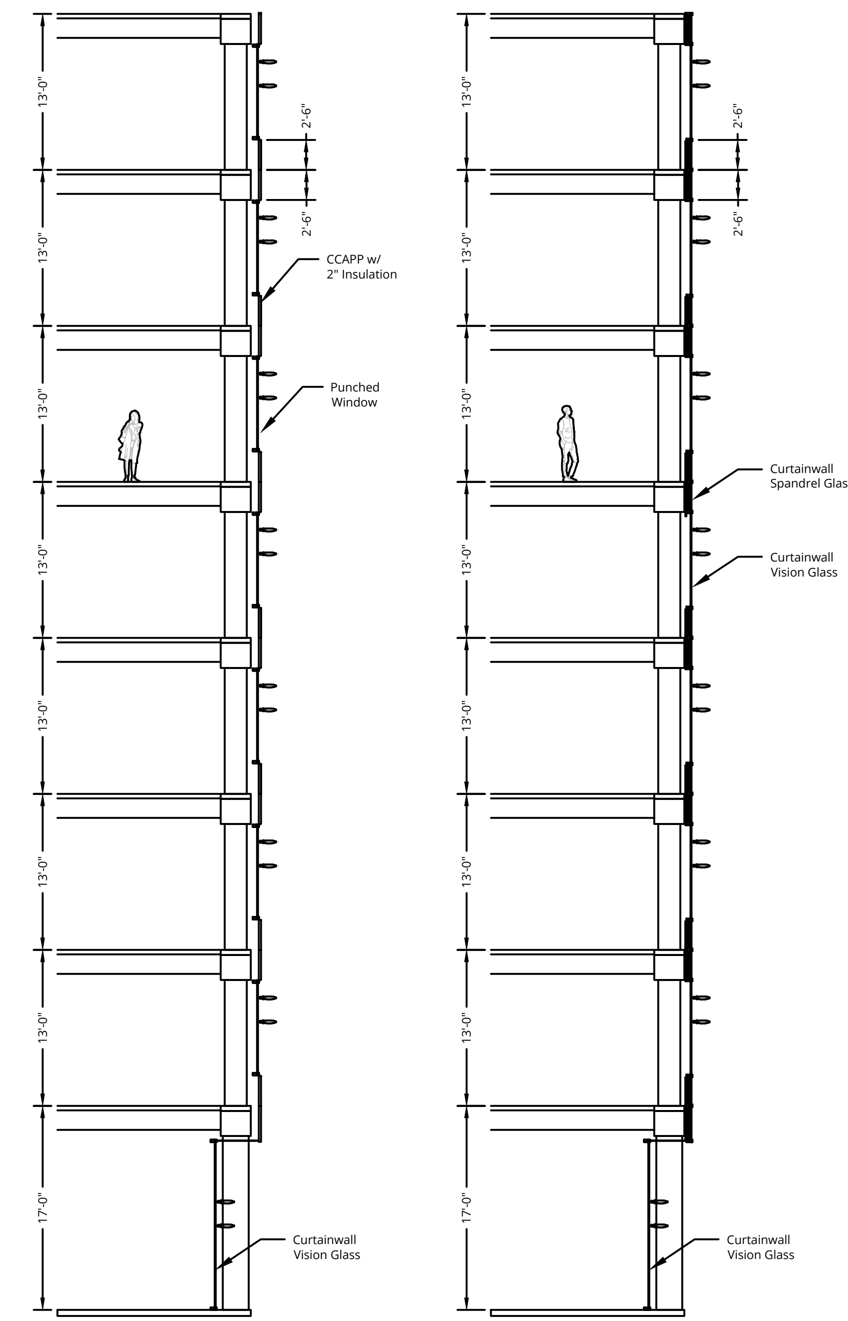
WEST ELEVATION
Baseline Steel Scenario



WEST ELEVATION
Clark Pacific Precast Scenario

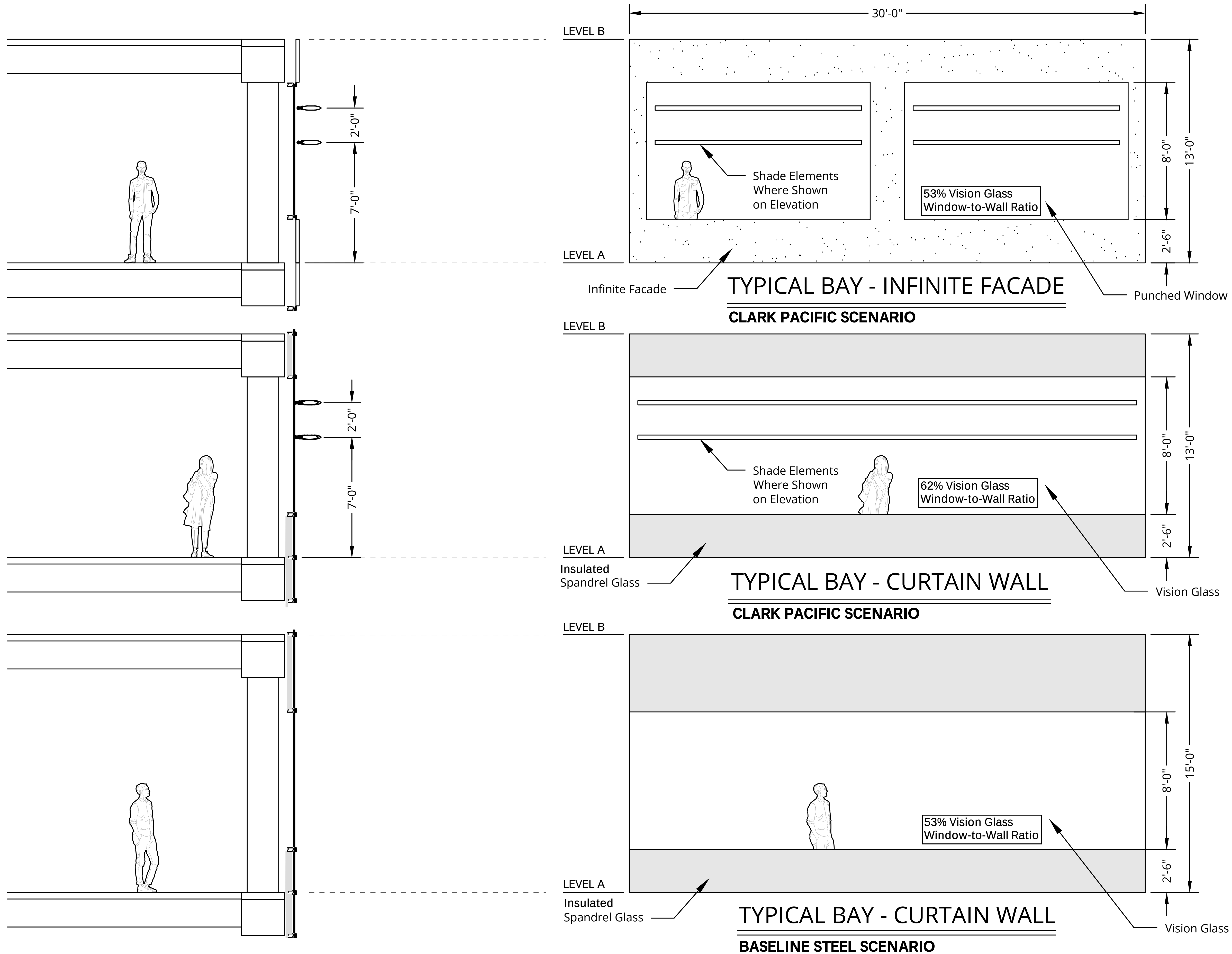


BUILDING SECTION
Baseline Steel Scenario



BUILDING SECTION
Clark Pacific Precast Scenario

3.5 Plans, Elevations, and Sections



3.5 Plans, Elevations, and Sections

3.6 Mechanical System Schematics

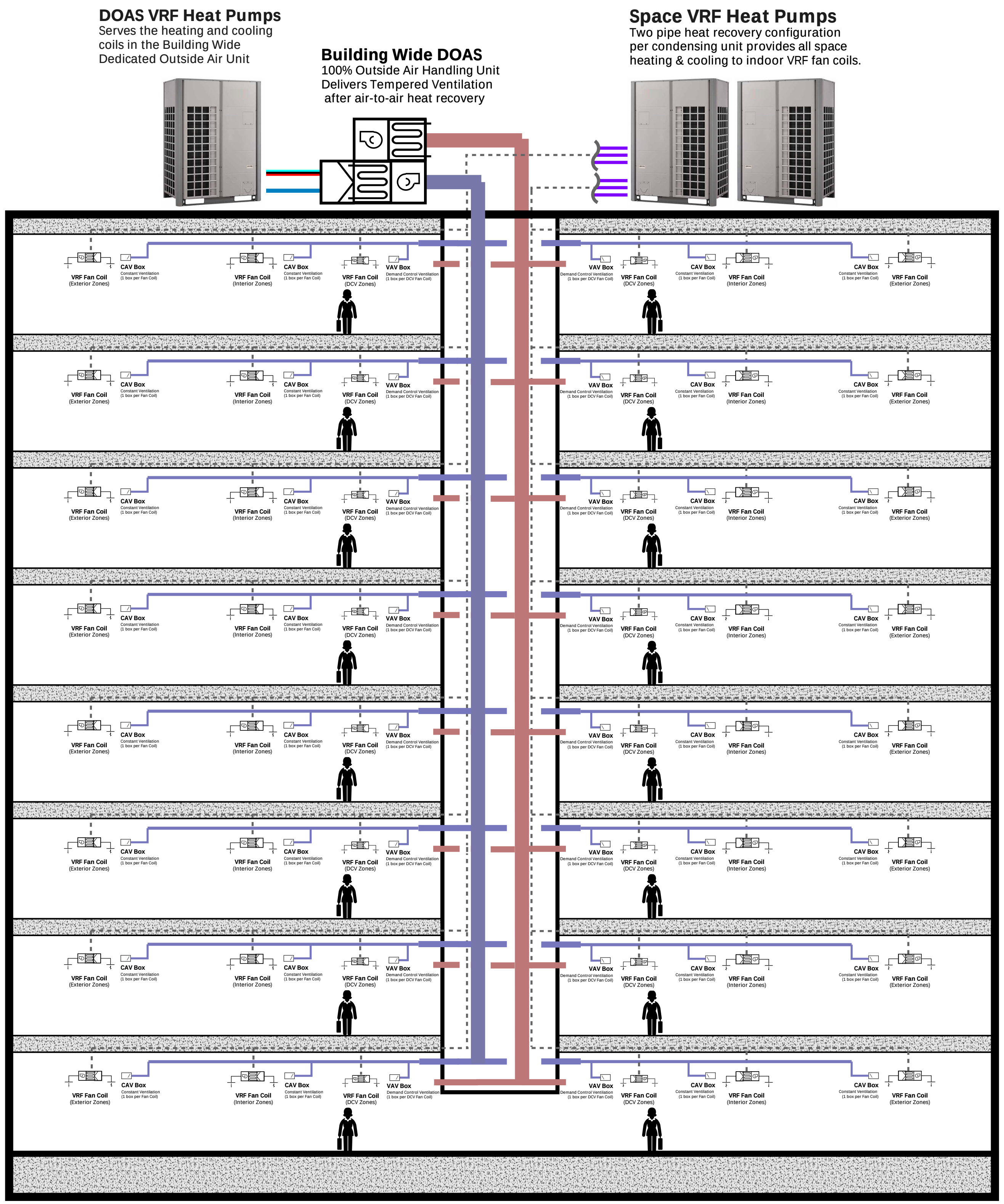
Baseline Scenario Steel + VRF

DOAS Ventilation System

Completely decoupled ventilation system provides outside air tempering and humidity control

VRF Heating & Cooling System

Provides 100% of space heating and cooling for all spaces. Two pipe heat recovery type configuration per condensing unit.



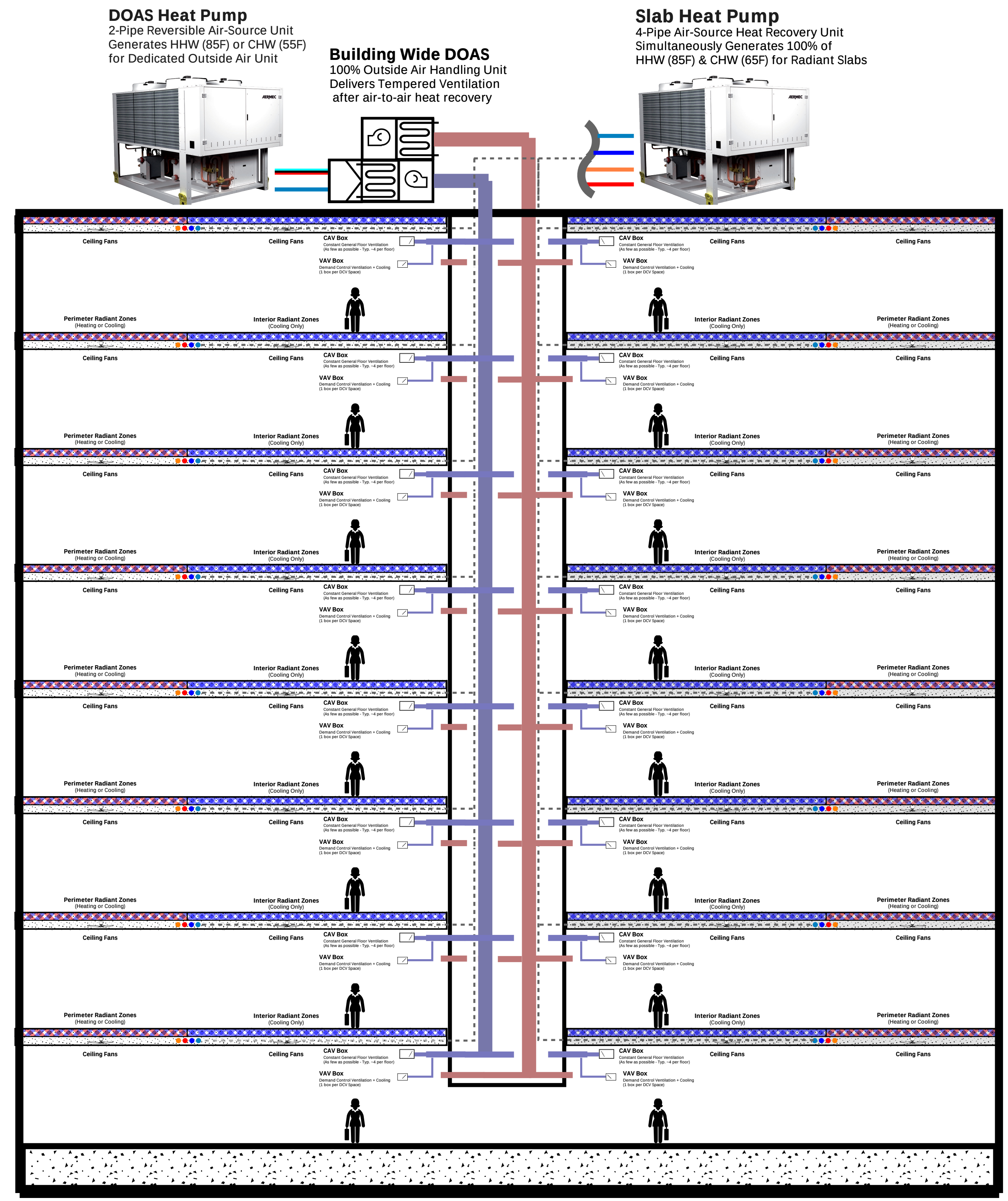
Clark Pacific Precast + Radiant

DOAS Ventilation System

Completely decoupled ventilation system provides outside air tempering and humidity control

Radiant Heating and Cooling System

Provides 100% of space heating and cooling for all spaces (DCV Conference rooms assisted by DOAS)



3.7 Quantities: Structure

The section is intended to show itemized quantities for all physical elements in the study and some clarity around how each was determined. All quantities derived from engineered designs of both scenarios. Additional tables in Appendix.

DETAIL TABLE B.1

Baseline - Steel Frame

	Beams (I-Section)	Columns (I-Section)	Beams (Wide Flange)	Columns (Wide Flange)	Braces (Wide Flange)
STRUCTURAL STEEL FRAME	**1,707,279 lbs**	**259,821 lbs**	**127,468 lbs**	**315,154 lbs**	**82,237 lbs**
Steel Grade	Grade 50	Grade 50	Grade 50	Grade 50	Grade 36

DETAIL TABLE B.2

Baseline - Cast in Place Items

	Topping Slab	Grade Slab	Foundation
CAST IN PLACE CONCRETE	**3,406 yd3** **4,588,506 kg**	**463 yd3** **822,210 kg**	**1,787 yd3** **3,173,057 kg**
Concrete Mix	Mix G	Mix E	Mix F
Concrete Strength (28-days)	3000 psi	4000 psi	5000 psi
Concrete Weight Classification	Light	Normal	Normal
Concrete Volume (yd3)	3,406	463	1786.8
Concrete Density (lbs/ft3)	110	145	145
Concrete Density (lbs/yd3)	2,970	3,915	3,915
Concrete Weight (lbs)	10,115,820	1,812,645	6,995,322
Cocnrete Mass (kg)	4,588,506	822,210	3,173,057
REBAR STEEL		**256,734 lbs**	
Rebar Density (lbs/yd3)	-	75	124
Rebar Weight (lbs)	-	34,725	222,009
MESH STEEL		**139,383 lbs**	
Mesh Density (lbs/ft2)	0.60	-	-
Mesh Weight (lbs)	139,383	-	-
MISC. METALS & EOS STEEL*		**151,634 lbs**	
Misc. Metals Density (lbs/yd3)*	45	-	-
Misc. Metals Weight (lbs)*	151,634	-	-

*Carbon emissions for "Misc. Metals & EOS Steel" intentionally uses the quantity of only EOS Steel (151,634 lbs), omitting all other Misc. Metals (480,000 lbs). This is meant to be a sizable overall safety factor in favor of the baseline scenario and to ensure no argument could be made that the baseline structure's steel is unfairly too heavy.

DETAIL TABLE B.3

Baseline - Steel Deck

	Deck (20 gage)
STEEL DECK	**485,516 lbs** **232,304 ft2**

DETAIL TABLE B.4

Baseline - Steel Quantities Summary

Beams (I-Section)	7.1 lbs/ft2
Columns (I-Section)	1.1 lbs/ft2
Beams (Wide Flange)	0.5 lbs/ft2
Columns (Wide Flange)	1.3 lbs/ft2
Braces (Wide Flange)	0.3 lbs/ft2
EOS Plate	0.6 lbs/ft2
Misc. Metals	2.0 lbs/ft2
Total	**13.0 lbs/ft2**

DETAIL TABLE C.1

Clark Pacific - Precast Structure

	Floor Planks	Hollow Core	Ext. Beams	Int. Beams	Shear Walls	Columns
PRECAST CONCRETE	**4,042 yd3** **6,682,654 kg**	**306 yd3** **543,889 kg**	**813 yd3** **1,473,415 kg**		**2,193 yd3** **3,974,773 kg**	
Concrete Mix	Mix A	Mix B	Mix C	Mix D	Mix D	Mix D
Concrete Strength (28-days)	7000 psi	4000 psi	8000 psi	9000 psi	9000 psi	9000 psi
Concrete Weight Classification	Normal	Normal	Normal	Normal	Normal	Normal
Concrete Volume (yd3)	4,042	306	813	903	929	360
Concrete Density (lbs/ft3)	135	145	148	148	148	148
Concrete Density (lbs/yd3)	3,645	3,915	3,996	3,996	3,996	3,996
Concrete Weight (lbs)	14,732,579	1,199,059	3,248,292	3,609,568	3,713,326	1,439,891
Cocnrete Mass (kg)	6,682,654	543,889	1,473,415	1,637,289	1,684,354	653,130
REBAR STEEL			**1,898,254 lbs**			
Rebar Density (lbs/yd3)	133	-	300	450	562	522
Rebar Weight (lbs)	537,567	-	243,866	406,483	522,245	188,094
STRAND STEEL			**203,579 lbs**			
Strand Density (lbs/yd3)	41	44	30	-	-	-
Strand Weight (lbs)	165,716	13,476	24,387	-	-	-
MISC. METALS & EOS STEEL			**165,999 lbs**			
Misc. Metals Density (lbs/yd3)	5	-	15	15	40	230
Misc. Metals Weight (lbs)	20,209	-	12,193	13,549	37,170	82,877

DETAIL TABLE C.2

Clark Pacific - Cast in Place Items

	Topping Slab	Grade Slab	Foundation
CAST IN PLACE CONCRETE	**747 yd3** **1,327,320 kg**	**463 yd3** **822,210 kg**	**2,882 yd3** **5,118,659 kg**
Concrete Mix	Mix E	Mix E	Mix F
Concrete Strength (28-days)	4000 psi	4000 psi	5000 psi
Concrete Weight Classification	Normal	Normal	Normal
Concrete Volume (yd3)	747	463	2,882
Concrete Density (lbs/ft3)	145	145	145
Concrete Density (lbs/yd3)	3,915	3,915	3,915
Concrete Weight (lbs)	2,926,210	1,812,645	11,284,596
Cocnrete Mass (kg)	1,327,320	822,210	5,118,659
REBAR STEEL		**419,480 lbs**	
Rebar Density (lbs/yd3)	52	75	120
Rebar Weight (lbs)	38,867	34,725	345,888

3.7 Quantities Envelope

The section is intended to show itemized quantities for all physical elements in the study and some clarity around how each was determined. All quantities derived from engineered designs of both scenarios. Additional tables in Appendix.

DETAIL TABLE L

Envelope Quantities

FACADE TYPE	BASELINE TYPE	CLARK TYPE 1	CLARK TYPE 2	CLARK TYPE 3	CLARK TYPE 4
Panel Type	Curtain Wall Panel	Infinite Façade	Infinite Façade	Curtain Wall Panel	Curtain Wall Panel
Floor-to-Floor Height (typ.)	15ft floors	13ft floors	13ft floors	13ft floors	13ft floors
Exterior Sun Shades	No Shades	(2) 14" Sun Shades	No Shades	(2) 14" Sun Shades	No Shades
Glass Height (from 30"AFF)	8ft tall vision glass	8ft tall glass	8ft tall glass	8ft tall vision glass	8ft tall vision glass
Punched or Ribbon Windows	Cont. Ribbon	Punched Windows	Punched Windows	Cont. Ribbon	Cont. Ribbon
Window-to-Wall Ratio	~53% WWR	~53% WWR	~53% WWR	~61% WWR	~61% WWR
Insulation	2" Insul. Spandrel	2" HFO Foam	2" HFO Foam	2" Insul. Spandrel	2" Insul. Spandrel
FAÇADE AMOUNTS	**BASELINE TYPE**	**CLARK TYPE 1**	**CLARK TYPE 2**	**CLARK TYPE 3**	**CLARK TYPE 4**
Façade Length (ft)	729	150.0	190.0	217.1	172.0
Façade Height (ft)	123	107.5	107.5	107.5	107.5
Total Façade Area (ft2)	89,685	16,125	20,425	23,343	18,490
Infinite Façade Area (ft2)	0	16,125	20,425	0	0
Curtain Wall Area (ft2)	89,685	0	0	23,343	18,490
Spandrel Insulation Area (ft2)	43,020	0	0	9,446	7,482
Sun Shades Length (ft)	0	1,920	0	3,301	0
SCENARIO TOTALS	**BASELINE**	**CLARK PACIFIC**			
Total Infinite Façade	0 ft2	36,550 ft2			
Total Curtain Wall	89,685 ft2	41,833 ft2			
Total Spandrel Insulation	43,020 ft2	16,928 ft2			
Total Sun Shade Length	0 ft	5,221 ft			

DETAIL TABLE M

Exterior Shades Aluminum Mass

PRODUCT INFO		
Manufacturer	Kawneer	
Model Series	Versoleil® SunShade	
Model Line	Single Blade System	
Size	14" Depth	
BLADE CROSS-SECTIONAL AREA		
Perimeter Aluminum Length	28.53	in
Perimeter Aluminum Thickness	0.11	in
Perimeter Aluminum Area	3.27	in2
Interior Supports Aluminum Length	5.50	in
Interior Supports Aluminum Thickness	0.11	in
Interior Supports Aluminum Area	0.63	in2
Interior Clips Aluminum Length	5.50	in
Interior Clips Aluminum Thickness	0.04	in
Interior Clips Aluminum Area	0.21	in2
Blade Cross-Sectional Aluminum Area	4.11	in2
Blade Cross-Sectional Aluminum Area	0.03	ft2
EXTERIOR SHADES MASS		
Total Sun Shade Blade Length	5,221	ft
Total Sun Shade Blade Volume	149	ft3
Additional % for Mounting Clips	5%	
Additional % for Safety Factor	10%	
Total Exterior Shade Aluminum Volume	171	ft3
Aluminum Density	169	lbs/ft3
Total Exterior Shade Aluminum Weight	28,863	lbs

3.7 Quantities Mechanical

The section is intended to show itemized quantities for all physical elements in the study and some clarity around how each was determined. All quantities derived from engineered designs of both scenarios. Additional tables in Appendix.

DETAIL TABLE P.1

Baseline Scenario - Mechanical Quantity Summary

VRF System Summary	QTY	Size
Outdoor VRF Condensing Units*	15 EA	100 kW
Indoor VRF Fan Coils**	344 EA	8 kW
Refrigerant Charge***	1,850 LBS	(839 kg)
Refrigerant	R-410a	
Refrigerant Pipe***	62,030 LF	(17,521 kg)
Refrigerant Pipe Insulation	1,123 ft3	(31.8 m3)
Branch Circuit Controllers****	53 (4-circuit)	44 (3-circuit)

*1491 kW nominal cooling capacity estimated from assessing completed built VRF installed capacities in the California Bay Area. At 560 sf/ton and , matches Business as Usual capacity consistent with the Baseline Scenario.

**Applied (1) 8kW Fan Coil per 500sf on the perimeter and (1) 8kW Fan Coil per 1000sf for the interior. A smaller number of larger size fan coils was chosen intentionally to be conservative in a favor of the baseline scenario. The relative emissions impact is higher from more smaller fan coil units than fewer larger fan coil units.

***See Tables P.2 and P.3 below for full details.

**** Branch Circuit Controllers carbon emissions were excluded to be conservative in favor of the baseline. At ~40 lbs per 4-BCC (qty 53) and~35 lbs per 3-circuit BCC (qty 44) this is ~3,660 lbs of copper. Not an insignificant amount.

Baseline Scenario Airside System Summary	
DOAS Building Air Handler (w/HR)*	Same as Clark Pacific scenario
Ductwork in mechanical shaft**	Same as Clark Pacific Scenario
Ductwork from shaft to VRF Fan Coils**	Same as Clark Pacific Scenario
VAV Boxes***	344
Diffusers, misc. accessories**	Excluded

*Same size and type as unit in Clark Pacific, except heat recovery either wheel or plate and frame (assuming same heat recovery effectivenss in Baseline and Clark Scenarios) and refrigerant coil instead of hydronic coil.

**To be conservative in favor of the baseline, all ductwork distribution on the fresh air side identical betwen Baseline and Clark scenarios from DOAS to VRF Fan coil. Ductwork downstream of VRF Fan Coils is excluded in the Baseline in the same fashion ductwork and diffusers downstream of VAV boxes is excluded in Clark scenario. The VRF Fan coils have more ductwork & diffusers downstream than Clark system.

***Same # of VAVs as Fan Coils. Required to enable modulation of air flow in demand control ventilation spaces while still providing constant ventilation in non DCV spaces.

DETAIL TABLE Q

Duct and Pipe Hangers & Supports

Pipe Hangers	(2) 0.5m long Pipe Hangers per 10 ft of pipe. Each hanger taken as 0.01m diameter steel rod			
Duct Hangers	(2) 0.5m long Duct Hangers per 10 ft of pipe. Each hanger taken as 0.01m diameter steel rod			
Pipe Unistrut Supports	(1) 0.5m long unistrut for every 10 ft of pipe. Each unistrut taken as 0.05m x 0.005m rectangular steel.			
Duct Unistrut Supports	(1) 0.5m long unistrut per 10 ft of duct. Each unistrut taken as 0.05m x 0.005m rectangular steel.			
Pipe Hangers and Supports	Baseline: 2.13 m3		Clark Pacific:*	1.97 m3
Duct Hangers and Supports	Baseline: 0.26 m3		Clark Pacific:	0.26 m3

*50% extra allowance provided for the Clark Pacific Pipe Hangers and Supports to be conservative in favor of the baseline

DETAIL TABLE N

Clark Pacific - Mechanical Hydronic System Quantities

Hydronic System Outside Shaft	QTY per Plank	# Planks / LVL	Floor QTY	Building QTY
1/2" PEX Pipe Radiant Tubing (9" o.c.)	1,193 LF	58	69,213 LF	553,707 LF
1" Radiant Manifolds (Six Circuit)**	1 EA	58	58 EA	464 EA
1" Radiant Manifolds (Three Circuit)**	1 EA	58	58 EA	464 EA
1" PEX Pipe (Exposed)**	22 LF	58	1,276 LF	10,208 LF
1-1/2" PEX Pipe (Exposed)	20 LF	58	1,160 LF	9,280 LF
2-1/2" PEX Pipe (Exposed)	20 LF	58	1,160 LF	9,280 LF
2-1/2" Copper Pipe Type L	20 LF	2	40 LF	320 LF
Pipe Insulation (1" Thickness)	-	-	2,360 LF	18,880 LF

*CHW Pipe sizes based on 12 gpm/1000sf flow rate density in perimeter radiant zones and 6 gpm/1000sf in interior zones. HHW Pipe sizes based on 6 gpm/100sf flow rate density in perimeter radiant zones. PEX Piping used for all horizontal distribution (in lieu of Copper) downstream of immediate split adjacent to mechanical shaft. Precast sleaves in plank ribs allow for continuous straight 4-pipe mains, and colocating manifolds adjacent to mains directly under planks reduces piping from mains to manifolds.

**Radiant manifolds plastic multi-port tee type. Plastic manifold material captured by length of 1" PEX.

Hydronic System in Mechanical Shaft	QTY Main / LVL	QTY Riser / LVL	Floor QTY	Building QTY
2-1/2" Copper Pipe Type L*	68 LF	0 LF	68 LF	544 LF
4" Steel Pipe Schd 40	0 LF	50 LF	-	400 LF
6" Steel Pipe Schd 40	0 LF	50 LF	-	400 LF
Pipe Insulation (1" Thickness)	-	68 LF	-	544 LF
Pipe Insulation (2" Thickness)	-	100 LF	-	800 LF

*Includes extra length allowance to get to floor main horizontal distribution

Hydronic System on Roof	Building QTY
DOAS 2-Pipe ASHP (Reversible Htg/Clg)*	1 EA
Radiant 4-Pipe ASHP (Simul Htg/Clg)*	1 EA
Steel Pipe Schd 40 (4")	160 LF
Steel Pipe Schd 40 (6")	40 LF
Steel Pipe Schd 40 (8")	0 LF
Pipe Insulation (2" Thickness)	200 LF

*Aermec NRP1800 + (1) 700 gal Buffer Tank (~1900lbs - included in Steel Pipe Total).

*Aermec NRP1250 + (2) 500 gal Buffer Tanks (~2250lbs (1125lbs each) - included in Steel Pipe Total).

Pipe Subtotals		
PEX Inslab (1/2")	553,707 LF	23,107 LBS
PEX Exposed Pipe (1")	10,208 LF	1,632 LBS
PEX Exposed Pipe (1-1/2")	9,280 LF	3,102 LBS
PEX Exposed Pipe (2-1/2")	9,280 LF	8,085 LBS
Copper Pipe Type L (2-1/2")	864 LF	2,143 LBS
Steel Pipe Schd 40 (4")	560 LF	6,048 LBS
Steel Pipe Schd 40 (6")	440 LF	8,316 LBS
Steel Buffer Tanks	331 SF	4,970 LBS
Pipe Insulation (1")	10,919 SF	910 FT3
Pipe Insulation (2")	1,755 SF	293 FT3

Hydronic System Totals		
PEX Inslab	553,707 LF	23,107 LBS
PEX Exposed	28,768 LF	12,819 LBS
Copper Pipe	864 LF	2,143 LBS
Steel Pipe (incld. Buffer Tanks)	1,000 LF	19,344 LBS
Pipe Insulation (incld. Buffer Tanks)	12,674 SF	1,202 FT3
Slab ASHP		(1) Aermec NRP1250
DOAS ASHP		(1) Aermec NRP1800

3.7 Quantities Mechanical

The section is intended to show itemized quantities for all physical elements in the study and some clarity around how each was determined. All quantities derived from engineered designs of both scenarios. Additional tables in Appendix.

DETAIL TABLE O

Clark Pacific - Mechanical Airside System Quantities

Airside System Outside Shaft	QTY per Plank*	# Planks / LVL	QTY per Plank	Floor QTY	Building QTY
Supply Duct (14"x42")	10 LF	2	142 LBS	284 LBS	2,269 LBS
Supply Duct (12"x26")	10 LF	42	79 LBS	3,324 LBS	26,589 LBS
Supply Duct (10"x18")	10 LF	14	58 LBS	817 LBS	6,532 LBS
Supply Duct (8"x10")	45 LF	20	29 LBS	586 LBS	4,685 LBS
Duct Insulation (14"x42")	10 LF	2	101 SF	201 SF	1,610 SF
Duct Insulation (12"x26")	10 LF	42	69 SF	2,884 SF	23,074 SF
Duct Insulation (10"x18")	10 LF	14	51 SF	713 SF	5,702 SF
Duct Insulation (8"x10")	45 LF	20	32 SF	639 SF	5,115 SF
VAV Box Cooling Only (10")**	1 EA	20	-	20 EA	160 EA
Ceiling Fans (50" Aeratron FR)	2 EA	29		58 EA	464 EA

*Conversion from duct size and length to weight based on steel gage and type consistent with application

**Only up to 4 VAV boxes needed per floor for non DCV constant ventiatlion. To be conservative, used ~1/3 # VAV boxes as baseline VRF Fan Coil quantitiy, equaling 20 VAV boxes per 30,000sf floor.

Airside System in Mechanical Shaft	QTY / LVL	Amount / LVL*	Floor QTY	Building QTY
Supply Duct Horiz. (14"x42")	34 LF	472 LBS	472 LBS	3,779 LBS
Relief Duct Horiz. (14"x42")	34 LF	472 LBS	472 LBS	3,779 LBS
Supply Duct Riser (48"x102")	12.5 LF	776 LBS	776 LBS	6,207 LBS
Relief Duct Riser (48"x102")	12.5 LF	776 LBS	776 LBS	6,207 LBS
Supply Duct Insulation (14"x42")	34 LF	337 SF	337 SF	2,700 SF
Supply Duct Insulation (48"x102")	12.5 LF	361 SF	361 SF	2,889 SF

*Conversion from duct size and length to weight based on steel gage and type consistent with application

Airside Mechanical System on Roof	Building QTY
DOAS Building Air Handler (w/HR)**	42,000 CFM

*IDF cooling system material takeoffs exlcuded from both scenarios to be conservative in favor of the baseline scenario. Operational electricity of IDF cooling is included in both scenarios. Baseline Scenario has a dedicated VRF fan coil for each IDF room and additional refrigerant piping and refrigerant. Clark Pacific scenario uses a small dedicated DOAS w/DX feeding supply shaft direct to IDF room VAV boxes.

**Air handler 100% outside air with supply fan wall, exhaust fans, hydronic coil, particulate filtration sections, and heat recovery via run around coils in extract air and fresh air intake. DOAS sized for the greater of ASHRAE 62.1 and T24 and 30% additional to meet LEED credit. Building DOAS are positoned on top mechanical shaft eliminating rooftop associated exterior ductwork. See mechanical section for more information.

***Additional mechanical equipment common to both scenarios, such as stair pressurization fans and restroom exhaust fans, are excluded from both scenarios

Duct Subtotals		
Duct (48"x102")	200 LF	12,414 LBS
Duct (14"x42")	704 LF	9,827 LBS
Duct (12"x26")	3,360 LF	26,589 LBS
Duct (10"x18")	1,120 LF	6,532 LBS
Duct (8"x10")	7,200 LF	4,685 LBS
Duct Insulation (48"x102")	2,889 SF	241 FT3
Duct Insulation (14"x42")	4,310 SF	359 FT3
Duct Insulation (12"x26")	23,074 SF	1,923 FT3
Duct Insulation (10"x18")	5,702 SF	475 FT3
Duct Insulation (8"x10")	5,115 SF	426 FT3

Airside System Totals		
Ductwork	12,584 LF	60,047 LBS
Duct Insulation	41,091 SF	3,424 FT3
Ceiling Fans		464 EA
VAV Boxes		160 EA
DOAS Air Handler		42,000 CFM

DETAIL TABLE S

Mechanical Product Replacement

	Service Life (yrs)	Baseline Scenario			Clark Pacific Scenario		
		Construction Quantity	Replacement Year 20*	Replacement Year 40*	Construction Quantity	Replacement Year 20*	Replacement Year 40*
Copper Pipe**	60	38,627 lbs	-	-	2,143 lbs	-	-
Steel Pipe	60	-	-	-	19,344 lbs	-	-
PEX Pipe (embedded)	60	-	-	-	23,107 lbs	-	-
PEX Pipe (exposed)	60	-	-	-	12,819 lbs	-	-
Pipe Insulation**	60	1,123 ft3	-	-	1,202 ft3	-	-
Pipe Hangers and Supports**	60	2.13 m3	-	-	1.97 m3	-	-
Ductwork***	40	60,047 lbs	-	60,047 lbs	60,047 lbs	-	60,047 lbs
Duct Insulation***	40	3,424 ft3	-	3,424 ft3	3,424 ft3	-	3,424 ft3
Duct Hangers and Supports***	40	0.26 m3	-	0.26 m3	0.26 m3	-	0.26 m3
VRF Outdoor Units (100 kW each)*	20	15 units	15 units	15 units	-	-	-
ASHP 4-Pipe (290 kW)*	20	-	-	-	1 units	1 units	1 units
ASHP 2-Pipe (420 kW)*	20	-	-	-	1 units	1 units	1 units
VRF Fan Coils (8 kW each)*	20	344 units	344 units	344 units	-	-	-
Air Handlers (42,000 cfm)*	20	1 units	1 units	1 units	1 units	1 units	1 units
VAV Boxes*	20	344 units	344 units	344 units	160 units	160 units	160 units
Ceiling Fans****	60	-	-	-	464 units	-	-

*The baseline scenario has substantially larger quantity of compressor based equipment and zonal equipment that would be replaced in a tenant improvement event. Accordingly, the B4 emissions increase more in the baseline scenario than Clark Pacific scenario each time there is a replacement event. To be conservative in favor of the baseline, a 20 year service life for all compressor based equipment and a 20 year gap between tenant improvements products was used. 20 years is the high end of the range for both time between retrofits in an occupied building and compressor based equipment service life. What would be replaced or kept intended to match business as usual in such applications

**Refrigerant copper pipe and associated pipe insulation, hangers, and supports in the baseline scenario will be replaced in part in any mechanical TI retrofit. To be conservative in favor of the baseline, this copper pipe was excluded from B4 stage. This amount of excluded copper pipe and supports is not insignificant.

***The 40 year service life comes from CIBSE Guide M for ductwork.The quantity of ductwork is the same in both scenarios so the impact is equal to both scenarios. Ducwork included in scope of study stops at the zonal fan coil / VAV box in each scenario. Any tenant improvement would be mostly limited to duct downstream of this boundary and as such is not considered a replacement event since it was not included in A stage. The amount of ductwork downstream of this boundary is greater in the baseline VRF Fan coil scenario. Excluding this replacement amount is conservative in favor of the baseline.

****Ceiling Fans in Clark Pacific scenario have brushless DC motors with a ultra low power draw maximum equivalent to a single typical residential CFL light bulb. While there will be some failures over the years, Aeratron ceiling fans, and others in this class of airfoil design and engineering quality that provide free 30 year motor warranties (like Aeratron), can last the whole building life. It's also possible a tenant improvement would remove but not replace ceiling fans due to changes in space use. Accordingly, the B3 Repair stage, set to 10% of the total of A1-A4 stage plus C1-C4 stage emissions following CIBSE TM65 Guide M (2021), essentially equates to 10% replacement as there is essentially no maintenance for these types of fans. Any arguments made that this still undercounts the replacement is more than offset by the large amount of excluded refrigerant pipe in VRF tenant imporvements that is excluded from the baseline.

Mechanical Replacement Totals	Total Avoided Mech. Replacement (Baseline - Clark Pacific)	Baseline Scenario (Total Replaced)	Clark Pacific Scenario (Total Replaced)
ASHP Outdoor Units	**1,580kW of Outdoor Heat Pump**		1,420 kW
VRF Outdoor Units		3,000 kW	
VRF Fan Coils	**5,504kW of Indoor Fan Coils**	5,504 kW	
VAV Boxes	**368 VAV boxes**	688 ea.	320 ea.
DOAS	-	84,000 cfm	84,000 cfm
Ductwork	-	60,047 lbs	60,047 lbs
Duct Insulation	-	3,424 ft3	3,424 ft3
Duct Hangers and Supports	-	0.26 m3	0.26 m3

4 Calculation Methodology

The Radiant Whole Life Carbon Study methodology divides the analysis into embodied vs. operational carbon emissions and assess each according to the following building categories. Embodied carbon and operational carbon emissions were calculated separately following different methodologies. In all cases, the study sought to combine best-in-class data, processes, and engineering experience.

- Structure (embodied carbon A1-A4, B3-B4, C1-C4)
- Envelope (embodied carbon A1-A4, B3-B4, C1-C4)
- Mechanical systems (embodied carbon A1-A4, B3-B4, C1-C3, C4)
- Refrigerant Leakage (embodied carbon B1, C1)
- Energy Use (operational carbon B6)

4.1 Embodied Carbon Overall Approach

For the embodied carbon assessment, emissions were calculated aligned with *Standard EN 15978 - Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method (2011),* and can be summarized as follows

1. Develop a complete product list that itemizes every unique category of physical element in both scenarios.
2. Determine the carbon emission rates (kgCO2e/kg of product) for every stage module for every product (See Summary Table A in the Appendix)
3. Determine the quantity of every product in A Stage and also B stage Replacement as applicable (See Summary Table B in the Appendix)
4. Apply the product emission rates to the product quantities to get carbon impact by stage module for every product in both scenarios (See Summary Table C in the Appendix)
5. Add up the carbon impact for all stages individually for each product to get the whole life carbon impact for every product, building category, and scenario overall total (See Summary Tables D and E in the Appendix).

More information on Structure, Envelope, and Mechanical embodied carbon calculation methodologies are provided in sections 4.4 through 4.7.

For refrigerant leakage embodied carbon, emissions were calculated in two steps: (1) applying a use stage leakage rate and an end of life recovery rate to the mechanical system refrigerant charge to assess leaked quantity, and (2) applying refrigerant GWP impact rate to the leaked quantities. Refrigerant system charge, leakage rates, and end of life recovery rates were determined from both scenarios engineered mechanical designs and the Refrigerant Best Practice Guide.[5] More information on refrigerant leakage carbon emissions methodology is provided in section 4.8.

4.2 Operational Carbon Overall Approach

For the electricity use operational carbon assessment, emissions were calculated using research grade building simulation modeling (EnergyPlus) for actual historical weather matched against actual historical annual hourly electrical grid emissions for the same exact time period. This results in electricity use for each hour of the year (kWh) and separate grid carbon emission intensities for each hour of the year (kgCO2e/kWh) to yield carbon emissions each hour and total from electricity use. Lastly, these grid emission factors were adjusted down (cleaner) each year over the life of the study to reflect the decarbonization of the electrical grid. More details on calculation of electricity use carbon emissions is provided in section 4.9.

4.3 Calculation Methodology by Life Cycle Stage

The carbon emissions were calculated for each of the following life cycle stages for each design options:

- **Product stage (A1-A3):** This includes carbon emissions associated with material extraction, manufacture, and any transport needed. This stage represents the most significant carbon impacts for all materials and products as the activities associated with extraction and manufacturing are the most carbon intensive. This stage is always by the scope of an Environmental Product Declaration (EPD – see section 4.4 for more information). For the mechanical systems where no EPDs were available, calculations followed CIBSE TM65 based on manufacturer material composition breakdown.
- **Transport from site to construction site (A4):** This includes carbon emissions associated with provision of materials on-site. One Click LCA (see section 4.4 for more information) was set up with a precise location of the project. Whenever the data was not available within One Click LCA or another database like Athena, but elsewhere, we manually calculated the carbon impact by multiplying the weight of the product by the distance and by the carbon factor associated with HGV half loaded.[6]
- **Use (B1):** In this study, this includes only carbon emissions associated with mechanical system refrigerant leakage during use (refer to section 4.8 for more details).
- **Repair (B3):** This includes carbon emissions associated with replacement of a component within an equipment during its service life. It applies only to equipment with moving parts (e.g. fan coils).
- **Replacement (B4):** This includes carbon emissions associated with replacement of an item over the building lifetime (60 years in this study). When a building element has an expected service-life aligned with the building's life there is no impact for this stage (e.g. rebar). If an item is replaced within a building lifetime, the carbon impact associated with product stage, transport and end of life stage needs to be added as a new item that is created and an old item that is disposed. Replacement rates (B4) for mechanical systems and equipment were estimated based on building type and use.
- **Operational energy use (B6):** This includes carbon emissions from the electrical grid to supply all building electricity consumption (e.g. HVAC, Equipment, Lighting, Life Safety, etc).
- **Deconstruction/demolition (C1):** This includes carbon emissions associated with deconstruction & demolition. Embodied carbon data for this stage is not always reported via an EPD. In cases when data is not available, expected values for this life cycle stage were estimated at 1% stage of A1-A4. The carbon emissions associated with refrigerant leakage that occur during decommissioning are also calculated and added to the overall result.
- **Transport to waste processing facility (C2):** Similar to C1 data, this information is not always available in EPDs and calculated by One Click LCA; The C2 stage can be calculated based upon carbon factor of transport vehicle to remove items from the site multiplied by the weight of the item and the distance to the waste facility (6 miles to *3SMaRT Station* in Sunnyvale in this study).
- **Waste processing & Disposal (C3 – C4):** This includes carbon emissions associated with waste processing and disposal. The information can be within the scope of an EPD and is always calculated within One Click LCA based on typical market scenario (estimating % reuse of the product, % going to landfill, etc.). For the mechanical systems where no EPDs were available, calculations followed CIBSE TM65.

[5] Refrigerants and Environmental Impacts: A Best Practice Guide [Elementa Consulting]. Published September 2020. https://issuu.com/deepgreenengineering/docs/refrigerants__environmental_impacts__elementa

[6] The HGV comes fully loaded, leaves empty – therefore, assumed one travel half loaded.

4.4 Embodied Carbon Data

Concerning the embodied carbon footprint of each material and product, the main source used for this study was One Click LCA. This program offers a library of EPDs and other embodied carbon footprint generic data per building material/element (in fact, One Click LCA is the largest database in the world).

An EPD (Environmental Product Declaration) is a standardized document created on behalf of a manufacturer or industry to report the carbon impacts of the building product throughout its life cycle (as well as other environmental impacts). An EPD can report carbon impacts over the life cycle stages (A-C) detailed above. It is considered to be the most reliable source of embodied carbon data information to carry out an embodied carbon assessment. Whenever an EPD was available for the listed material of product, it was used.

However, EPDs are not yet very mainstream in all building disciplines, therefore other sources of data had to be used as well: such as generic data (not precise to a product but rather to a product type). For mechanical systems, where EPDs are even more rare and could not be found on One Click LCA, CIBSE TM65 calculation methodology based on manufacturer information was applied using manual calculations.

See Summary Table A in the Appendix for a complete list of all embodied carbon data source(s) individually for every product. See Detail Tables in Appendix for more information on exact quantities, rationale, and nuances regarding inclusions and exclusions.

4.5 Structure – Embodied Carbon

A primary focus of The Radiant Whole Life Carbon Study was the carbon emissions of the Clark Pacific precast concrete structural system. Clark Pacific's structural design leverages very high SCM (supplementary cementitious materials) mix designs to attempt to lower the carbon emissions associate with the structure. Since EPDs are not yet available for these precast concrete elements, the publicly available ZGA Concrete LCA Tool_v3.0 was used to determine precast element carbon emission rates for the exact precast mix design ingredients and quantities provided to Integral Group by Clark Pacific for this Study (and included within the report). For more information, see Detail Table A on the following page.

4.6 Envelope – Embodied Carbon

The three most differentiating aspects of the Clark Pacific Scenario envelope are the use of aluminum exterior sun shades, Clark Pacific's mix of curtain wall and prefabricated panels (Infinite Façade) vs. the baseline scenarios singular use of curtain wall, and the reduced quantity of façade area from Clark Pacific's reduced floor to floor height. With panelized facades encompassing such a large portion of envelope emissions, it was critical to accurately capture the embodied carbon rate of the curtain wall and Infinite Façade products. For the Infinite Façade, A1-A3 carbon emissions were taken from the Clark Pacific Infinite Façade LCA Report_Rev1 (a previously completed study performed by others for Clark Pacific and provided to Integral Group). For the curtain wall, an average of three separate typical aluminum curtail wall product EPDs (from 3 separate manufacturers) was used to provide the most representative emissions rate. For more information, see Summary Table A in the Appendix.

4.7 Mechanical Systems – Embodied Carbon

For this study, carbon impact associated with the mechanical systems was assessed using the following methodology.

1. Extract all relevant data available within One Click LCA to create an average value per product type. This includes sources ranging from EPDs to professional databases across the United States and Europe.
2. When no data was available on One Click LCA (e.g for VRF Fan Coil Unit), CIBSE TM65 Calculations combined with manufacturer data was used. CIBSE TM65 – *Embodied carbon of building services: a calculation methodology* is an official guidance published by the Chartered Institution of Building Services Engineers, authored by Integral Group in London, to calculate embodied carbon of MEP equipment when no EPDs are available, based on key information from manufacturers. For more information, see CIBSE TM65 Calculation Methodology Section in the Appendix.

DETAIL TABLE A

Precast Concrete Mixes A1-A3 Rates[1]

Mix A - Floor Planks Precast - 7000 psi - Clark Pacific		
SCM Ratio (of SCM+Cement)	70.0 %	
Component Ingredients	Mix Design Weight per 1 CY of Mix (lbs)	Global Warming Potential (kgCO2eq)
Cement	225	106
Fly ash	-	-
Slag	525	7
Coarse Aggregate	1,112	13
Volcanic LW Agg.*	351	21
Fine Aggregate (Sand)	1,206	37
Water	300	3
Steel Reinforcement	-	-
Air Content	4.00%	-
Per 1 CY of MIX	**3,719**	**186.9**

*Lightweight Aggregate is commonly from an expanded shale product. There are high carbon emissions associated with expanded shale due heating in a kiln to 1200degC. This mix uses a locally-sourced (<100 miles) lightweight volcanic aggregate that does not have a kiln process (mined and crushed). In the absence of an exact value from this calculator, it was assumed that this lightweight volcanic aggregate has a kgCO2e/kg rate twice that of Fine Aggregate (Sand). It is reasonable to expect the kgCO2e is less, but this was chosen to be conservative yet still capture a reduction from the expanded shale based numbers.

Mix B - Hollow Core Precast - 4000 psi - Clark Pacific		
SCM Ratio (of SCM+Cement)	0.0 %	
Component Ingredients	Mix Design Weight per 1 CY of Mix (lbs)	Global Warming Potential (kgCO2eq)
Cement	600	283
Fly ash	-	-
Slag	-	-
Coarse Aggregate	970	12
Lightweight Aggregate	-	-
Fine Aggregate (Sand)	2,318	71
Water	192	2
Steel Reinforcement	-	-
Air Content	3.70%	-
Per 1 CY of MIX	**4,080**	**366.8**

Mix C - Exterior Beams Precast - 8000 psi - Clark Pacific		
SCM Ratio (of SCM+Cement)	60.0 %	
Component Ingredients	Mix Design Weight per 1 CY of Mix (lbs)	Global Warming Potential (kgCO2eq)
Cement	320	151
Fly ash	-	-
Slag	480	6
Coarse Aggregate	1,633	19
Lightweight Aggregate	-	-
Fine Aggregate (Sand)	1,228	38
Water	300	3
Steel Reinforcement	-	-
Air Content	2.00%	-
Per 1 CY of MIX	**3,961**	**216.5**

Mix D - Int. Beams, Shear Walls, Columns Precast - 9000 psi - Clark Pa		
SCM Ratio (of SCM+Cement)	70.0 %	
Component Ingredients	Mix Design Weight per 1 CY of Mix (lbs)	Global Warming Potential (kgCO2eq)
Cement	255	120
Fly ash	-	-
Slag	595	7
Coarse Aggregate	1,618	19
Lightweight Aggregate	-	-
Fine Aggregate (Sand)	1,205	37
Water	300	3
Steel Reinforcement	-	-
Air Content	2.00%	-
Per 1 CY of MIX	**3,973**	**186.5**

1. Calculated using mix design reports from Clark Pacific and applying those ingredients to ZGF's public Concrete LCA Tool (v3.0). Tables here are reformatted from ZGA's output for better report clarity. All values are unaltered and directly from ZGA tool unless noted.

4.8 Refrigerant Leakage – Embodied Carbon

The Radiant Whole Life Carbon Study followed the Refrigerants & Environmental Impacts: A Best Practice Guide[7] to assess carbon impact in both scenarios from refrigerant leakage over the building's use and during decommissioning at end of life. The methodology is straight forward in its calculation.

1. Determine the leakage rate (%) per year during use for the mechanical system refrigerant application
2. Determine the global warming potential of the refrigerant (kgCO2e/kg) and total quantity of refrigerant (kg)
3. Apply the annual leakage rate for the total years of use to determine quantity of refrigerant leakage (kg)
4. Multiply the refrigerant GWP by the refrigerant leakage kg to get the total carbon impact (kgCO2e) during use
5. For end of life recovery, multiply the refrigerant GWP by [1 –recovery rate %] to carbon impact at end of life

Refrigerant type and quantity was determined as part of the mechanical VRF system design in the Baseline Scenario and from the manufacturer product data for the ASHPs in the Clark Pacific Scenario. For more information on what leakage and recovery rates were used in this study, see Detail Table R in the Appendix, also presented here below.

DETAIL TABLE R - Refrigerant Leakage Rates

VRF Annual Leakage Rate*	3%	ASHP Annual Leakage Rate**	1%
VRF End of Life Recovery Rate	98%	ASHP End of Life Recovery Rate	99%

VRF Annual Leakage rate was chosen to be intentionally conservative to best support the statement "the total whole life carbon emissions for the Baseline Scenario are this or worse". This gives the most credence to any claims of Clark Pacific carbon savings in this study. To that end, refrigerant leakage rate is a very influential factor. A leakage rate in the lower third of industry aggregated 1-10% VRF leakage rates range was chosen in support of achieving that conservative perspective. There are many built VRF systems measured at 10% leakage rate or higher, so it is justifiable to have picked a middle a higher leakage rate to reflect actual impact. Additionally, compared to a factory assembled refrigerant piping system for the ASHPs, the VRF system has a significantly larger refrigerant piping network, significantly larger number of refrigerant piping fittings, and worse fabrication quality in a field setting. Accordingly, there are far more opportunities for leakage, a higher risk per opportunity, and a reduced visibility to identify occurrences of refrigerant leakage. Taken together this intuits that refrigerant leakage is significantly more likely to occur, and for longer time before detection, and be "plugged" less effectively compared to the ASHPs. Lastly, given typical operation and maintenance practices for VRF systems, refrigerant leakage is only examined when the system starts to underperform it's heating and cooling functions or the central system issues an alarm for drop in pressure, both of which indicate refrigerant leakage of at least 20%-30% has already occurred. All this supports that 3% annual leakage rate is abundantly conservative in favor of the Baseline Scenario.

ASHPs Annual Leakage rate was chosen to reflect better piping fabrication quality due to factory assembly and better ability to service and detect leaks compared to field fabricated VRF system.

For more information see Refrigerants and Environmental Impacts: A Best Practice Guide [Elementa Consulting]. https://issuu.com/deepgreenengineering/docs/refrigerants__environmental_impacts__elementa

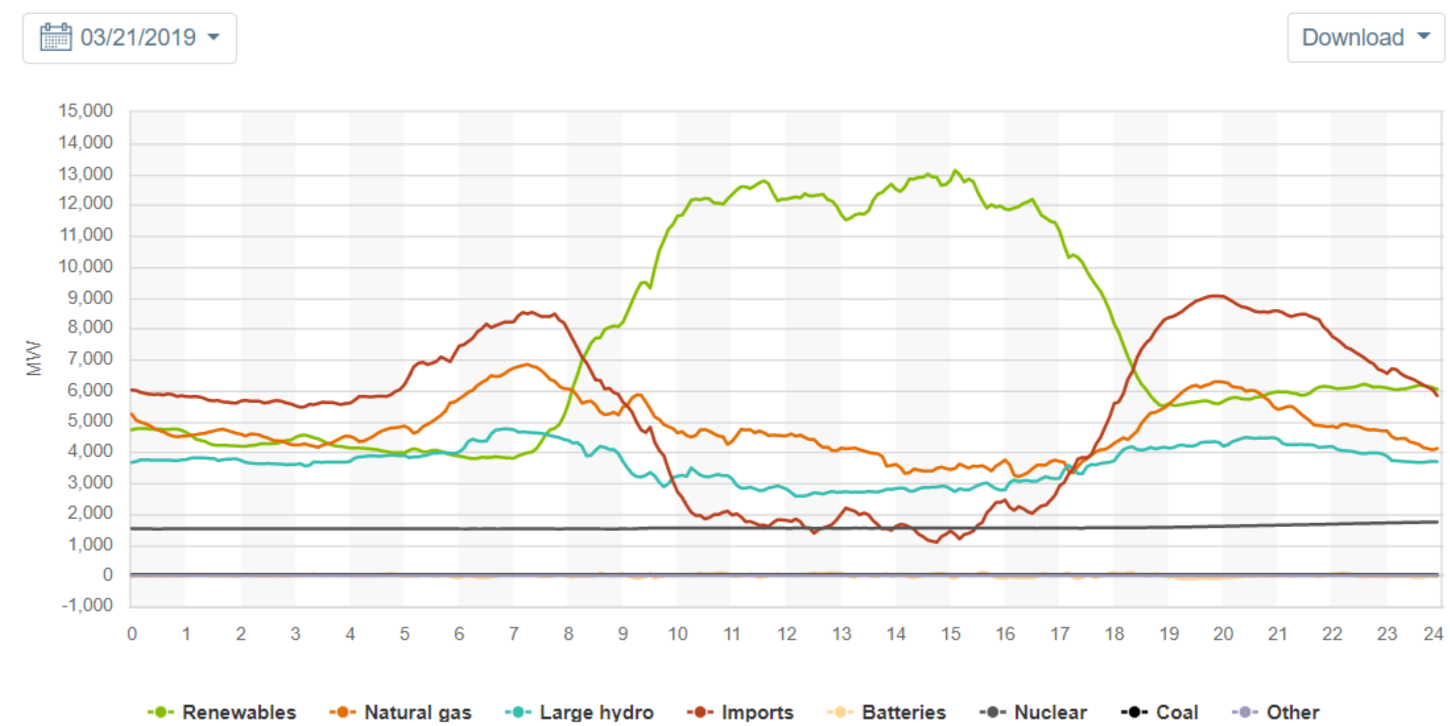
[7] Refrigerants and Environmental Impacts: A Best Practice Guide [Elementa Consulting]. Published September 2020. https://issuu.com/deepgreenengineering/docs/refrigerants__environmental_impacts__elementa

4.9 Electricity Use – Operational Carbon

Grid Carbon Emission Rates were determined by obtaining the actual grid emission intensities that occurred in 2019 in the CAISO system and calculating the hourly average intensity separately for all 8760 hours of that year. The process is summarized below. 2019 was chosen as it was the last complete calendar year that had "normal" consumer side supply and demand, unaffected by the COVID-19 pandemic. The California Independent Service Operator (CAISO) was chosen as the source of grid supply and emissions data as they are the electrical grid managing authority in the area of study (along with the majority of California).

- (365) Daily CAISO Emissions (mTCO2e) csv files (at 5-minute resolution) for all of 2019
- (365) Daily CAISO Supply (MW) by resource csv files (at 5-minute resolution) for all of 2019
- Scrubbing data for stated reporting outages, missing data, and inconsistencies
- Taking hourly averages of mTCO2e 5-minute data separately for all 8760 hours
- Taking hourly averages of MW 5-minute data separately for all 8760 hours.
- Dividing each hours average (mTCO2e) by average (MW) to get hourly average emission rate (kgCo2e/kWh)*

**mTCO2e = metric ton = 1000kgCO2e. MWh = 1000kWh. 1000kgCO2e / 1000kWh = 1 kgCO2e/kWh*



Electricity Use for the Baseline (Steel + VRF) and Clark Pacific (Precast + Radiant) scenarios comes from EnergyPlus simulations that use the 2019 Actual Meteorological Year (AMY) weather file to directly match the 2019 actual carbon intensities of the CAISO grid on an hourly basis. Specifically, the 2019 AMY Palo Alto weather file was used in the study. This location was chosen for the quality of the data and its proximity to the study location.[8] EnergyPlus was used for its research grade capabilities with thermal mass, surface heat transfer and radiant systems. Model inputs, systems, and procedures are described in the Appendix in Detail Tables U.1 through U.6 and Detail Tables D through K.

Carbon and Electricity Alignment: The Radiant Whole Life Carbon Study undertook considerable effort to obtain and process CAISO emissions data so models run with real historical weather could pair with time-aligned grid emissions. This effort was essential. All simulations became carbon simulations and enabled a complexity and depth of investigation, without which, would not have been even remotely possible.

[8] Mountain View 2019 AMY was not used because its data is incomplete. For reasons unknown, the second half of the year has a flatlined unchanging dry bulb air temperature every second. The Palo Alto data was inspected thoroughly and found to be complete.

Novelty of Radiant Controls

Advanced radiant controls were used in this analysis, including a simple yet powerful learning control sequence. Each radiant control zone is separately controlled to a slab setpoint, fixed for one value every 24hrs. Algorithms compare monitored room air temperature to desired outcomes and dynamically tune the slab setpoint temperature each day to achieve near optimal conditions. EnergyPlus Runtime Language (Erl) was used to accomplish this. This code was originally developed by the Center for the Built Environment (CBE) and has been tested in real buildings with favorable outcomes[9]. Integral Group updated the code for this project, primarily in different implementations of setbacks and deadbands, as further described in subsequent paragraphs.

Learning Slab-Setpoint & Increased Load Shifting

Even traditionally controlled radiant slabs provide significant load shifting. The mass in the floor slabs provides an inherent thermal buffer, resulting in the ability to flatten the peak loads and to some extent, treat the loads at different times than they occur. This is in contrast to a thermally light building, where the loads must be treated when they occur, or discomfort will result.

The learning control sequence provides the ability for more aggressive and more reliable load shifting. This can be to flatten loads and use smaller plant equipment for first costs savings, and/or to run the plant only at certain times, such as locking out the plant equipment when the grid is at its highest carbon intensity. The learning control sequence unlocks the ability for more aggressive load shifting using the self-corrective nature of the dynamically tuned slab setpoint for each thermal zone. These topics, and their benefits, are addressed in detail in the Concrete as Thermal Battery portion of the Results section.

Consider the case of a lockout in the summer in cooling mode. Without the learning component, a lockout may lead to discomfort as the systems are preventing from running. With the learning component however, a cooler slab setpoint is learned and reached prior to the lockout being initiated. The cooler slab setpoint is able to maintain comfort, and if it couldn't, it would learn, and the next day would use a cooler slab setpoint. This feedback loop is an important step in the direction of predictive control as opposed to only reactive control. The slab is in effect pre-charged, similar to the way a battery would be. The learning sequence determines how much pre-charging is appropriate, based on maintaining comfortable conditions given the more aggressive load shifting.

Center for Built Environment's Radiant Sequence

The CBE provides a detailed description of the sequences[10], and is well said in their Summary section, and by their graphic detail:

"The intent of these sequences of operation is to use slowly adjusted slab temperature setpoints to control radiant system operation to maintain comfort in the zone. The strategy operates based on a slab temperature measurement and uses information from the zone temperature during the occupied period to make minor adjustments to the slab setpoint for the next day. The strategy constrains the radiant system to take advantage of thermal inertia and condition the slab only during certain periods of time. For a given project, this allows designers to select for either: more efficient and cost effective operating hours (e.g. system only operates at night), longer operating hours to yield smaller heating or cooling plant sizes (e.g. system sized assuming 18 or 24 hour operation on the design day), or aim to provide a more uniform daily range of comfort conditions (e.g., time pre-cooling such that it approximately accounts for the slab time constant and the peak loads)."

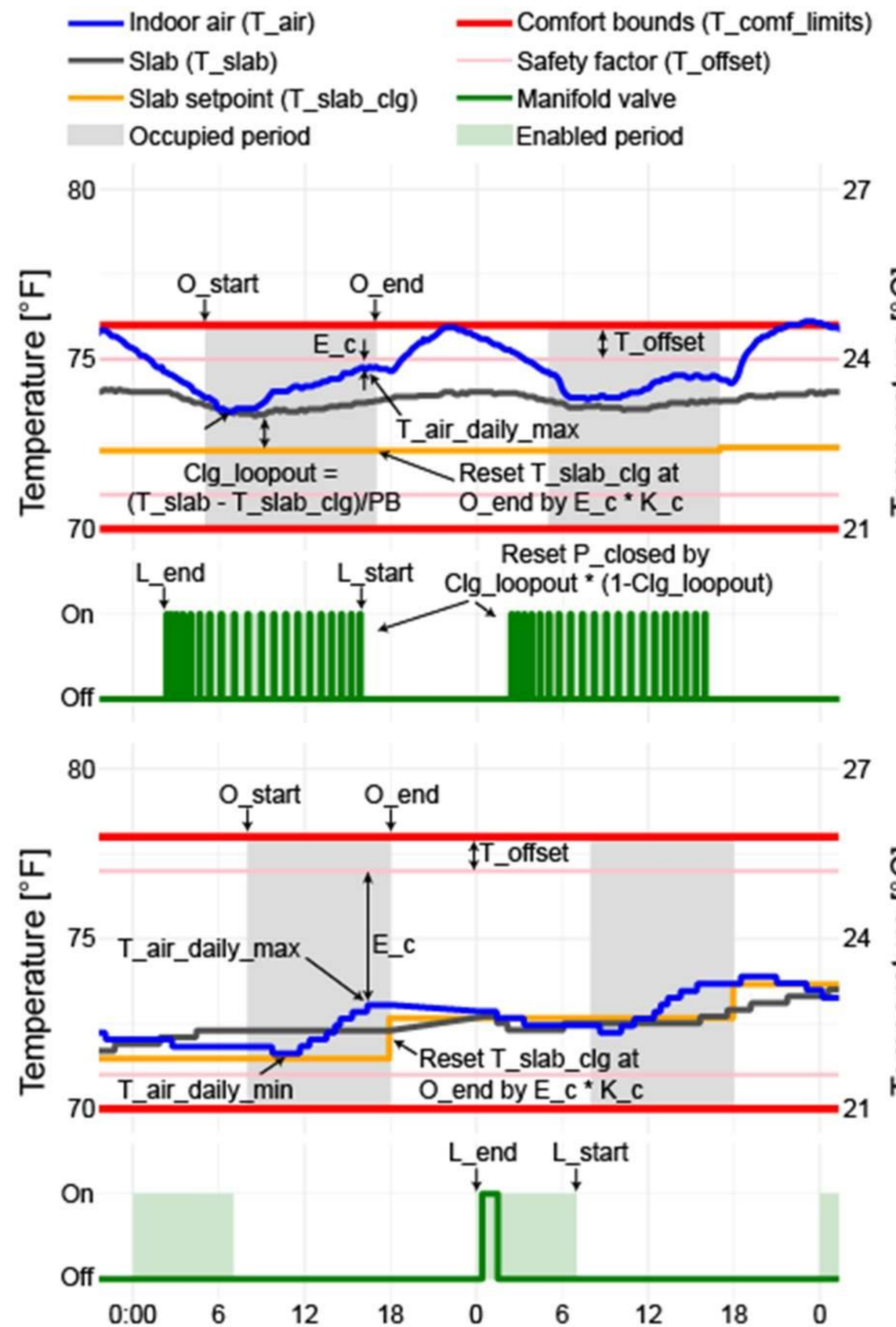


Figure from CBE with caption "Visual representation of radiant sequences in cooling mode with Top) pulse width modulation (PWM) and Bottom) ON/OFF manifold valve control. Data is from the building automation systems of two different California large office buildings, not from simulation."

[9] http://radiant.cbe.berkeley.edu/resources

[10] http://radiant.cbe.berkeley.edu/resources/rad_control_sequences

Sequence Changes for Clark Pacific

As written by the CBE, the slab setpoint learns to relax as much as possible, approaching the air temperature limits used in its learning. That is to say that if the indoor air temperature limit was set to 78°F in a particular zone, the slab would not only adjust to a cooler setpoint if 78°F room air temperature was ever reached, but it would also adjust to a warmer slab setpoint if room air temperature never got as high as 78°F.

This feature is present to save energy, but careful review showed learning warmer setpoints with the intention to reduce cooling resulted in some unfavorable heating to maintain the warmer setpoint (specifically, summer-time morning warmup when the zone is not too cold). It was not significant, and the result was still a low energy / high comfort building, but it was also not necessary.

Integral Group worked with the CBE to update the controls sequence to address this concern. As a result, the sequence implemented for this project still learns to relax setpoints as much as possible, but changes in the heating and cooling modes make it so heating can only resume if the lower room air temperature limit is reached. This eliminates unnecessary heating in the summer without sacrificing comfort, but also has a far more profound purpose. The thermal mass of each zone is now allowed to float within the comfort limits. This empowers the radiant slabs to maximally act as a battery to reduce central plant equipment size, or charge only during the 8 typically cleanest grid carbon hours of the day (both of which are demonstrably accomplished in this study), while reliably maintaining excellent comfort at all times of day. This also opens the door to a better integration with compressor-free cooling solutions, such as nighttime charging from the inside, via cool water made by a dry cooler, or from the outside, via cool air from delivered by night-flush.

Setbacks in the sequence were also updated for use in this project. As written by the CBE, there was a weekend setback that would begin Friday after work and end Monday morning when occupancy resumes. If a significant setback was used, it was observed that discomfort would be present on Monday morning, and while the slab would then quickly relearn its ideal temperature, this weekly pattern negated the energy gains of the weekend setback.

For this project the setbacks were rewritten to turn off Monday morning at midnight, such that the building had adequate time to recover. Additionally, a daily setback was included beginning at 6pm and lasting until midnight. This was primarily done to allow the building to coast at the end of a summer day. Rather than cooling the slab past the time the cooling could be delivered to the space (due to time shift that the mass causes), and then potentially reheating the mass in the morning, the mass is able to coast; initially retaining its heat and then slowly losing heat passively through the envelope over the night.

As a result of all these changes, mass temperatures are allowed to float within comfort bounds more, significantly reducing heating and cooling energy, and empowering the slab to learn and act significantly more effectively as a thermal battery.

5 Results

The Radiant Whole Life Carbon Study found the Clark Pacific (Precast + Radiant) scenario produces significantly less carbon emissions than the Baseline Business as Usual (Steel + VRF) scenario over not just the building life, but across every stage of use and building category along the way.

The Whole Life Carbon emissions of the Clark Pacific scenario are conservatively at least **40% less** than a Business as Usual All-Electric Building

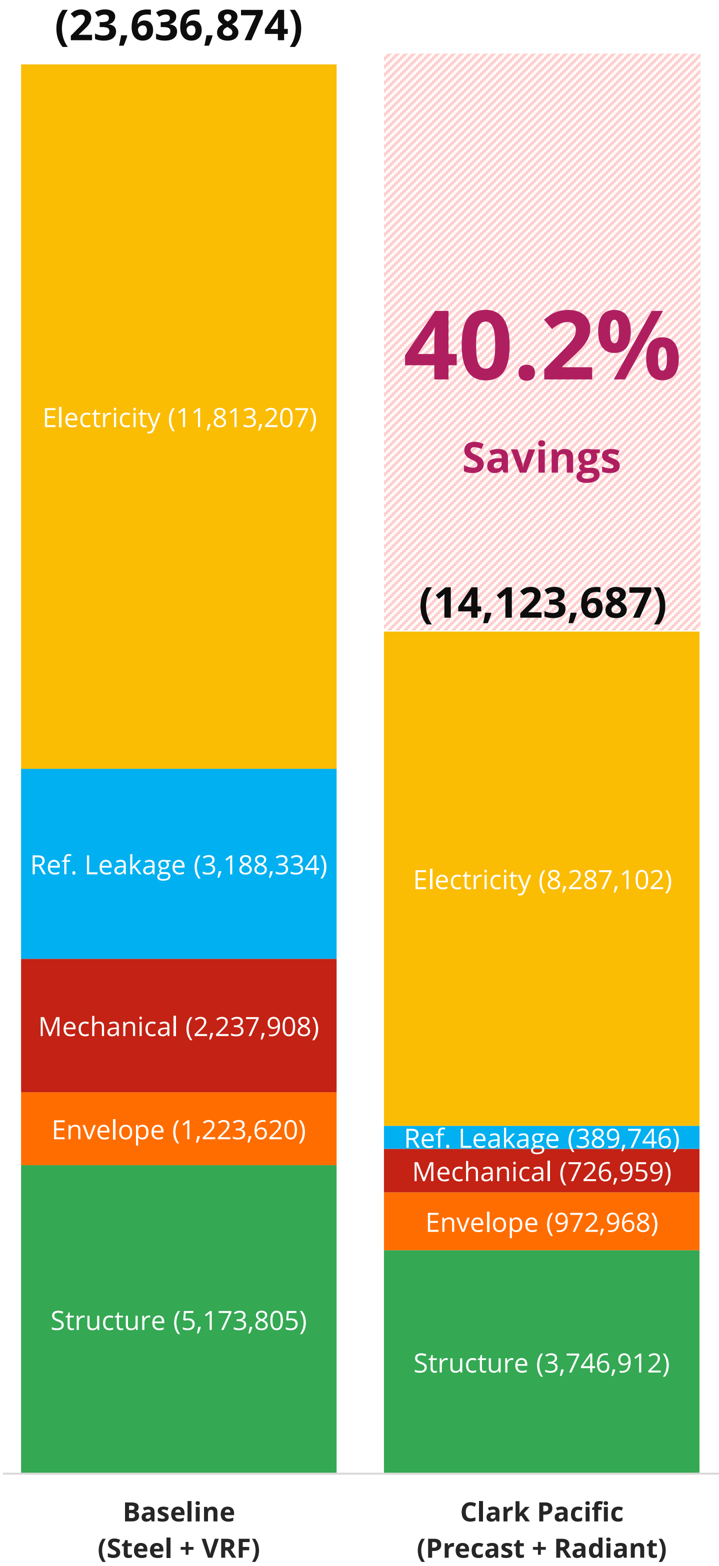
There is a lot going on here and a lot to look at it. The following sections seek to summarize and allow the reader a chance to explore for themselves. See Appendix for more information.

Whole Life Carbon Totals - Comparisons of Note

- **Business as Usual** has **already created more carbon by Day 1 of Use** (7,125,141 kgCO2e, 319.6/m2) than the **Clark Pacific scenario does until Year 10 of Use**.
- **By Year 18 of Use, Business as Usual Carbon** will have **already exceeded Clark Pacific's Whole Life 60 Year Total** (14,123,687 kgCO2e, 633.4/m2).
- The **Lightweight Concrete Topping Slabs in the Steel Baseline** (1,915,680 kgCO2e, 85.9/m2) have **more embodied carbon** than **All Concrete Above Ground in the Clark Pacific Building** (1,762,709 kgCO2e, 79.1/m2).
- The **Clark Pacific Structure's Carbon Savings** (1,426,728 kgCO2e less, 64.0/m2) are **Equivalent to Offsetting the Entire Envelope and Slab on Grade** embodied carbon emissions (1,320,918 kgCO2e, 59.2/m2) to make a **new Business as Usual Building.**
- **Business as Usual VRF Fan Coils** (1,271,188 kgCO2e, 57.0/m2) have an **embodied carbon 75% larger** than **Clark Pacific's Entire Mechanical System** (726,959 kgCO2e, 32.6/m2) and **Over 3x larger** than **All Clark Pacific Mechanical Equipment** (368,702 kgCO2e, 16.5/m2).
- **Business as Usual Refrigerant Leakage** (3,188,334 kgCO2e, 143.0/m2), conservatively estimated, has a **larger carbon impact** than **Clark Pacific's Entire Lifetime of HVAC Electrical Emissions & Refrigerant Leakage combined** (3,010,900 kgCO2e, 135.0/m2).
- **Clark Pacific's HVAC Use** (Electricity + Ref. Leakage) **emits less than 1/3rd the carbon** (3,010,896 kgCO2e, 135.0/m2) of a **Business as Usual Building** (9,335,589 kgCO2e, 418.7/m2)
- **Over 60 Years of Use, Clark Pacific's Carbon Savings** (7,344,665 kgCO2e less, 329.4/m2) accrued are **Equivalent to Offsetting the Entire Structure, Envelope, and Mechanical** embodied carbon (7,125,141 kgCO2e, 319.6/m2) **to make a new Business as Usual Building**.

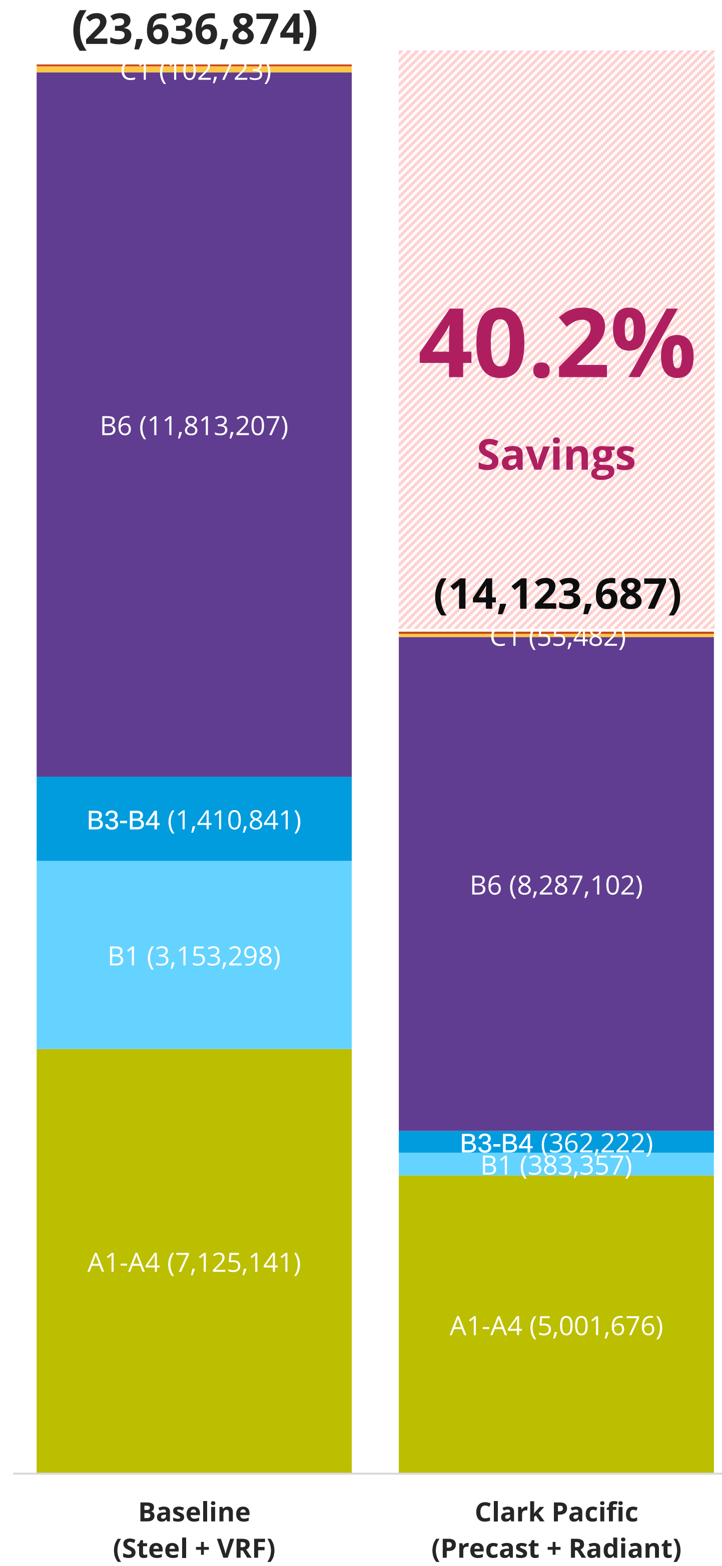
Whole Life Carbon (kgCO2e)

Total kgCO2e grouped by physical category

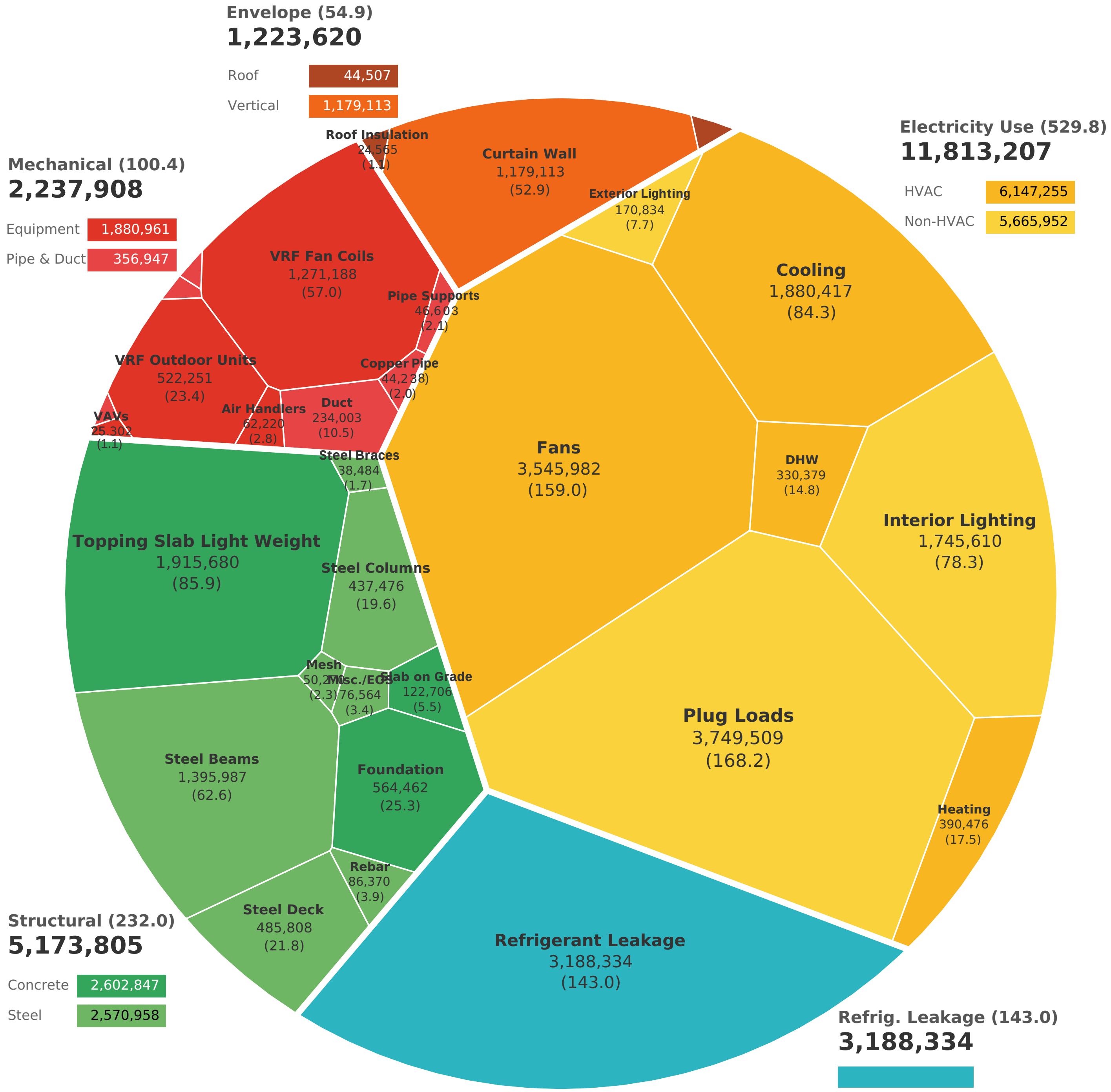


Whole Life Carbon (kgCO2e)

Total kgCO2e grouped by stage



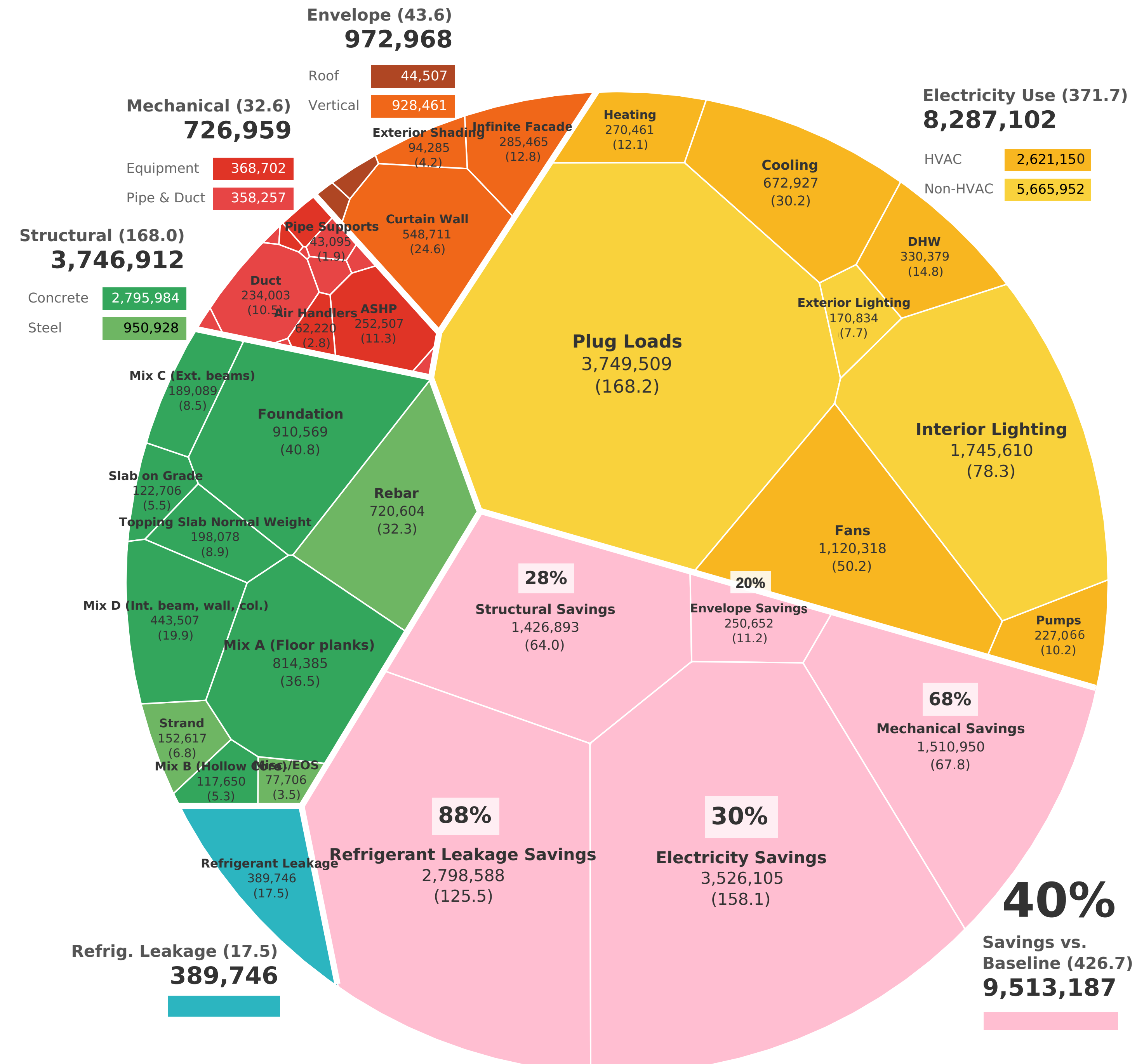
SUMMARY TABLE G Whole Life Total by **Bldg Category**	Baseline Scenario (Steel + VRF)	Clark Pacific (Precast + Radiant)	Savings vs. Baseline (Whole Life Carbon)
Structure 27.6% Carbon Savings	5,173,805 kgCO2e 232.0 kgCO2e/m2	3,746,912 kgCO2e 168.0 kgCO2e/m2	1,426,893 kgCO2e 64.0 kgCO2e/m2
Envelope 20.5% Carbon Savings	1,223,620 kgCO2e 54.9 kgCO2e/m2	972,968 kgCO2e 43.6 kgCO2e/m2	250,652 kgCO2e 11.2 kgCO2e/m2
Mechanical 67.5% Carbon Savings	2,237,908 kgCO2e 100.4 kgCO2e/m2	726,959 kgCO2e 32.6 kgCO2e/m2	1,510,950 kgCO2e 67.8 kgCO2e/m2
Refrig. Leakage 87.8% Carbon Savings	3,188,334 kgCO2e 143.0 kgCO2e/m2	389,746 kgCO2e 17.5 kgCO2e/m2	2,798,588 kgCO2e 125.5 kgCO2e/m2
Electricity Use 29.8% Carbon Savings	11,813,207 kgCO2e 529.8 kgCO2e/m2	8,287,102 kgCO2e 371.7 kgCO2e/m2	3,526,105 kgCO2e 158.1 kgCO2e/m2
Scenario Total 40.2% Carbon Savings	23,636,874 kgCO2e 1,060.1 kgCO2e/m2	14,123,687 kgCO2e 633.4 kgCO2e/m2	9,513,187 kgCO2e 426.7 kgCO2e/m2



Baseline Scenario: Steel + VRF

23,636,874 kgCO2e (**1,060.1** kgCO2e/m2)

Whole Life Carbon Breakdown



Clark Pacific: Precast + Radiant

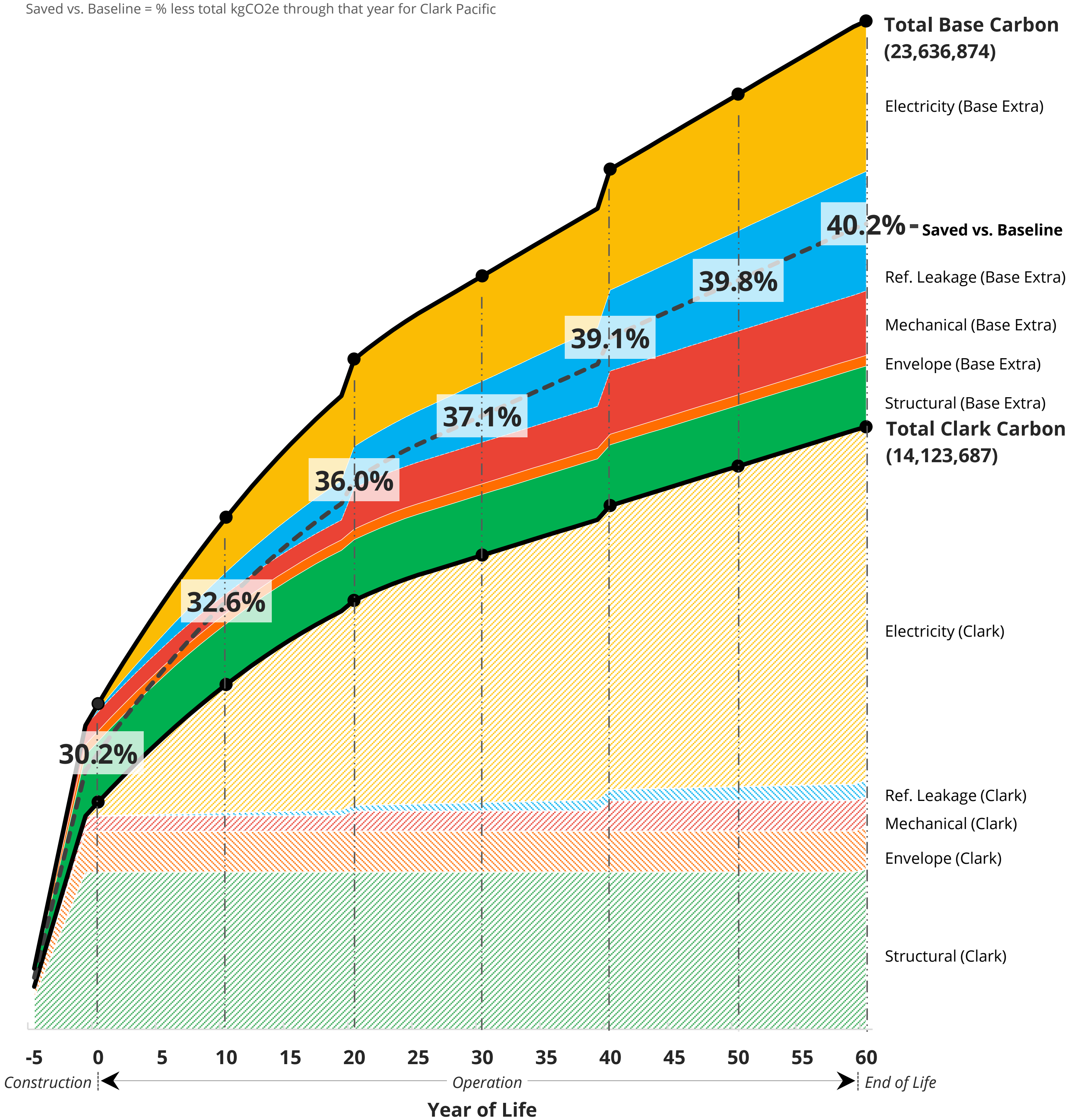
14,123,687 kgCO2e (**633.4** kgCO2e/m2)

Whole Life Carbon Breakdown

Whole Life Time of Carbon (kgCO2e)

Component Amounts and Savings vs. Baseline Over 60 Year Life Cycle

Base Extra = Additional amount greater kgCO2e in Baseline above Clark Pacific amount
Saved vs. Baseline = % less total kgCO2e through that year for Clark Pacific



5.1 Structure

The Clark Pacific Scenario's Structure creates significantly less carbon emissions than the Baseline Business as Usual Steel Building Structure (28% less whole life carbon). In fact, the Steel Building's Lightweight Topping Slab, by itself, causes more carbon emissions than all concrete above grade in the Clark Pacific Building.

Key Levers

1. Concrete Mix Supplementary Cementitious Material (SCM) %
2. Use of Expanded Shale Lightweight Aggregates

Spotlight Topic 1: Mix Design Carbon

The table below shows the embodied carbon rate per unit volume (CY) of all the different concretes in both scenarios. The largest standout is the significantly higher emissions rate of the lightweight topping slab in the Steel Building compared to any other concrete. More on this topic below. See Summary Table A (Appendix) for a complete list of sources for each products emissions rates. See Detail Table A (Appendix) for more information on each Precast Mix's emission rates. The Precast Concrete in the Clark Pacific Building is a combined 66% SCM (volume-weighted average). The total embodied carbon of all concrete in the Clark Pacific Building is only 7% more than the embodied carbon of the Concrete in the Business as Usual Steel Building. This is significant.

DETAIL TABLE Z
A1-A4 Concrete Rates Comparison

		Carbon Rate kgCO2e/CY	Carbon Rate Relative (%)	Baseline Volume (CY)	Clark Pacific Volume (CY)
Mix A	Precast Floor Planks	197.5	36%	0	4,042
Mix B	Precast Hollow Core	378.2	68%	0	306
Mix C	Precast Exterior Beams	228.1	41%	0	813
Mix D	Precast Interior Beams, Shear Walls, and Columns	198.1	36%	0	2,193
Mix E	Cast-in-Place Normal Weight Topping Slab (Clark Pacific Scenario), Slab on Grade (Both Scenarios)	260.3	47%	463	1,210
Mix F	Cast-in-Place Foundation (Both Scenarios)	310.7	56%	1,787	2,882
Mix G	Cast-in-Place Lightweight Topping Slab (Baseline Scenario)	555.3	100%	3,406	0
Totals Volume (CY)				5,656	11,447
Total Volume-Weighted Average Carbon Rate (kgCO2e/CY)				453.9	239.8
Total A1-A4 Stage Concrete Embodied Carbon (kgCO2e)				2,567,067	2,744,644

Spotlight Topic 2: Lightweight Concrete Aggregate

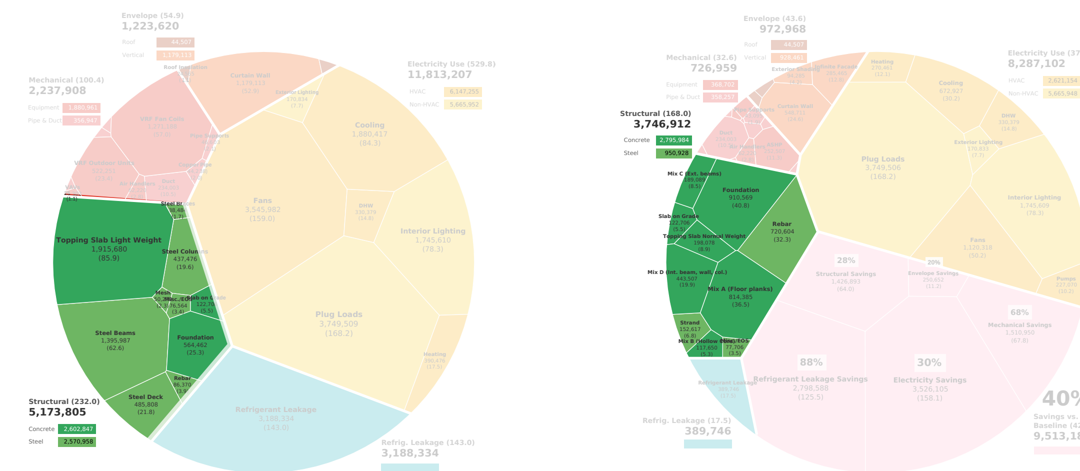
This is relevant to all buildings, even mass timber – please read. Lightweight aggregates seem great. They are lighter so the building structure can be lighter, and as such they are extremely common in Steel Structures. Unfortunately, there is a very large amount of primary energy that goes into making them. Most lightweight aggregate is produced from materials such as clay, shale, or slate. To produce the lightweight aggregate, aggregates are mined and crushed then heated, typically to 1,200°C (2,192°F). As the material is heated, materials within the aggregate form gas bubbles which expand the material, giving it the low-density property desired.[11] These manufactured lightweight aggregates are very energy intensive to heat and they are usually shipped over long distances (e.g. from the Rocky Mountains to the California Bay Area).

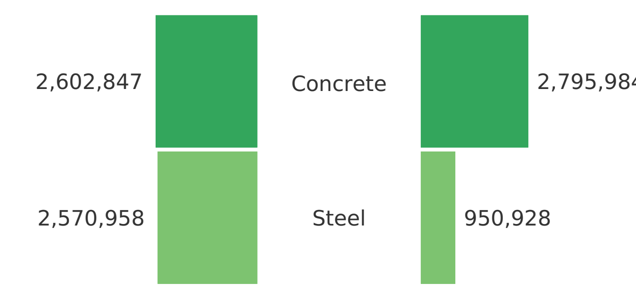
Steel Buildings and Mass Timber Buildings both can have this huge source of embodied carbon that is easy to overlook since it isn't a "Concrete" structure. The Business as Usual Steel Building uses an incredibly common 2-hour fire rated metal deck with 3.25" thick lightweight concrete (above 3" flutes). And, while every building is different and this Study does not directly examine Mass Timber, it is not uncommon for Mass Timber structures to have a thin concrete topping slab. Keep an eye out and work as a design team to explore alternatives, even if it means making the structure heavier to support extra weight. Chances are it still will save a lot of carbon overall compared to expanded shale lightweight aggregates. We all can do this.

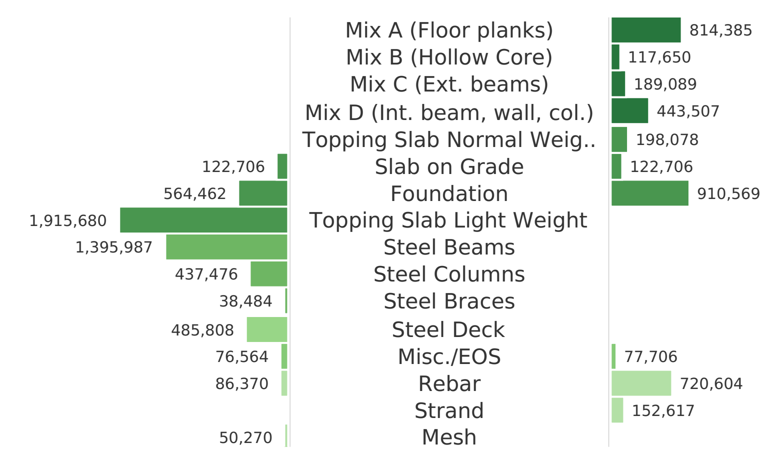
[11] AP-42, CH 11.20: Lightweight Aggregate Manufacturing (epa.gov)

Structure

Baseline Scenario (Steel + VRF)		Clark Pacific (Precast + Radiant)
5,173,805 kgCO2e	28% Carbon Savings	3,746,912 kgCO2e
232.0 kgCO2e/m2		168.0 kgCO2e/m2







The Ways These Results are Conservative

- The amount of miscellaneous metal in the Steel Baseline is intentionally on the very low end of typical design, and even lower end of what is typically actually used in construction. This was done to not have misc. metal emissions be a distraction.
- The Baseline has a very efficient steel structure design. Clark Pacific is very good at making efficient precast concrete structures (it's their job). It was important that the Baseline Steel Building be equally efficient, so results could not be delegitimized as simply an artifact of one design being good and the other being bad. Accordingly, the Baseline Scenario's steel quantity is possibly undercounting a bit. This was intentional.
- A5 (Construction Stage) emissions were excluded from this study as there is not yet broadly comprehensive industry accepted data available. A4 (transportation to the construction site) emissions were included, however. Thus, the study has already captured all emissions to get every piece to the job site. In the Baseline, all assembly happens in the field. In the Clark Pacific Scenario, a large amount of assembly has already happened and its emissions already "paid for" so to speak. As a proxy, Construction Stage carbon is primarily a function of efficiency of Time and Material Waste. The Clark Pacific precast structure will absolutely have less A5 Construction Stage emissions than a non-prefabricated structure, and the exclusion of A5 emissions is certainly conservative in favor of the baseline.

Clark Pacific Building Opportunities

1. Further Reductions in Portland Cement? –The concrete is still ~50% Portland Cement
2. Carbon Sequestering Aggregates? – Anything that is carbon negative is a positive
3. Rebar Carbon Reduction? – the embodied carbon from concrete reinforcement stands out

5.2 Envelope

The Clark Pacific Scenario's Envelope creates 20% less carbon emissions than the Baseline Business as Usual Building Envelope. With a shorter floor-to-floor height, the main point of investigation centered around how much the exterior sunshades would offset the height savings.

Key Levers

1. Floor-to-Floor Height
2. Curtain Walls

Spotlight Topic 1: Exterior Sunshades

The Clark Pacific Building uses exterior sunshades to prevent rapid changes in direct solar heat in order to let the radiant system flourish. The Radiant Whole Life Carbon Study employs a simple scalable sunshade scheme that has been employed successfully on many projects. The only drawback is the sunshades are entirely aluminum. One question for the study was if the amount of aluminum was enough to matter. The answer? It matters some (4.2 kgCO2e/m2), but keep the payoff in mind. The electrical use whole life savings are over 158 kgCO2e/m2, and that's not possible without the sun shading. So, spend 4 to save 158 ain't bad. Sun shading can be a sensitive topic for designers, and understandably so, as it changes the visual organization of the building. But if sun shading is the only thing standing in the way of a building that conservatively emits 40% less carbon, I'd hope we'd all do our best to do the right thing. Conclusion: Carbon optimization time and effort likely would be better spent elsewhere.

Spotlight Topic 2: Floor-to-Floor Height

This one's simple. Less height equals less envelope area. Clark Pacific's Building has a 13ft floor to floor height and is able to maintain at least 10ft ceiling throughout due to the mechanical system distribution's smaller size and integration into the structure. The Business as Usual requires a 15ft floor-to-floor height to maintain a 10ft ceiling throughout, due to the non-integrated mechanical system and larger size as an air-based conditioning system. This is a large part of how the Clark Pacific Building Envelope has less embodied carbon. But, it is not the only reason. Curtain Walls are a big part of the story too (see below).

Spotlight Topic 3: Panelized Facades

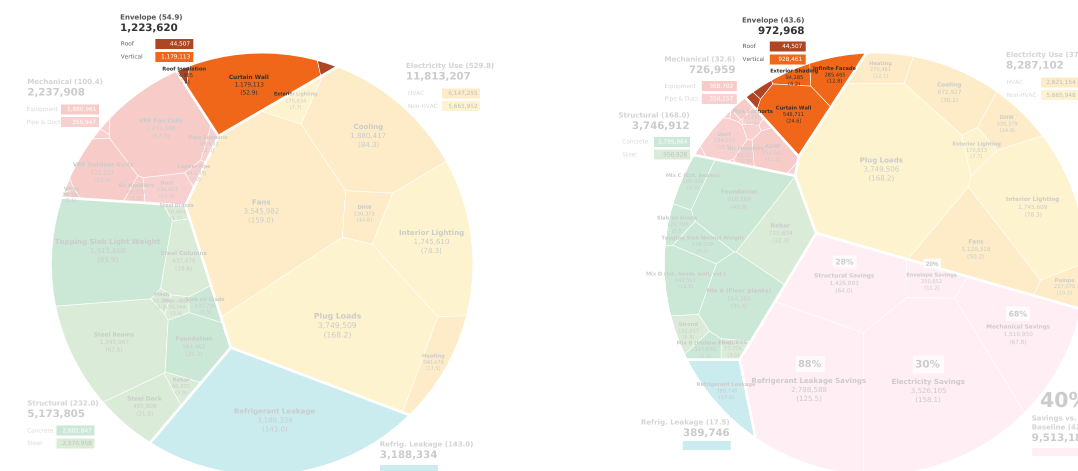
The Business as Usual Building's Envelope embodied carbon is nearly entirely from Aluminum Curtain Walls, and the Clark Pacific Scenario's almost entirely from Curtain Walls and Infinite Façade (the company's envelope panel system). Extra effort was made to calibrate product stage emission factors for these panelized systems. For the curtain walls, the study took an average of (3) EPDs for market typical aluminum curtain wall products from (3) different manufacturers (all with the same functional unit) to best represent the product stage emissions (see Summary Table A in the Appendix for full details). For the Infinite Façade, the study used the product stage emissions from the separate life cycle assessment, Clark Pacific Infinite Façade LCA Report_Rev1, performed by others and provided to Integral Group by Clark Pacific. The Clark Pacific Building has 344,937 kgCO2e (15.5/m2) less embodied carbon from its panelized façade total (curtain wall + infinite façade) than the Business as Usual Building (curtain wall), a 29% reduction. This is the result of both reductions in area and the lower product stage emissions of the Infinite Façade product than market rate curtain walls.

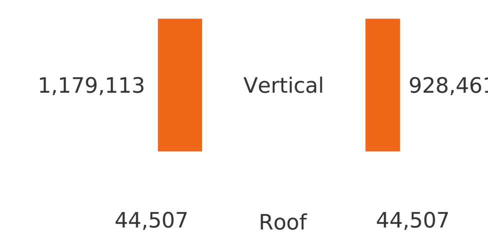
Clark Pacific Building Opportunities

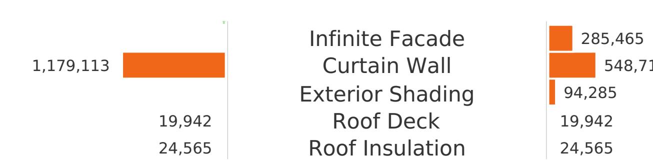
- Improve the Infinite Façade embodied carbon – the concrete has no SCMs and the CO2e rate could be less

Envelope

Baseline Scenario (Steel + VRF)		Clark Pacific (Precast + Radiant)
1,223,620 kgCO2e	20%	972,968 kgCO2e
54.9 kgCO2e/m2	Carbon Savings	43.6 kgCO2e/m2







5.3 Mechanical

The Clark Pacific Scenario's Mechanical Systems have 68% less Whole Life Carbon than the Business as Usual VRF building. While a lot of items contribute to this enormous reduction the biggest by far is the difference in equipment, both day 1 and in replacement over the 60-year life. This savings is conservative.

Business as Usual VRF Fan Coils (1,271,188 kgCO2e, 57.0/m2) have an **embodied carbon 75% larger** than **Clark Pacific's Entire Mechanical System** (726,959 kgCO2e, 32.6/m2) and **Over 3x larger** than **All Clark Pacific Mechanical Equipment** (368,702 kgCO2e, 16.5/m2).

Key Levers

1. Mechanical Equipment (if it's heavy to lift it's heavy on the carbon)
2. Replacement Frequency (how much, how often)

Spotlight Topic 1: Equipment Replacement is substantial

The table below (taken from Detail Table S in the Appendix) itemizes the amount of avoided mechanical equipment replacement in the Clark Pacific Scenario. This likely will be even greater, as the study used a 20-year equipment replacement period for the compressor-based equipment. Even giving Business as Usual that handicap, Clark Pacific still has 75% less use stage mechanical embodied carbon (47kgCO2e/m2 avoided).

Mechanical Replacement Totals	Total Avoided Mech. Replacement (Baseline - Clark Pacific)	Baseline Scenario (Total Replaced)	Clark Pacific Scenario (Total Replaced)
ASHP Outdoor Units	1,580kW of Outdoor Heat Pump		1,420 kW
VRF Outdoor Units		3,000 kW	
VRF Fan Coils	5,504kW of Indoor Fan Coils	5,504 kW	
VAV Boxes	368 VAV boxes	688 ea.	320 ea.
DOAS	-	84,000 cfm	84,000 cfm
Ductwork	-	60,047 lbs	60,047 lbs
Duct Insulation	-	3,424 ft3	3,424 ft3
Duct Hangers and Supports	-	0.26 m3	0.26 m3

Spotlight Topic 2: Downsizing Equipment Saves a lot of Carbon

It's not just replacement where equipment size and quantity matters – it's also day 1. The significant reduction in central plant cooling size translates to a lot of avoided embodied carbon. The smaller Clark Pacific Air-Source Heat Pumps emit 3.7 kgCO2e/m2 less embodied carbon (51% reduction) than the Business as Usual VRF Outdoor Condensing Units. Remember the 4.2 kgCO2e/m2 for the aluminum sunshades. Nearly took care of that just with this. This downsize also avoids emissions every replacement. The Clark ASHP's avoid another 8.2 kgCO2e/m2 in Use Stage emissions. That's 12.4 kgCO2e/m2 in avoided embodied carbon emissions, from A through B stage use for just the smaller ASHPs vs. VRF Condensing units.

Spotlight Topic 3: Pipes Matter, but less than we expected

The Clark Pacific Building focused heavily on reducing pipe distances and using PEX instead of Copper. This did help reduce pipe embodied carbon emissions a large %, but had a less noticeable % impact on the total mechanical embodied carbon than first anticipated, as it is dwarfed by equipment.

Spotlight Topic 4: **Ceiling Fans offset way more carbon than they create**

Just like the Exterior Sunshades, the Ceiling fans enable the radiant system to flourish. The embodied carbon of the Ceiling Fans (42,307 kgCO2e/m2, 1.9/m2) is less than half that of the Exterior Sunshades. The Ceiling Fans and Sunshades combined whole life carbon (136,941 kgCO2e, 6.1/m2) together trade 6/m2 in embodied carbon to enable the radiant system to use158/m2 less electricity use carbon. That's about as good as a deal gets.

Mechanical

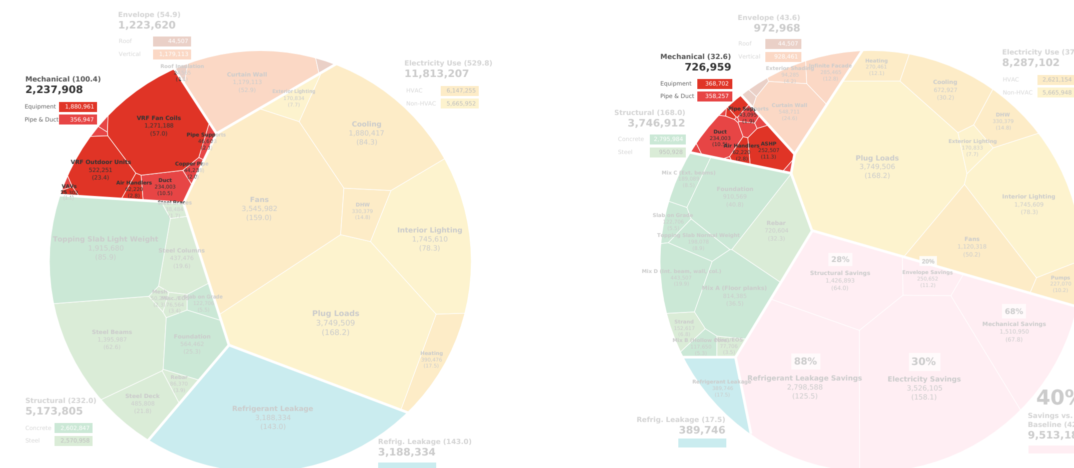
Baseline Scenario (Steel + VRF)

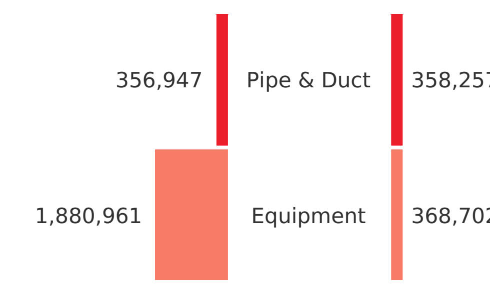
2,237,908 kgCO2e
100.4 kgCO2e/m2

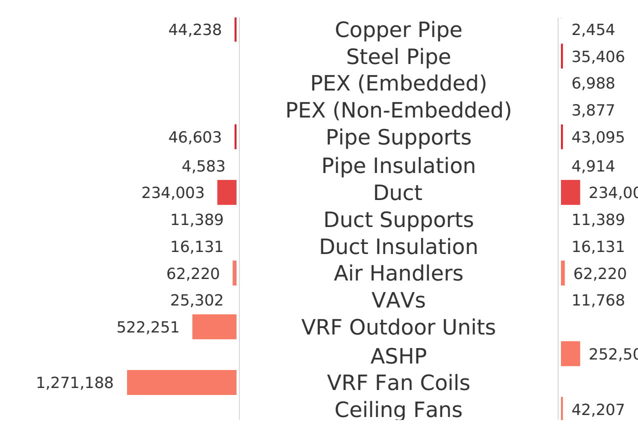
68% Carbon Savings

Clark Pacific (Precast + Radiant)

726,959 kgCO2e
32.6 kgCO2e/m2







The Ways These Results are Conservative

- Frequency of Equipment Replacement: The baseline scenario has substantially larger quantity of compressor-based equipment and zonal equipment that would be replaced in a tenant improvement event. Accordingly, the B4 emissions increase more in the baseline scenario than the Clark Pacific scenario each time there is a replacement event. To be conservative in favor of the baseline, a 20-year service life for all compressor-based equipment and a 20-year gap between tenant improvements products was used. 20 years is the high end of the range for both time between retrofits in an occupied building and compressor-based equipment service life. What would be replaced or kept intended to match business as usual in such applications
- Exclusion of refrigerant piping network replacement in a TI retrofit: Refrigerant copper pipe and associated pipe insulation, hangers, and supports in the baseline scenario will be replaced in part in any mechanical TI retrofit. To be conservative in favor of the baseline, this copper pipe was excluded from B4 stage. This amount of excluded copper pipe and supports is not insignificant.
- Exclusion of Branch Circuit Controllers but inclusion of Buffer tanks: The baseline scenario VRF branch circuit controllers were fully quantified, but their embodied carbon was excluded to be conservative in favor of the baseline. At ~40 lbs per 4-BCC (qty 53) and~35 lbs per 3-circuit BCC (qty 44) this is ~3,660 lbs of copper. This is not an insignificant amount. This is conservative because the Steel Buffer tanks in the Clark Pacific Building (4,150 lbs of steel) are included in the Clark Pacific Scenario as part of the Steel Pipe quantity (see Detail Table N in the Appendix). Buffer tanks are the in some ways an analogous hydronic part to branch circuit controller
- Exclusion of Duct & Diffuser downstream of VAVs and Fan Coil Units: To be conservative in favor of the baseline, all ductwork distribution downstream of VRF Fan Coils is excluded in the Baseline in the same fashion ductwork and diffusers downstream of VAV boxes is excluded in the Clark Pacific scenario. The VRF Fan coils have more ductwork & diffusers downstream than the Clark Pacific system. This too is not insignificant.

5.4 Refrigerant Leakage

The Clark Pacific Scenario's has 88% less Whole Life Carbon from Refrigerant Leakage than the Business as Usual VRF building. This is based on low end refrigerant leakage rates. These savings are truly conservative.

Business as Usual Refrigerant Leakage (3,188,334 kgCO2e, 143.0/m2), conservatively estimated, is **larger than Clark Pacific's Entire Lifetime of HVAC Electrical Emissions & Refrigerant Leakage combined** (3,010,900 kgCO2e, 135.0/m2).

Key Levers

1. Volume of Refrigerant
2. Length of Field Fabricated Refrigerant Piping
3. Maximum Length and Elevation Difference in the System
4. Leakage Rate
5. End of Life Recovery Rate

Spotlight Topic 1: All things suggest refrigerant impact is even worse

Refrigerant is invisible, so people instinctively give it less concern. When hydronic piping leaks, you see water. If ductwork leaks enough, someone says it's stuffy. When refrigerant leaks it may not be noticed for months, or even years. Until someone notices that a system can't heat or cool enough and tracks it down precisely to the slow loss of refrigerant charge, the leakage just keeps happening. To say refrigerant doesn't leak, isn't to act in good faith. So the question is how much? The Business as Usual All Electric Building of the size in this study, doesn't have a small VRF system. In fact, one VRF condenser can't even necessarily serve a whole floor (in this study's 8 story building, the baseline VRF system needed two condensing units to serve the bottom floor due to the length and load required). All this is to say, if these larger application VRF systems aren't at the high end of the leakage rate range, what is?

If refrigerant leakage was even in the mid -range for the VRF system and the ASHP (increasing to 6% and 3% leakage rate respectively), the gulf between Business as Usual and Clark Pacific refrigerant leakage carbon emissions would widen by another 2,408,842 kgCO2e (108.0/m2) to 5,207,430 kgCO23 (233.6/m2). That's now more additional refrigerant leakage emissions in the Business as Usual Building than its entire Structure. And this isn't even the extent of the error bar. This is staggering.

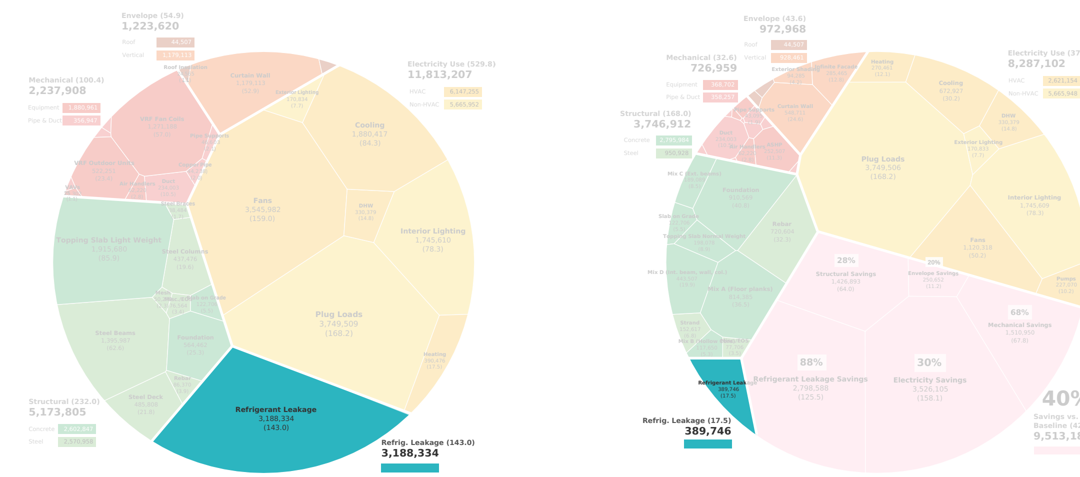
Spotlight Topic 2: How Refrigerant changes the balance of total emissions

Embodied carbon is a still nascent field, but there are rules of thumb out there. Typically, they are just for the above ground structure and envelope, and are in the 150-350 kgCO2e/m2 range. The Business as Usual Building's excess low-end refrigerant leakage emissions (125.5/m2) beyond the Clark Pacific Building System is nearly a whole rule of thumb "typical" building's worth. With mid-range leakage (233.6 kg/m2), that extra carbon impact becomes solidly a whole rule of thumb "typical building's worth". Looking at just the envelope and structure is woefully incomplete, unhelpful, and plain irresponsible when it leads to harmful outcomes.

Baseline Scenario (Steel + VRF)
3,188,334 kgCO2e
143.0 kgCO2e/m2

Refrig. Leakage
88%
Carbon Savings

Clark Pacific (Precast + Radiant)
389,746 kgCO2e
17.5 kgCO2e/m2



5.5 Electricity Use

The **Clark Pacific Radiant Building** has **Total Electricity (30% less)**, **HVAC only (57% less)**, and **Space Heating & Cooling (65% less)** carbon emissions than a **Business as Usual VRF Building**. Savings (%) should only be expected to increase in locations with harsher summers/winters or more wind power than the California bay area. The implications are enormous.

Key Levers

1. Time of Grid Emissions, Electricity Use, and Thermal Loads
2. Ability to Shift and Store
3. Simultaneous Loading

Spotlight Topic 1: Grid Alignment

CAISO 2019 Hourly Grid Emissions (next page) shows hourly grid emissions intensity (kgCO2e/kWh) binned by hour and month and then averaged in a heatmap style plot using a Red-White-Green diverging gradient. The midpoint, shown as white, is set not to the exact halfway between the highest and lowest hourly emission intensity of the year, as that doesn't correspond to anything meaningful. Instead white corresponds to the grid emission intensity amount observed when roughly 50% of the Grid Supply is served by Solar PV. This is not a consistent nor exact value, but it is a helpful proxy for the balance point of what moments are good vs. bad emissions times in the CAISO system. Accordingly, green suggests over 50% grid supply provided by solar and red suggests under 50%, with lighter being closer to 50% and darker being closer to all or none.

Some Observations - CAISO 2019 Grid Emission Intensities

1 Daytime generally is lower carbon than nighttime.
Nearly all renewable power generated in the CAISO system in 2019 was provided by solar PV. Without the sun, wind does not currently provide a meaningful amount of power, so dirtier plants make up the difference.

2 Spring is the winning carbon season, May is the winning month, and April noon is the winning hour
Solar generation rises throughout spring as it nears the solstice, but total demand remains fairly low. CAISO's variation from weather is mostly a proxy for air-conditioning. It isn't nearly as hot in April in the CAISO system as it is in August (equidistant from solstice). High PV yield and lower daily peak demand means CAISO can forgo dirty peaker plants. This keeps emissions lower day and night. May especially benefits as it's still cooler and near solstice.

3 Fall is challenging and the most dynamic carbon season. October in particular.
Early to mid-fall often is the hottest and PV generation is declining as it gets further from the summer solstice. This means the renewable power shortfall from the day's peak demand can be substantial. Dirtier plants fill the gap.

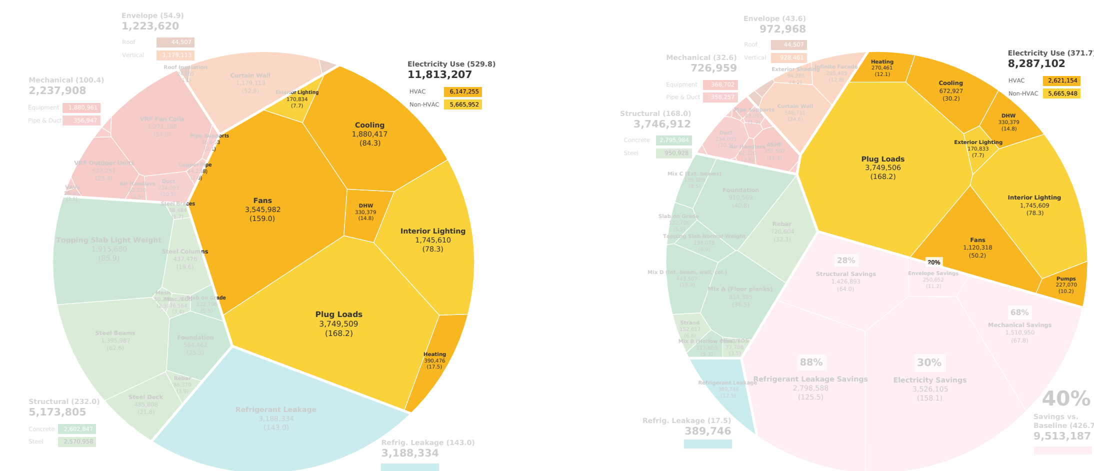
4 Winter is the losing carbon season, December in particular
Nearly all of CAISO's renewable generation is PV, and the winter solstice is the worst PV generation time of the year.

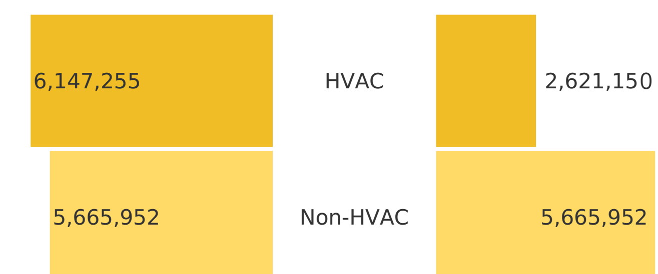
5 You can see the "Duck Curve[12]" – Especially in Late Summer and Early Fall
When the worst emissions of the day are a couple hours before sunset, that's the duck's "head". This is the culmination of rapid decreasing solar PV output being offset by increasingly dirtier plants.
Graphic – CAISO 2019 Hourly Grid Emission Intensities

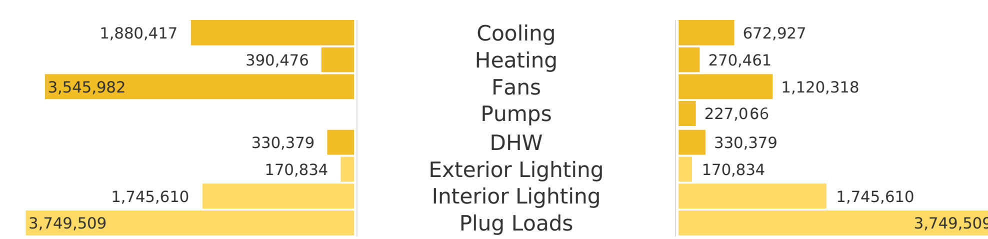
These patterns are all specific to CAISO, which has large renewable generation dominated almost entirely by PV. While the CAISO grid may seem favorable to the Radiant system, it's actually instead quite favorable to Business as Usual. The VRF cooling load is fairly aligned with when it's sunny, and in CAISO that's generally a cleaner time (strong exception for duck curve moments near day's end).

Electricity Use

Baseline Scenario (Steel + VRF)		Clark Pacific (Precast + Radiant)
11,813,207 kgCO2e	30% Carbon Savings	8,287,102 kgCO2e
529.8 kgCO2e/m2		371.7 kgCO2e/m2







[12] If you can't picture why it's called a "Duck", http://insideenergy.org/2014/10/02/ie-questions-why-is-california-trying-to-behead-the-duck/

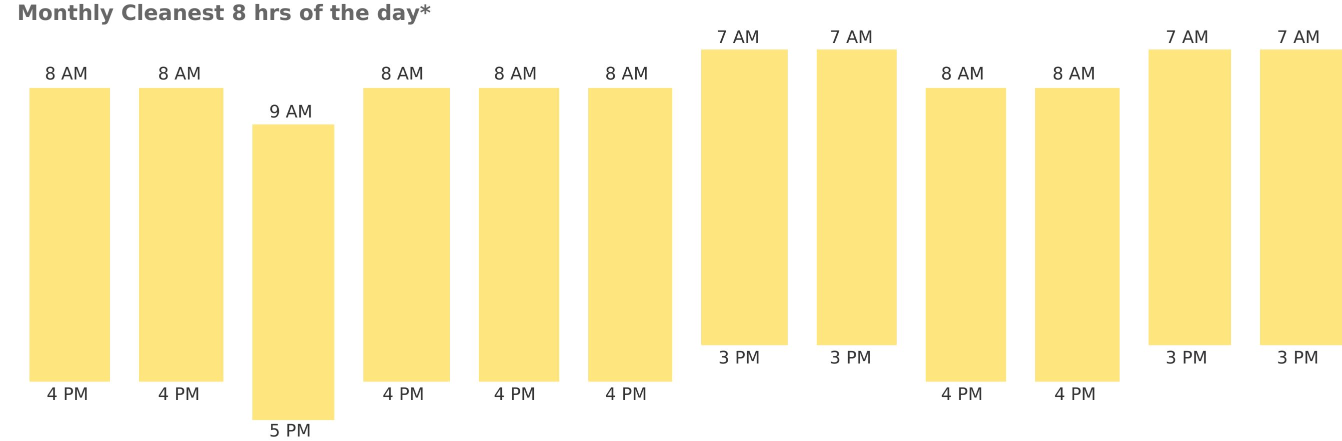
2019 CAISO Hourly Grid Emission Intensities

Total Hourly Emissions divided by Supply (kgCO2e/kWh)

0.090 – 0.360

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12 AM	0.321	0.294	0.268	0.223	0.213	0.232	0.264	0.303	0.327	0.336	0.345	0.329
1 AM	0.323	0.292	0.264	0.219	0.213	0.231	0.262	0.301	0.327	0.335	0.345	0.329
2 AM	0.323	0.294	0.261	0.216	0.214	0.233	0.262	0.302	0.328	0.337	0.344	0.329
3 AM	0.323	0.294	0.260	0.218	0.214	0.236	0.263	0.304	0.329	0.338	0.343	0.328
4 AM	0.322	0.292	0.260	0.227	0.224	0.242	0.267	0.306	0.330	0.335	0.342	0.327
5 AM	0.322	0.291	0.264	0.243	0.226	0.234	0.264	0.310	0.335	0.339	0.344	0.327
6 AM	0.324	0.298	0.276	0.222	0.185	0.188	0.224	0.274	0.313	0.324	0.314	0.319
7 AM	0.319	0.278	0.264	0.173	0.145	0.151	0.184	0.221	0.250	0.260	0.265	0.286
8 AM	0.276	0.226	0.207	0.131	0.128	0.139	0.171	0.201	0.215	0.208	0.242	0.262
9 AM	0.240	0.199	0.161	0.110	0.118	0.134	0.166	0.194	0.206	0.189	0.237	0.252
10 AM	0.225	0.184	0.140	0.101	0.110	0.131	0.166	0.195	0.207	0.187	0.237	0.247
11 AM	0.217	0.182	0.129	0.096	0.104	0.128	0.165	0.199	0.209	0.187	0.240	0.247
12 PM	0.217	0.182	0.125	0.095	0.104	0.130	0.170	0.207	0.214	0.190	0.244	0.251
1 PM	0.219	0.184	0.127	0.096	0.106	0.132	0.175	0.216	0.219	0.194	0.256	0.263
2 PM	0.229	0.189	0.128	0.096	0.109	0.142	0.184	0.226	0.228	0.207	0.288	0.289
3 PM	0.257	0.207	0.138	0.113	0.117	0.152	0.194	0.236	0.244	0.238	0.337	0.320
4 PM	0.306	0.249	0.161	0.137	0.135	0.170	0.210	0.253	0.275	0.303	0.357	0.331
5 PM	0.328	0.295	0.203	0.191	0.182	0.206	0.241	0.292	0.326	0.345	0.356	0.329
6 PM	0.332	0.310	0.263	0.251	0.234	0.252	0.284	0.327	0.343	0.348	0.352	0.328
7 PM	0.331	0.308	0.293	0.271	0.250	0.269	0.296	0.329	0.343	0.349	0.352	0.327
8 PM	0.333	0.307	0.293	0.265	0.242	0.265	0.291	0.324	0.340	0.346	0.352	0.327
9 PM	0.333	0.305	0.285	0.249	0.229	0.254	0.283	0.321	0.336	0.344	0.347	0.326
10 PM	0.331	0.299	0.277	0.236	0.219	0.244	0.278	0.315	0.332	0.341	0.344	0.328
11 PM	0.327	0.296	0.272	0.225	0.214	0.237	0.268	0.308	0.329	0.337	0.344	0.329

Monthly Cleanest 8 hrs of the day*



*Each day ranks hours from 1 (cleanest) to 24 (dirtiest) by that calendar day's grid's hourly kgCO2e/kWh. Each month ranks hour-bins 1 to 24 by the median of these daily rank scores. This is intended to represent a typical day's 8 cleanest hours in a given month.

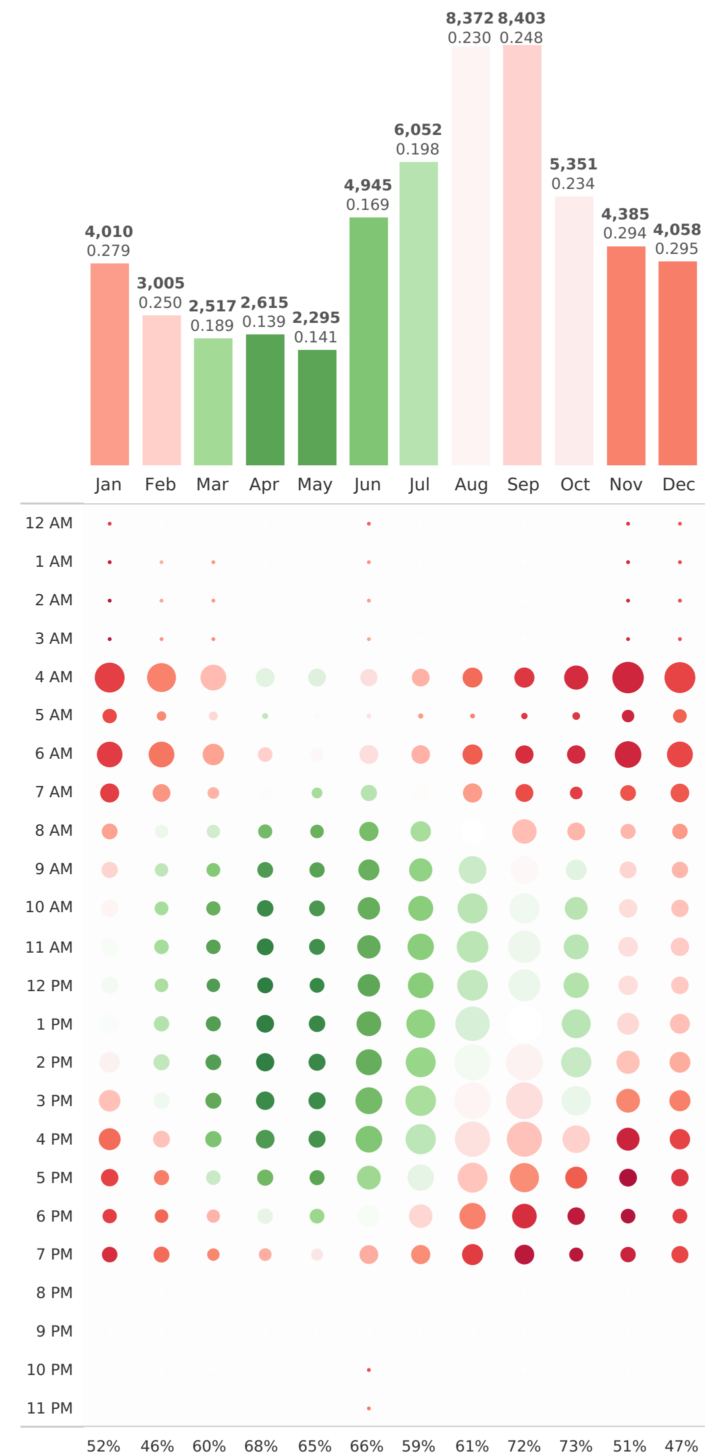
Space Heating & Cooling - Year One Carbon Emissions

2019 CAISO Actual Hourly Emissions Rates and 2019 CALMAC Actual Weather Data

Baseline Steel + VRF

Grid Intensity (kgCO2e/kWh) 0.090 – 0.360

Total **56,006** kgCO2e **0.218** kgCO2e/kWh



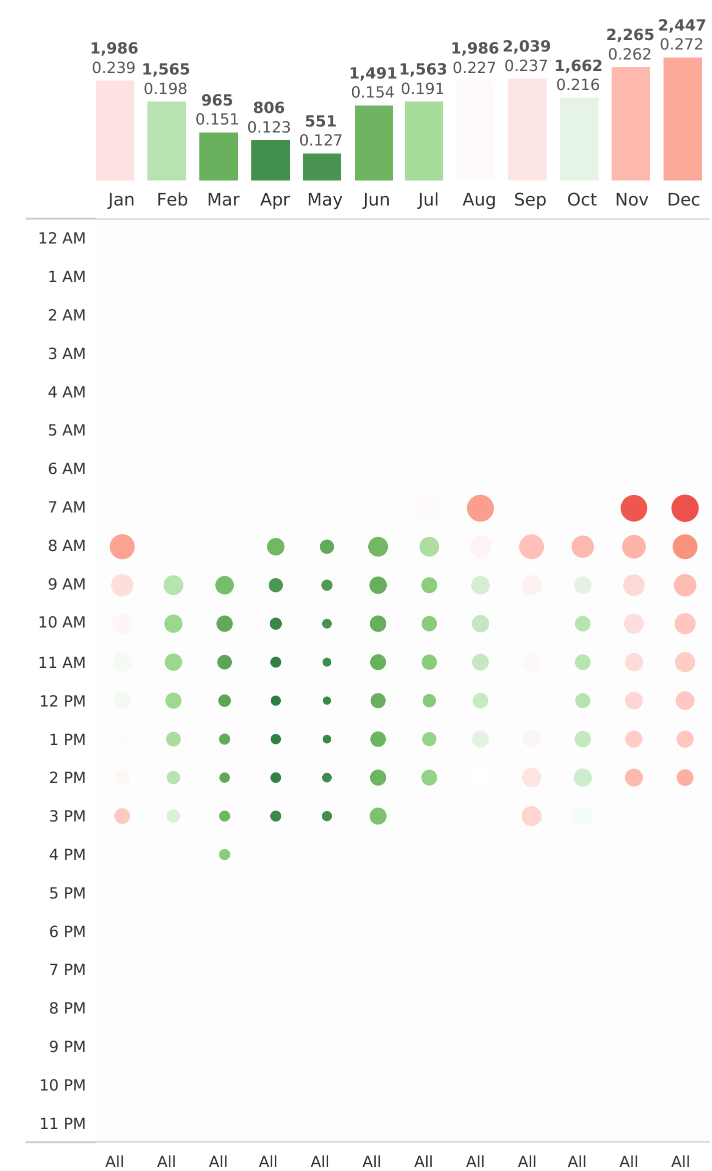
62% **of VRF kWh** in Month's Typ. Cleanest 8 hrs

Clark Precast + Radiant

Grid Intensity (kgCO2e/kWh) 0.090 – 0.360

Total **19,325** kgCO2e **0.205** kgCO2e/kWh

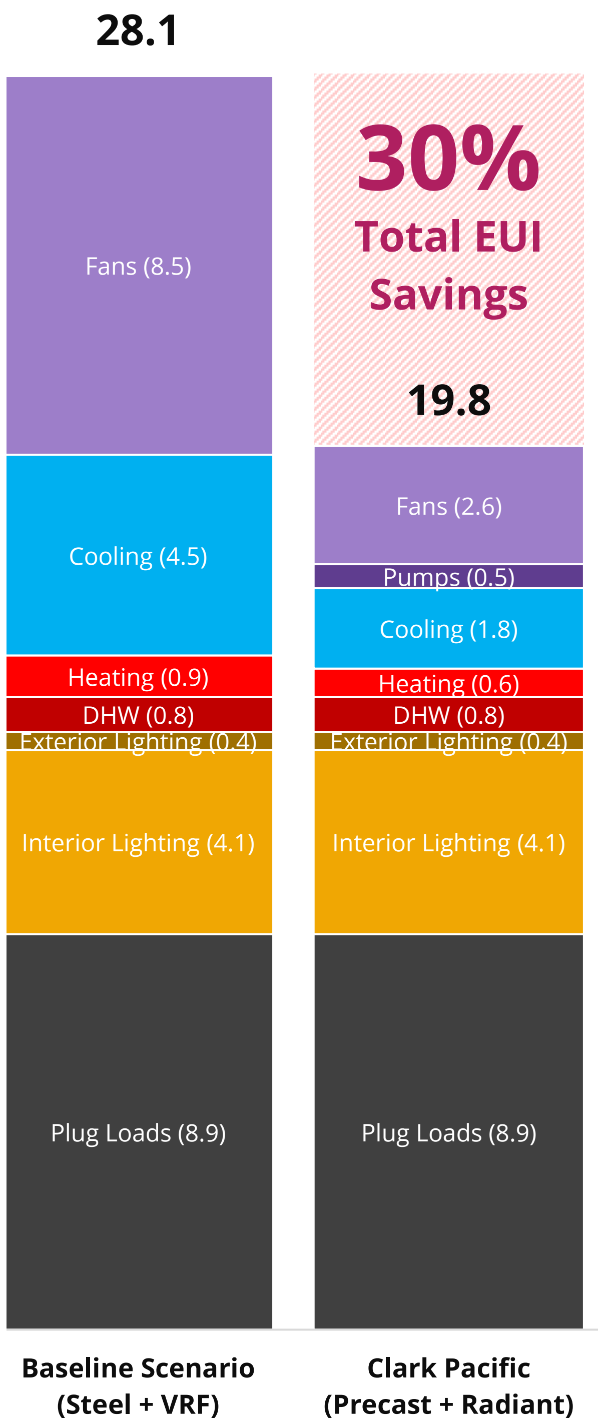
Electricity Use	Emissions Rate	Grid Carbon
63.3%	**5.9%**	**65.5%**
less kWh	**less kgCO2e/kWh**	**less kgCO2e**



100% **of Radiant kWh** in Month's Typ. Cleanest 8 hrs

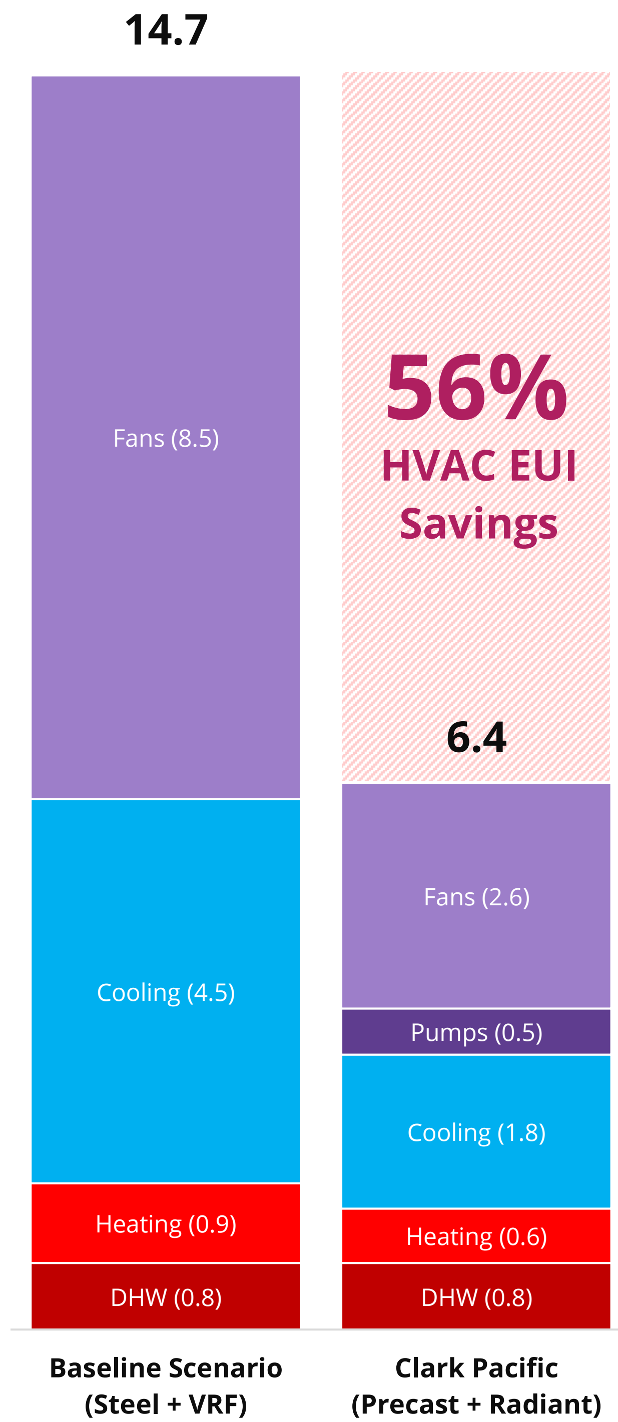
Electricity Use Intensity

Total EUI (kbtu/sf/yr)



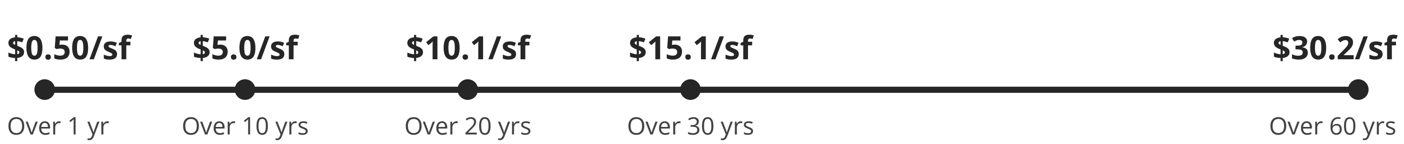
Electricity Use Intensity

HVAC Only EUI (kbtu/sf/yr)



Clark Pacific Electricity Cost Savings ($/sf)

PG&E 2019 E-19 Rate Schedule @ 3%/yr escalation rate & 3% ROI



DETAIL TABLE V
Electricity EUI Breakdown by Use

	Baseline Scenario (Steel + VRF)	Clark Pacific (Precast + Radiant)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Fans	8.5	2.6	*5.8*	*68.8%*
Pumps	0.0	0.5	*-0.5*	*0.0%*
Cooling	4.5	1.8	*2.7*	*59.9%*
Heating	0.9	0.6	*0.3*	*31.7%*
DHW	0.8	0.8	*0.0*	*0.0%*
Exterior Lighting	0.4	0.4	*0.0*	*0.0%*
Interior Lighting	4.1	4.1	*0.0*	*0.0%*
Plug Loads	8.9	8.9	*0.0*	*0.0%*
Total EUI (kbtu/sf/yr)	**28.1**	**19.8**	***8.3***	***29.5%***
HVAC Subtotal	**14.7**	**6.4**	***8.3***	***56.4%***

DETAIL TABLE W
Year One Electricity Use (kWh)

	Baseline Scenario (Steel + VRF) (kWh)	Clark Pacific (Precast + Radiant) (kWh)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Fans	596,297	186,108	*410,189*	*68.8%*
Pumps	0	37,807	*-37,807*	*0.0%*
Cooling	316,288	126,880	*189,408*	*59.9%*
Heating	65,625	44,820	*20,805*	*31.7%*
DHW	54,855	54,855	*0*	*0.0%*
Exterior Lighting	28,379	28,379	*0*	*0.0%*
Interior Lighting	289,923	289,923	*0*	*0.0%*
Plug Loads	622,870	622,870	*0*	*0.0%*
Total Electricity Year 1 (kWh)	**1,974,237**	**1,391,643**	***582,595***	***29.5%***
HVAC Subtotal	**1,033,065**	**450,470**	***582,595***	***56.4%***

DETAIL TABLE X
Year One Electricity (kgCO2e)

	Baseline Scenario (Steel + VRF) (kgCO2e)	Clark Pacific (Precast + Radiant) (kgCO2e)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Fans	136,096	42,998	*93,098*	*68.4%*
Pumps	0	8,715	*-8,715*	*0.0%*
Cooling	72,171	25,827	*46,344*	*64.2%*
Heating	14,987	10,380	*4,606*	*30.7%*
DHW	12,680	12,680	*0*	*0.0%*
Exterior Lighting	6,557	6,557	*0*	*0.0%*
Interior Lighting	66,997	66,997	*0*	*0.0%*
Plug Loads	143,907	143,907	*0*	*0.0%*
Total Electricity Year 1 (kgCO2e)	**453,395**	**318,062**	***135,333***	***29.8%***
HVAC Subtotal	**235,934**	**100,601**	***135,333***	***57.4%***

DETAIL TABLE Y
Electricity B6 Whole Life Emissions

	Baseline Scenario (Steel + VRF) (kgCO2e)	Clark Pacific (Precast + Radiant) (kgCO2e)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Heating	390,476	270,461	*120,016*	*30.7%*
Cooling	1,880,417	672,927	*1,207,491*	*64.2%*
Fans	3,545,982	1,120,318	*2,425,664*	*68.4%*
Pumps	0	227,066	*-227,066*	*0.0%*
DHW	330,379	330,379	*0*	*0.0%*
Interior Lighting	1,745,610	1,745,610	*0*	*0.0%*
Exterior Lighting	170,834	170,834	*0*	*0.0%*
Plug Loads	3,749,509	3,749,509	*0*	*0.0%*
Total Electricity (kgCO2e)	**11,813,207**	**8,287,102**	***3,526,105***	***29.8%***
HVAC Subtotal	**6,147,255**	**2,621,150**	***3,526,105***	***57.4%***
Non-HVAC Subtotal	**5,665,952**	**5,665,952**	***0***	***0.0%***

The Grid will Change and it's different Everywhere

When grid emission patterns change, the Business as Usual VRF system won't be able to or think to do anything different. Business as Usual Steel + VRF is a burden on our carbon infrastructure, constantly taking but unable to shift or stop any HVAC loads of consequence to help in return. The marginal emissions from this rigidity are significant now, but will grow exponentially more over the Building's lifetime, as both the need for load shifting and the grid's capacity to store accelerates. This problem is not specific to VRF and applies to most buildings connected to the grid today. We need to expect our building infrastructure to be carbon helpful assets.

The Clark Pacific Scenario's Radiant Building System loves change and learns to work successfully with any 8 hours given. The Radiant Building System is a helpful and adaptable carbon asset for any electrical grid, and is in no way limited to the CAISO grid or California Bay Area. In fact, the greater the carbon variance in the grid (like from wind power and solar intersection) and the harsher the climate summers and winters, the more the Radiant Building System can thrive and help. In a future study, Integral Group seeks to redo this study's analysis for all ASHRAE Climate Zones in the United States to further unlock the benefits of radiant concrete slabs as thermal batteries.

5.6 Concrete as a Thermal Battery

This is the backbone of the Radiant Building System's low carbon emission operation and value as a carbon infrastructure asset. **The Implications are immense**.

Load Shifting & Carbon Lockout

As an optimization for lower operational carbon, lockouts were used to keep the radiant system from running during selected hours when the carbon intensity of the grid is at its highest periods of the day. These hours were chosen by examining the actual 2019 CAISO hourly average emissions factors for each day and choosing which to make available. Our testing and understanding ended up following this progression as we learned.

	Test	**Outcome**
1	Lockout 6 Hours, different each day, based on CAISO worst 6 hours (hours not necessarily continuous)	No unmet hours or uncomfortable conditions. 6-hour lockout was very beneficial in the cooling seasons, better integrating with the Duck Curve, but that it was not adequate to make a meaningful difference in the winter when the grid has less solar power
2	Lockout 12 Hours, different each day, based on CAISO worst 12 hours (hours not necessarily continuous)	No unmet hours or uncomfortable conditions. 12-hour lockout shifted loads effectively, but after the lockout was complete the heating would resume at earnest, Also observed that the grid is often much worse at the 12th best hour than it is at the 8th best hour (15-40% better improvement).
3	Lockout 16 Hours, different each day, based on CAISO worst 16 hours (hours not necessarily continuous)	No unmet hours or uncomfortable conditions. Reduced total load substantially by moving more cooling load to overlap with heating load (more on this below). The 16-hour lockout schedule was effective, able to shift the loads to a more meaningfully improved grid-emission periods. Wondered if we could simplify and keep the gains
4	Lockout 16 Hours, monthly cleanest 8hrs of the day, different each month	No unmet hours or uncomfortable conditions. Essentially identical (0.3% increase in space heating and cooling year one annual carbon).

In all cases, the lockout schedule did not create any unmet hours or uncomfortable conditions in the building. It is very significant that the plant can be locked out for 16-hours a day and still maintain comfort, which exceeded our own expectations at that time. The learning setpoint is a key aspect to making these lockout periods possible without leading to discomfort, through its continuous tuning of the slab setpoint. As a general pattern, more aggressive lockouts lead to a warmer learned slab setpoint in heating, and a cooler slab setpoint in cooling. This was observed to be more prevalent in heating, and less impactful in cooling. The basic premise is that if the plant has only 8-hours per day to run, it may will try to achieve a warmer slab setpoint for heating, such that it is able to coast through the day without discomfort.

An unexpected benefit is that by forcing all plant operation into an 8-hour period, the amount of simultaneous heating and cooling increased, as they better overlapped. With no lockout, the simultaneous heating and cooling load was 26% of the total annual radiant load. With the lockout, this increased to 35%. This finding is hugely consequential. With the 4-pipe Aermec NRP style heat pumps, any load made simultaneous is load removed.

Make it Simple: The last run, which only changed which 8 hours to make available, by simplifying it, was enormously important to empowering real world success. Grid emissions are complex and changing constantly. Building engineers should not expected to be grid carbon experts and this has to be simple. Finding that making available the same 8-hour window each day, different by month, caused only a 0.3% increase in slab heat pump heating and cooling grid emissions was game changing. That is functionally zero. Every grid will be different, and will change over time. As it evolves people will know when generally the best 8 hours are in a given month. And, as long as people are talking about this, they will make the right choice. This approach ensures that perfect isn't the enemy of the good (or we'd say great!). Building operators have a start time and stop time buttons separate for each month. It is pre-set with values that are the best choice at the time the building opens. If things change over time, the operator will be able to easily adjust.

Heat Pump (down)Sizing

Prior to any restriction on the plant size in the model, the radiant slab system cooling load reached 200 tons. This is too large to be served by a single NRP1800 and the expectation had been there would be two slab heat pumps for a building as large as 240,000sf. This model reflected the final simplified lockout schedule, controls, and supply water temps (65F, 85F). The DOAS Heat Pump peak cooling load was (and remained) 143 tons. From this starting point, our heat pump size testing ended up following this progression as we learned.

Reduction #1 – Single NRP1800: In order for the radiant to be served by a single Aermec NRP1800 at 65°F supply temperature, only approximately 160 tons of cooling and 98 tons of heating could be provided. This posed no comfort problems whatsoever, and the 16-hour lockout was still robust with this downsizing in place. In other words, the ability to shift and flatten these loads facilitated the use of a single heat pump, rather than two. The first cost implications were already exciting. It got better.

Reduction #2 - Testing lower cooling: At first, as purely a test, a model was run with 120 tons of capacity available for radiant cooling and 98 tons for radiant heating, and again, it caused no unmet cooling hours. This ease of shrinking the capacity of the heat pumps and forcing it to work over a longer period crystalized for us that the learning and the heat pump size are not separable, and in fact the learning is why this is possible. Nothing yet had indicated we were reaching a bottom of workable size. So, we tried a bigger drop.

Reduction #3 – Single Aermec NRP1250: As a final test, we ran a model with 110 tons of capacity available for radiant cooling and 68 tons available for radiant heating – the exact design condition capacities we get from a single Aermec NRP1250 producing 65F CHWS and 85F HHWS. The unusually moderate supply water temperatures allow us to get these capacities out of nominally much smaller equipment. This final run, like all before, had no unmet cooling hours.

It's important to pause and consider what this empowers.

- The Slab Heat Pump is just (1) Aermec NRP1250 (83 nom. ton unit) making 65F CHW and 85F HHW.
- The DOAS Heat Pump is just (1) Aermec NRP1800 (120 nom. ton unit) making 55F CHW or 85F HHW.
- This totals to just 203 tons nominal capacity or 1180 sf/nom-ton for a 240,000 sf building.
- Leveraging the concrete as a thermal battery eliminates over half the cooling plant size while only charging the battery when grid emissions are lowest.
- The same units providing cooling also provide all heating.
- The DOAS heat pump operates at an annual weighted average 5.1 COP (cooling) and 4.4 COP (heating)
- The Slab Heat Pump achieves an annual weighted average of 5.4 COP (cooling) and 5.0 COP (heating) with 35% annual load simultaneous
- Slab learning and heat pump size reduction made 9% more of the annual total slab load occur simultaneously

Low eXergy Supply Water Temperatures

The Slab Heat Pump (65F CHWS, 85F HHWS) had an annual weighted average 5.4 COP (cooling) and 5.0 COP (heating). The DOAS heat pump (55F CHWS, 85F HHWS) had an annual weighted average 5.1 COP (cooling) and 4.4 COP (heating). These are impressive values, derived from actual part load performance curves, specific to supply water temperatures and ambient air conditions, obtained from Aermec.

There are three phenomena primarily driving these high operational COPs. See Detail Table F through K in the Appendix for full Aermec NRP performance data and more information.

1. **Very Moderate Temp Slab Supply Water (65F CHWS, 85F HHWS)**: The Radiant Slab System, by choice, uses very moderate temperatures specifically to achieve these higher COPs. The research done by the Center for the Built Environment very much is of the mindset that these temperatures are if anything more "extreme" than they need to be (and could be even more moderate) – and from our investigation we would be inclined to agree. We hope to explore the potential for even more moderate water temperatures in a future study.
2. **Simultaneous Loading & Heat Recovery**: **35% of the annual slab total CHW & HHW load is simultaneous**. The Radiant Slab Heat Pump, Aermec NRP1250, is a heat recovery type unit producing all CHW and HHW for the radiant slab systems. Heat Recovery is taken as free generation for the non-dominant load. This occurs from a combination of naturally occurring simultaneous loading primarily between interior and exterior zones, and load shifted to be simultaneous as a result of the carbon lockout and intentionally reduced sized heat pump. This effect is very real, commonly the first few hours of slab heat pump operation, as zones start charging their slab for the day. See Load Visualizations at the end of this section and in the Appendix.
3. **Moderate Temp DOAS Supply Water (55F CHWS, 85F HHWS)**: DOAS Heat Pump (by choice) uses comparably very moderate temperatures. The 55F CHWS is able to maintain 60F maximum supply air dewpoint leaving the chilled water coil. A benefit of using higher temp water to cool the slabs is it completely removes any need to extra dehumidify to avoid condensation. With 65F slab supply water temp, slab surface temperatures will struggle to get below 70F (and that's fine!). Combined with how moisture physics actually work, there is not a concern of condensation. The 85F HHWS is employed because there is no barrier of cost or difficulty in doing so, and the COP is so much higher than 100F HHWS, let alone 110F or 120F. This is primarily possible due to the use of air-to-air heat recovery to drastically reduce the DOAS heating peak load. The DOAS Heat Pump's only job when it is cold is to make air leave the coils warmed up to 65F. Any heating beyond that is not only not needed, it is harmful as the interior conference rooms, that don't care what season it is use the DOAS air to help cool in DCV spaces.

A Realization

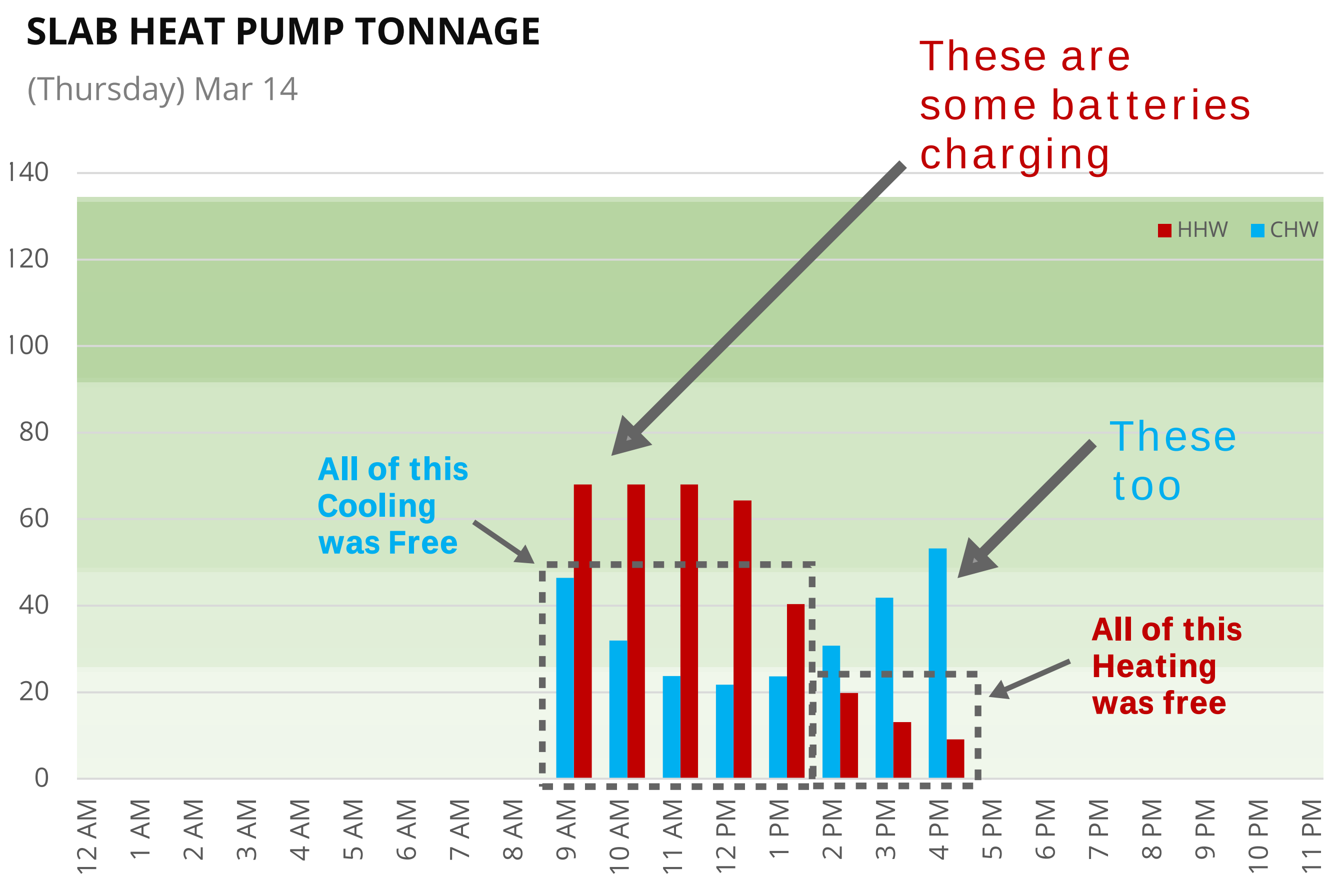
What we've learned, is that in one very important way, a radiant slab is just like a domestic hot water system. There's a Storage Tank and a Water Heater (in this analogy also a cooler). The Radiant Slab is the "Storage Tank" and the Slab Heat Pump is the "Water Heater". You know the ballpark total hot water demand for the day and your tank and water heater are a team to deliver it. The larger your storage tank, the longer the water heater can take to recharge it. The water heater can be as small as you want, so long as the tank can always have enough charge to meet the hot water demand. People never know or care what % charge the tank is at as long as the hot water keeps coming.

Radiant slabs are enormous storage tanks, easily capable of holding an entire day's worth of heating or cooling. With that perspective, allowing 8 hours for the slab heat pump to do its job, means it has almost a third of the day to charge a tank. That's forever. Even for a small heat pump. No wonder a small recovery rate was proven to be no problem. When you shrink the heat pump size, your slab storage capacity isn't changing, and we already know the slab capacity is plenty – all that is changing is the recovery rate.

Connecting this all together is the slab learning. Each day, the slab starts at a certain temperature and tries to keep it there in the 8-hour window the slab heat pumps are allowed to run. Each day the slab looks to see how it did, and adjusts the starting temperature up or down a little bit accordingly the next day. If you change the hours the heat pump can run or make the heat pump smaller, it doesn't know, or even care. It just rolls up its sleeves and tries to make it work with what its given, trying anew each day to make it better than the last. What's exciting is how easy it is to test all of this and get a clear and convincing answer. You simply set the slab heat pump capacity and hours of availability to whatever you hope works, run it, and find out.

See it in Action

With radiant slabs, loads are not just unmoveable forces, you can and do shape them, a lot. We conclude our Concrete as a Thermal Battery section with some loads data visualizations showing just that. See Appendix for more information.


SLAB HEAT PUMP TONNAGE
(Thursday) Mar 14
These are some batteries charging
These too
All of this Cooling was Free
All of this Heating was free
HHW
CHW
140
120
100
80
60
40
20
0
12 AM
1 AM
2 AM
3 AM
4 AM
5 AM
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
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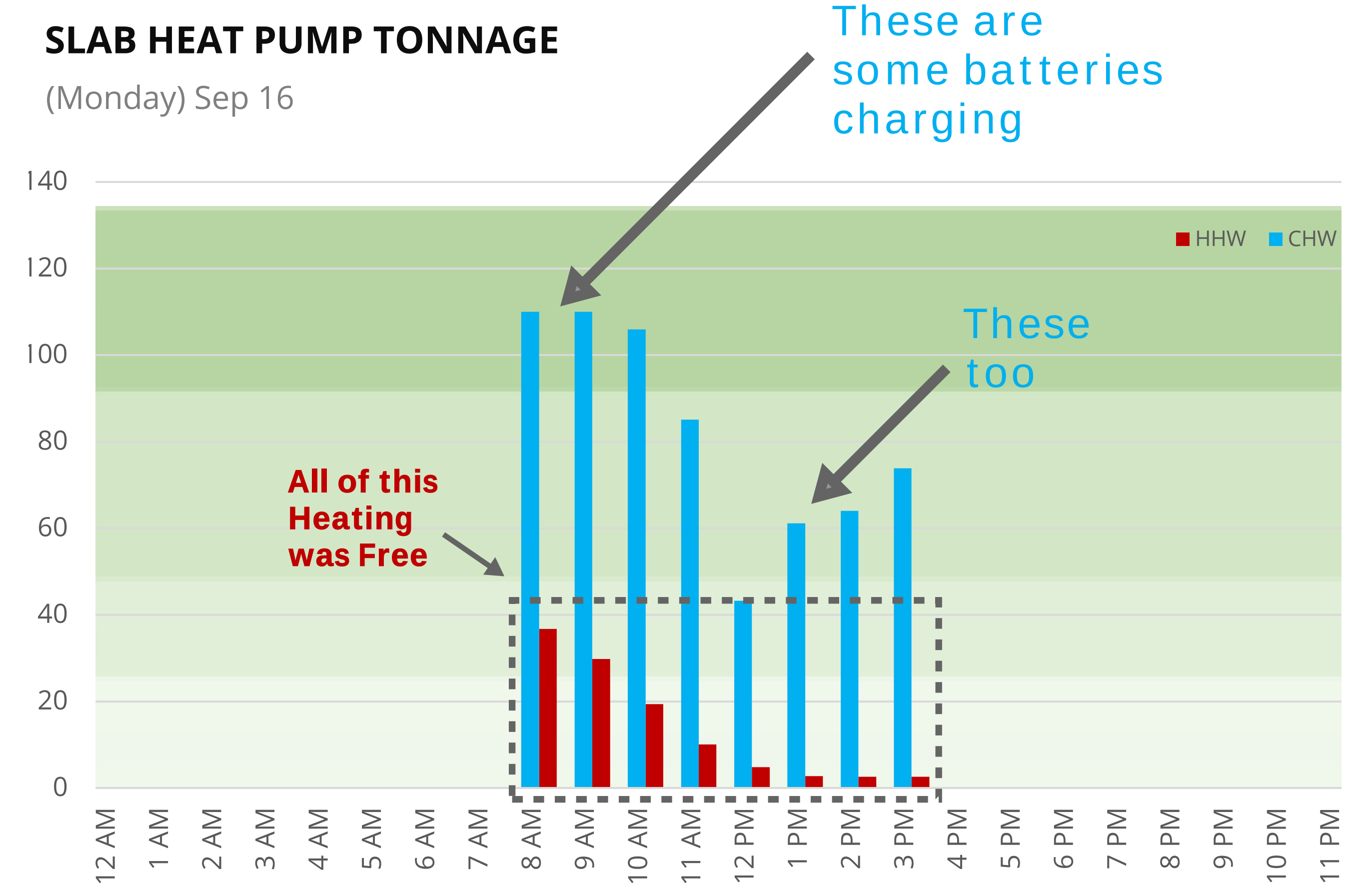
8 PM
9 PM
10 PM
11 PM


SLAB HEAT PUMP TONNAGE
(Monday) Sep 16
These are some batteries charging
These too
All of this Heating was Free
HHW
CHW
140
120
100
80
60
40
20
0
12 AM
1 AM
2 AM
3 AM
4 AM
5 AM
6 AM
7 AM
8 AM
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12 PM
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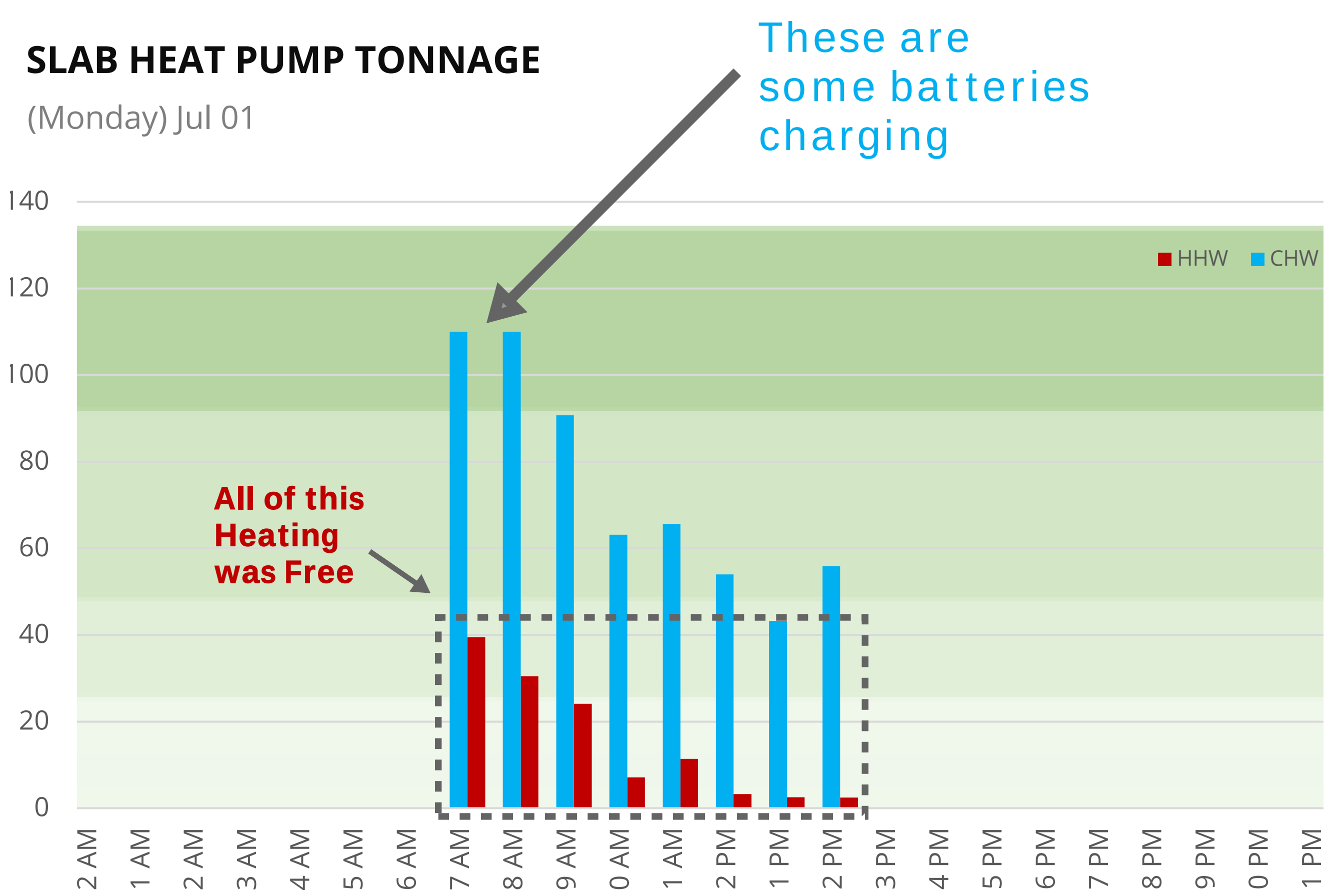
SLAB HEAT PUMP TONNAGE
(Monday) Jul 01
These are some batteries charging
All of this Heating was Free
HHW
CHW
140
120
100
80
60
40
20
0
12 AM
1 AM
2 AM
3 AM
4 AM
5 AM
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
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4 PM
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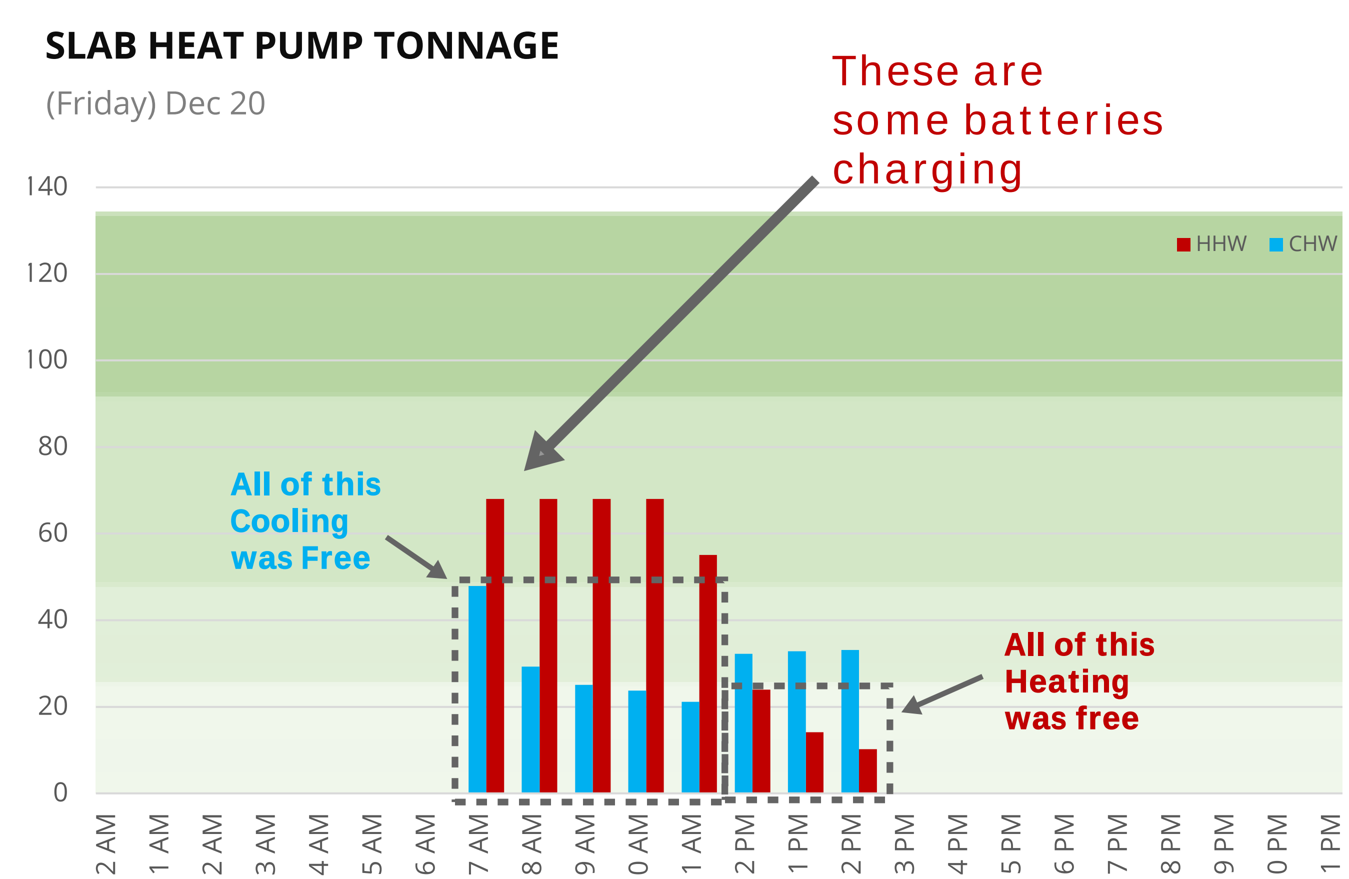
9 PM
10 PM
11 PM


SLAB HEAT PUMP TONNAGE
(Friday) Dec 20
These are some batteries charging
All of this Cooling was Free
All of this Heating was free
HHW
CHW
140
120
100
80
60
40
20
0
12 AM
1 AM
2 AM
3 AM
4 AM
5 AM
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
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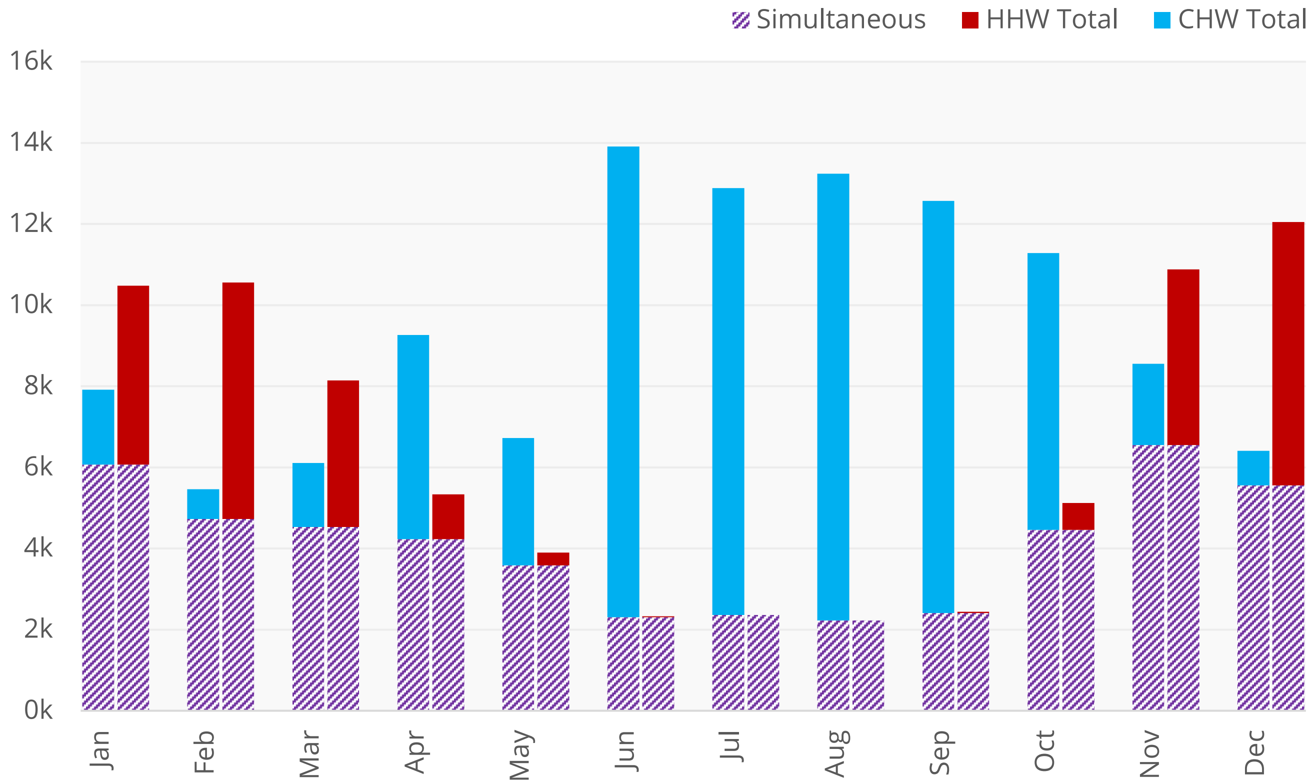
10 PM
11 PM

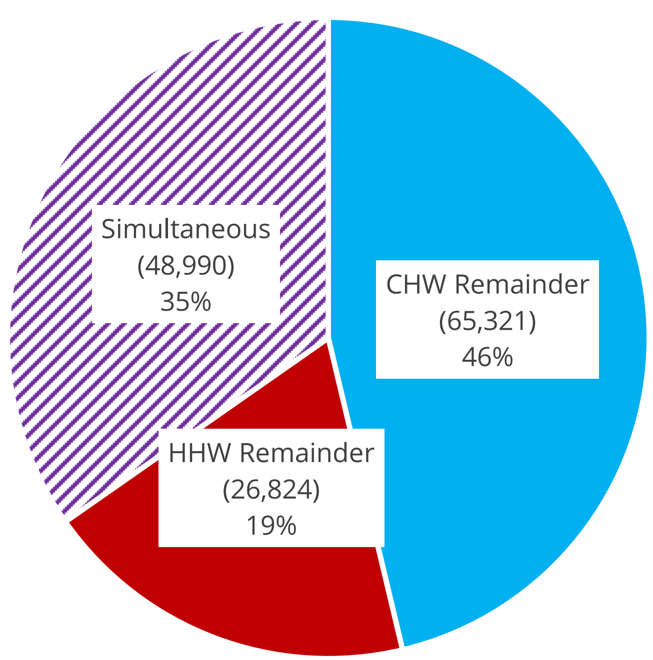
RADIANT SLAB LOAD TOTALS

Slab Heat Pump CHW and HHW Annually

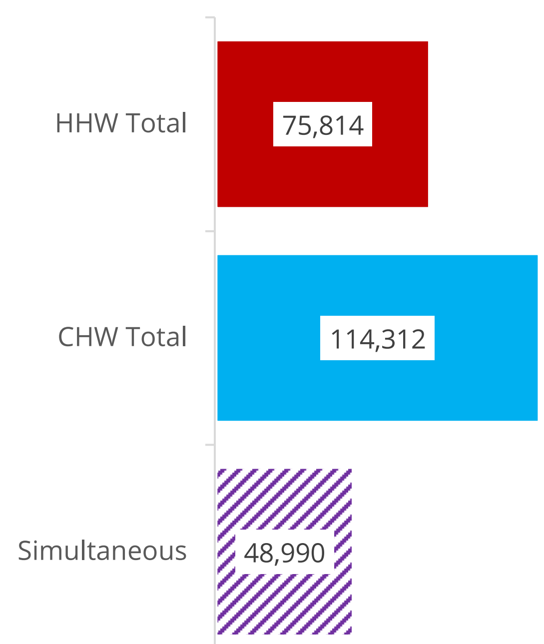
Monthly Ton-Hours



Annual Ton-Hours

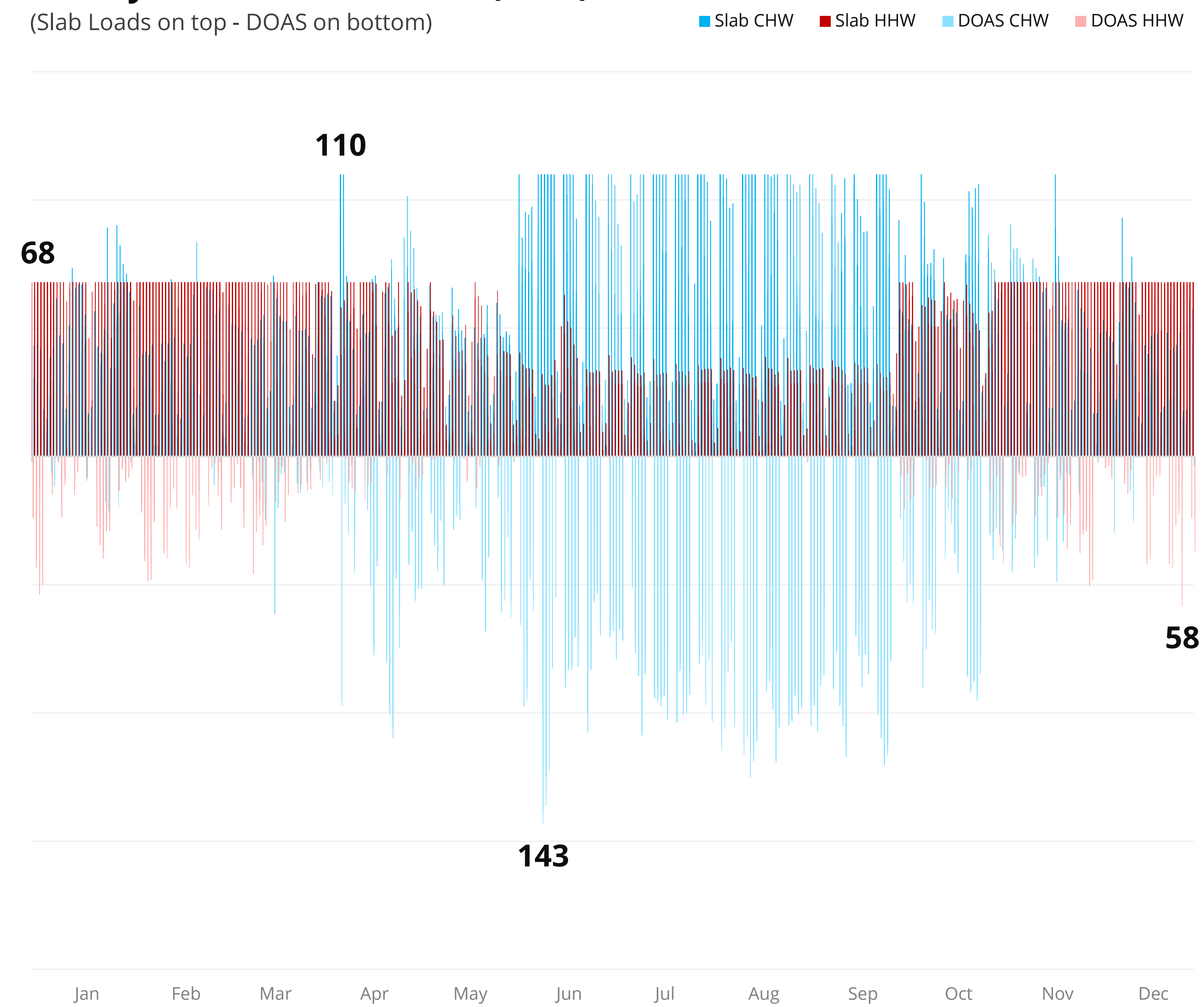


Annual Ton-Hours



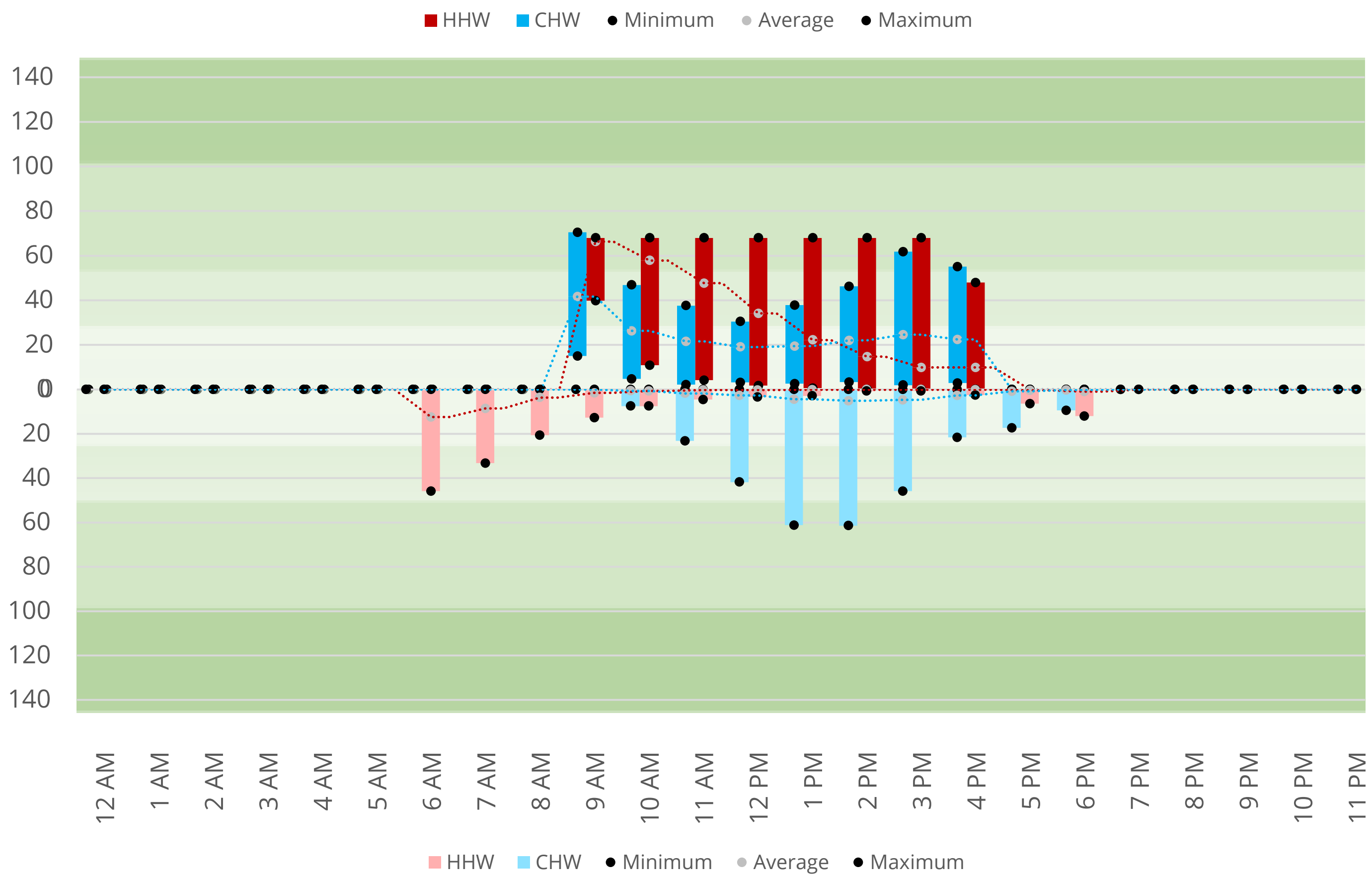
Hourly CHW & HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



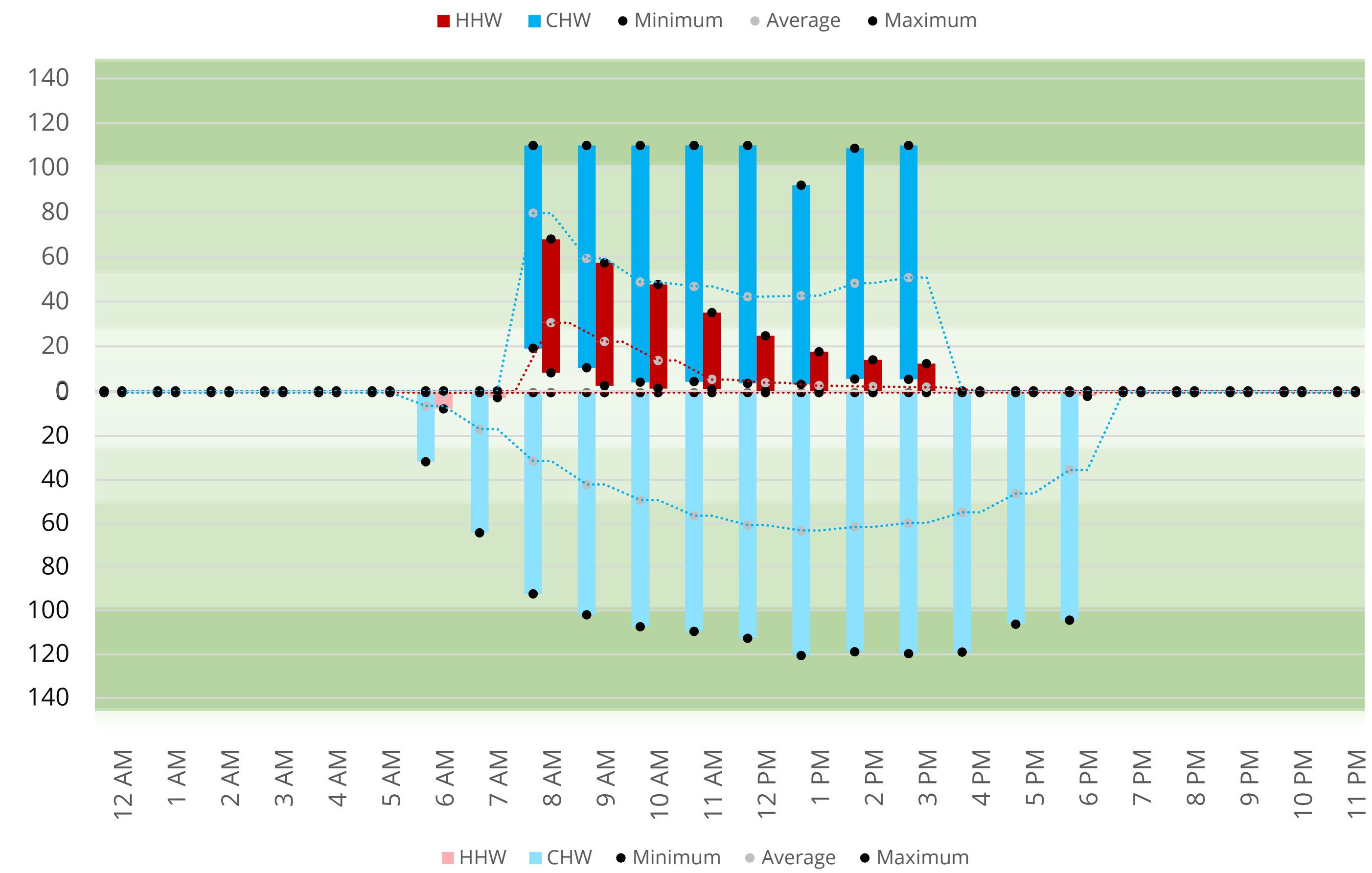
March CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



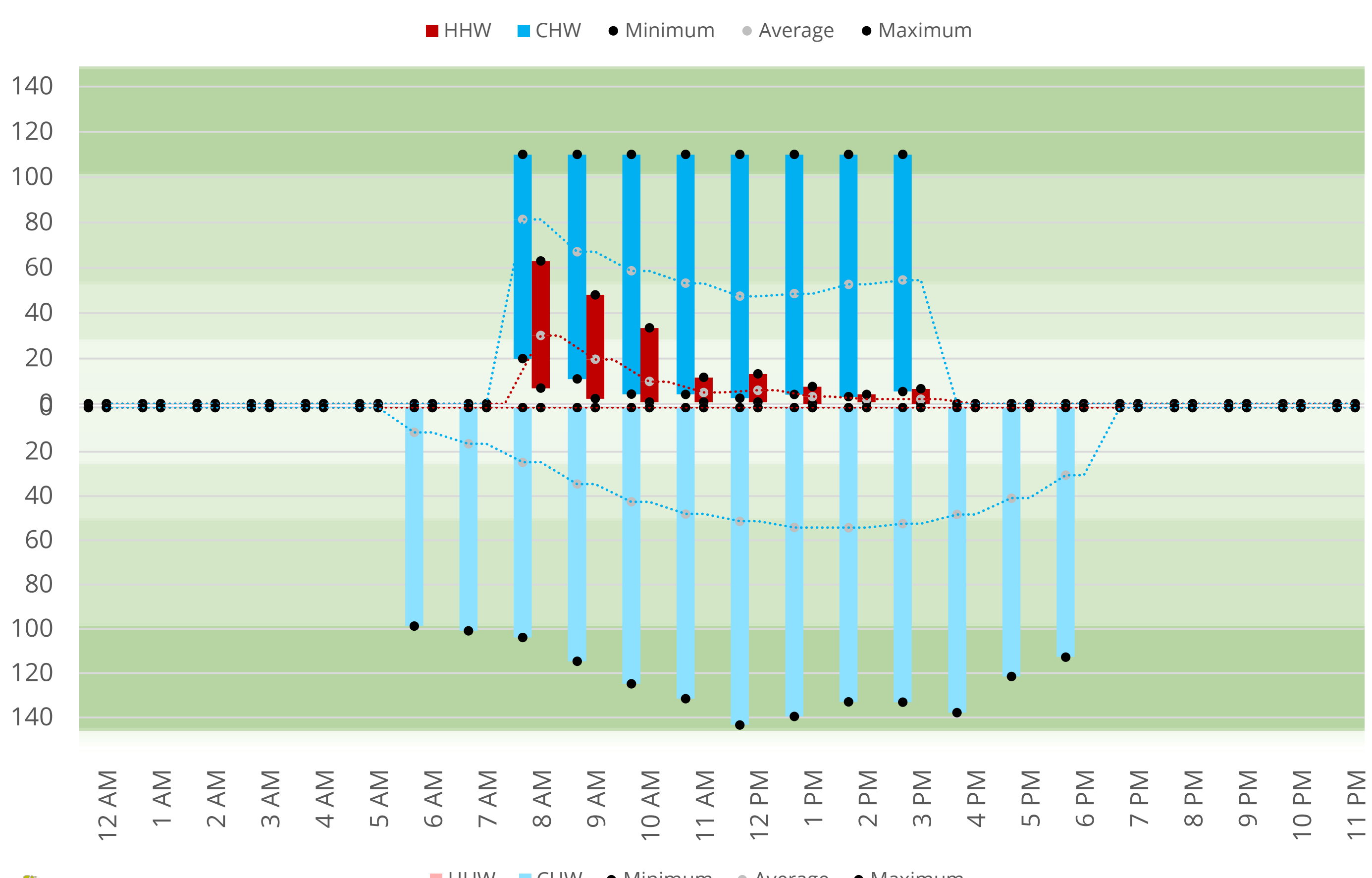
September CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



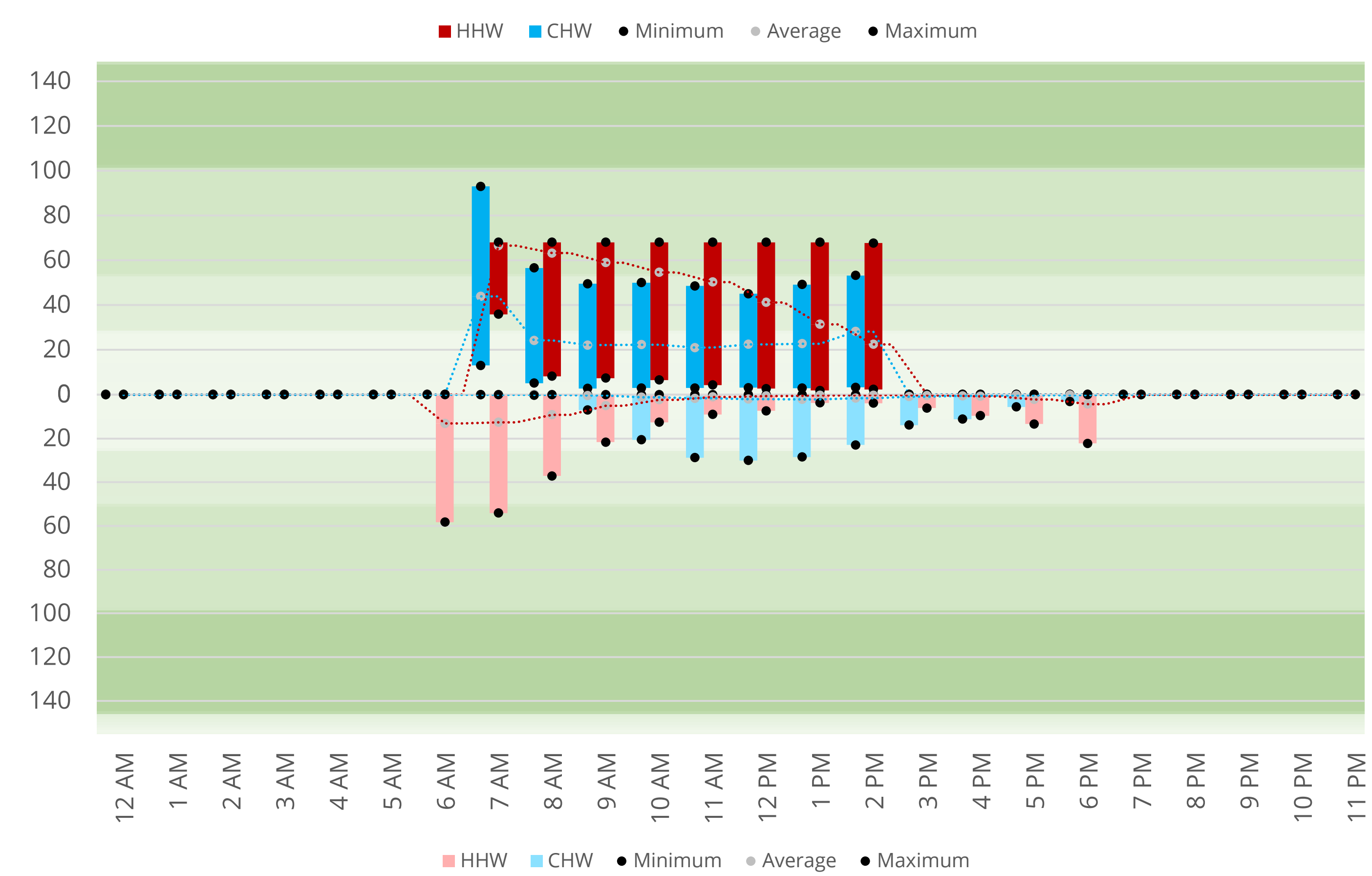
June CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



December CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



The Radiant Building System Also Works in More Extreme Climates

Cold Climates: In climates with below 15F winter conditions, The Radiant Building System includes additional Electric Boilers sized for peak heating load and run when it's below the air-source heat pumps' operational limit. Electric boilers are cold climate's default all-electric building hydronic system unless WSHPs are an option.

The Slab Heat Pump size would remain intentionally as much as possible unchanged through envelope improvements, such as increasing to 4" wall insulation, triple pane windows, and improved air tightness. The Electric Boilers for the Slab system are sized equal to the small Slab Heat Pump, and will be viewed as small for the location.

The DOAS Heat Pump heating capacity required would increase, but be kept relatively low for the climate because of the air-to-air heat recovery. The Electric Boilers for the DOAS system would be sized equal to the small DOAS Heat Pump's heating capacity, and again be viewed as small for its location.

The balance of load met by electric boilers vs. heat pumps will vary, but in most cold climates the ASHP would still do the vast majority of annual heating load, and all the savings that come from higher efficiency ASHPs at 85°F HHWS and "free" heat recovery from perimeter heating while simultaneously cooling interior spaces would be amplified. *We hope to quantify detailed results for the Radiant Building System in Cold Climates in a future study.*

Hot Humid Climates: The Radiant Building System is designed to work just as well and in the same manner in hot humid climates. The Slab Heat Pump size will remain intentionally unchanged through envelope improvements.

The Slab Heat Pump is already sized for a 97°F dry bulb day, so envelope changes if any, would center around mitigating humidity infiltration. The space cooling carbon emission savings opportunity with 65°F CHWS is extraordinary given the higher frequency of cooling in humid climates compared to the California Bay Area.

The DOAS Heat Pump size will increase substantially depending on the peak humidity condition, but be relatively very small compared to an all-air system AHU, and the kit of parts, configuration, and controls all remain the same. The DOAS in the Radiant Building System controls the supply air dew point to a maximum of 60°F to balance humidity people produce. It will just work harder and more often to accomplish that in a hot humid climate than in the California Bay Area. The amount of moisture people emit doesn't change, so the only change in space humidity comes from any additional infiltration relative to the Bay Area. Envelope Improvements would be done to intentionally minimize this. Condensation is not a concern as it would take sustained hours of over 70°F dew point air inside the building (that's 76°F dry bulb at 81% RH), which would never happen in any building without massive system wide failures that equal liabilities for any building system.

There are countless examples of successful radiant slab cooled buildings in tropical climates around the world (including Suvarnabhumi International Airport in Bangkok, Thailand). The key is understanding the air system need not remove more moisture on account of the radiant system. In fact, with the prevalence of ceiling fans through the Radiant Building System, improved comfort could be achieved by dehumidifying a little less and moving a little more air over the body, much like a gentle breeze outside (which feels miserable when 55°F but wonderful when 75°F). Ceiling Fans really shine in humid environments and is a huge positive differentiator for the Radiant Building System over other humid climate mechanical systems. *We hope to quantify detailed results for the Radiant Building System in Hot Humid Climates in a future study*.

Extreme Hot and Dry Climates: The Radiant Building System operates no differently in extreme hot and dry climates.

The Slab Heat Pump size would be kept intentionally unchanged through envelope improvements, such as additional sun shading to eliminate the additional solar gain in such locations. Conduction is not nearly as large of a factor as solar heat gain, and one radiant systems, by the nature of their heat transfer, are very well able to handle.

The DOAS Heat Pump will increase in size, but the air-to-air heat recovery will help lessen the additional burden substantially (80°F building exhaust can meaningfully pre-cool 105°F+ air), and the DOAS Heat Pump will be viewed as very small for its location.

The opportunities from large day night temperature swings and the hotter air temp's amplifying the 65°F CHWS electricity savings is right in the Radiant Building System's wheelhouse and could have enormous carbon saving improvements over climates like the bay area. The hotter the climate the larger the carbon savings with the Radiant Building System over Business as Usual. With the planet getting hotter, this is truly significant. We hope to quantify detailed results for the Radiant Building System in Extreme Hot and Dry Climates in a future study.

6 Final Thoughts

This is real. This is exciting. The authors of this study would love to talk to you.

Climate change makes so much of the Clark Pacific Scenario's Building System matter. Hot places are only getting hotter, and for longer. Electrical grids are only going to be more desirous of load shifting, and the carbon emission impact for not being able to is only going to get worse. We need to start thinking of our buildings as infrastructure, and build a future where buildings can help, meaningfully help, the electrical grid by working together.

Lastly, thank you for reading.

7 Acknowledgments

Integral Group would like to thank all the team members, spanning organizations and continents, whose dedication, passion, and expertise made The Radiant Whole Life Carbon Study possible.

Clark Pacific: First, for funding the Study and allowing Integral Group the opportunity to research, canonize, and fundamentally advance what radiant slabs can offer the world. Second, for the years of collaborative partnership driving ambitious and important ideas of mechanical, structural, and architectural integration into reality. And lastly, for providing the opportunity to work with Jon Mohle, whose tireless support and rare mix of pragmatism and creativity is simultaneously refreshing and a genuine pleasure.

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INTEGRAL

8 Appendix

The Radiant Whole Life Carbon Study aimed to be exhaustive in documentation and clarity to best support dissemination and discussion. The following pages are intended to provide as much detailed explanation and justification as possible for everything presented in the report.

SUMMARY TABLE H
Whole Life Total by **Stage Module**

Stage Module	Carbon Savings	Baseline Scenario (Steel + VRF)	Clark Pacific (Precast + Radiant)	Savings vs. Baseline (Whole Life Carbon)
A1 - A4	29.8%	7,125,141 kgCO2e 319.6 kgCO2e/m2	5,001,676 kgCO2e 224.3 kgCO2e/m2	2,123,465 kgCO2e 95.2 kgCO2e/m2
B1	87.8%	3,153,298 kgCO2e 141.4 kgCO2e/m2	383,357 kgCO2e 17.2 kgCO2e/m2	2,769,941 kgCO2e 124.2 kgCO2e/m2
B3 - B4	74.3%	1,410,841 kgCO2e 63.3 kgCO2e/m2	362,222 kgCO2e 16.2 kgCO2e/m2	1,048,619 kgCO2e 47.0 kgCO2e/m2
B6	29.8%	11,813,207 kgCO2e 529.8 kgCO2e/m2	8,287,102 kgCO2e 371.7 kgCO2e/m2	3,526,105 kgCO2e 158.1 kgCO2e/m2
C1	46.0%	102,723 kgCO2e 4.6 kgCO2e/m2	55,482 kgCO2e 2.5 kgCO2e/m2	47,241 kgCO2e 2.1 kgCO2e/m2
C2 - C4	-6.9%	31,665 kgCO2e 1.4 kgCO2e/m2	33,848 kgCO2e 1.5 kgCO2e/m2	-2,183 kgCO2e -0.1 kgCO2e/m2
Scenario Total	40.2%	23,636,874 kgCO2e 1,060.1 kgCO2e/m2	14,123,687 kgCO2e 633.4 kgCO2e/m2	9,513,187 kgCO2e 426.7 kgCO2e/m2

SUMMARY TABLE A
Emission Rates (kgCO2e/kg)

	A1 - A3 ($kgCO_2e/kg$)	A4 ($kgCO_2e/kg$)	B1 ($kgCO_2e/kg$)	B3 ($kgCO_2e/kg$)	B4 ($kgCO_2e/kg$)	C1 ($kgCO_2e/kg$)	C2 ($kgCO_2e/kg$)	C3 - C4 ($kgCO_2e/kg$)	SOURCE TYPE	NOTES
STRUCTURAL										
Concrete										
Precast										
Mix A (Floor planks) - Precast	0.1131	0.0064	-	-	-	0.0011	0.0013	-	ZGF Concrete LCA Tool	Summary: 7000 PSI 70% Slag. A1-A3 calculated from exact mix ingredients. Precast transportation rate from Athena specific to mix density
Mix B (Hollow Core) - Precast	0.2066	0.0064	-	-	-	0.0021	0.0013	-	ZGF Concrete LCA Tool	Summary: 4000 PSI 0% Slag. A1-A3 calculated from exact mix ingredients. Precast transportation rate from Athena specific to mix density
Mix C (Exterior beams) - Precast	0.1195	0.0064	-	-	-	0.0012	0.0013	-	ZGF Concrete LCA Tool	Summary: 8000 PSI 60% Slag. A1-A3 calculated from exact mix ingredients. Precast transportation rate from Athena specific to mix density
Mix D (Int. beam, wall, column) - Precast	0.1029	0.0064	-	-	-	0.0010	0.0013	-	ZGF Concrete LCA Tool	Summary: 9000 PSI 70% Slag. A1-A3 calculated from exact mix ingredients. Precast transportation rate from Athena specific to mix density
Cast in Place										
Mix E (Top. Slab Normal Wgt.) - Clark Bldg.	0.1370	0.0096	-	-	-	0.0014	0.0013	-	EPD	4000 PSI (California Bay Area Average). Transportation rate from Athena specific to mix density
Mix G (Top. Slab Light Wgt.) - Steel Bldg.	0.4026	0.0096	-	-	-	0.0040	0.0013	-	Quartz Common Products Database	3000-4000 PSI (California Bay Area Average, Ready Mixed Light Weight Concrete). Transportation rate from Athena specific to mix density
Mix E (Slab on Grade) - Clark Bldg.	0.1370	0.0096	-	-	-	0.0014	0.0013	-	EPD	4000 PSI (California Bay Area Average). Transportation rate from Athena specific to mix density
Mix E (Slab on Grade) - Steel Bldg.	0.1370	0.0096	-	-	-	0.0014	0.0013	-	EPD	Same concrete mix as Clark Slab on Grade. Transportation rate from Athena specific to mix density
Mix F (Foundation) - Clark Bldg.	0.1654	0.0096	-	-	-	0.0017	0.0013	-	EPD	5000 PSI (California Bay Area Average). Transportation rate from Athena specific to mix density
Mix F (Foundation) - Steel Bldg.	0.1654	0.0096	-	-	-	0.0017	0.0013	-	EPD	Same concrete mix as Clark Foundation. Transportation rate from Athena specific to mix density
Steel										
Structural Frame										
Steel Beams (I-Section)	1.4991	0.1620	-	-	-	0.0150	0.0013	-	EPD	EPD Chosen for industry average for North America Grade 50 Steel. Transportation from Athena
Steel Beams (Wide Flange)	1.4991	0.1620	-	-	-	0.0150	0.0013	-	EPD	EPD Chosen for industry average for North America Grade 50 Steel. Transportation from Athena
Steel Columns (I-Section)	1.4991	0.1620	-	-	-	0.0150	0.0013	-	EPD	EPD Chosen for industry average for North America Grade 50 Steel. Transportation from Athena
Steel Columns (Wide Flange)	1.4991	0.1620	-	-	-	0.0150	0.0013	-	EPD	EPD Chosen for industry average for North America Grade 50 Steel. Transportation from Athena
Steel Braces (Wide Flange)	0.8598	0.1620	-	-	-	0.0086	0.0013	-	EPD	EPD Chosen for industry average for North America Grade 36 Steel. Transportation from Athena
Concrete Reinforcement										
Rebar	0.5291	0.2060	-	-	-	0.0053	0.0013	-	OneClick Databse	97% Recycled Content (typical). Transportation rate from Athena
Rebar - Precast	0.5291	0.1373	-	-	-	0.0053	0.0013	-	OneClick Databse	97% Recycled Content (typical). Precast transportation rate from Athena
Mesh	0.5820	0.2060	-	-	-	0.0058	0.0013	-	Quartz Common Products Database	To be conservative (since Mesh only in Baseline), using 10% over rebar, as it's the low end of possibility. Transportation from Athena
Strand - Precast	1.4991	0.1373	-	-	-	0.0150	0.0013	-	Quartz Common Products Database	To be conservative (since Strand only in Clark), using Grade 50, as it's the high end of possiblity. Precast transportation rate from Athena
Floor and Misc. Steel										
Steel Deck	2.0675	0.1165	-	-	-	0.0207	0.0013	-	EPD	EPD for 20 Gauge Thickness (0.889mm). Transportation from Athena
Misc. Metals & Edge of Slab	0.8598	0.2435	-	-	-	0.0086	0.0013	-	EPD	Plate Steel Grade 36. EPD Chosen for indsutry average for North America Grade 46 Steel. Transportation from Athena
Misc. Metals & Edge of Slab - Precast	0.8598	0.1623	-	-	-	0.0086	0.0013	-	EPD	Plate, Steel Grade 36. EPD Chosen for indsutry average for North America Grade 46 Steel. Precast Transportation from Athena
ENVELOPE										
Vertical Enclosure										
Infinite Façade	0.7524		-	-	-	0.0075	0.0013	-	Infinite Facade LCA Report	Config. 2" HFO, 55% glazing. Report only provides kgCO2e A to D stage sum. To be conservative, value used for A1-A4 and C stage added.
Curtain Wall	1.9824	0.0201	-	-	-	0.0198	0.0013	-	Average of EPD and Other Database	Average of aluminum curtain wall EPD's for 3 major manufacturers (Kawneer, EFCO, YKK). EPDs don't include insulation.
Curtain Wall Insulation (mineral wool - 2")	0.6688	0.0000	-	-	-	0.0067	0.0013	-	EPD	2" mineral wool rigid board insulation. EPD used directly to determine impact per SF per 2-inch thickness
Exterior Sunshades (aluminum)	7.0200	0.1102	-	-	-	0.0702	0.0013	-	EPD	EPD Kawneer Versoleil SunShades (Extruded Aluminum Anodized Finish). Transportation Rate from Athena.
Roof										
Roof Insulation (mineral wool - 4")	0.6696	0.0002	-	-	-	0.0067	0.0013	-	EPD	4" mineral wool rigid board insulation. EPD used directly to determine impact per SF per 4-inch thickness
Roof Deck (DensDeck)	0.3367	0.0005	-	-	0.3801	0.0034	0.0013	-	EPD	Typical 1/2" DensDeck Roof Board
MECHANICAL										
Pipes & Ducts										
Copper pipe	2.4450	0.0510	-	-	-	0.0250	0.0013	0.0026	Average of EPD and Other Database	Average of Quartz and IBU EPDs
Steel pipe	3.9500	0.0397	-	-	-	0.0399	0.0013	0.0044	Average of EPD and Other Database	Risers and Central Plant piping. Average of INIES, EPiC, and Okobaudat
PEX pipe (embedded)	0.6077	0.0509	-	-	-	0.0066	0.0002	0.0015	Average of EPD and Other Database	Nominal 1/2" PEXa embedded in precast floor planks for radiant system. Average of Quartz and OCL default.
PEX pipe (exposed)	0.6077	0.0509	-	-	-	0.0066	0.0002	0.0015	Average of EPD and Other Database	Horizontal PEX PEX Mechanical Distribution in lieu of Copper Pipe. Average of Quartz and OCL default
Pipe Insulation	2.2229	0.0045	-	-	-	0.0223	0.0000	0.0021	Average of EPD and Other Database	Mineral Wool. Average of UL Environment EPDs and Quartz. C2 value is 0.000002 kgCO2e/kg. It displays as 0.0000 to 4 decimal places.
Pipe Supports	2.7000	0.0510	-	-	-	0.0275	0.0013	0.0026	Quartz Common Products Database	Metal Hangers + Unistrut
Ductwork	4.2033	0.0453	-	-	4.2957	0.0425	0.0013	0.0033	Average of EPD and Other Database	Steel Sheetmetal. Average of INIES, Okobaudat, and Norge EPD
Duct Insulation	1.2809	0.0026	-	-	1.2992	0.0128	0.0016	0.0013	Average of EPD and Other Database	Glass wool. Average of US Manufacturer EPDs, INIES, and Italian manufacturer EPD
Duct Supports	2.7000	0.0510	-	-	2.7824	0.0275	0.0013	0.0026	Quartz Common Products Database	Metal Hangers + Unistrut
Equipment										
VRF Outdoor Condenser Units	17.1075		-	1.8008	36.3580	0.1711	0.9004	-	CIBSE TM65	CIBSE TM65 calcs based on manufacturer data for 100 kW size VRF Outdoor Condensing Units. Data includes A4, but value not broken out.
ASHP-1 (2 pipes - Reversible)	9.2851		-	0.9494	19.6400	0.0929	0.4421	-	CIBSE TM65	CIBSE TM65 calc uses 500kW & 100kW manufacturer data scaled to 422 kW NRP1800 size. Data includes A4, but value not broken out.
ASHP-2 (4 pipes - Heating & Cooling)	6.9609		-	0.7117	14.7238	0.0696	0.3314	-	CIBSE TM65	CIBSE TM65 calc uses 500kW & 100kW manufacturer data scaled to 290 kW NRP1250 size. Data includes A4, but value not broken out.
Air Handling Units	3.8986	0.0522	-	0.3995	7.9907	0.0395	0.0013	0.0038	Okobaudat	Based on type's largest available: ventilation centralized with heat recovery, 35,000 m3/h (20,600 cfm). Actual (1) 42,000 cfm calc.'d as (2) 20,600 cfm
VRF Fan Coils	12.0224		-	0.8426	24.8356	0.1202	0.2752	-	CIBSE TM65	CIBSE TM65 calc uses 8kW VRF Fan Coil Units. Data includes A4 (value not broken out). B4 uses 5kW (in lieu of 8kW) to conservatively favor baseline
VAV box (w/o coil)	4.8880	0.0509	-	-	9.9866	0.0494	0.0013	0.0037	EPD	EPD Wildeboer Bauteile VKE Electronic Volume Flow Controller, Rectangular Galvanized Steel, 34-5430 m3/h. Transportation from OneClick.
Ceiling Fans	13.6574		-	-	-	1.0412	0.7188	-	CIBSE TM65	CIBSE TM65 calc based on Aeratron FR 50". Data includes A4, but value not broken out
REFRIGERANT LEAKAGE										
Refrigerant Leakage VRF System	-	-	2,088	-	-	2,088	-	-	Manufacturer Data	R410a. See Mechanical Table for more information on Leakage Rates and EOL Recovery Rates
Refrigerant Leakage ASHPs	-	-	2,088	-	-	2,088	-	-	Manufacturer Data	R410a. See Mechanical Table for more information on Leakage Rates and EOL Recovery Rates

SUMMARY TABLE B
Product Quantities (kg)

	Different Takeoff Units		Same Units (kg)	
	Base Scenario	Clark Pacific	Base Scenario	Clark Pacific
STRUCTURAL SUBTOTAL			**10,182,805 kg**	**21,161,878 kg**
Concrete			**8,583,773 kg**	**19,942,922 kg**
Precast			-	12,674,732 kg
Mix A (Floor planks) - Precast	-	4,042 yd3	-	6,682,654 kg
Mix B (Hollow Core) - Precast	-	306 yd3	-	543,889 kg
Mix C (Exterior beams) - Precast	-	813 yd3	-	1,473,415 kg
Mix D (Int. beam, wall, column) - Precast	-	2,193 yd3	-	3,974,773 kg
Cast in Place			8,583,773 kg	7,268,190 kg
Mix E (Top. Slab Normal Wgt.) - Clark Bldg.	-	747 yd3	-	1,327,320 kg
Mix G (Top. Slab Light Wgt.) - Steel Bldg.	3,406 yd3		4,588,506 kg	
Mix E (Slab on Grade) - Clark Bldg.	-	463 yd3	-	822,210 kg
Mix E (Slab on Grade) - Steel Bldg.	463 yd3	-	822,210 kg	
Mix F (Foundation) - Clark Bldg.	-	2,882 yd3	-	5,118,659 kg
Mix F (Foundation) - Steel Bldg.	1,787 yd3	-	3,173,057 kg	
Steel			**1,599,032 kg**	**1,218,957 kg**
Structural Frame			1,130,345 kg	-
Steel Beams (I-Section)	1,707,279 lbs	-	774,417 kg	-
Steel Beams (Wide Flange)	127,468 lbs	-	57,819 kg	-
Steel Columns (I-Section)	259,821 lbs	-	117,854 kg	-
Steel Columns (Wide Flange)	315,154 lbs	-	142,953 kg	-
Steel Braces (Wide Flange)	82,237 lbs	-	37,302 kg	-
Concrete Reinforcement			179,677 kg	1,143,660 kg
Rebar	256,734 lbs	419,480 lbs	116,454 kg	190,275 kg
Rebar - Precast	-	1,898,254 lbs	-	861,043 kg
Mesh	139,383 lbs	-	63,224 kg	-
Strand - Precast	-	203,579 lbs	-	92,343 kg
Floor and Misc. Steel			289,009 kg	75,297 kg
Steel Deck	232,304 ft2	-	220,229 kg	-
Misc. Metals & Edge of Slab	151,634 lbs	-	68,781 kg	-
Misc. Metals & Edge of Slab - Precast	-	165,999 lbs	-	75,297 kg
ENVELOPE SUBTOTAL			**663,842 kg**	**729,924 kg**
Vertical Enclosure			**599,973 kg**	**666,055 kg**
Infinite Façade	-	36,550 ft2	-	375,003 kg
Curtain Wall	89,685 ft2	41,833 ft2	573,985 kg	267,734 kg
Curtain Wall Insulation (mineral wool - 2")	43,020 ft2	16,928 ft2	25,988 kg	10,226 kg
Exterior Sunshades (aluminum)	-	28,863 lbs	-	13,092 kg
Roof			**63,869 kg**	**63,869 kg**
Roof Insulation (mineral wool - 4")	30,000 ft2	30,000 ft2	36,245 kg	36,245 kg
Roof Deck (DensDeck)	30,000 ft2	30,000 ft2	27,624 kg	27,624 kg
MECHANICAL SUBTOTAL			**121,148 kg**	**97,183 kg**
Pipes & Ducts			**71,797 kg**	**79,203 kg**
Copper pipe	17,521 kg	972 kg	17,521 kg	972 kg
Steel pipe	-	8,774 kg	-	8,774 kg
PEX pipe (embedded)	-	10,481 kg	-	10,481 kg
PEX pipe (exposed)	-	5,814 kg	-	5,814 kg
Pipe Insulation	31.80 m3	34.10 m3	2,035 kg	2,182 kg
Pipe Supports	2.13 m3	1.97 m3	16,749 kg	15,488 kg
Ductwork	27,237 kg	27,237 kg	27,237 kg	27,237 kg
Duct Insulation	97.00 m3	97.00 m3	6,208 kg	6,208 kg
Duct Supports	0.26 m3	0.26 m3	2,047 kg	2,047 kg
Equipment			**49,351 kg**	**17,980 kg**
VRF Outdoor Condenser Units	15 ea	-	9,270 kg	-
ASHP-1 (4 pipes - Heating & Cooling)	-	1 ea	-	4,922 kg
ASHP-2 (2 pipes - Reversible)	-	1 ea	-	4,511 kg
Air Handling Units	2 ea	2 ea	5,024 kg	5,024 kg
VRF Fan Coils	344 ea	-	33,368 kg	-
VAV box (w/o coil)	344 ea	160 ea	1,689 kg	786 kg
Ceiling Fans	-	464 ea	-	2,738 kg
REFRIGERANT LEAKAGE SUBTOTAL			**1,527 kg**	**187 kg**
Refrigerant Leakage VRF System	1,527 kg	-	1,527 kg	-
Refrigerant Leakage ASHPs	-	187 kg	-	187 kg

SUMMARY TABLE C
Stage Subtotals (kgCO2e)

	Baseline Scenario: Steel + VRF					Clark Pacific: Precast + Radiant				
	A1 - A4	B1	B3 - B4	C1	C2 - C4	A1 - A4	B1	B3 - B4	C1	C2 - C4
GRAND TOTAL	**7,125,141**	**3,153,298**	**1,410,841**	**102,723**	**31,665**	**5,001,676**	**383,357**	**362,222**	**55,482**	**33,848**
STRUCTURAL SUBTOTAL	**5,113,152**	**-**	**-**	**47,682**	**12,971**	**3,686,424**	**-**	**-**	**33,532**	**26,956**
Concrete	**2,567,067**	**-**	**-**	**24,847**	**10,934**	**2,744,644**	**-**	**-**	**25,938**	**25,403**
Precast	-	-	-	-	-	1,533,958	-	-	14,528	16,145
Mix A (Floor planks) - Precast	-	-	-	-	-	798,317	-	-	7,555	8,512
Mix B (Hollow Core) - Precast	-	-	-	-	-	115,834	-	-	1,124	693
Mix C (Exterior beams) - Precast	-	-	-	-	-	185,452	-	-	1,760	1,877
Mix D (Int. beam, wall, column) - Precast	-	-	-	-	-	434,355	-	-	4,089	5,063
Cast in Place	2,567,067	-	-	24,847	10,934	1,210,686	-	-	11,409	9,258
Mix E (Top. Slab Normal Wgt.) - Clark Bldg.	-	-	-	-	-	194,569	-	-	1,818	1,691
Mix G (Top. Slab Light Wgt.) - Steel Bldg.	1,891,362	-	-	18,473	5,845	-	-	-	-	-
Mix E (Slab on Grade) - Clark Bldg.	-	-	-	-	-	120,532	-	-	1,126	1,047
Mix E (Slab on Grade) - Steel Bldg.	120,532	-	-	1,126	1,047	-	-	-	-	-
Mix F (Foundation) - Clark Bldg.	-	-	-	-	-	895,585	-	-	8,464	6,520
Mix F (Foundation) - Steel Bldg.	555,173	-	-	5,247	4,042	-	-	-	-	-
Steel	**2,546,085**	**-**	**-**	**22,835**	**2,037**	**941,781**	**-**	**-**	**7,594**	**1,553**
Structural Frame	1,853,799	-	-	16,707	1,440	-	-	-	-	-
Steel Beams (I-Section)	1,286,405	-	-	11,609	986	-	-	-	-	-
Steel Beams (Wide Flange)	96,045	-	-	867	74	-	-	-	-	-
Steel Columns (I-Section)	195,771	-	-	1,767	150	-	-	-	-	-
Steel Columns (Wide Flange)	237,463	-	-	2,143	182	-	-	-	-	-
Steel Braces (Wide Flange)	38,115	-	-	321	48	-	-	-	-	-
Concrete Reinforcement	135,427	-	-	984	229	864,818	-	-	6,947	1,457
Rebar	85,606	-	-	616	148	139,872	-	-	1,007	242
Rebar - Precast	-	-	-	-	-	573,831	-	-	4,556	1,097
Mesh	49,821	-	-	368	81	-	-	-	-	-
Strand - Precast	-	-	-	-	-	151,115	-	-	1,384	118
Floor and Misc. Steel	556,859	-	-	5,145	368	76,963	-	-	647	96
Steel Deck	480,974	-	-	4,553	281	-	-	-	-	-
Misc. Metals & Edge of Slab	75,885	-	-	591	88	-	-	-	-	-
Misc. Metals & Edge of Slab - Precast	-	-	-	-	-	76,963	-	-	647	96
ENVELOPE SUBTOTAL	**1,200,386**	**-**	**10,500**	**11,888**	**846**	**952,086**	**-**	**10,500**	**9,452**	**930**
Vertical Enclosure	**1,166,796**	**-**	**-**	**11,553**	**764**	**918,496**	**-**	**-**	**9,117**	**848**
Infinite Façade	-	-	-	-	-	282,166	-	-	2,822	478
Curtain Wall	1,149,416	-	-	11,379	731	536,142	-	-	5,308	341
Curtain Wall Insulation (mineral wool - 2")	17,380	-	-	174	33	6,839	-	-	68	13
Exterior Sunshades (aluminum)	-	-	-	-	-	93,349	-	-	919	17
Roof	**33,590**	**-**	**10,500**	**336**	**81**	**33,590**	**-**	**10,500**	**336**	**81**
Roof Insulation (mineral wool - 4")	24,276	-	-	243	46	24,276	-	-	243	46
Roof Deck (DensDeck)	9,314	-	10,500	93	35	9,314	-	10,500	93	35
MECHANICAL SUBTOTAL	**811,603**	**-**	**1,400,341**	**8,116**	**17,849**	**363,166**	**-**	**351,722**	**6,108**	**5,963**
Pipes & Ducts	**223,663**	**-**	**130,762**	**2,237**	**287**	**224,951**	**-**	**130,762**	**2,250**	**295**
Copper pipe	43,733	-	-	437	68	2,426	-	-	24	4
Steel pipe	-	-	-	-	-	35,005	-	-	350	50
PEX pipe (embedded)	-	-	-	-	-	6,902	-	-	69	17
PEX pipe (exposed)	-	-	-	-	-	3,829	-	-	38	10
Pipe Insulation	4,533	-	-	45	4	4,861	-	-	49	5
Pipe Supports	46,078	-	-	461	65	42,609	-	-	426	60
Ductwork	115,721	-	117,002	1,157	123	115,721	-	117,002	1,157	123
Duct Insulation	7,968	-	8,066	80	18	7,968	-	8,066	80	18
Duct Supports	5,630	-	5,694	56	8	5,630	-	5,694	56	8
Equipment	**587,940**	**-**	**1,269,579**	**5,879**	**17,562**	**138,215**	**-**	**220,960**	**3,859**	**5,668**
VRF Outdoor Condenser Units	158,587	-	353,732	1,586	8,347	-	-	-	-	-
ASHP-1 (4 pipes - Heating & Cooling)	-	-	-	-	-	45,697	-	101,331	457	2,176
ASHP-2 (2 pipes - Reversible)	-	-	-	-	-	31,403	-	69,635	314	1,495
Air Handling Units	19,847	-	42,149	198	25	19,847	-	42,149	198	25
VRF Fan Coils	401,165	-	856,830	4,012	9,181	-	-	-	-	-
VAV box (w/o coil)	8,342	-	16,868	83	8	3,880	-	7,845	39	4
Ceiling Fans	-	-	-	-	-	37,388	-	-	2,850	1,968
REFRIGERANT LEAKAGE SUBTOTAL	**-**	**3,153,298**	**-**	**35,037**	**-**	**-**	**383,357**	**-**	**6,389**	**-**
Refrigerant Leakage	-	3,153,298	-	35,037	-	-	383,357	-	6,389	-

SUMMARY TABLE D

Scenario Totals

	Baseline Scenario: Steel + VRF					Clark Pacific: Precast + Radiant				
	Carbon	Per Area	Per Mass	Quantity	GWP	Carbon	Per Area	Per Mass	Quantity	GWP
	$kgCO_2e$	$kgCO_2/m^2$	$kgCO_2/kg$	kg	%	$kgCO_2e$	$kgCO_2/m^2$	$kgCO_2/kg$	kg	%
GRAND TOTAL	**23,636,874**	**1,060.1**	**2.15**	**10,969,323**	**100%**	**14,123,687**	**633.4**	**0.64**	**21,989,172**	**100%**
STRUCTURAL SUBTOTAL	**5,173,805**	**232.0**	**0.51**	**10,182,805**	**21.89%**	**3,746,912**	**168.0**	**0.18**	**21,161,878**	**26.53%**
Concrete	**2,602,847**	**116.7**	**0.30**	**8,583,773**	**11.01%**	**2,795,984**	**125.4**	**0.14**	**19,942,922**	**19.80%**
Precast	-	-	-	-	-	1,564,631	70.2	0.12	12,674,732	11.08%
Mix A (Floor planks) - Precast	-	-	-	-	-	814,385	36.5	0.12	6,682,654	5.77%
Mix B (Hollow Core) - Precast	-	-	-	-	-	117,650	5.3	0.22	543,889	0.83%
Mix C (Exterior beams) - Precast	-	-	-	-	-	189,089	8.5	0.13	1,473,415	1.34%
Mix D (Int. beam, wall, column) - Precast	-	-	-	-	-	443,507	19.9	0.11	3,974,773	3.14%
Cast in Place	2,602,847	116.7	0.30	8,583,773	11.01%	1,231,353	55.2	0.17	7,268,190	8.72%
Mix E (Top. Slab Normal Wgt.) - Clark Bldg.	-	-	-	-	-	198,078	8.9	0.15	1,327,320	1.40%
Mix G (Top. Slab Light Wgt.) - Steel Bldg.	1,915,680	85.9	0.42	4,588,506	8.10%	-	-	-	-	-
Mix E (Slab on Grade) - Clark Bldg.	-	-	-	-	-	122,706	5.5	0.15	822,210	0.87%
Mix E (Slab on Grade) - Steel Bldg.	122,706	5.5	0.15	822,210	0.52%	-	-	-	-	-
Mix F (Foundation) - Clark Bldg.	-	-	-	-	-	910,569	40.8	0.18	5,118,659	6.45%
Mix F (Foundation) - Steel Bldg.	564,462	25.3	0.18	3,173,057	2.39%	-	-	-	-	-
Steel	**2,570,958**	**115.3**	**1.61**	**1,599,032**	**10.88%**	**950,928**	**42.6**	**0.78**	**1,218,957**	**6.73%**
Structural Frame	1,871,946	84.0	1.66	1,130,345	7.92%	-	-	-	-	-
Steel Beams (I-Section)	1,299,001	58.3	1.68	774,417	5.50%	-	-	-	-	-
Steel Beams (Wide Flange)	96,985	4.3	1.68	57,819	0.41%	-	-	-	-	-
Steel Columns (I-Section)	197,688	8.9	1.68	117,854	0.84%	-	-	-	-	-
Steel Columns (Wide Flange)	239,788	10.8	1.68	142,953	1.01%	-	-	-	-	-
Steel Braces (Wide Flange)	38,484	1.7	1.03	37,302	0.16%	-	-	-	-	-
Concrete Reinforcement	136,640	6.1	0.76	179,677	0.58%	873,222	39.2	0.76	1,143,660	6.18%
Rebar	86,370	3.9	0.74	116,454	0.37%	141,121	6.3	0.74	190,275	1.00%
Rebar - Precast	-	-	-	-	-	579,484	26.0	0.67	861,043	4.10%
Mesh	50,270	2.3	0.80	63,224	0.21%	-	-	-	-	-
Strand - Precast	-	-	-	-	-	152,617	6.8	1.65	92,343	1.08%
Floor and Misc. Steel	562,372	25.2	1.95	289,009	2.38%	77,706	3.5	1.03	75,297	0.55%
Steel Deck	485,808	21.8	2.21	220,229	2.06%	-	-	-	-	-
Misc. Metals & Edge of Slab	76,564	3.4	1.11	68,781	0.32%	-	-	-	-	-
Misc. Metals & Edge of Slab - Precast	-	-	-	-	-	77,706	3.5	1.03	75,297	0.55%
ENVELOPE SUBTOTAL	**1,223,620**	**54.9**	**1.84**	**663,842**	**5.18%**	**972,968**	**43.6**	**1.33**	**729,924**	**6.89%**
Vertical Enclosure	**1,179,113**	**52.9**	**1.97**	**599,973**	**4.99%**	**928,461**	**41.6**	**1.39**	**666,055**	**6.57%**
Infinite Façade	-	-	-	-	-	285,465	12.8	0.76	375,003	2.02%
Curtain Wall	1,161,525	52.1	2.02	573,985	4.91%	541,790	24.3	2.02	267,734	3.84%
Curtain Wall Insulation (mineral wool - 2")	17,587	0.8	0.68	25,988	0.07%	6,920	0.3	0.68	10,226	0.05%
Exterior Sunshades (aluminum)	-	-	-	-	-	94,285	4.2	7.20	13,092	0.67%
Roof	**44,507**	**2.0**	**0.70**	**63,869**	**0.19%**	**44,507**	**2.0**	**0.70**	**63,869**	**0.32%**
Roof Insulation (mineral wool - 4")	24,565	1.1	0.68	36,245	0.10%	24,565	1.1	0.68	36,245	0.17%
Roof Deck (DensDeck)	19,942	0.9	0.72	27,624	0.08%	19,942	0.9	0.72	27,624	0.14%
MECHANICAL SUBTOTAL	**2,237,908**	**100.4**	**18.47**	**121,148**	**9.47%**	**726,959**	**32.6**	**7.48**	**97,183**	**5.15%**
Pipes & Ducts	**356,947**	**16.0**	**4.97**	**71,797**	**1.51%**	**358,257**	**16.1**	**4.52**	**79,203**	**2.54%**
Copper pipe	44,238	2.0	2.52	17,521	0.19%	2,454	0.1	2.52	972	0.02%
Steel pipe	-	-	-	-	-	35,406	1.6	4.04	8,774	0.25%
PEX pipe (embedded)	-	-	-	-	-	6,988	0.3	0.67	10,481	0.05%
PEX pipe (exposed)	-	-	-	-	-	3,877	0.2	0.67	5,814	0.03%
Pipe Insulation	4,583	0.2	2.25	2,035	0.02%	4,914	0.2	2.25	2,182	0.03%
Pipe Supports	46,603	2.1	2.78	16,749	0.20%	43,095	1.9	2.78	15,488	0.31%
Ductwork	234,003	10.5	8.59	27,237	0.99%	234,003	10.5	8.59	27,237	1.66%
Duct Insulation	16,131	0.7	2.60	6,208	0.07%	16,131	0.7	2.60	6,208	0.11%
Duct Supports	11,389	0.5	5.56	2,047	0.05%	11,389	0.5	5.56	2,047	0.08%
Equipment	**1,880,961**	**84.4**	**38.11**	**49,351**	**7.96%**	**368,702**	**16.5**	**20.51**	**17,980**	**2.61%**
VRF Outdoor Condenser Units	522,251	23.4	56.34	9,270	2.21%	-	-	-	-	-
Hydronic Air-Source Heat Pumps	-	-	-	-	-	252,507	11.3	26.77	9,433	1.79%
Air Handling Units	62,220	2.8	12.39	5,024	0.26%	62,220	2.8	12.39	5,024	0.44%
VRF Fan Coils	1,271,188	57.0	38.10	33,368	5.38%	-	-	-	-	-
VAV box (w/o coil)	25,302	1.1	14.98	1,689	0.11%	11,768	0.5	14.98	786	0.08%
Ceiling Fans	-	-	-	-	-	42,207	1.9	15.42	2,738	0.30%
REFRIGERANT LEAKAGE SUBTOTAL	**3,188,334**	**143.0**	**2,088.00**	**1,527**	**13.49%**	**389,746**	**17.5**	**2,088.00**	**187**	**2.76%**
Refrigerant Leakage	3,188,334	143.0	2,088.00	1,527	13.49%	389,746	17.5	2,088.00	187	2.76%
ELECTRICITY USE SUBTOTAL	**11,813,207**	**529.8**	**-**	**-**	**49.98%**	**8,287,102**	**371.7**	**-**	**-**	**58.68%**

SUMMARY TABLE E

Whole LIfe Carbon Result Totals

	Baseline Scenario: Steel + VRF						Overall Totals					Clark Pacific: Precast + Radiant						Overall Totals				
	A1-A4	B1	B3-B4	B6	C1	C2-C4	Carbon	Per Area	Per Mass	Quantity	GWP	A1-A4	B1	B3-B4	B6	C1	C2-C4	Carbon	Per Area	Per Mass	Quantity	GWP
	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2/m^2$	$kgCO_2/kg$	kg	%	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2/m^2$	$kgCO_2/kg$	kg	%
GRAND TOTAL	**7,125,141**	**3,153,298**	**1,410,841**	**11,813,207**	**102,723**	**31,665**	**23,636,874**	**1,060.1**	**2.15**	**10,969,323**	**100.00%**	**5,001,676**	**383,357**	**362,222**	**8,287,102**	**55,482**	**33,848**	**14,123,687**	**633.4**	**0.64**	**21,989,172**	**100.00%**
STRUCTURAL SUBTOTAL	**5,113,152**	**-**	**-**	**-**	**47,682**	**12,971**	**5,173,805**	**232.0**	**0.51**	**10,182,805**	**21.89%**	**3,686,424**	**-**	**-**	**-**	**33,532**	**26,956**	**3,746,912**	**168.0**	**0.18**	**21,161,878**	**26.53%**
Concrete	**2,567,067**	**-**	**-**	**-**	**24,847**	**10,934**	**2,602,847**	**116.7**	**0.30**	**8,583,773**	**11.01%**	**2,744,644**	**-**	**-**	**-**	**25,938**	**25,403**	**2,795,984**	**125.4**	**0.14**	**19,942,922**	**19.80%**
Precast	-	-	-	-	-	-	-	-	-	-	-	1,533,958	-	-	-	14,528	16,145	1,564,631	70.2	0.12	12,674,732	11.08%
Mix A (Floor planks)	-	-	-	-	-	-	-	-	-	-	-	798,317	-	-	-	7,555	8,512	814,385	36.5	0.12	6,682,654	5.77%
Mix B (Hollow Core)	-	-	-	-	-	-	-	-	-	-	-	115,834	-	-	-	1,124	693	117,650	5.3	0.22	543,889	0.83%
Mix C (Ext. beam)	-	-	-	-	-	-	-	-	-	-	-	185,452	-	-	-	1,760	1,877	189,089	8.5	0.13	1,473,415	1.34%
Mix D (Int. beam, wall, col.)	-	-	-	-	-	-	-	-	-	-	-	434,355	-	-	-	4,089	5,063	443,507	19.9	0.11	3,974,773	3.14%
Cast in Place	2,567,067	-	-	-	24,847	10,934	2,602,847	116.7	0.30	8,583,773	11.01%	1,210,686	-	-	-	11,409	9,258	1,231,353	55.2	0.17	7,268,190	8.72%
Topping Slab Normal Weight	-	-	-	-	-	-	-	-	-	-	-	194,569	-	-	-	1,818	1,691	198,078	8.9	0.15	1,327,320	1.40%
Topping Slab Light Weight	1,891,362	-	-	-	18,473	5,845	1,915,680	85.9	0.42	4,588,506	8.10%	-	-	-	-	-	-	-	-	-	-	-
Slab on Grade	120,532	-	-	-	1,126	1,047	122,706	5.5	0.15	822,210	0.52%	120,532	-	-	-	1,126	1,047	122,706	5.5	0.15	822,210	0.87%
Foundation	555,173	-	-	-	5,247	4,042	564,462	25.3	0.18	3,173,057	2.39%	895,585	-	-	-	8,464	6,520	910,569	40.8	0.18	5,118,659	6.45%
Steel	**2,546,085**	**-**	**-**	**-**	**22,835**	**2,037**	**2,570,958**	**115.3**	**1.61**	**1,599,032**	**10.88%**	**941,781**	**-**	**-**	**-**	**7,594**	**1,553**	**950,928**	**42.6**	**0.78**	**1,218,957**	**6.73%**
Structural Frame	1,853,799	-	-	-	16,707	1,440	1,871,946	84.0	1.66	1,130,345	7.92%	-	-	-	-	-	-	-	-	-	-	-
Beams	1,382,450	-	-	-	12,476	1,060	1,395,987	62.6	1.68	832,236	5.91%	-	-	-	-	-	-	-	-	-	-	-
Columns	433,234	-	-	-	3,910	332	437,476	19.6	1.68	260,807	1.85%	-	-	-	-	-	-	-	-	-	-	-
Braces	38,115	-	-	-	321	48	38,484	1.7	1.03	37,302	0.16%	-	-	-	-	-	-	-	-	-	-	-
Concrete Reinforcement	135,427	-	-	-	984	229	136,640	6.1	0.76	179,677	0.58%	864,818	-	-	-	6,947	1,457	873,222	39.2	0.76	1,143,660	6.18%
Rebar	85,606	-	-	-	616	148	86,370	3.9	0.74	116,454	0.37%	713,703	-	-	-	5,563	1,339	720,604	32.3	0.69	1,051,317	5.10%
Mesh	49,821	-	-	-	368	81	50,270	2.3	0.80	63,224	0.21%	-	-	-	-	-	-	-	-	-	-	-
Strand	-	-	-	-	-	-	-	-	-	-	-	151,115	-	-	-	1,384	118	152,617	6.8	1.65	92,343	1.08%
Steel Deck	480,974	-	-	-	4,553	281	485,808	21.8	2.21	220,229	2.06%	-	-	-	-	-	-	-	-	-	-	-
Misc. Metals & Edge of Slab	75,885	-	-	-	591	88	76,564	3.4	1.11	68,781	0.32%	76,963	-	-	-	647	96	77,706	3.5	1.03	75,297	0.55%
ENVELOPE SUBTOTAL	**1,200,386**	**-**	**10,500**	**-**	**11,888**	**846**	**1,223,620**	**54.9**	**1.84**	**663,842**	**5.18%**	**952,086**	**-**	**10,500**	**-**	**9,452**	**930**	**972,968**	**43.6**	**1.33**	**729,924**	**6.89%**
Vertical Enclosure	**1,166,796**	**-**	**-**	**-**	**11,553**	**764**	**1,179,113**	**52.9**	**1.97**	**599,973**	**4.99%**	**918,496**	**-**	**-**	**-**	**9,117**	**848**	**928,461**	**41.6**	**1.39**	**666,055**	**6.57%**
Infinite Façade	-	-	-	-	-	-	-	-	-	-	-	282,166	-	-	-	2,822	478	285,465	12.8	0.76	375,003	2.02%
Curtain Wall	1,166,796	-	-	-	11,553	764	1,179,113	52.9	1.97	599,973	4.99%	542,981	-	-	-	5,376	354	548,711	24.6	1.97	277,960	3.89%
Exterior Shading	-	-	-	-	-	-	-	-	-	-	-	93,349	-	-	-	919	17	94,285	4.2	7.20	13,092	0.67%
Roof	**33,590**	**-**	**10,500**	**-**	**336**	**81**	**44,507**	**2.0**	**0.70**	**63,869**	**0.19%**	**33,590**	**-**	**10,500**	**-**	**336**	**81**	**44,507**	**2.0**	**0.70**	**63,869**	**0.32%**
Roof Deck	9,314	-	10,500	-	93	35	19,942	0.9	0.72	27,624	0.08%	9,314	-	10,500	-	93	35	19,942	0.9	0.72	27,624	0.14%
Roof Insulation	24,276	-	-	-	243	46	24,565	1.1	0.68	36,245	0.10%	24,276	-	-	-	243	46	24,565	1.1	0.68	36,245	0.17%
MECHANICAL SUBTOTAL	**811,603**	**-**	**1,400,341**	**-**	**8,116**	**17,849**	**2,237,908**	**100.4**	**18.47**	**121,148**	**9.47%**	**363,166**	**-**	**351,722**	**-**	**6,108**	**5,963**	**726,959**	**32.6**	**7.48**	**97,183**	**5.15%**
Pipes & Supports	**89,811**	**-**	**-**	**-**	**898**	**133**	**90,841**	**4.1**	**2.65**	**34,271**	**0.38%**	**90,771**	**-**	**-**	**-**	**908**	**141**	**91,820**	**4.1**	**2.21**	**41,529**	**0.65%**
Copper Pipe	43,733	-	-	-	437	68	44,238	2.0	2.52	17,521	0.19%	2,426	-	-	-	24	4	2,454	0.1	2.52	972	0.02%
Steel Pipe	-	-	-	-	-	-	-	-	-	-	-	35,005	-	-	-	350	50	35,406	1.6	4.04	8,774	0.25%
PEX Pipe	-	-	-	-	-	-	-	-	-	-	-	10,731	-	-	-	107	27	10,865	0.5	0.67	16,295	0.08%
Embedded PEX	-	-	-	-	-	-	-	-	-	-	-	6,902	-	-	-	69	17	6,988	0.3	0.67	10,481	0.05%
Non-Embedded PEX	-	-	-	-	-	-	-	-	-	-	-	3,829	-	-	-	38	10	3,877	0.2	0.67	5,814	0.03%
Pipe Supports	46,078	-	-	-	461	65	46,603	2.1	2.78	16,749	0.20%	42,609	-	-	-	426	60	43,095	1.9	2.78	15,488	0.31%
Ducts & Supports	**121,351**	**-**	**122,696**	**-**	**1,214**	**131**	**245,392**	**11.0**	**8.38**	**29,284**	**1.04%**	**121,351**	**-**	**122,696**	**-**	**1,214**	**131**	**245,392**	**11.0**	**8.38**	**29,284**	**1.74%**
Ductwork	115,721	-	117,002	-	1,157	123	234,003	10.5	8.59	27,237	0.99%	115,721	-	117,002	-	1,157	123	234,003	10.5	8.59	27,237	1.66%
Duct Supports	5,630	-	5,694	-	56	8	11,389	0.5	5.56	2,047	0.05%	5,630	-	5,694	-	56	8	11,389	0.5	5.56	2,047	0.08%
Insulation	**12,501**	**-**	**8,066**	**-**	**125**	**22**	**20,714**	**0.9**	**2.51**	**8,243**	**0.09%**	**12,829**	**-**	**8,066**	**-**	**128**	**23**	**21,045**	**0.9**	**2.51**	**8,390**	**0.15%**
Pipe Insulation	4,533	-	-	-	45	4	4,583	0.2	2.25	2,035	0.02%	4,861	-	-	-	49	5	4,914	0.2	2.25	2,182	0.03%
Duct Insulation	7,968	-	8,066	-	80	18	16,131	0.7	2.60	6,208	0.07%	7,968	-	8,066	-	80	18	16,131	0.7	2.60	6,208	0.11%
Equipment	**587,940**	**-**	**1,269,579**	**-**	**5,879**	**17,562**	**1,880,961**	**84.4**	**38.11**	**49,351**	**7.96%**	**138,215**	**-**	**220,960**	**-**	**3,859**	**5,668**	**368,702**	**16.5**	**20.51**	**17,980**	**2.61%**
ASHP & VRF Outdoor Units	158,587	-	353,732	-	1,586	8,347	522,251	23.4	56.34	9,270	2.21%	77,099	-	170,965	-	771	3,671	252,507	11.3	26.77	9,433	1.79%
VRF Outdoor Units	158,587	-	353,732	-	1,586	8,347	522,251	23.4	56.34	9,270	2.21%	-	-	-	-	-	-	-	-	-	-	-
ASHP 4-Pipe	-	-	-	-	-	-	-	-	-	-	-	45,697	-	101,331	-	457	2,176	149,660	6.7	30.41	4,922	1.06%
ASHP 2-Pipe	-	-	-	-	-	-	-	-	-	-	-	31,403	-	69,635	-	314	1,495	102,847	4.6	22.80	4,511	0.73%
Air Handlers	19,847	-	42,149	-	198	25	62,220	2.8	12.39	5,024	0.26%	19,847	-	42,149	-	198	25	62,220	2.8	12.39	5,024	0.44%
VRF Fan Coils	401,165	-	856,830	-	4,012	9,181	1,271,188	57.0	38.10	33,368	5.38%	-	-	-	-	-	-	-	-	-	-	-
VAV Boxes	8,342	-	16,868	-	83	8	25,302	1.1	14.98	1,689	0.11%	3,880	-	7,845	-	39	4	11,768	0.5	14.98	786	0.08%
Ceiling Fans	-	-	-	-	-	-	-	-	-	-	-	37,388	-	-	-	2,850	1,968	42,207	1.9	15.42	2,738	0.30%
REFRIGERANT LEAKAGE SUBTOTAL	**-**	**3,153,298**	**-**	**-**	**35,037**	**-**	**3,188,334**	**143.0**	**2,088.00**	**1,527**	**13.49%**	**-**	**383,357**	**-**	**-**	**6,389**	**-**	**389,746**	**17.5**	**2,088.00**	**187**	**2.76%**
VRF Refrigerant Leakage	-	3,153,298	-	-	35,037	-	3,188,334	143.0	2,088.00	1,527	13.49%	-	-	-	-	-	-	-	-	-	-	-
ASHP Refrigerant Leakage	-	-	-	-	-	-	-	-	-	-	-	-	383,357	-	-	6,389	-	389,746	17.5	2,088.00	187	2.76%
ELECTRICITY USE SUBTOTAL	**-**	**-**	**-**	**11,813,207**	**-**	**-**	**11,813,207**	**529.8**	**-**	**-**	**49.98%**	**-**	**-**	**-**	**8,287,102**	**-**	**-**	**8,287,102**	**371.7**	**-**	**-**	**58.68%**

SUMMARY TABLE F

Time of Carbon Totals (kgCO2e)

Assumes Electrical Grid decreases carbon emissions intensity factors linearly to a minimum of 27% in 2045. Impact of Electricity Use emissions reduces each year accordingly.

				Structure		Envelope		Mechanical		Refrigerant Leakage		Operational Electricity		Cumulative Total Carbon		Cumulative % of WLC Total		% Savings vs. Baseline	
Life Year	Stage	Calendar Year	Grid Decarb %*	Baseline	Clark Pacific	Baseline	Clark Pacific	Baseline	Clark Pacific	Baseline	Clark Pacific	Baseline	Clark Pacific	Baseline	Clark Pacific	Baseline	Clark Pacific	Baseline	Clark Pacific
-5	A	2014	x	1,022,630	737,285	240,077	190,417	162,321	72,633	x	x	x	x	1,425,028	1,000,335	6.0%	7.1%	-	29.80%
-4	A	2015	x	1,022,630	737,285	240,077	190,417	162,321	72,633	x	x	x	x	2,850,056	2,000,670	12.1%	14.2%	-	29.80%
-3	A	2016	x	1,022,630	737,285	240,077	190,417	162,321	72,633	x	x	x	x	4,275,085	3,001,006	18.1%	21.2%	-	29.80%
-2	A	2017	x	1,022,630	737,285	240,077	190,417	162,321	72,633	x	x	x	x	5,700,113	4,001,341	24.1%	28.3%	-	29.80%
-1	A	2018	x	1,022,630	737,285	240,077	190,417	162,321	72,633	x	x	x	x	7,125,141	5,001,676	30.1%	35.4%	-	29.80%
0	B	2019	100%	x	x	175	175	780	165	52,555	6,389	453,395	318,062	7,632,046	5,326,467	32.3%	37.7%	-	30.21%
1	B	2020	97%	x	x	175	175	780	165	52,555	6,389	440,665	309,132	8,126,221	5,642,328	34.4%	39.9%	-	30.57%
2	B	2021	94%	x	x	175	175	780	165	52,555	6,389	427,935	300,201	8,607,667	5,949,259	36.4%	42.1%	-	30.88%
3	B	2022	92%	x	x	175	175	780	165	52,555	6,389	415,205	291,271	9,076,382	6,247,259	38.4%	44.2%	-	31.17%
4	B	2023	89%	x	x	175	175	780	165	52,555	6,389	402,475	282,341	9,532,368	6,536,329	40.3%	46.3%	-	31.43%
5	B	2024	86%	x	x	175	175	780	165	52,555	6,389	389,745	273,411	9,975,623	6,816,469	42.2%	48.3%	-	31.67%
6	B	2025	83%	x	x	175	175	780	165	52,555	6,389	377,015	264,481	10,406,149	7,087,679	44.0%	50.2%	-	31.89%
7	B	2026	80%	x	x	175	175	780	165	52,555	6,389	364,285	255,550	10,823,944	7,349,959	45.8%	52.0%	-	32.10%
8	B	2027	78%	x	x	175	175	780	165	52,555	6,389	351,556	246,620	11,229,010	7,603,308	47.5%	53.8%	-	32.29%
9	B	2028	75%	x	x	175	175	780	165	52,555	6,389	338,826	237,690	11,621,346	7,847,727	49.2%	55.6%	-	32.47%
10	B	2029	72%	x	x	175	175	780	165	52,555	6,389	326,096	228,760	12,000,952	8,083,216	50.8%	57.2%	-	32.65%
11	B	2030	69%	x	x	175	175	780	165	52,555	6,389	313,366	219,830	12,367,828	8,309,775	52.3%	58.8%	-	32.81%
12	B	2031	66%	x	x	175	175	780	165	52,555	6,389	300,636	210,899	12,721,974	8,527,403	53.8%	60.4%	-	32.97%
13	B	2032	64%	x	x	175	175	780	165	52,555	6,389	287,906	201,969	13,063,390	8,736,102	55.3%	61.9%	-	33.13%
14	B	2033	61%	x	x	175	175	780	165	52,555	6,389	275,176	193,039	13,392,076	8,935,870	56.7%	63.3%	-	33.27%
15	B	2034	58%	x	x	175	175	780	165	52,555	6,389	262,446	184,109	13,708,032	9,126,708	58.0%	64.6%	-	33.42%
16	B	2035	55%	x	x	175	175	780	165	52,555	6,389	249,716	175,179	14,011,258	9,308,616	59.3%	65.9%	-	33.56%
17	B	2036	52%	x	x	175	175	780	165	52,555	6,389	236,986	166,248	14,301,755	9,481,594	60.5%	67.1%	-	33.70%
18	B	2037	49%	x	x	175	175	780	165	52,555	6,389	224,256	157,318	14,579,521	9,645,641	61.7%	68.3%	-	33.84%
19	B	2038	47%	x	x	175	175	780	165	52,555	6,389	211,526	148,388	14,844,557	9,800,758	62.8%	69.4%	-	33.98%
20	B	2039	44%	x	x	175	175	612,162	105,700	52,555	6,389	198,796	139,458	15,708,246	10,052,480	66.5%	71.2%	-	36.01%
21	B	2040	41%	x	x	175	175	780	165	52,555	6,389	186,066	130,528	15,947,822	10,189,737	67.5%	72.1%	-	36.11%
22	B	2041	38%	x	x	175	175	780	165	52,555	6,389	173,336	121,597	16,174,669	10,318,064	68.4%	73.1%	-	36.21%
23	B	2042	35%	x	x	175	175	780	165	52,555	6,389	160,606	112,667	16,388,785	10,437,460	69.3%	73.9%	-	36.31%
24	B	2043	33%	x	x	175	175	780	165	52,555	6,389	147,877	103,737	16,590,172	10,547,926	70.2%	74.7%	-	36.42%
25	B	2044	30%	x	x	175	175	780	165	52,555	6,389	135,147	94,807	16,778,829	10,649,462	71.0%	75.4%	-	36.53%
26	B	2045	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	16,954,756	10,742,068	71.7%	76.1%	-	36.64%
27	B	2046	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	17,130,683	10,834,674	72.5%	76.7%	-	36.75%
28	B	2047	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	17,306,610	10,927,280	73.2%	77.4%	-	36.86%
29	B	2048	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	17,482,536	11,019,886	74.0%	78.0%	-	36.97%
30	B	2049	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	17,658,463	11,112,491	74.7%	78.7%	-	37.07%
31	B	2050	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	17,834,390	11,205,097	75.5%	79.3%	-	37.17%
32	B	2051	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	18,010,317	11,297,703	76.2%	80.0%	-	37.27%
33	B	2052	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	18,186,244	11,390,309	76.9%	80.6%	-	37.37%
34	B	2053	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	18,362,171	11,482,915	77.7%	81.3%	-	37.46%
35	B	2054	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	18,538,098	11,575,520	78.4%	82.0%	-	37.56%
36	B	2055	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	18,714,025	11,668,126	79.2%	82.6%	-	37.65%
37	B	2056	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	18,889,951	11,760,732	79.9%	83.3%	-	37.74%
38	B	2057	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	19,065,878	11,853,338	80.7%	83.9%	-	37.83%
39	B	2058	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	19,241,805	11,945,944	81.4%	84.6%	-	37.92%
40	B	2059	27%	x	x	175	175	742,924	236,462	52,555	6,389	122,417	85,877	20,159,875	12,274,846	85.3%	86.9%	-	39.11%
41	B	2060	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	20,335,802	12,367,452	86.0%	87.6%	-	39.18%
42	B	2061	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	20,511,729	12,460,058	86.8%	88.2%	-	39.25%
43	B	2062	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	20,687,656	12,552,664	87.5%	88.9%	-	39.32%
44	B	2063	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	20,863,583	12,645,270	88.3%	89.5%	-	39.39%
45	B	2064	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	21,039,510	12,737,875	89.0%	90.2%	-	39.46%
46	B	2065	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	21,215,437	12,830,481	89.8%	90.8%	-	39.52%
47	B	2066	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	21,391,364	12,923,087	90.5%	91.5%	-	39.59%
48	B	2067	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	21,567,290	13,015,693	91.2%	92.2%	-	39.65%
49	B	2068	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	21,743,217	13,108,299	92.0%	92.8%	-	39.71%
50	B	2069	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	21,919,144	13,200,904	92.7%	93.5%	-	39.77%
51	B	2070	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	22,095,071	13,293,510	93.5%	94.1%	-	39.83%
52	B	2071	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	22,270,998	13,386,116	94.2%	94.8%	-	39.89%
53	B	2072	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	22,446,925	13,478,722	95.0%	95.4%	-	39.95%
54	B	2073	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	22,622,852	13,571,328	95.7%	96.1%	-	40.01%
55	B	2074	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	22,798,779	13,663,934	96.5%	96.7%	-	40.07%
56	B	2075	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	22,974,705	13,756,539	97.2%	97.4%	-	40.12%
57	B	2076	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	23,150,632	13,849,145	97.9%	98.1%	-	40.18%
58	B	2077	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	23,326,559	13,941,751	98.7%	98.7%	-	40.23%
59	B	2078	27%	x	x	175	175	780	165	52,555	6,389	122,417	85,877	23,502,486	14,034,357	99.4%	99.4%	-	40.29%
60	C	2079	x	60,653	60,488	12,734	10,382	25,965	12,071	35,037	6,389	x	x	23,636,874	14,123,687	100.0%	100.0%	-	40.25%

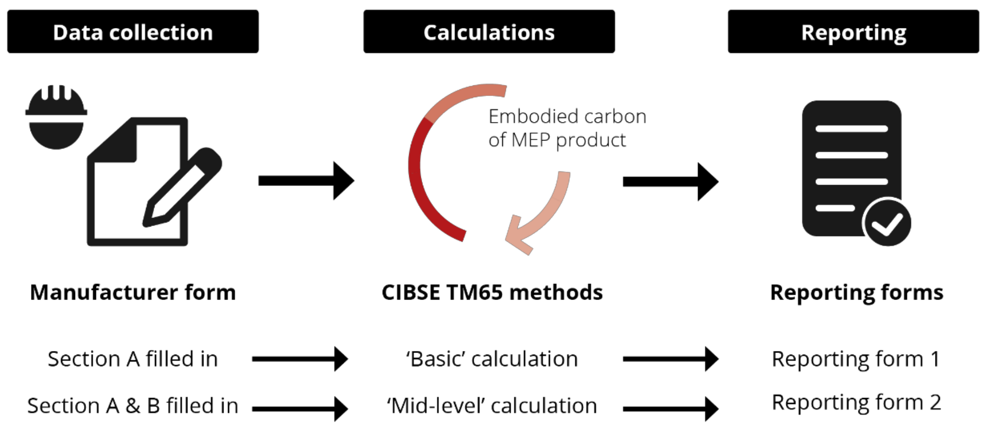
CIBSE TM65 CALCULATION METHODOLOGY

The Chartered Institute of Building Services Engineers (CIBSE) are the professional body representing MEP engineers in the UK and Ireland, with regions in the UAE, Hong Kong, Australia and New Zealand, and members in 95 countries.

In 2020, Integral Group was appointed by CIBSE to develop the methodology for calculating the embodied carbon of MEP equipment to be used when no EPDs are available. This was published in January 2021 as a Technical Memoranda: CIBSE TM65 – *Embodied carbon in building services: a calculation methodology.*

CIBSE TM65 does not aim at replacing EPDs, but rather allows initial conservative embodied carbon estimations for MEP products to be made, while waiting for EPDs to become available. It provides a consistent approach to facilitate research and thus increase understanding on embodied carbon in MEP design.

Two calculation methods are provided by CIBSE TM65 depending on the amount of information collected through a manufacturer form, as showed in figure below:



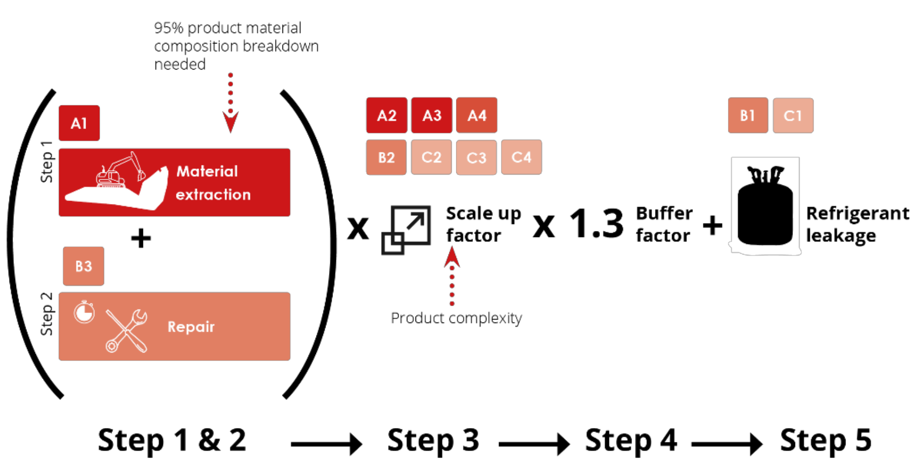
'Basic' Calculation Method

The basic calculation method is based on the following information from the manufacturer:

- Product Weight (kg)
- Material Composition Breakdown for at least 95% of the product weight (excluding refrigerant charge)
- Type and Quantity of Refrigerant within product (kg)
- Product Service Life (years)

This method is relatively easy and is composed of 4 main steps:

- Calculation of the emissions related to material extraction (A1) based on the material composition breakdown information given by the manufacturer.
- Calculation of emissions resulting from repair (components replaced during within the product service life)
- Multiplication by a scale up factor which changes depending on product complexity (longer supply chain)
- Multiplication by a buffer factor as it meant to be a conservative estimation
- Calculation of the emissions resulting from refrigerant leakage during the system use and at end of life of the equipment when decommissioning.



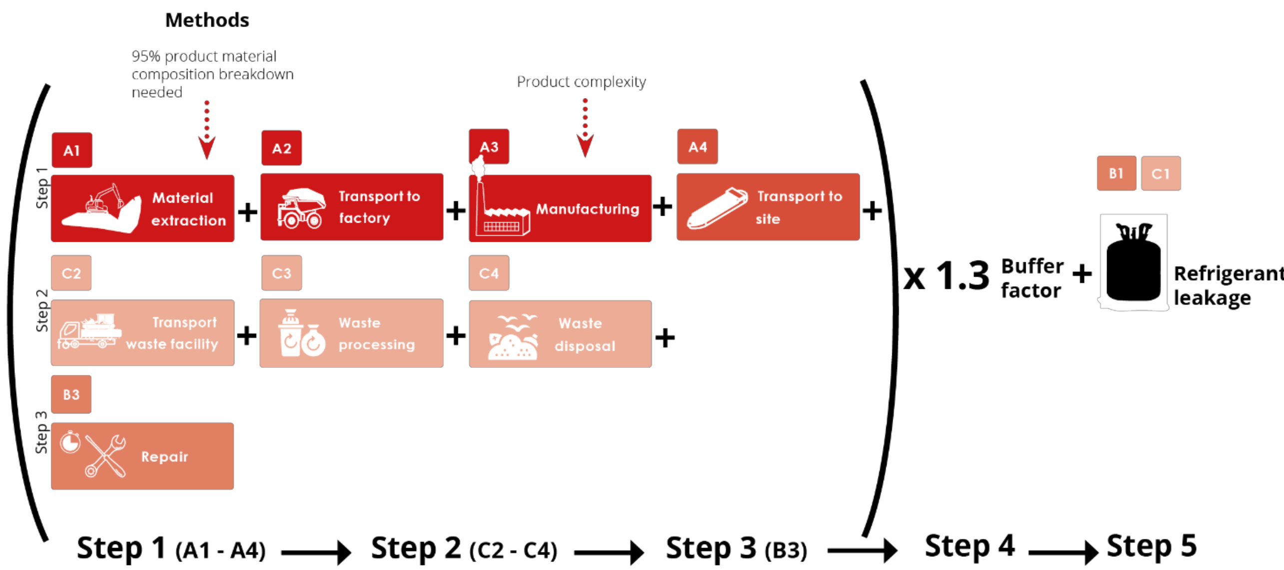
'Mid-level' Calculation Method

The mid-level calculation method is based on the same information from the manufacturer as for the basic calculation method, plus the additional following information:

- Assumed proportion of factory energy use associated with the product (kWh)
- Final assembly location (country or region).

Where possible, the 'mid-level' calculation method should be used over the basic as it provides more robust calculations. The different calculations steps are as follow:

- Calculations the emissions for each different lifecycle stages as showed in Figure X
- Multiplication by a buffer factor as it meant to be a conservative estimation
- Calculation of the emissions resulting from refrigerant leakage during the system use and at end of life of the equipment when decommissioning.



How CIBSE TM65 was used in this study

For this study, CIBSE TM65 'mid-level' calculation method was used to establish embodied carbon for the following mechanical equipment based on different manufacturer data as no other embodied carbon data was available:

- Ceiling Fans
- Air-Source Heat Pumps
- VRF Outdoor Condensing Units
- VRF Fan Coils

The transport distances, carbon factors were adapted to the CA context. The embodied carbon coefficient used are global averages from the ICE database[12].

The methodology to account for refrigerant leakage impact during the use phase (B1) and when decommissioning the system (C1) followed as well CIBSE TM65. For more information on leakage and recovery rates used, see Detail Table R in the body of the report and in the Appendix.

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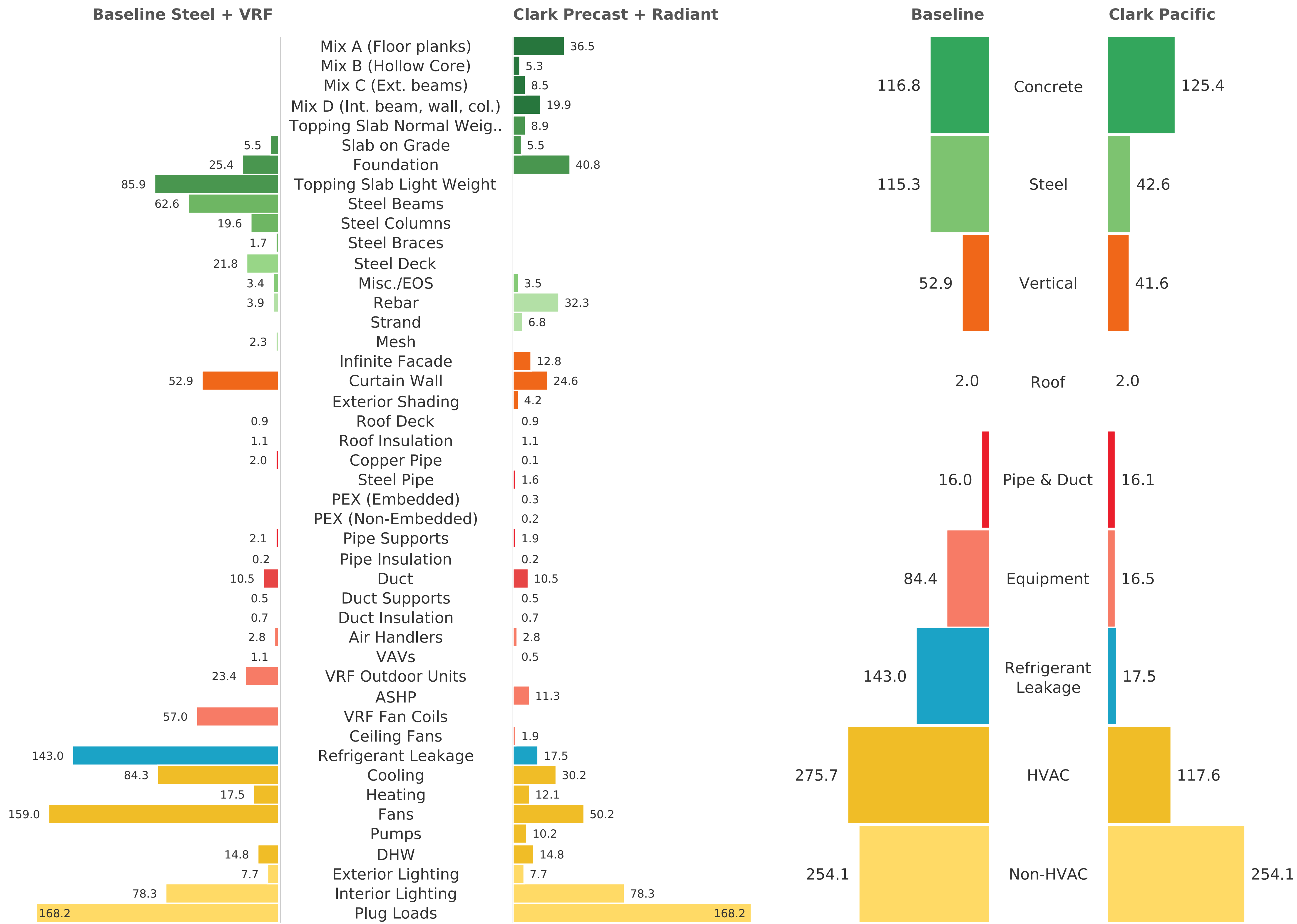
[12] : https://circularecology.com/embodied-carbon-footprint-database.html

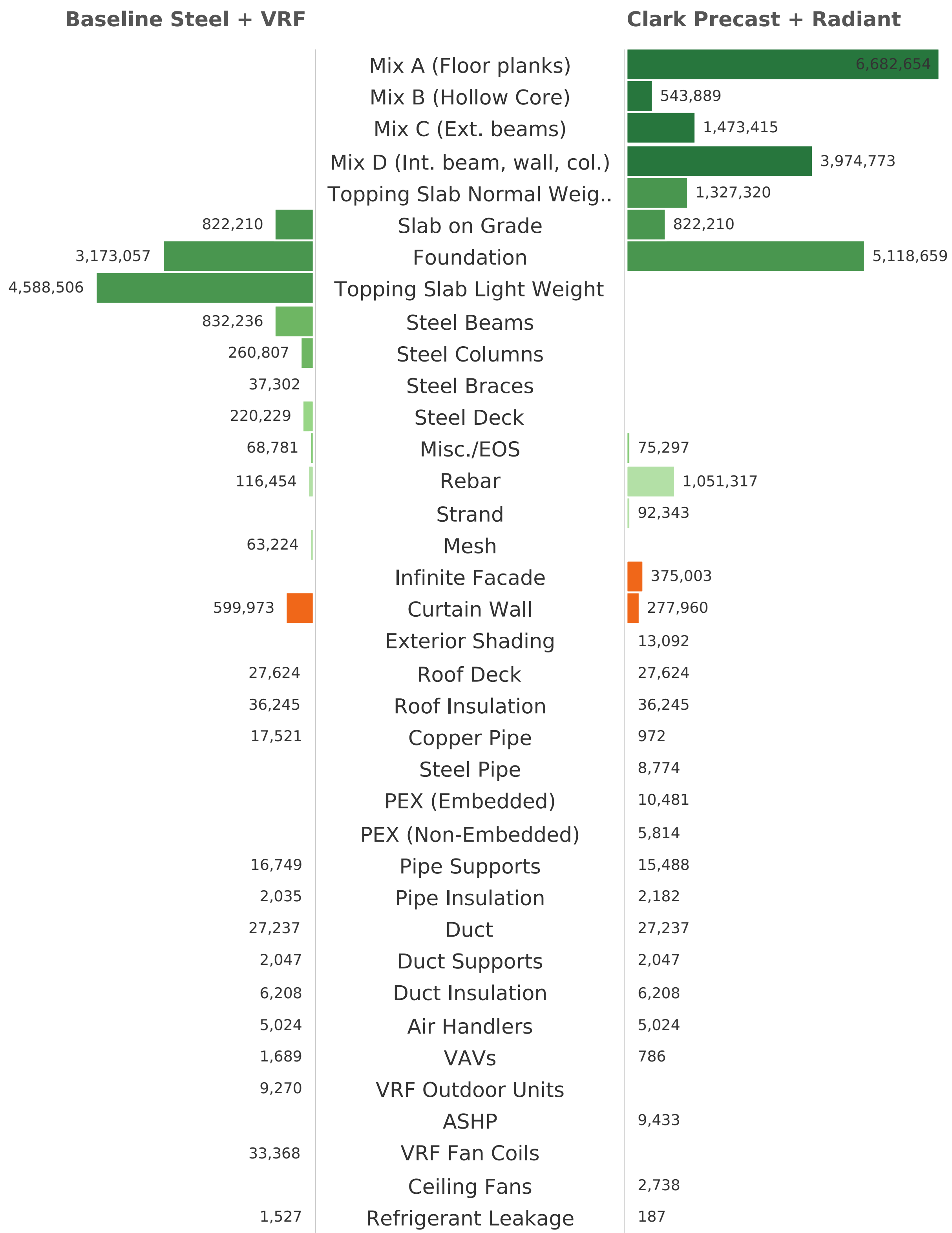
Whole Life Carbon Emissions (kgCO2e/m2)

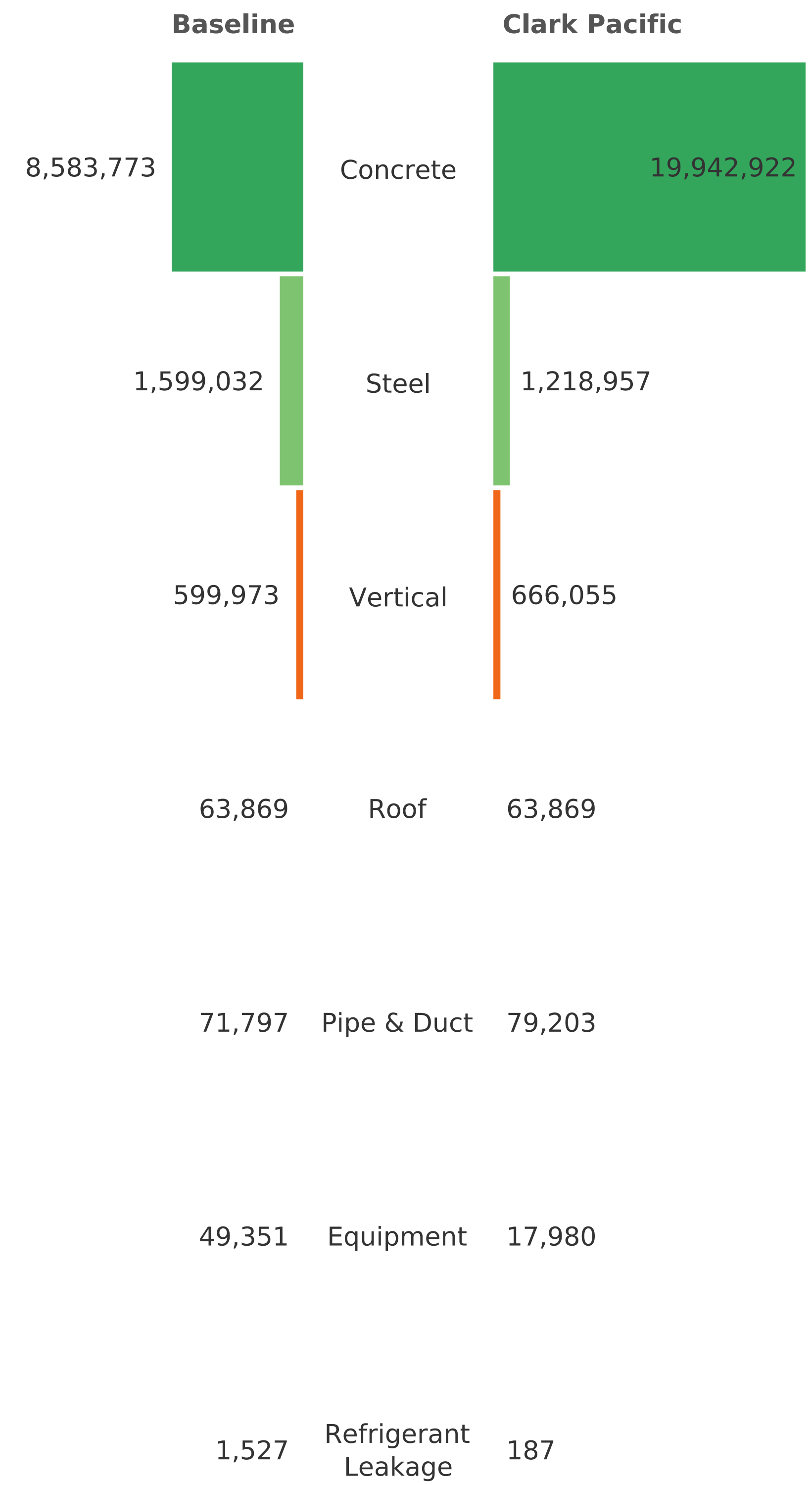
Total emissions per area for all physical products and operational electricity



Whole Life Carbon Physical Mass (kg)

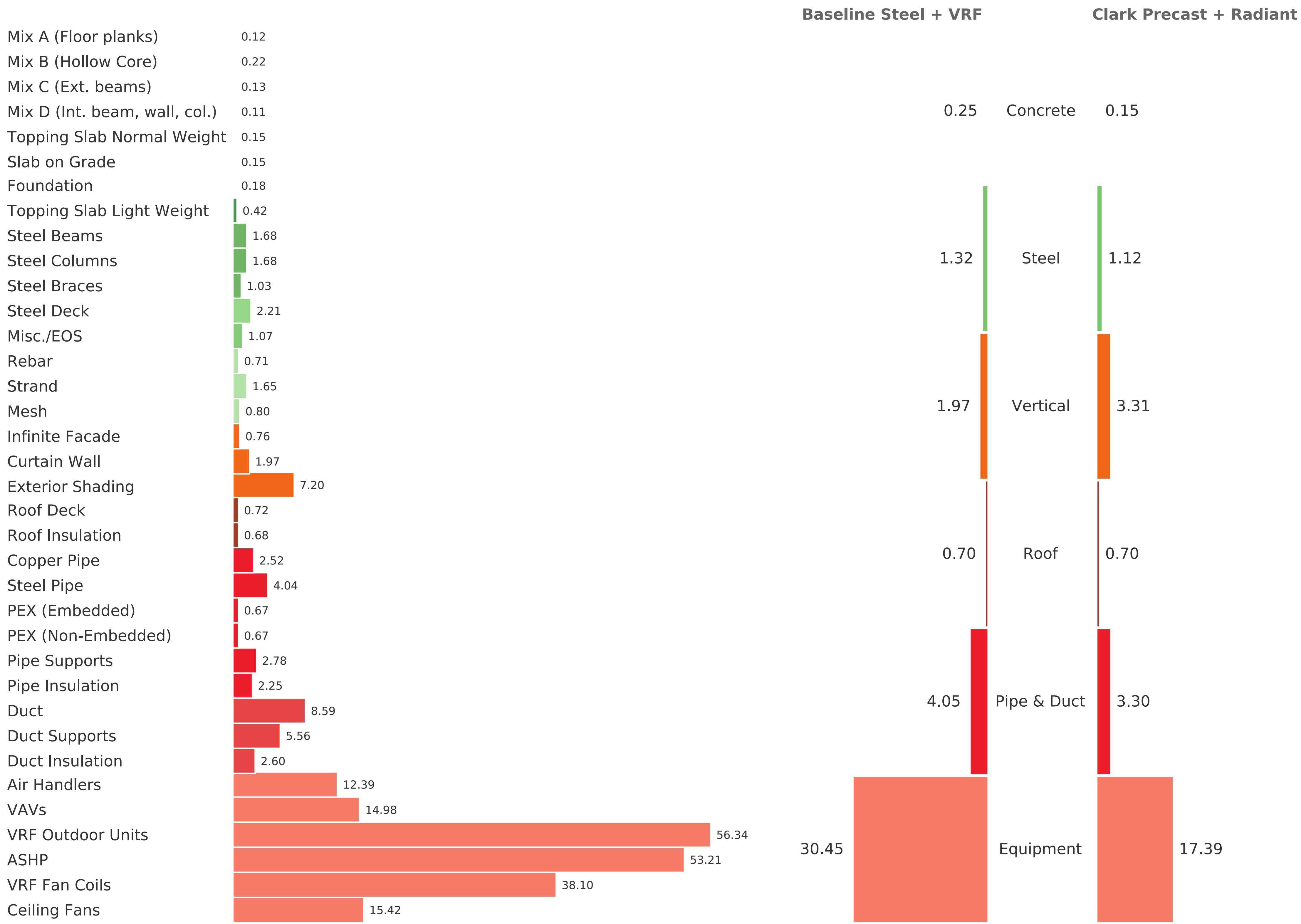
Total mass for all physical products. Operational electricity excluded from this chart





Whole Life Carbon (kgCO2e/kg)

Overall emissions rate per unit mass. Refrigerant leakage not shown,
as it's nearly 100 times larger than anything else and makes chart unreadable.



Structure

DETAIL TABLE A

Precast Concrete Mixes A1-A3 Rates[1]

Mix A - Floor Planks Precast - 7000 psi - Clark Pacific		
SCM Ratio (of SCM+Cement)	**70.0 %**	
Component Ingredients	**Mix Design Weight per 1 CY of Mix (lbs)**	**Global Warming Potential (kgCO2eq)**
Cement	225	106
Fly ash	-	-
Slag	525	7
Coarse Aggregate	1,112	13
Volcanic LW Agg.*	351	21
Fine Aggregate (Sand)	1,206	37
Water	300	3
Steel Reinforcement	-	-
Air Content	4.00%	-
Per 1 CY of MIX	**3,719**	**186.9**

*Lightweight Aggregate is commonly from an expanded shale product. There are high carbon emissions associated with expanded shale due heating in a kiln to 1200degC. This mix uses a locally-sourced (<100 miles) lightweight volcanic aggregate that does not have a kiln process (mined and crushed). In the absence of an exact value from this calculator, it was assumed that this lightweight volcanic aggregate has a kgCO2e/kg rate twice that of Fine Aggregate (Sand). It is reasonable to expect the kgCO2e is less, but this was chosen to be conservative yet still capture a reduction from the expanded shale based numbers.

Mix B - Hollow Core Precast - 4000 psi - Clark Pacific		
SCM Ratio (of SCM+Cement)	**0.0 %**	
Component Ingredients	**Mix Design Weight per 1 CY of Mix (lbs)**	**Global Warming Potential (kgCO2eq)**
Cement	600	283
Fly ash	-	-
Slag	-	-
Coarse Aggregate	970	12
Lightweight Aggregate	-	-
Fine Aggregate (Sand)	2,318	71
Water	192	2
Steel Reinforcement	-	-
Air Content	3.70%	-
Per 1 CY of MIX	**4,080**	**366.8**

Mix C - Exterior Beams Precast - 8000 psi - Clark Pacific		
SCM Ratio (of SCM+Cement)	**60.0 %**	
Component Ingredients	**Mix Design Weight per 1 CY of Mix (lbs)**	**Global Warming Potential (kgCO2eq)**
Cement	320	151
Fly ash	-	-
Slag	480	6
Coarse Aggregate	1,633	19
Lightweight Aggregate	-	-
Fine Aggregate (Sand)	1,228	38
Water	300	3
Steel Reinforcement	-	-
Air Content	2.00%	-
Per 1 CY of MIX	**3,961**	**216.5**

Mix D - Int. Beams, Shear Walls, Columns Precast - 9000 psi - Clark Pa		
SCM Ratio (of SCM+Cement)	**70.0 %**	
Component Ingredients	**Mix Design Weight per 1 CY of Mix (lbs)**	**Global Warming Potential (kgCO2eq)**
Cement	255	120
Fly ash	-	-
Slag	595	7
Coarse Aggregate	1,618	19
Lightweight Aggregate	-	-
Fine Aggregate (Sand)	1,205	37
Water	300	3
Steel Reinforcement	-	-
Air Content	2.00%	-
Per 1 CY of MIX	**3,973**	**186.5**

1. Calculated using mix design reports from Clark Pacific and applying those ingredients to ZGF's public Concrete LCA Tool (v3.0). Tables here are reformatted from ZGA's output for better report clarity. All values are unaltered and directly from ZGA tool unless noted.

Structure

DETAIL TABLE B.1

Baseline - Steel Frame

	Beams (I-Section)	Columns (I-Section)	Beams (Wide Flange)	Columns (Wide Flange)	Braces (Wide Flange)
STRUCTURAL STEEL FRAME	**1,707,279 lbs**	**259,821 lbs**	**127,468 lbs**	**315,154 lbs**	**82,237 lbs**
Steel Grade	Grade 50	Grade 50	Grade 50	Grade 50	Grade 36

DETAIL TABLE B.2

Baseline - Cast in Place Items

	Topping Slab	Grade Slab	Foundation
CAST IN PLACE CONCRETE	**3,406 yd3** **4,588,506 kg**	**463 yd3** **822,210 kg**	**1,787 yd3** **3,173,057 kg**
Concrete Mix	Mix G	Mix E	Mix F
Concrete Strength (28-days)	3000 psi	4000 psi	5000 psi
Concrete Weight Classification	Light	Normal	Normal
Concrete Volume (yd3)	3,406	463	1786.8
Concrete Density (lbs/ft3)	110	145	145
Concrete Density (lbs/yd3)	2,970	3,915	3,915
Concrete Weight (lbs)	10,115,820	1,812,645	6,995,322
Cocnrete Mass (kg)	4,588,506	822,210	3,173,057
REBAR STEEL	**256,734 lbs**		
Rebar Density (lbs/yd3)	-	75	124
Rebar Weight (lbs)	-	34,725	222,009
MESH STEEL	**139,383 lbs**		
Mesh Density (lbs/ft2)	0.60	-	-
Mesh Weight (lbs)	139,383	-	-
MISC. METALS & EOS STEEL*	**151,634 lbs**		
Misc. Metals Density (lbs/yd3)*	45	-	-
Misc. Metals Weight (lbs)*	151,634	-	-

*Carbon emissions for "Misc. Metals & EOS Steel" intentionally uses the quantity of only EOS Steel (151,634 lbs), omitting all other Misc. Metals (480,000 lbs). This is meant to be a sizable overall safety factor in favor of the baseline scenario and to ensure no argument could be made that the baseline structure's steel is unfairly too heavy.

DETAIL TABLE B.3

Baseline - Steel Deck

	Deck (20 gage)
STEEL DECK	**485,516 lbs** **232,304 ft2**

DETAIL TABLE B.4

Baseline - Steel Quantities Summary

Beams (I-Section)	7.1 lbs/ft2
Columns (I-Section)	1.1 lbs/ft2
Beams (Wide Flange)	0.5 lbs/ft2
Columns (Wide Flange)	1.3 lbs/ft2
Braces (Wide Flange)	0.3 lbs/ft2
EOS Plate	0.6 lbs/ft2
Misc. Metals	2.0 lbs/ft2
Total	**13.0 lbs/ft2**

DETAIL TABLE C.1

Clark Pacific - Precast Structure

	Floor Planks	Hollow Core	Ext. Beams	Int. Beams	Shear Walls	Columns
PRECAST CONCRETE	**4,042 yd3** **6,682,654 kg**	**306 yd3** **543,889 kg**	**813 yd3** **1,473,415 kg**		**2,193 yd3** **3,974,773 kg**	
Concrete Mix	Mix A	Mix B	Mix C	Mix D	Mix D	Mix D
Concrete Strength (28-days)	7000 psi	4000 psi	8000 psi	9000 psi	9000 psi	9000 psi
Concrete Weight Classification	Normal	Normal	Normal	Normal	Normal	Normal
Concrete Volume (yd3)	4,042	306	813	903	929	360
Concrete Density (lbs/ft3)	135	145	148	148	148	148
Concrete Density (lbs/yd3)	3,645	3,915	3,996	3,996	3,996	3,996
Concrete Weight (lbs)	14,732,579	1,199,059	3,248,292	3,609,568	3,713,326	1,439,891
Cocnrete Mass (kg)	6,682,654	543,889	1,473,415	1,637,289	1,684,354	653,130
REBAR STEEL				**1,898,254 lbs**		
Rebar Density (lbs/yd3)	133	-	300	450	562	522
Rebar Weight (lbs)	537,567	-	243,866	406,483	522,245	188,094
STRAND STEEL				**203,579 lbs**		
Strand Density (lbs/yd3)	41	44	30	-	-	-
Strand Weight (lbs)	165,716	13,476	24,387	-	-	-
MISC. METALS & EOS STEEL				**165,999 lbs**		
Misc. Metals Density (lbs/yd3)	5	-	15	15	40	230
Misc. Metals Weight (lbs)	20,209	-	12,193	13,549	37,170	82,877

DETAIL TABLE C.2

Clark Pacific - Cast in Place Items

	Topping Slab	Grade Slab	Foundation
CAST IN PLACE CONCRETE	**747 yd3** **1,327,320 kg**	**463 yd3** **822,210 kg**	**2,882 yd3** **5,118,659 kg**
Concrete Mix	Mix E	Mix E	Mix F
Concrete Strength (28-days)	4000 psi	4000 psi	5000 psi
Concrete Weight Classification	Normal	Normal	Normal
Concrete Volume (yd3)	747	463	2,882
Concrete Density (lbs/ft3)	145	145	145
Concrete Density (lbs/yd3)	3,915	3,915	3,915
Concrete Weight (lbs)	2,926,210	1,812,645	11,284,596
Cocnrete Mass (kg)	1,327,320	822,210	5,118,659
REBAR STEEL		**419,480 lbs**	
Rebar Density (lbs/yd3)	52	75	120
Rebar Weight (lbs)	38,867	34,725	345,888

Envelope

DETAIL TABLE L

Envelope Quantities

FACADE TYPE	BASELINE TYPE	CLARK TYPE 1	CLARK TYPE 2	CLARK TYPE 3	CLARK TYPE 4
Panel Type	Curtain Wall Panel	Infinite Façade	Infinite Façade	Curtain Wall Panel	Curtain Wall Panel
Floor-to-Floor Height (typ.)	15ft floors	13ft floors	13ft floors	13ft floors	13ft floors
Exterior Sun Shades	No Shades	(2) 14" Sun Shades	No Shades	(2) 14" Sun Shades	No Shades
Glass Height (from 30"AFF)	8ft tall vision glass	8ft tall glass	8ft tall glass	8ft tall vision glass	8ft tall vision glass
Punched or Ribbon Windows	Cont. Ribbon	Punched Windows	Punched Windows	Cont. Ribbon	Cont. Ribbon
Window-to-Wall Ratio	~53% WWR	~53% WWR	~53% WWR	~61% WWR	~61% WWR
Insulation	2" Insul. Spandrel	2" HFO Foam	2" HFO Foam	2" Insul. Spandrel	2" Insul. Spandrel
FAÇADE AMOUNTS	**BASELINE TYPE**	**CLARK TYPE 1**	**CLARK TYPE 2**	**CLARK TYPE 3**	**CLARK TYPE 4**
Façade Length (ft)	729	150.0	190.0	217.1	172.0
Façade Height (ft)	123	107.5	107.5	107.5	107.5
Total Façade Area (ft2)	89,685	16,125	20,425	23,343	18,490
Infinite Façade Area (ft2)	0	16,125	20,425	0	0
Curtain Wall Area (ft2)	89,685	0	0	23,343	18,490
Spandrel Insulation Area (ft2)	43,020	0	0	9,446	7,482
Sun Shades Length (ft)	0	1,920	0	3,301	0
SCENARIO TOTALS	**BASELINE**	**CLARK PACIFIC**			
Total Infinite Façade	0 ft2	36,550 ft2			
Total Curtain Wall	89,685 ft2	41,833 ft2			
Total Spandrel Insulation	43,020 ft2	16,928 ft2			
Total Sun Shade Length	0 ft	5,221 ft			

DETAIL TABLE M

Exterior Shades Aluminum Mass

PRODUCT INFO		
Manufacturer	Kawneer	
Model Series	Versoleil® SunShade	
Model Line	Single Blade System	
Size	14" Depth	
BLADE CROSS-SECTIONAL AREA		
Perimeter Aluminum Length	28.53	in
Perimeter Aluminum Thickness	0.11	in
Perimeter Aluminum Area	3.27	in2
Interior Supports Aluminum Length	5.50	in
Interior Supports Aluminum Thickness	0.11	in
Interior Supports Aluminum Area	0.63	in2
Interior Clips Aluminum Length	5.50	in
Interior Clips Aluminum Thickness	0.04	in
Interior Clips Aluminum Area	0.21	in2
Blade Cross-Sectional Aluminum Area	4.11	in2
Blade Cross-Sectional Aluminum Area	0.03	ft2
EXTERIOR SHADES MASS		
Total Sun Shade Blade Length	5,221	ft
Total Sun Shade Blade Volume	149	ft3
Additional % for Mounting Clips	5%	
Additional % for Safety Factor	10%	
Total Exterior Shade Aluminum Volume	171	ft3
Aluminum Density	169	lbs/ft3
Total Exterior Shade Aluminum Weight	28,863	lbs

Mechanical

DETAIL TABLE P.1

Baseline Scenario - Mechanical Quantity Summary

VRF System Summary	QTY	Size
Outdoor VRF Condensing Units*	15 EA	100 kW
Indoor VRF Fan Coils**	344 EA	8 kW
Refrigerant Charge***	1,850 LBS	(839 kg)
Refrigerant	R-410a	
Refrigerant Pipe***	62,030 LF	(17,521 kg)
Refrigerant Pipe Insulation	1,123 ft3	(31.8 m3)
Branch Circuit Controllers****	53 (4-circuit)	44 (3-circuit)

*1491 kW nominal cooling capacity estimated from assessing completed built VRF installed capacities in the California Bay Area. At 560 sf/ton and , matches Business as Usual capacity consistent with the Baseline Scenario.

**Applied (1) 8kW Fan Coil per 500sf on the perimeter and (1) 8kW Fan Coil per 1000sf for the interior. A smaller number of larger size fan coils was chosen intentionally to be conservative in a favor of the baseline scenario. The relative emissions impact is higher from more smaller fan coil units than fewer larger fan coil units.

***See Tables P.2 and P.3 below for full details.

**** Branch Circuit Controllers carbon emissions were excluded to be conservative in favor of the baseline. At ~40 lbs per 4-BCC (qty 53) and~35 lbs per 3-circuit BCC (qty 44) this is ~3,660 lbs of copper. Not an insignificant amount.

Baseline Scenario Airside System Summary	
DOAS Building Air Handler (w/HR)*	Same as Clark Pacific scenario
Ductwork in mechanical shaft**	Same as Clark Pacific Scenario
Ductwork from shaft to VRF Fan Coils**	Same as Clark Pacific Scenario
VAV Boxes***	344
Diffusers, misc. accessories**	Excluded

*Same size and type as unit in Clark Pacific, except heat recovery either wheel or plate and frame (assuming same heat recovery effectivenss in Baseline and Clark Scenarios) and refrigerant coil instead of hydronic coil.

**To be conservative in favor of the baseline, all ductwork distribution on the fresh air side identical betwen Baseline and Clark scenarios from DOAS to VRF Fan coil. Ductwork downstream of VRF Fan Coils is excluded in the Baseline in the same fashion ductwork and diffusers downstream of VAV boxes is excluded in Clark scenario. The VRF Fan coils have more ductwork & diffusers downstream than Clark system.

***Same # of VAVs as Fan Coils. Required to enable modulation of air flow in demand control ventilation spaces while still providing constant ventilation in non DCV spaces.

DETAIL TABLE P.2

Baseline VRF System by Section

From Condensing Units to Floor Main Wyes and Roof DOAS

	QTY	Pipe Distance (ft)				Pipe Size (inches)		
Level	# CU's to level (ea go to only 1)	CU to DOAS	CU to Shaft Top (avg)	Shaft Top to Floor Wye	Total on Level	Liquid Line	High Pres. Gas	Low Pres. Gas
Roof DOAS	5	10	-	-	50	0.750	1.125	1.375
8	1	0	15	4	19	0.875	1.125	1.500
7	1	0	15	19	34	0.875	1.125	1.500
6	1	0	15	34	49	0.875	1.125	1.500
5	1	0	15	49	64	0.875	1.125	1.750
4	1	0	15	64	79	1.125	1.250	1.875
3	1	0	15	79	94	1.125	1.375	1.875
2	2	0	15	94	218	1.375	1.625	2.125
1	2	0	15	109	248	1.375	1.750	2.125
Totals	15	Condensing Units						

From Floor Main Wyes to BCC Wyes

	Pipe Distance (ft)		Pipe Size (inches)		
Level	Floor Wye to BCC Wyes (avg)	Total on Level (+10% fittings)	Liquid Line	High Pres. Gas	Low Pres. Gas
8	1,063	1,169	0.75	0.875	1.375
7	1,063	1,169	0.75	0.875	1.375
6	1,063	1,169	0.75	0.875	1.375
5	1,063	1,169	0.75	0.875	1.625
4	1,063	1,169	0.875	1.125	1.75
3	1,063	1,169	1.125	1.125	1.75
2	1,020	2,244	1.125	1.375	1.875
1	1,019	2,242	1.125	1.5	1.875

From BCC Wyes to BCC

	QTY	Pipe Distance (ft)		Pipe Size (inches)		
Level	# BCC's per CU	BCC Wye to BCC (avg)	Total on Level (+5% fittings)	Liquid Line	High Pres. Gas	Low Pres. Gas
8	10	10	105	0.75	0.75	1.125
7	10	10	105	0.75	0.75	1.125
6	10	10	105	0.75	0.75	1.125
5	11	10	115.5	0.75	0.75	1.125
4	12	10	126	0.75	0.75	1.125
3	12	10	126	0.875	1.125	1.375
2	8	10	168	0.875	1.125	1.375
1	8	10	168	0.875	1.125	1.375
Totals	97	Branch Circuit Controllers				

From BCCs to FCUs

	QTY	Pipe Distance (ft)		Pipe Size (inches)	
Level	# FCU's per BCC	BCC to FCU (avg)	Total on Level (+10% fittings)	Liquid Line	Gas Line
8	4	30	1380	0.5	0.75
7	4	30	1380	0.5	0.75
6	4	30	1380	0.5	0.75
5	4	30	1518	0.5	0.75
4	4	30	1656	0.5	0.75
3	3	24	993.6	0.5	0.75
2	3	24	1324.8	0.5	0.75
1	3	24	1324.8	0.5	0.75
Totals	344	Fan Coils			

Mechanical

DETAIL TABLE P.3

Baseline VRF System Piping Totals

Pipe Size (inches)	CU to Floor Wyes / DOAS			Floor Wyes to BCC Wyes			BCC Wyes to BCC's			BCC's to FCU's		VRF System Piping Totals				
	Liquid Line	High Pres. Gas	Low Pres. Gas	Liquid Line	High Pres. Gas	Low Pres. Gas	Liquid Line	High Pres. Gas	Low Pres. Gas	Liquid Line	Gas Line	Total Length (ft)	Pipe Density (lbs/ft)	Total Weight (lbs)	**Total Mass (kg)**	**Total Insul. (m3)**
0.375	0	0	0	0	0	0	0	0	0	0	0	0	0.134	0	0	0.0
0.500	0	0	0	0	0	0	0	0	0	10,957	0	10,957	0.182	1,994	905	3.7
0.625	0	0	0	0	0	0	0	0	0	0	0	0	0.251	0	0	0.0
0.750	50	0	0	4,675	0	0	557	557	0	0	10,957	16,795	0.305	5,123	2,324	7.0
0.875	166	0	0	1,169	4,675	0	462	0	0	0	0	6,472	0.455	2,945	1,336	3.0
1.125	173	216	0	5,655	2,338	0	0	462	557	0	0	9,400	0.655	6,157	2,793	5.1
1.250	0	79	0	0	0	0	0	0	0	0	0	79	0.770	61	28	0.0
1.375	466	94	50	0	2,244	3,506	0	0	462	0	0	6,822	0.884	6,031	2,736	4.3
1.500	0	0	102	0	2,242	0	0	0	0	0	0	2,344	1.050	2,461	1,116	1.6
1.625	0	218	0	0	0	1,169	0	0	0	0	0	1,387	1.140	1,581	717	1.0
1.750	0	248	64	0	0	2,338	0	0	0	0	0	2,650	1.450	3,842	1,743	2.0
1.875	0	0	173	0	0	4,486	0	0	0	0	0	4,659	1.600	7,454	3,381	3.7
2.000	0	0	0	0	0	0	0	0	0	0	0	0	1.750	0	0	0.0
2.125	0	0	466	0	0	0	0	0	0	0	0	466	2.100	979	444	0.4
2.500	0	0	0	0	0	0	0	0	0	0	0	0	2.480	0	0	0.0
Totals	855	855	855	11,498	11,498	11,498	1,019	1,019	1,019	10,957	10,957	62,030		38,626	**17,521**	**31.8**

*Refrigerant Line Set type copper used for up to 1-5/8". Type ACR used for larger

DETAIL TABLE Q

Duct and Pipe Hangers & Supports

Pipe Hangers	(2) 0.5m long Pipe Hangers per 10 ft of pipe. Each hanger taken as 0.01m diameter steel rod			
Duct Hangers	(2) 0.5m long Duct Hangers per 10 ft of pipe. Each hanger taken as 0.01m diameter steel rod			
Pipe Unistrut Supports	(1) 0.5m long unistrut for every 10 ft of pipe. Each unistrut taken as 0.05m x 0.005m rectangular steel.			
Duct Unistrut Supports	(1) 0.5m long unistrut per 10 ft of duct. Each unistrut taken as 0.05m x 0.005m rectangular steel.			
Pipe Hangers and Supports	Baseline:	2.13 m3	Clark Pacific:*	1.97 m3
Duct Hangers and Supports	Baseline:	0.26 m3	Clark Pacific:	0.26 m3

*50% extra allowance provided for the Clark Pacific Pipe Hangers and Supports to be conservative in favor of the baseline

DETAIL TABLE R

Refrigerant Leakage Rates

VRF Annual Leakage Rate*	3%	ASHP Annual Leakage Rate**	1%
VRF End of Life Recovery Rate	98%	ASHP End of Life Recovery Rate	99%

*VRF Annual Leakage rate chosen to be intentionally conservative to best support the statement "the total whole life carbon emissions for the Baseline Scenario are this or worse" in order to give the most support to any conclusions of relative emission savings between Clark Pacific and Baseline scenarios. To that end, refrigerant leakage rate is a very influential factor. A leakage rate in the lower third of industry aggregated[1] 1-10% VRF leakage rates range was chosen in support of achieving that conservative perspective. There are many built VRF systems measured at 10% leakage rate or higher, so it is justifiable to have picked a middle a higher leakage rate to reflect actual impact. Additionally, compared to a factory assembled refrigerant piping system for the ASHPs, the VRF system has a significantly larger refrigerant piping network, significantly larger number of refrigerant piping fittings, and worse fabrication quality in a field setting. Accordingly, there are far more opportunities for leakage, a higher risk per opportunity, and a reduced visibility to identify occurances of refrigerant leakage. Taken together this intuits that refrigerant leakage is significantly more likely to occur, and for longer time before detection, and be "plugged" less effectively compared to the ASHPs. Lastly, given typical operation and maintenance practices for VRF systems, refrigerant leakage is only examined when the system starts to under perform it's heating and cooling functions or the central system issues an alarm for drop in pressure, both of which indicate refrigerant leakage of at least 20%-30% has already occured. All this is supports that 3% annual leakage rate is abundantly convservative in favor of the Baseline Scenario.

**ASHPs Annual Leakage rate chosen to reflect better piping fabrication quality due to factory assembly and better ability to service and detect leaks compared to field fabricated VRF system. For more information see Refrigerants and Environmental Impacts: A Best Practice Guide [Elementa Consulting]. https://issuu.com/deepgreenengineering/docs/refrigerants___environmental_impacts__elementa

[1]Refrigerants and Environmental Impacts: A Best Practice Guide [Elementa Consulting]. Published September 2020. https://issuu.com/deepgreenengineering/docs/refrigerants___environmental_impacts__elementa

Mechanical

DETAIL TABLE N

Clark Pacific - Mechanical Hydronic System Quantities

Hydronic System Outside Shaft	QTY per Plank	# Planks / LVL	Floor QTY	Building QTY
1/2" PEX Pipe Radiant Tubing (9" o.c.)	1,193 LF	58	69,213 LF	553,707 LF
1" Radiant Manifolds (Six Circuit)**	1 EA	58	58 EA	464 EA
1" Radiant Manifolds (Three Circuit)**	1 EA	58	58 EA	464 EA
1" PEX Pipe (Exposed)**	22 LF	58	1,276 LF	10,208 LF
1-1/2" PEX Pipe (Exposed)	20 LF	58	1,160 LF	9,280 LF
2-1/2" PEX Pipe (Exposed)	20 LF	58	1,160 LF	9,280 LF
2-1/2" Copper Pipe Type L	20 LF	2	40 LF	320 LF
Pipe Insulation (1" Thickness)	-	-	2,360 LF	18,880 LF

*CHW Pipe sizes based on 12 gpm/1000sf flow rate density in perimeter radiant zones and 6 gpm/1000sf in interior zones. HHW Pipe sizes based on 6 gpm/100sf flow rate density in perimeter radiant zones. PEX Piping used for all horizontal distribution (in lieu of Copper) downstream of immediate split adjacent to mechanical shaft. Precast sleeves in plank ribs allow for continuous straight 4-pipe mains, and colocating manifolds adjacent to mains directly under planks reduces piping from mains to manifolds.

**Radiant manifolds plastic multi-port tee type. Plastic manifold material captured by length of 1" PEX.

Hydronic System in Mechanical Shaft	QTY Main / LVL	QTY Riser / LVL	Floor QTY	Building QTY
2-1/2" Copper Pipe Type L*	68 LF	0 LF	68 LF	544 LF
4" Steel Pipe Schd 40	0 LF	50 LF	-	400 LF
6" Steel Pipe Schd 40	0 LF	50 LF	-	400 LF
Pipe Insulation (1" Thickness)	-	68 LF	-	544 LF
Pipe Insulation (2" Thickness)	-	100 LF	-	800 LF

*Includes extra length allowance to get to floor main horizontal distribution

Hydronic System on Roof	Building QTY
DOAS 2-Pipe ASHP (Reverisble Htg/Clg)*	1 EA
Radiant 4-Pipe ASHP (Simul Htg/Clg)*	1 EA
Steel Pipe Schd 40 (4")	160 LF
Steel Pipe Schd 40 (6")	40 LF
Steel Pipe Schd 40 (8")	0 LF
Pipe Insulation (2" Thickness)	200 LF

*Aermec NRP1800 + (1) 700 gal Buffer Tank (~1900lbs - included in Steel Pipe Total).

*Aermec NRP1250 + (2) 500 gal Buffer Tanks (~2250lbs (1125lbs each) - included in Steel Pipe Total).

Pipe Subtotals		
PEX Inslab (1/2")	553,707 LF	23,107 LBS
PEX Exposed Pipe (1")	10,208 LF	1,632 LBS
PEX Exposed Pipe (1-1/2")	9,280 LF	3,102 LBS
PEX Exposed Pipe (2-1/2")	9,280 LF	8,085 LBS
Copper Pipe Type L (2-1/2")	864 LF	2,143 LBS
Steel Pipe Schd 40 (4")	560 LF	6,048 LBS
Steel Pipe Schd 40 (6")	440 LF	8,316 LBS
Steel Buffer Tanks	331 SF	4,970 LBS
Pipe Insulation (1")	10,919 SF	910 FT3
Pipe Insulation (2")	1,755 SF	293 FT3

Hydronic System Totals		
PEX Inslab	553,707 LF	23,107 LBS
PEX Exposed	28,768 LF	12,819 LBS
Copper Pipe	864 LF	2,143 LBS
Steel Pipe (incld. Buffer Tanks)	1,000 LF	19,344 LBS
Pipe Insulation (incld. Buffer Tanks)	12,674 SF	1,202 FT3
Slab ASHP		(1) Aermec NRP1250
DOAS ASHP		(1) Aermec NRP1800

DETAIL TABLE O

Clark Pacific - Mechanical Airside System Quantities

Airside System Outside Shaft	QTY per Plank*	# Planks / LVL	QTY per Plank	Floor QTY	Building QTY
Supply Duct (14"x42")	10 LF	2	142 LBS	284 LBS	2,269 LBS
Supply Duct (12"x26")	10 LF	42	79 LBS	3,324 LBS	26,589 LBS
Supply Duct (10"x18")	10 LF	14	58 LBS	817 LBS	6,532 LBS
Supply Duct (8"x10")	45 LF	20	29 LBS	586 LBS	4,685 LBS
Duct Insulation (14"x42")	10 LF	2	101 SF	201 SF	1,610 SF
Duct Insulation (12"x26")	10 LF	42	69 SF	2,884 SF	23,074 SF
Duct Insulation (10"x18")	10 LF	14	51 SF	713 SF	5,702 SF
Duct Insulation (8"x10")	45 LF	20	32 SF	639 SF	5,115 SF
VAV Box Cooling Only (10")**	1 EA	20	-	20 EA	160 EA
Ceiling Fans (50" Aeratron FR)	2 EA	29		58 EA	464 EA

*Conversion from duct size and length to weight based on steel gage and type consistent with application

**Only up to 4 VAV boxes needed per floor for non DCV constant ventiatlion. To be conservative, used ~1/3 # VAV boxes as baseline VRF Fan Coil quantitiy, equaling 20 VAV boxes per 30,000sf floor.

Airside System in Mechanical Shaft	QTY / LVL	Amount / LVL*	Floor QTY	Building QTY
Supply Duct Horiz. (14"x42")	34 LF	472 LBS	472 LBS	3,779 LBS
Relief Duct Horiz. (14"x42")	34 LF	472 LBS	472 LBS	3,779 LBS
Supply Duct Riser (48"x102")	12.5 LF	776 LBS	776 LBS	6,207 LBS
Relief Duct Riser (48"x102")	12.5 LF	776 LBS	776 LBS	6,207 LBS
Supply Duct Insulation (14"x42")	34 LF	337 SF	337 SF	2,700 SF
Supply Duct Insulation (48"x102")	12.5 LF	361 SF	361 SF	2,889 SF

*Conversion from duct size and length to weight based on steel gage and type consistent with application

Airside Mechanical System on Roof	Building QTY
DOAS Building Air Handler (w/HR)**	42,000 CFM

*IDF cooling system material takeoffs exlcuded from both scenarios to be conservative in favor of the baseline scenario. Operational electricity of IDF cooling is included in both scenarios. Baseline Scenario has a dedicated VRF fan coil for each IDF room and additional refrigerant piping and refrigerant. Clark Pacific scenario uses a small dedicated DOAS w/DX feeding supply shaft direct to IDF room VAV boxes.

**Air handler 100% outside air with supply fan wall, exhaust fans, hydronic coil, particulate filtration sections, and heat recovery via run around coils in extract air and fresh air intake. DOAS sized for the greater of ASHRAE 62.1 and T24 and 30% additional to meet LEED credit. Building DOAS are positoned on top mechanical shaft eliminating rooftop associated exterior ductwork. See mechanical section for more information.

***Additional mechanical equipment common to both scenarios, such as stair pressurization fans and restroom exhaust fans, are excluded from both scenarios

Duct Subtotals		
Duct (48"x102")	200 LF	12,414 LBS
Duct (14"x42")	704 LF	9,827 LBS
Duct (12"x26")	3,360 LF	26,589 LBS
Duct (10"x18")	1,120 LF	6,532 LBS
Duct (8"x10")	7,200 LF	4,685 LBS
Duct Insulation (48"x102")	2,889 SF	241 FT3
Duct Insulation (14"x42")	4,310 SF	359 FT3
Duct Insulation (12"x26")	23,074 SF	1,923 FT3
Duct Insulation (10"x18")	5,702 SF	475 FT3
Duct Insulation (8"x10")	5,115 SF	426 FT3

Airside System Totals		
Ductwork	12,584 LF	60,047 LBS
Duct Insulation	41,091 SF	3,424 FT3
Ceiling Fans		464 EA
VAV Boxes		160 EA
DOAS Air Handler		42,000 CFM

Mechanical

DETAIL TABLE S

Mechanical Product Replacement

	Service Life (yrs)	Baseline Scenario			Clark Pacific Scenario		
		Construction Quantity	Replacement Year 20*	Replacement Year 40*	Construction Quantity	Replacement Year 20*	Replacement Year 40*
Copper Pipe**	60	38,627 lbs	-	-	2,143 lbs	-	-
Steel Pipe	60	-	-	-	19,344 lbs	-	-
PEX Pipe (embedded)	60	-	-	-	23,107 lbs	-	-
PEX Pipe (exposed)	60	-	-	-	12,819 lbs	-	-
Pipe Insulation**	60	1,123 ft3	-	-	1,202 ft3	-	-
Pipe Hangers and Supports**	60	2.13 m3	-	-	1.97 m3	-	-
Ductwork***	40	60,047 lbs	-	60,047 lbs	60,047 lbs	-	60,047 lbs
Duct Insulation***	40	3,424 ft3	-	3,424 ft3	3,424 ft3	-	3,424 ft3
Duct Hangers and Supports***	40	0.26 m3	-	0.26 m3	0.26 m3	-	0.26 m3
VRF Outdoor Units (100 kW each)*	20	15 units	15 units	15 units	-	-	-
ASHP 4-Pipe (290 kW)*	20	-	-	-	1 units	1 units	1 units
ASHP 2-Pipe (420 kW)*	20	-	-	-	1 units	1 units	1 units
VRF Fan Coils (8 kW each)*	20	344 units	344 units	344 units	-	-	-
Air Handlers (42,000 cfm)*	20	1 units	1 units	1 units	1 units	1 units	1 units
VAV Boxes*	20	344 units	344 units	344 units	160 units	160 units	160 units
Ceiling Fans****	60	-	-	-	464 units	-	-

*The baseline scenario has subsantially larger quantity of compressor based equipment and zonal equipment that would be replaced in a tenant improvement event. Accordingly, the B4 emissions increase more in the baseline scenario than Clark Pacific scenario each time there is a replacement event. To be conservative in favor of the baseline, a 20 year service life for all compressor based equipment and a 20 year gap between tenant improvements products was used. 20 years is the high end of the range for both time between retrofits in an occupied building and compressor based equipment service life. What would be replaced or kept intended to match business as usual in such applications

**Refrigerant copper pipe and associated pipe insulation, hangers, and supports in the baseline scenario will be replaced in part in any mechancial TI retrofit. To be conservative in favor of the baseline, this copper pipe was excluded from B4 stage. This amount of excluded copper pipe and supports is not insignificant.

***The 40 year service life comes from CIBSE Guide M for ductwork.The quantity of ductwork is the same in both scenarios so the impact is equal to both scenarios. Ducwork included in scope of study stops at the zonal fan coil / VAV box in each scenario. Any tenant improvement would be mostly limited to duct downstream of this boundary and as such is not considered a replacement event since it was not included in A stage. The amount of ductwork downstream of this boundary is greater in the baseline VRF Fan coil scenario. Excluding this replacement amount is conservative in favor of the baseline.

****Ceiling Fans in Clark Pacific scenario have brushless DC motors with a ultra low power draw maximum equivalent to a single typical residential CFL light bulb. While there will be some failures over the years, Aeratron ceiling fans, and others in this class of airfoil design and engineering quality that provide free 30 year motor warranties (like Aeratron), can last the whole building life. It's also possible a tenant improvement would remove but not replace ceiling fans due to changes in space use. Accordingly, the B3 Repair stage, set to 10% of the total A1-A4 stage emissions following CIBSE Guide M, essentially equates to 10% replacement as there is essentially no maintenance for these types of fans. Any arguments made that this still undercounts the replacement is more than offset by the large amount of excluded refrigerant pipe in VRF tenant imporvements that is excluded from the baseline.

Mechanical Replacement Totals	**Total Avoided Mech. Replacement** (Baseline - Clark Pacific)	**Baseline Scenario** (Total Replaced)	**Clark Pacific Scenario** (Total Replaced)
ASHP Outdoor Units	**1,580kW of Outdoor Heat Pump**		1,420 kW
VRF Outdoor Units		3,000 kW	
VRF Fan Coils	**5,504kW of Indoor Fan Coils**	5,504 kW	
VAV Boxes	**368 VAV boxes**	688 ea.	320 ea.
DOAS	**-**	84,000 cfm	84,000 cfm
Ductwork	**-**	60,047 lbs	60,047 lbs
Duct Insulation	**-**	3,424 ft3	3,424 ft3
Duct Hangers and Supports	**-**	0.26 m3	0.26 m3

DETAIL TABLE U.1

Operational Electricity Model Inputs – **Building Physical Composition**

BASELINE SCENARIO: STEEL + VRF

Overall Geometry

- 240,000 sf building composed of 8 equal (30,000 sf) levels

Floor Height

- 15ft floor-to-floor

Glazing (transparent)

- Amount: 8ft high continuous ribbon from sill 2'6" AFF
- Type: Solarban 70XL (SHGC: 0.32 clear; U-Value: 0.36 including frames; Tvis: 0.56)

Exterior Shading

- None

Wall (opaque elements)

- Insulated Spandrel: R-Value: 7.0 overall assembly from combination of opaque spandrel glass and lightweight wall w/6" studs @ 24" o.c and R19 batt)

Roof

- R-Value: 20.0 overall assembly (4" continuous rigid insulation)

CLARK PACIFIC SCENARIO: PRECAST + RADIANT

Overall Geometry

- 240,000 sf building composed of 8 equal (30,000 sf) levels

Floor Height

- 13ft floor-to-floor

Glazing (transparent)

- Amount:* 8ft high continuous ribbon from sill 2'6" AFF
- Type: Solarban 70XL (SHGC: 0.32 clear; U-Value: 0.36 including frames; Tvis: 0.56)

**Actual glazing amount in Clark Pacific scenario is lower in portions with Infinite Façade, which has have the same height glazing, but with punched openings (with small amount of wall in between) instead of a continuous ribbon. For model simplicity, Infinite Façade sections modeled as continuous ribbon with glass at correct height. This additional glazing is conservative in favor of the baseline from the perspective of electricity use carbon.*

Exterior Shading

- Where: South and West Facades
- Amount: (2) continuous rows of 14" depth shades
- Height: (lower shade 7ft AFF, upper shade 9ft AFF)

Wall (opaque elements)

- Insulated Spandrel: R-Value: 7.0 overall assembly from combination of opaque spandrel glass and lightweight wall w/6" studs @ 24" o.c and R19 batt)
- Infinite façade: R-Value: 10.55 overall assembly to represent W3 Wall Type* (2" continuous insulation + precast concrete + airgap with furred out walls.

**Infinite Façade physical composition taken from Clark Pacific Infinite Façade LCA Report_Rev1 - provided to Integral Group by Clark Pacific.*

Roof

- R-Value: 20.0 overall assembly (4" continuous rigid insulation)

DETAIL TABLE U.2

Operational Electricity Model Inputs – **Building Physical Composition (continued)**

BASELINE SCENARIO: STEEL + VRF

Thermal Mass

- "Floor Slab" (excluding roof slab and slab on grade)
  - All mass: lightweight topping slab on metal deck is entirely thermally isolated behind finishes
  - On top: thin carpet tile (same as Clark Pacific scenario)*
  - On bottom: full ACT ceiling below
- Slab on grade: same as Clark Pacific scenario. 1" insulation is not business as usual (typ. none). conservative in favor of the baseline.
- Roof Slab: Same as Clark Pacific scenario.
- Conference Rooms: thermal mass 100% blocked by ACT ceiling
- Office and Support: thermal mass 100% blocked by ACT ceiling
- Furniture: internal mass of furniture included.
- Other thermal mass: All structural steel columns, beams, braces are not included in this model to limit file complexity. Steel is mostly thermally isolated in-reality via either fire protection or above a ceiling.

**Carpet modeled same as the (R-0.5) thin carpet tile in Clark Pacific Scenario for model simplicity. Without a radiant system, attention would not be given to carpet R-Value and likely would be R-1.0 or higher. Using R-0.5 results in more thermal mass exchange and thus is conservative in favor of the baseline.*

CLARK PACIFIC SCENARIO: PRECAST + RADIANT

Thermal Mass

- Floor Slab (excluding roof slab and slab on grade):
  - Mass: 5" thick concrete (density: 135 lbs/ft3**, conductivity: 2.31 W/mK, heat capacitance: 832 J/kgK).
  - On top: thin carpet tile in all spaces (R-0.5 overall assembly including backing).
  - On bottom: exposed. no covering.
- Slab on Grade: same as floor slab except 1" of insulation on bottom.
- Roof Slab: same as floor slab except insulation on top instead of carpet.
- Conference Rooms: Partially exposed overhead mass (64% ACT ceiling coverage)***
- Office and Support: Fully exposed overhead mass (no ceilings). See note below****
- Furniture: internal mass of furniture included.
- Other thermal mass: floor plank ribs, interior beams, exterior beams, and columns are all not included in this model to limit file complexity. This is conservative in favor of the baseline.

***Density matches that of Mix A used for the floor planks.*

****See note below. That study also showed that 64% ceiling coverage and no fan results in a roughly 20% lower overall cooling from the actively cooled surface. 64% ceiling coverage is typically more than sufficient for acoustical needs, resulting in only a 1-2ft gap at the edge of the ceiling from the wall. This effect allows the radiant to help in conference rooms and is important feature of this simulation.*

*****Office and support areas modeled with fully exposed mass and no ceilings to represent the reality of varying amounts of partial ceiling with ceiling fans. The CBE performed chamber testing on varying amounts of ceiling and ceiling fans and direction, publishing a research paper of their findings quantifying the relationship.[13] The study found that a cooled surface provided the same total cooling to the space with 64% ceiling coverage and a ceiling fan blowing down vs. no ceiling and no fan. This phenomenon has also been empirically verified by successful applications in real built Integral Group designs. Accordingly, while the CBE also demonstrated that ceiling fans and ceiling clouds can be modeled in EnergyPlus, without final tenant specific wall arrangement modeling partial ceiling and ceiling fans would be more likely to be further from reality than modeling as no ceiling and no ceiling fans.*

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[13] **Effect of acoustical clouds coverage and air movement on radiant chilled cooling capacity**. *Caroline Karmann, Fred Bauman, Paul Raftery, Stefano Schiavon, Mike Koupriyanov*. Energy and Buildings; January 2018. (https://www.sciencedirect.com/science/article/abs/pii/S0378778817319898)

DETAIL TABLE U.3

Operational Electricity Model Inputs – **Space Types**

Office

Occupancy: 190 sf/person
Equipment: 1.0 W/sf
Lighting: 0.5 W/sf

Occupancy Schedules: careful attention was given to develop occupancy schedules that reflected the ground truths of only so many people are in an office building at one time and that a person cannot be in two places at once (at their desk and in a meeting room at the same time). Adding up every zone at max occupancy simultaneously leads to enormously large and wrong people counts. See Building Occupancy graphic shortly after this table.

Equipment Schedules: careful attention was given to match any per person equipment use to the same profile patterns in the occupancy schedules. 24/7 equipment baseload and after-hours equipment baseload were broken out as separate schedules to allow the people variable equipment loads to vary.

Lighting Schedules: follows a separate binary schedule composed from occupancy schedule, such that any time occupancy fraction = 0, the lighting schedule fraction = 0 (reflecting that no one is actually there so lights should turn off). All other times lighting schedule fraction = 1. On top of lighting schedule, daylight harvesting is carried in perimeter offices with 35 foot candle setpoint.

Core Support

The support space type represents additional corridors, circulation, and breakroom style gathering spaces. These are low lighting power density zones as no occupants are permanently seated. Most of total building occupancy is intended to be handled in the office and conference type spaces

Occupancy: 1000 sf/person
Equipment: 0.85 W/sf
Lighting: 0.15 W/sf

Schedules: occupancy, plug loads, and lighting is unvarying for all occupied hours.

Baseloads Common to All

24/7 Equipment: 0.0335 W/sf applied every hour of the year to reflect time independent electrical use
After-hours Equipment: 0.15 W/sf applied outside occupancy every hour to reflect realistic electric nighttime use (which is stubbornly never as near zero as we'd all like).
24/7 Interior Lighting: 0.05 W/sf applied every hour of the year to reflect time independent lighting and better match actual observed lighting behavior.

This approach, combined with the occupancy varying plug loads, results in total plug loads more consistent with empirically observed hourly, daily, and annual amounts than conventional modeling approaches.

Conference

Occupancy: 20 sf/person
Equipment: 1.5 W/sf
Lighting: 0.6 W/sf

Occupancy Schedules: like office, careful attention was given to develop occupancy schedules that reflected actual use. Four different conference room types were created: Type A and B, to represent conditions of sparse use (1-2 people working); Type C, for more typical medium use with intermediate empty periods; and Type D, for rooms seeing repeated dense use. See Building Occupancy graphic shortly after this table.

Equipment Schedules: careful attention was given to match any per person equipment use to the same profile patterns in the occupancy schedules. High peak plug loads (consistent with typical modeling practices) still occur, but are only realized 1 hour per day in the densest conference rooms. E.g. schedules achieve the real-world diversity in use rather than lower more constant values ending at similar annual plug loads. 24/7 equipment baseload and after-hours equipment baseload were broken out as separate schedules to allow the people variable equipment loads to vary.

Lighting Schedules: follows a separate binary schedule composed in the same manner as the office lighting schedules.

Core Unoccupied

The unoccupied space type represents mechanical rooms, elevator rooms, and IDF rooms. No people or lights are modeled in these spaces (as while people will go in these rooms and turn on lights, this happens for a negligible amount of time). Total power draw meant to reflect typically observed for these space types.

Occupancy: none
Equipment 2.1 W/sf
Lighting: none

Schedules: plug loads are taken as unvarying for all hours of the year.

Zoning

See Thermal Zones graphic following shortly after this table. 20' perimeter office zones, 20' core office ring, 10' core conference room ring, 25' core split into two zones for semi-occupied and unoccupied support zones. 112 zone model.

DETAIL TABLE U.4

Operational Electricity Model Inputs – **Systems (Part 1)**

BASELINE SCENARIO: STEEL + VRF

Space Heating and Cooling

VRF Condenser System – Space Heating & Cooling: Following the Baseline Mechanical Schematic illustration, all building space heating and cooling is modeled as served by a single VRF heat recovery type condensers system. This differs from the actual baseline mechanical design in one critical way. The actual building is served by a total of 10 separate condensing units, not one single combined one. This is due to the physical limitations of VRF systems given the building height and size. Accordingly, the model overestimates the amount of VRF heat recovery from simultaneous heating and cooling. Without having exact floor plans, it is difficult to answer the degree to which this is overstating VRF heat recovery, but it is certainly doing so. This is not insignificant.

VRF modeled using default VRF Object from Open Studio v3.1.0, the most recent release (at the time of this publication). Changed minimum turndown from 25% to 50% to reflect high refrigerant piping distances and elevation in this 8-story 240,000 sf building application. Field observations of real installed VRF systems have consistently shown much less turndown than catalog equipment minimum in large installations. This adjustment is intended to be still conservative in favor of the baseline.

VRF Fan Coils operate continuously during occupied hours, and are allowed to cycle at night. 1.4" w.c. total static representing pressure drop across the coil, return air grille and ductwork, and supply air ductwork through farthest diffuser. Total fan efficiency of 0.55.

Cooling gross rated COP is 3.34 and gross rated heating COP is 3.41

DOAS Heating and Cooling

VRF Condenser System – DOAS Heating & Cooling: Following the Baseline Mechanical Schematic illustration, all DOAS heating and cooling is modeled as served by a separate single VRF condenser system (reversible non-heat recovery type). This differs from the actual baseline mechanical design in that a single unit is modeled as serving the DOAS instead of (5) separate condensing units; however, without heat recovery and the close proximity of the condensing units to the DOAS make this nuance insignificant.

VRF modeled using default VRF Object from Open Studio v3.1.0, the most recent release (at the time of this publication). Unlike the Space Heating & Cooling VRF Condensing System, minimum turndown left at default 25% to reflect short refrigerant piping distance from DOAS VRF Condensing Units to DOAS.

CLARK PACIFIC SCENARIO: PRECAST + RADIANT

Space Heating and Cooling

Slab ASHP – Space Heating & Cooling: Following the Clark Pacific Mechanical Schematic illustration, all space heating and cooling electricity use is modeled in the following manner

- Step 1 - Loads: EnergyPlus simulation models separate district heating and district cooling loops with COP set equal to 1 to allow for export of raw heating and cooling loads. This simulation uses the radiant slab controls, availability schedule, and learning modules described in the Methodology section. The capacity of each district loop is hard sized at the exact design capacities of the actual mechanical design ASHP (final iteration used (1) Aermec NRP1250). This sizing influences the learning and thus loads of the simulation. A thorough review of unmet hours and PMV is performed to ensure system was able to maintain excellent comfort with chosen hard-sized district capacities. 8760 hourly loads for both loops are exported to excel.
- Step 2 – Simultaneous Loading, Mode, and % Part Load: Slab Heating and Slab Cooling loads are examined on an hourly basis to identify simultaneous heating and cooling. This is used to define the Aermec unit mode of operation (heating dominant or cooling dominant) and the capacity required in that mode) and the resultant % compressor loading for each hour. Unit Capacity is based on manufacturer provided data for specific Slab supply water temps
- Step 3 – Apply COP Curves: The hourly loads are converted to electricity use using manufacturer provided COP performance data specific for 3 independent variables (% loading, ambient air temp, and supply water temp).

DOAS Heating and Cooling

DOAS ASHP – DOAS Heating & Cooling: Following the Clark Pacific Mechanical Schematic illustration, all DOAS heating and cooling electricity use is modeled in the following manner

- Step 1 – Loads: EnergyPlus simulation models separate heating and cooling loops for the coils in the modeled DOAS unit. Resulting Loads from ventilation air flow, current outside air conditions, impact of air-to-air heat recovery, and LAT set point yield annual hourly DOAS heating and cooling loads that are exported to excel
- Step 2 –Mode and % Part Load: DOAS Heating and Cooling loads are examined on an hourly basis to identify mode of operation and the resultant % compressor loading for each hour. Unit capacity is based on manufacturer provided capacities at the specific DOAS supply water temps.
- Step 3 – Apply COP Curves: The hourly loads are converted to electricity use using manufacturer provided COP performance data specific for 3 independent variables (% loading, ambient air temp, and supply water temp).

DETAIL TABLE U.5

Operational Electricity Model Inputs – **Systems (Part 2)**

BASELINE SCENARIO: STEEL + VRF

DOAS Air Handler

DOAS Ventilation & Exhaust: Following the Baseline Mechanical Schematic illustration, the baseline DOAS is modeled as a single air handler system in EnergyPlus that provides 100% outside air based on ventilation requirements from each space. This airflow includes constant volume spaces (office and support) and variable volume spaces (DCV conference rooms). Air-to-air heat recovery preheat/precool is modeled using design heating condition 40% heat recovery effectiveness to represent a run-around coil type heat recovery system. Exhaust is set equal to Ventilation for model simplicity. This may slightly overstate exhaust fan energy, but the difference is negligible, applies equally to both scenarios, and is well within the margin of error of the impact of actual building infiltration, wind, and other pressurization impacting phenomenon. Fan size and energy modeled off design condition 2.5” TSP supply fan and 1.5” TSP exhaust fan. In actual operation TSP will be both lower and higher depending on where particulate filters are in their service life.

Conference Rooms (DCV)

VAV Box – Demand Control Ventilation: Following the Baseline Mechanical Schematic illustration, the baseline conference room zones are all modeled with their own VAV box to do deliver ventilation based on occupancy (using 15 cfm/person DCV minimum). All heating or cooling is provided by VRF fan coils.

Zonal Heating and Cooling

VRF Fan Coil Units: Each zone is modeled as having its own VRF Fan Coil to provide full space heating and cooling. This was modeled using the default controls in Open Studio v3.1.0, the most recent release (at the time of this publication).

IDF Room Cooling

VRF Condenser System – IDF Rooms: Following the Baseline Mechanical Schematic illustration, a separate dedicated VRF Condenser System is modeled as serving all IDF rooms via zonal VRF Fan Coils. VRF Fan Coils sized to maintain 76F maximum room temp. Uses default VRF Object from Open Studio v3.1.0, the most recent release (at the time of this publication). Minimum turndown left at default 25% to reflect shorter refrigerant piping length than Building Space Heating and Cooling VRF Condensing Systems.

CLARK PACIFIC SCENARIO: PRECAST + RADIANT

DOAS Air Handler

DOAS Ventilation & Exhaust: Following the Clark Pacific Mechanical Schematic illustration, the baseline DOAS is modeled as a single air handler system in EnergyPlus that provides 100% outside air based on ventilation requirements from each space. This airflow includes constant volume spaces (office and support) and variable volume spaces (DCV +cooling assist conference rooms). Air-to-air heat recovery preheat/precool is modeled using design heating condition 40% heat recovery effectiveness to represent a run-around coil type heat recovery system. Exhaust is set equal to Ventilation for model simplicity. This may slightly overstate exhaust fan energy, but the difference is negligible, applies equally to both scenarios, and is well within the margin of error of the impact of actual building infiltration, wind, and other pressurization impacting phenomenon. Fan size and energy modeled off design condition 2.5” TSP supply fan and 1.5” TSP exhaust fan. In actual operation TSP will be both lower and higher depending on where particulate filters are in their service life.

Conference Rooms (DCV)

VAV Box – Demand Control Ventilation + Cooling: Following the Baseline Mechanical Schematic illustration, the baseline conference room zones are all modeled with their own VAV box to do deliver ventilation based on occupancy (using 15 cfm/person DCV minimum) and maintain zone air temp cooling set point as needed in response to what the radiant slab isn’t able to accomplish. VAV boxes are hard sized to 1 cfm/sf to ensure enough air flow is available to use elevated 65F DOAS SAT. The resulting coincident DOAS peak airflow from diversified peak load is minusculey higher because of this cooling air flow assist.

Zonal Heating and Cooling

Radiant Slab Heating & Cooling: Each zone is modeled in Open Studio v3.1.0 as having its own Radiant Slab system following the approach provided in the methodology section. Perimeter zones can do heating or cooling; interior are cooling only.

IDF Room Cooling

DOAS DX Package Unit – IDF Rooms: Following the Clark Pacific Mechanical Schematic illustration, a separate dedicated 100% outside air rooftop package DX unit serves only IDF rooms via VAV boxes (no coil). Zone VAV boxes auto-sized to maintain 76F maximum room temp with 65F supply air. AHU only cools air if OAT above 65F. VAV closes when room temp below room cooling set point. Uses, the default 1 speed DX condenser object from Open Studio v3.1.0

DETAIL TABLE U.6

Operational Electricity Model Inputs – **Controls**

BASELINE SCENARIO: STEEL + VRF

DOAS Air Handler

DOAS Ventilation & Exhaust: SAT setpoint uses the following logic.

- SAT = 70F when in operation

Zone Air Set Point

Occupied Hours: 72F heating setpoint; 74F cooling set point
Unoccupied Hours: 60F heating setback; 80F cooling setback

CLARK PACIFIC SCENARIO: PRECAST + RADIANT

DOAS Air Handler

DOAS Ventilation & Exhaust: SAT setpoint uses the following logic.

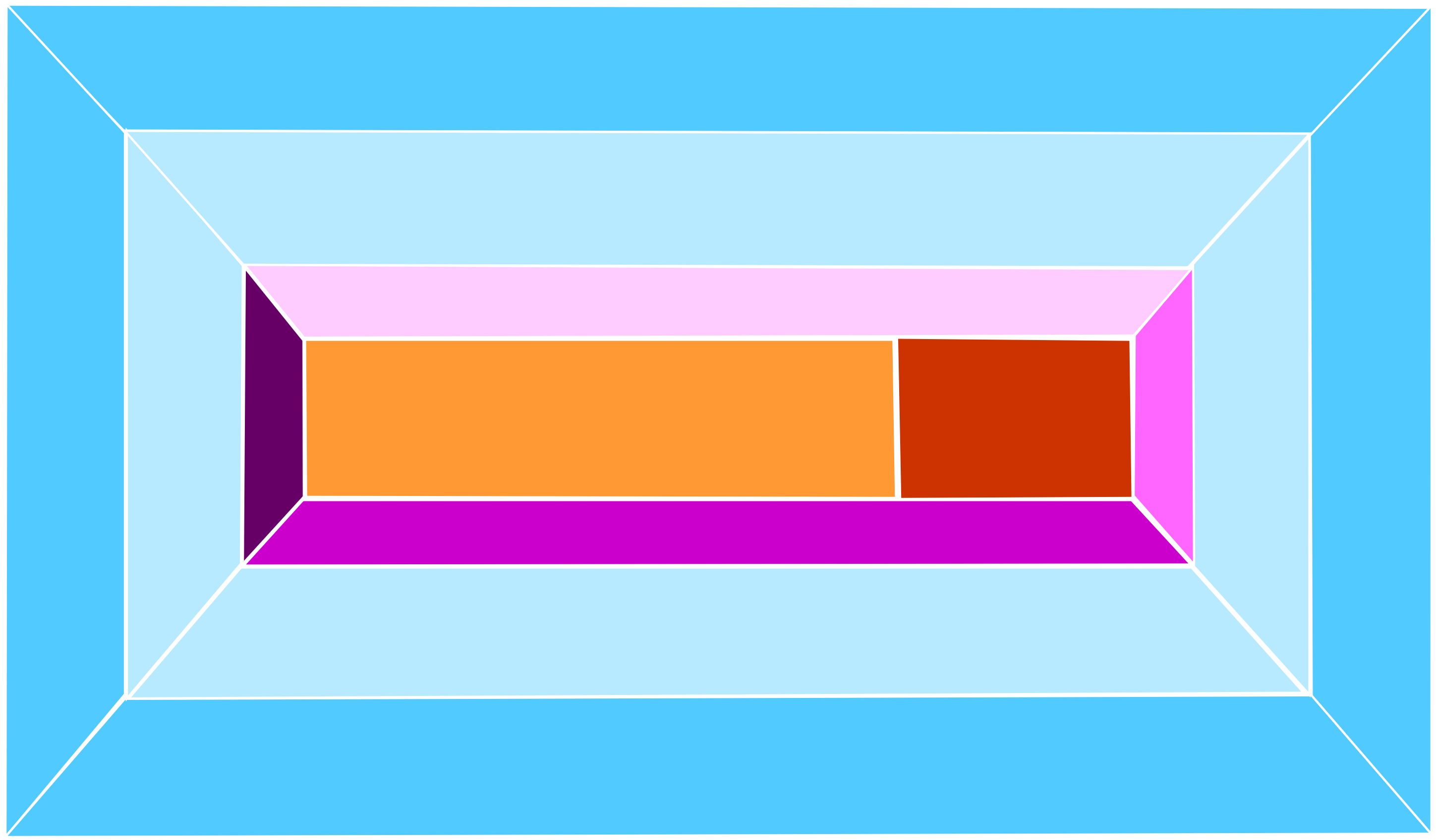
- IF OAT < 55F THEN SAT = 65F
- ELSE IF OAT > 75F THEN SAT = 60F
- ELSE IF 55F≤OAT≤75F THEN SAT linear reset 65F to 60F

Zone Air Set Point

Dynamic slab setpoint learns to ensure room air temp stays within 68F heating and 78F cooling air temp limits. See Methodology section for more information

PMV was reviewed to ensure that the expanded air temperature ranges along with active mean radiant temperature control result in a PMV of +0.5 (superior comfort). With ceiling fans and a 0.61 clothing factor (trousers, button-up shirt, no tie), the 78F upper limit is appropriate in cooling, and 68F heating is appropriate for heating.

Thermal Zones by Space Type for Typical Floor Plate



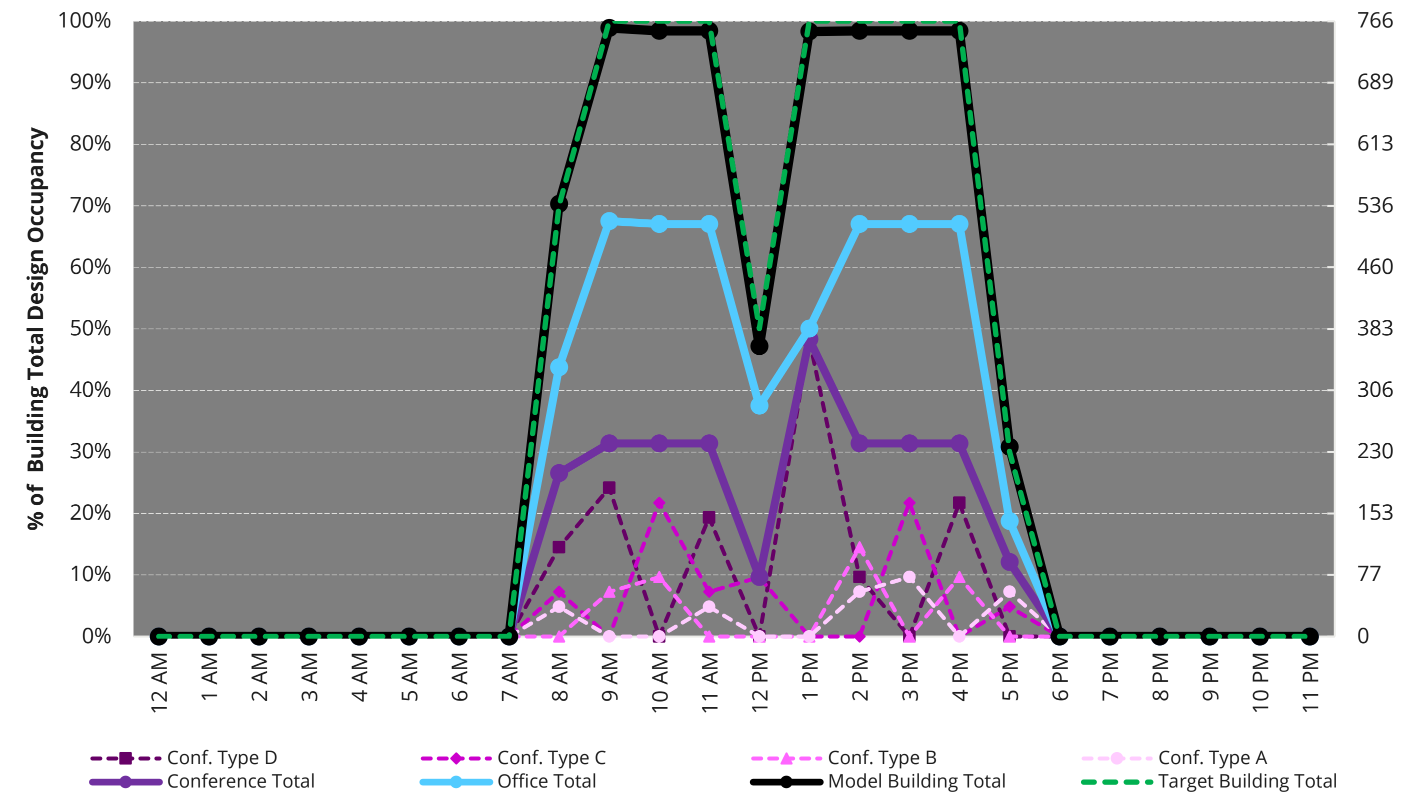
Zone Map

Legend			Building Area Total
1		Office - Exterior	104,000 sf
2		Office - Interior	78,400 sf
3		Conference Type A	7,400 sf
4		Conference Type B	7,400 sf
5		Conference Type C	7,400 sf
6		Conference Type D	7,400 sf
7		Core Support	8,000 sf
8		Core Unoccupied	20,000 sf

*Note: Conference type assignement changes per level, such that each type has equal area building wide.

Building Occupancy

Hourly Profiles by Space Type



DETAIL TABLE T

Modeled Occupancy Totals and Hourly Profiles

Target Total Building Occupancy																								
(Based on on all building's office space at 190 sf/person with 80% diversity. That total population moves between office and conference)																								
Diversity	0%	0%	0%	0%	0%	0%	0%	0%	56%	80%	80%	80%	40%	80%	80%	80%	80%	24%	0%	0%	0%	0%	0%	0%
Target Total People	0	0	0	0	0	0	0	0	536	766	766	766	383	766	766	766	766	230	0	0	0	0	0	0
Office Modeled																								
(Target fraction based on 2/3rd of diversified total building occupancy located in the 182,000sf of office area)																								
Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.54	0.54	0.54	0.30	0.40	0.54	0.54	0.54	0.15	0.00	0.00	0.00	0.00	0.00	0.00
# Office People	0	0	0	0	0	0	0	0	335	517	513	513	287	383	513	513	513	144	0	0	0	0	0	0
% Building Total	0%	0%	0%	0%	0%	0%	0%	0%	62%	68%	68%	68%	80%	51%	68%	68%	68%	61%	0%	0%	0%	0%	0%	0%
Conference Modeled																								
(Target fraction based on 1/3rd of diversified total building occupancy located in 29,600sf of conference rooms)																								
Conference Type A - Lightest Occupancy Use (7,400sf)																								
Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.15	0.20	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00
# People	0	0	0	0	0	0	0	0	37	0	0	37	0	0	56	74	0	56	0	0	0	0	0	0
Conference Type B - Light Occupancy Use (7,400sf)																								
Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.20	0.00	0.00	0.00	0.30	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
# People	0	0	0	0	0	0	0	0	0	56	74	0	0	0	111	0	74	0	0	0	0	0	0	0
Conference Type C - Medium Occupancy Use (7,400sf)																								
Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.45	0.15	0.20	0.00	0.00	0.45	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
# People	0	0	0	0	0	0	0	0	56	0	167	56	74	0	0	167	0	37	0	0	0	0	0	0
Conference Type D - High Occupancy Use (7,400sf)																								
Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.50	0.00	0.40	0.00	1.00	0.20	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
# People	0	0	0	0	0	0	0	0	111	185	0	148	0	370	74	0	167	0	0	0	0	0	0	0
Conference Total Modeled																								
# Conference People	0	0	0	0	0	0	0	0	204	241	241	241	74	370	241	241	241	93	0	0	0	0	0	0
% Building Total	0%	0%	0%	0%	0%	0%	0%	0%	38%	32%	32%	32%	20%	49%	32%	32%	32%	39%	0%	0%	0%	0%	0%	0%
Modeled Total Building Occupancy																								
# Model Total People	0	0	0	0	0	0	0	0	539	758	754	754	361	753	754	754	754	236	0	0	0	0	0	0

DETAIL TABLE D

Aermec NRP CHW COP Performance Data

NRP 1800 COP Performance Data @ 65F CHWS						
% Compressor	Ambient Air Temp					
Loading	50°F	60°F	70°F	80°F	90°F	100°F
100%	5.89	5.46	4.91	4.32	3.73	3.18
75%	6.43	6.04	5.50	4.87	4.24	3.62
50%	6.74	6.44	5.95	5.34	4.70	4.05
25%	5.79	5.59	5.23	4.74	4.21	3.66

NRP 1800 COP Performance Data @ 60F CHWS						
% Compressor	Ambient Air Temp					
Loading	50°F	60°F	70°F	80°F	90°F	100°F
100%	5.78	5.34	4.79	4.19	3.60	3.05
75%	6.32	5.92	5.37	4.73	4.09	3.48
50%	6.63	6.30	5.80	5.17	4.52	3.88
25%	5.77	5.54	5.15	4.64	4.09	3.53

NRP 1800 COP Performance Data @ 55F CHWS						
% Compressor	Ambient Air Temp					
Loading	50°F	60°F	70°F	80°F	90°F	100°F
100%	5.65	5.20	4.63	4.03	3.44	2.89
75%	6.17	5.76	5.19	4.54	3.91	3.29
50%	6.47	6.12	5.59	4.95	4.30	3.65
25%	5.73	5.46	5.03	4.49	3.92	3.35

NRP 1800 COP Performance Data @ 45F CHWS						
% Compressor	Ambient Air Temp					
Loading	50°F	60°F	70°F	80°F	90°F	100°F
100%	5.35	4.88	4.31	3.69	3.10	2.57
75%	5.84	5.39	4.81	4.14	3.51	2.91
50%	6.10	5.71	5.15	4.49	3.83	3.21
25%	5.56	5.22	4.74	4.14	3.55	2.98

DETAIL TABLE E

Aermec NRP HHW COP Performance Data

NRP 1800 COP Performance Data @ 85F HHWS							
% Compressor	Ambient Air Temp						
Loading	35°F	40°F	45°F	50°F	55°F	60°F	65°F
100%	3.26	4.01	4.60	4.91	5.15	5.32	5.45
75%	3.36	4.10	4.66	5.00	5.28	5.48	5.61
50%	3.46	4.21	4.73	5.09	5.39	5.60	5.76
25%	3.35	4.05	4.56	4.88	5.13	5.31	5.43

NRP 1800 COP Performance Data @ 90F HHWS							
% Compressor	Ambient Air Temp						
Loading	35°F	40°F	45°F	50°F	55°F	60°F	65°F
100%	3.02	3.69	4.25	4.54	4.76	4.93	5.06
75%	3.12	3.79	4.32	4.63	4.88	5.07	5.22
50%	3.21	3.90	4.40	4.74	5.00	5.20	5.36
25%	3.11	3.76	4.24	4.55	4.77	4.95	5.07

NRP 1800 COP Performance Data @ 100F HHWS							
% Compressor	Ambient Air Temp						
Loading	35°F	40°F	45°F	50°F	55°F	60°F	65°F
100%	2.64	3.20	3.70	3.96	4.16	4.31	4.43
75%	2.74	3.30	3.78	4.05	4.28	4.44	4.57
50%	2.85	3.42	3.88	4.17	4.40	4.58	4.71
25%	2.76	3.31	3.75	4.02	4.22	4.37	4.48

NRP 1800 COP Performance Data @ 110F HHWS							
% Compressor	Ambient Air Temp						
Loading	35°F	40°F	45°F	50°F	55°F	60°F	65°F
100%	2.31	2.79	3.24	3.48	3.66	3.81	3.91
75%	2.42	2.90	3.33	3.57	3.77	3.94	4.04
50%	2.52	3.02	3.44	3.68	3.91	4.07	4.18
25%	2.45	2.92	3.34	3.57	3.76	3.90	4.00

**COP performance data provided directly from manufacturer stating that COP variance between NRP sizes 800 and up is very small.*

DETAIL TABLE F

Radiant Slab Heat Pump Cooling COP Performance Data

NRP1250 COP Performance Data @ 65F CHWS

% Compressor Loading	Ambient Air Temp																									
	50°F	52°F	54°F	56°F	58°F	60°F	62°F	64°F	66°F	68°F	70°F	72°F	74°F	76°F	78°F	80°F	82°F	84°F	86°F	88°F	90°F	92°F	94°F	96°F	98°F	100°F
100%	5.89	5.80	5.72	5.63	5.55	5.46	5.35	5.24	5.13	5.02	4.91	4.79	4.67	4.56	4.44	4.32	4.20	4.08	3.97	3.85	3.73	3.62	3.51	3.40	3.29	3.18
95%	6.00	5.91	5.83	5.75	5.66	5.58	5.47	5.36	5.25	5.14	5.03	4.91	4.79	4.67	4.55	4.43	4.31	4.19	4.07	3.95	3.83	3.72	3.61	3.49	3.38	3.27
90%	6.11	6.02	5.94	5.86	5.78	5.69	5.58	5.47	5.37	5.26	5.15	5.03	4.90	4.78	4.66	4.54	4.42	4.30	4.18	4.05	3.93	3.82	3.70	3.59	3.47	3.36
85%	6.22	6.13	6.05	5.97	5.89	5.81	5.70	5.59	5.48	5.37	5.27	5.14	5.02	4.90	4.77	4.65	4.53	4.41	4.28	4.16	4.03	3.92	3.80	3.68	3.56	3.44
80%	6.32	6.24	6.16	6.09	6.01	5.93	5.82	5.71	5.60	5.49	5.38	5.26	5.14	5.01	4.89	4.76	4.64	4.51	4.39	4.26	4.14	4.02	3.89	3.77	3.65	3.53
75%	6.43	6.35	6.28	6.20	6.12	6.04	5.93	5.83	5.72	5.61	5.50	5.38	5.25	5.12	5.00	4.87	4.75	4.62	4.49	4.36	4.24	4.11	3.99	3.87	3.74	3.62
70%	6.49	6.42	6.35	6.27	6.20	6.12	6.02	5.91	5.80	5.70	5.59	5.47	5.34	5.22	5.09	4.97	4.84	4.71	4.58	4.46	4.33	4.21	4.08	3.96	3.83	3.71
65%	6.56	6.49	6.42	6.34	6.27	6.20	6.10	5.99	5.89	5.79	5.68	5.56	5.43	5.31	5.18	5.06	4.93	4.80	4.68	4.55	4.42	4.30	4.17	4.05	3.92	3.79
60%	6.62	6.55	6.49	6.42	6.35	6.28	6.18	6.08	5.98	5.87	5.77	5.65	5.52	5.40	5.28	5.15	5.02	4.90	4.77	4.64	4.51	4.39	4.26	4.13	4.01	3.88
55%	6.68	6.62	6.55	6.49	6.43	6.36	6.26	6.16	6.06	5.96	5.86	5.74	5.61	5.49	5.37	5.25	5.12	4.99	4.86	4.73	4.61	4.48	4.35	4.22	4.09	3.97
50%	6.74	6.68	6.62	6.56	6.50	6.44	6.34	6.25	6.15	6.05	5.95	5.83	5.71	5.58	5.46	5.34	5.21	5.08	4.95	4.83	4.70	4.57	4.44	4.31	4.18	4.05
45%	6.55	6.50	6.44	6.39	6.33	6.27	6.18	6.09	5.99	5.90	5.81	5.69	5.57	5.45	5.34	5.22	5.10	4.97	4.85	4.72	4.60	4.47	4.35	4.23	4.10	3.98
40%	6.36	6.31	6.26	6.21	6.16	6.10	6.01	5.93	5.84	5.75	5.66	5.55	5.44	5.32	5.21	5.10	4.98	4.86	4.74	4.62	4.50	4.38	4.26	4.14	4.02	3.90
35%	6.17	6.13	6.08	6.03	5.98	5.93	5.85	5.77	5.68	5.60	5.52	5.41	5.30	5.19	5.09	4.98	4.87	4.75	4.64	4.52	4.41	4.29	4.17	4.05	3.94	3.82
30%	5.98	5.94	5.90	5.85	5.81	5.76	5.68	5.61	5.53	5.45	5.37	5.27	5.17	5.06	4.96	4.86	4.75	4.64	4.53	4.42	4.31	4.20	4.08	3.97	3.85	3.74
25%	5.79	5.75	5.71	5.67	5.63	5.59	5.52	5.45	5.37	5.30	5.23	5.13	5.03	4.94	4.84	4.74	4.64	4.53	4.42	4.32	4.21	4.10	3.99	3.88	3.77	3.66

DETAIL TABLE G

Radiant Slab Heat Pump Heating COP Performance Data

NRP1250 COP Performance Data @ 85F HHWS

% Compressor Loading	Ambient Air Temp																													
	35°F	36°F	37°F	38°F	39°F	40°F	41°F	42°F	43°F	44°F	45°F	46°F	47°F	48°F	49°F	50°F	51°F	52°F	53°F	54°F	55°F	56°F	57°F	58°F	59°F	60°F	61°F	62°F	63°F	64°F	65°F
100%	3.26	3.41	3.56	3.71	3.86	4.01	4.13	4.25	4.36	4.48	4.60	4.66	4.72	4.79	4.85	4.91	4.96	5.01	5.05	5.10	5.15	5.18	5.22	5.25	5.29	5.32	5.35	5.37	5.40	5.42	5.45
95%	3.28	3.43	3.58	3.73	3.88	4.03	4.15	4.26	4.38	4.50	4.61	4.68	4.74	4.80	4.87	4.93	4.98	5.03	5.08	5.13	5.18	5.21	5.25	5.28	5.32	5.35	5.38	5.40	5.43	5.46	5.48
90%	3.30	3.45	3.60	3.75	3.90	4.05	4.16	4.28	4.39	4.51	4.62	4.69	4.75	4.82	4.88	4.95	5.00	5.05	5.10	5.15	5.20	5.24	5.27	5.31	5.35	5.38	5.41	5.44	5.46	5.49	5.52
85%	3.32	3.47	3.62	3.77	3.92	4.07	4.18	4.29	4.41	4.52	4.64	4.70	4.77	4.83	4.90	4.97	5.02	5.07	5.12	5.17	5.23	5.26	5.30	5.34	5.38	5.41	5.44	5.47	5.49	5.52	5.55
80%	3.34	3.49	3.64	3.79	3.94	4.08	4.20	4.31	4.42	4.54	4.65	4.72	4.78	4.85	4.92	4.99	5.04	5.09	5.14	5.20	5.25	5.29	5.33	5.37	5.41	5.44	5.47	5.50	5.53	5.55	5.58
75%	3.36	3.51	3.66	3.81	3.96	4.10	4.22	4.33	4.44	4.55	4.66	4.73	4.80	4.87	4.94	5.00	5.06	5.11	5.17	5.22	5.28	5.32	5.36	5.40	5.44	5.48	5.50	5.53	5.56	5.59	5.61
70%	3.38	3.53	3.68	3.83	3.98	4.12	4.23	4.34	4.46	4.57	4.68	4.75	4.81	4.88	4.95	5.02	5.08	5.13	5.19	5.24	5.30	5.34	5.38	5.42	5.46	5.50	5.53	5.56	5.59	5.61	5.64
65%	3.40	3.55	3.70	3.85	4.00	4.14	4.25	4.36	4.47	4.58	4.69	4.76	4.83	4.90	4.97	5.04	5.10	5.15	5.21	5.27	5.32	5.36	5.40	5.44	5.49	5.53	5.55	5.58	5.61	5.64	5.67
60%	3.42	3.57	3.72	3.87	4.02	4.17	4.27	4.38	4.49	4.60	4.71	4.78	4.85	4.92	4.99	5.06	5.11	5.17	5.23	5.29	5.35	5.39	5.43	5.47	5.51	5.55	5.58	5.61	5.64	5.67	5.70
55%	3.44	3.59	3.74	3.89	4.04	4.19	4.29	4.40	4.51	4.61	4.72	4.79	4.86	4.93	5.00	5.07	5.13	5.19	5.25	5.31	5.37	5.41	5.45	5.49	5.53	5.58	5.61	5.64	5.67	5.70	5.73
50%	3.46	3.61	3.76	3.91	4.06	4.21	4.31	4.42	4.52	4.63	4.73	4.81	4.88	4.95	5.02	5.09	5.15	5.21	5.27	5.33	5.39	5.43	5.48	5.52	5.56	5.60	5.63	5.66	5.69	5.72	5.76
45%	3.44	3.58	3.73	3.88	4.03	4.18	4.28	4.39	4.49	4.59	4.70	4.77	4.84	4.91	4.98	5.05	5.11	5.16	5.22	5.28	5.34	5.38	5.42	5.46	5.50	5.54	5.57	5.60	5.63	5.66	5.69
40%	3.41	3.56	3.71	3.85	4.00	4.14	4.25	4.35	4.46	4.56	4.66	4.73	4.80	4.87	4.94	5.00	5.06	5.12	5.17	5.23	5.29	5.33	5.37	5.41	5.44	5.48	5.51	5.54	5.57	5.60	5.63
35%	3.39	3.54	3.68	3.82	3.97	4.11	4.22	4.32	4.42	4.53	4.63	4.70	4.76	4.83	4.90	4.96	5.02	5.07	5.13	5.18	5.23	5.27	5.31	5.35	5.39	5.43	5.45	5.48	5.51	5.53	5.56
30%	3.37	3.51	3.65	3.80	3.94	4.08	4.18	4.29	4.39	4.49	4.59	4.66	4.72	4.79	4.86	4.92	4.97	5.02	5.08	5.13	5.18	5.22	5.26	5.29	5.33	5.37	5.39	5.42	5.44	5.47	5.49
25%	3.35	3.49	3.63	3.77	3.91	4.05	4.15	4.25	4.36	4.46	4.56	4.62	4.69	4.75	4.81	4.88	4.93	4.98	5.03	5.08	5.13	5.17	5.20	5.24	5.27	5.31	5.33	5.36	5.38	5.41	5.43

DETAIL TABLE J

Radiant Slab Heat Pump Aermec NRP Nominal vs. Design Condition Capacities

Aermec NRP Capacity Adjustment by Unit Size and Water Supply Temp

Model Size	Nominal CLG Capacity (btuh)	Nominal HTG Capacity (btuh)	CHWS Temp (F)	HHWS Temp (F)	CLG Capacity Adjustment Factor	HTG Capacity Adjustment Factor	Actual CLG Capacity (btuh)	Actual HTG Capacity (btuh)	Nominal CLG Capacity (tons)	Actual CLG Capacity (tons)	Nominal HTG Capacity (tons)	Actual HTG Capacity (tons)
NRP1800	1,443,600	1,689,276	65	85	135%	70%	1,948,860	1,182,493	120.3	162.4	140.8	98.5
NRP1500	1,279,200	1,498,599	65	85	135%	70%	1,726,920	1,049,019	106.6	143.9	124.9	87.4
NRP1250	992,400	1,178,567	65	85	135%	70%	1,339,740	824,997	82.7	111.6	98.2	68.7
NRP1000	783,600	928,939	65	85	135%	70%	1,057,860	650,257	65.3	88.2	77.4	54.2

Total Avg COP (incld. simul)
7.1

HHW Avg COP (weighted)	CHW Avg COP (weighted)
5.0	5.4

HHW EUI (kbtuh/sf/yr)	CHW EUI (kbtuh/sf/yr)
0.54	0.80

NRP Size (nominal tons) to meet both CHW & HHW peak loads
NRP1250

Peak HHW Load (tons)	Peak CHW Load (tons)
68	110

DETAIL TABLE H

DOAS Heat Pump Cooling COP Performance Data

NRP 1800 COP Performance Data @ 65F CHWS

% Compressor Loading	Ambient Air Temp 50°F	52°F	54°F	56°F	58°F	60°F	62°F	64°F	66°F	68°F	70°F	72°F	74°F	76°F	78°F	80°F	82°F	84°F	86°F	88°F	90°F	92°F	94°F	96°F	98°F	100°F
100%	5.65	5.56	5.47	5.38	5.29	5.20	5.09	4.97	4.86	4.74	4.63	4.51	4.39	4.27	4.15	4.03	3.91	3.79	3.68	3.56	3.44	3.33	3.22	3.11	3.00	2.89
95%	5.75	5.67	5.58	5.49	5.40	5.31	5.20	5.08	4.97	4.86	4.74	4.62	4.50	4.38	4.25	4.13	4.01	3.89	3.77	3.65	3.53	3.42	3.31	3.20	3.08	2.97
90%	5.86	5.77	5.68	5.60	5.51	5.42	5.31	5.19	5.08	4.97	4.85	4.73	4.61	4.48	4.36	4.23	4.11	3.99	3.87	3.75	3.63	3.51	3.40	3.28	3.17	3.05
85%	5.96	5.88	5.79	5.71	5.62	5.53	5.42	5.31	5.19	5.08	4.96	4.84	4.71	4.59	4.46	4.34	4.21	4.09	3.97	3.84	3.72	3.60	3.48	3.37	3.25	3.13
80%	6.07	5.98	5.90	5.81	5.73	5.65	5.53	5.42	5.30	5.19	5.07	4.95	4.82	4.69	4.57	4.44	4.31	4.19	4.06	3.94	3.81	3.69	3.57	3.45	3.33	3.21
75%	6.17	6.09	6.01	5.92	5.84	5.76	5.64	5.53	5.41	5.30	5.19	5.06	4.93	4.80	4.67	4.54	4.42	4.29	4.16	4.03	3.91	3.78	3.66	3.54	3.41	3.29
70%	6.23	6.15	6.07	5.99	5.91	5.83	5.72	5.60	5.49	5.38	5.27	5.14	5.01	4.88	4.75	4.62	4.50	4.37	4.24	4.11	3.99	3.86	3.74	3.61	3.49	3.36
65%	6.29	6.21	6.14	6.06	5.98	5.90	5.79	5.68	5.57	5.46	5.35	5.22	5.09	4.96	4.83	4.71	4.58	4.45	4.32	4.19	4.06	3.94	3.81	3.69	3.56	3.44
60%	6.35	6.28	6.20	6.13	6.05	5.98	5.87	5.76	5.65	5.54	5.43	5.30	5.17	5.04	4.92	4.79	4.66	4.53	4.40	4.27	4.14	4.02	3.89	3.76	3.64	3.51
55%	6.41	6.34	6.27	6.19	6.12	6.05	5.94	5.83	5.72	5.62	5.51	5.38	5.25	5.12	5.00	4.87	4.74	4.61	4.48	4.35	4.22	4.09	3.97	3.84	3.71	3.58
50%	6.47	6.40	6.33	6.26	6.19	6.12	6.02	5.91	5.80	5.70	5.59	5.46	5.33	5.21	5.08	4.95	4.82	4.69	4.56	4.43	4.30	4.17	4.04	3.91	3.78	3.65
45%	6.32	6.25	6.19	6.12	6.06	5.99	5.89	5.78	5.68	5.58	5.48	5.35	5.23	5.11	4.98	4.86	4.73	4.61	4.48	4.35	4.23	4.10	3.97	3.85	3.72	3.59
40%	6.17	6.11	6.05	5.98	5.92	5.86	5.76	5.66	5.56	5.46	5.36	5.24	5.12	5.00	4.89	4.77	4.64	4.52	4.40	4.27	4.15	4.03	3.90	3.78	3.66	3.53
35%	6.02	5.96	5.90	5.84	5.78	5.72	5.63	5.54	5.44	5.35	5.25	5.14	5.02	4.90	4.79	4.67	4.55	4.43	4.31	4.19	4.08	3.95	3.83	3.71	3.59	3.47
30%	5.87	5.82	5.76	5.70	5.65	5.59	5.50	5.41	5.32	5.23	5.14	5.03	4.92	4.80	4.69	4.58	4.46	4.35	4.23	4.12	4.00	3.88	3.76	3.65	3.53	3.41
25%	5.73	5.67	5.62	5.57	5.51	5.46	5.37	5.29	5.20	5.11	5.03	4.92	4.81	4.70	4.60	4.49	4.38	4.26	4.15	4.04	3.92	3.81	3.70	3.58	3.47	3.35

DETAIL TABLE I

DOAS Heat Pump Heating COP Performance Data

NRP 1800 COP Performance Data @ 85F HHWS

% Compressor Loading	Ambient Air Temp 35°F	36°F	37°F	38°F	39°F	40°F	41°F	42°F	43°F	44°F	45°F	46°F	47°F	48°F	49°F	50°F	51°F	52°F	53°F	54°F	55°F	56°F	57°F	58°F	59°F	60°F	61°F	62°F	63°F	64°F	65°F
100%	3.26	3.41	3.56	3.71	3.86	4.01	4.13	4.25	4.36	4.48	4.60	4.66	4.72	4.79	4.85	4.91	4.96	5.01	5.05	5.10	5.15	5.18	5.22	5.25	5.29	5.32	5.35	5.37	5.40	5.42	5.45
95%	3.28	3.43	3.58	3.73	3.88	4.03	4.15	4.26	4.38	4.50	4.61	4.68	4.74	4.80	4.87	4.93	4.98	5.03	5.08	5.13	5.18	5.21	5.25	5.28	5.32	5.35	5.38	5.40	5.43	5.46	5.48
90%	3.30	3.45	3.60	3.75	3.90	4.05	4.16	4.28	4.39	4.51	4.62	4.69	4.75	4.82	4.88	4.95	5.00	5.05	5.10	5.15	5.20	5.24	5.27	5.31	5.35	5.38	5.41	5.44	5.46	5.49	5.52
85%	3.32	3.47	3.62	3.77	3.92	4.07	4.18	4.29	4.41	4.52	4.64	4.70	4.77	4.83	4.90	4.97	5.02	5.07	5.12	5.17	5.23	5.26	5.30	5.34	5.38	5.41	5.44	5.47	5.49	5.52	5.55
80%	3.34	3.49	3.64	3.79	3.94	4.08	4.20	4.31	4.42	4.54	4.65	4.72	4.78	4.85	4.92	4.99	5.04	5.09	5.14	5.20	5.25	5.29	5.33	5.37	5.41	5.44	5.47	5.50	5.53	5.55	5.58
75%	3.36	3.51	3.66	3.81	3.96	4.10	4.22	4.33	4.44	4.55	4.66	4.73	4.80	4.87	4.94	5.00	5.06	5.11	5.17	5.22	5.28	5.32	5.36	5.40	5.44	5.48	5.50	5.53	5.56	5.59	5.61
70%	3.38	3.53	3.68	3.83	3.98	4.12	4.23	4.34	4.46	4.57	4.68	4.75	4.81	4.88	4.95	5.02	5.08	5.13	5.19	5.24	5.30	5.34	5.38	5.42	5.46	5.50	5.53	5.56	5.59	5.61	5.64
65%	3.40	3.55	3.70	3.85	4.00	4.14	4.25	4.36	4.47	4.58	4.69	4.76	4.83	4.90	4.97	5.04	5.10	5.15	5.21	5.27	5.32	5.36	5.40	5.44	5.49	5.53	5.55	5.58	5.61	5.64	5.67
60%	3.42	3.57	3.72	3.87	4.02	4.17	4.27	4.38	4.49	4.60	4.71	4.78	4.85	4.92	4.99	5.06	5.11	5.17	5.23	5.29	5.35	5.39	5.43	5.47	5.51	5.55	5.58	5.61	5.64	5.67	5.70
55%	3.44	3.59	3.74	3.89	4.04	4.19	4.29	4.40	4.51	4.61	4.72	4.79	4.86	4.93	5.00	5.07	5.13	5.19	5.25	5.31	5.37	5.41	5.45	5.49	5.53	5.58	5.61	5.64	5.67	5.70	5.73
50%	3.46	3.61	3.76	3.91	4.06	4.21	4.31	4.42	4.52	4.63	4.73	4.81	4.88	4.95	5.02	5.09	5.15	5.21	5.27	5.33	5.39	5.43	5.48	5.52	5.56	5.60	5.63	5.66	5.69	5.72	5.76
45%	3.44	3.58	3.73	3.88	4.03	4.18	4.28	4.39	4.49	4.59	4.70	4.77	4.84	4.91	4.98	5.05	5.11	5.16	5.22	5.28	5.34	5.38	5.42	5.46	5.50	5.54	5.57	5.60	5.63	5.66	5.69
40%	3.41	3.56	3.71	3.85	4.00	4.14	4.25	4.35	4.46	4.56	4.66	4.73	4.80	4.87	4.94	5.00	5.06	5.12	5.17	5.23	5.29	5.33	5.37	5.41	5.44	5.48	5.51	5.54	5.57	5.60	5.63
35%	3.39	3.54	3.68	3.82	3.97	4.11	4.22	4.32	4.42	4.53	4.63	4.70	4.76	4.83	4.90	4.96	5.02	5.07	5.13	5.18	5.23	5.27	5.31	5.35	5.39	5.43	5.45	5.48	5.51	5.53	5.56
30%	3.37	3.51	3.65	3.80	3.94	4.08	4.18	4.29	4.39	4.49	4.59	4.66	4.72	4.79	4.86	4.92	4.97	5.02	5.08	5.13	5.18	5.22	5.26	5.29	5.33	5.37	5.39	5.42	5.44	5.47	5.49
25%	3.35	3.49	3.63	3.77	3.91	4.05	4.15	4.25	4.36	4.46	4.56	4.62	4.69	4.75	4.81	4.88	4.93	4.98	5.03	5.08	5.13	5.17	5.20	5.24	5.27	5.31	5.33	5.36	5.38	5.41	5.43

DETAIL TABLE K

DOAS Heat Pump Aermec NRP Nominal vs. Design Condition Capacities

Aermec NRP Capacity Adjustment by Unit Size and Water Supply Temp

Model Size	Nominal CLG Capacity	Nominal HTG Capacity	CHWS Temp (F)	HHWS Temp (F)	CLG Capacity Adjustment	HTG Capacity Adjustment	Actual CLG Capacity	Actual HTG Capacity	Nominal CLG Capacity	Actual CLG Capacity	Nominal HTG Capacity	Actual HTG Capacity
NRP1800	1,443,600	1,689,276	55	85	120%	70%	1,732,320	1,182,493	120.3	144.4	140.8	98.5
NRP1500	1,279,200	1,498,599	55	85	120%	70%	1,535,040	1,049,019	106.6	127.9	124.9	87.4
NRP1250	992,400	1,178,567	55	85	120%	70%	1,190,880	824,997	82.7	99.2	98.2	68.7
NRP1000	783,600	928,939	55	85	120%	70%	940,320	650,257	65.3	78.4	77.4	54.2

Total Avg COP (incld simul)
5.0

HHW Avg COP (weighted)	CHW Avg COP (weighted)
4.4	5.1

HHW EUI (kbtuh/sf/yr)	CHW EUI (kbtuh/sf/yr)
0.10	0.93

NRP Size (nominal tons) to meet both CHW & HHW peak loads
NRP1800

Peak HHW Load (tons)	Peak CHW Load (tons)
58	143

DETAIL TABLE V
Electricity EUI Breakdown by Use

	Baseline Scenario (Steel + VRF)	Clark Pacific (Precast + Radiant)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Fans	8.5	2.6	*5.8*	*68.8%*
Pumps	0.0	0.5	*-0.5*	*0.0%*
Cooling	4.5	1.8	*2.7*	*59.9%*
Heating	0.9	0.6	*0.3*	*31.7%*
DHW	0.8	0.8	*0.0*	*0.0%*
Exterior Lighting	0.4	0.4	*0.0*	*0.0%*
Interior Lighting	4.1	4.1	*0.0*	*0.0%*
Plug Loads	8.9	8.9	*0.0*	*0.0%*
Total EUI (kbtu/sf/yr)	**28.1**	**19.8**	***8.3***	***29.5%***
HVAC Subtotal	**14.7**	**6.4**	***8.3***	***56.4%***

DETAIL TABLE W
Year One Electricity Use (kWh)

	Baseline Scenario (Steel + VRF) (kWh)	Clark Pacific (Precast + Radiant) (kWh)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Fans	596,297	186,108	*410,189*	*68.8%*
Pumps	0	37,807	*-37,807*	*0.0%*
Cooling	316,288	126,880	*189,408*	*59.9%*
Heating	65,625	44,820	*20,805*	*31.7%*
DHW	54,855	54,855	*0*	*0.0%*
Exterior Lighting	28,379	28,379	*0*	*0.0%*
Interior Lighting	289,923	289,923	*0*	*0.0%*
Plug Loads	622,870	622,870	*0*	*0.0%*
Total Electricity Year 1 (kWh)	**1,974,237**	**1,391,643**	***582,595***	***29.5%***
HVAC Subtotal	**1,033,065**	**450,470**	***582,595***	***56.4%***

DETAIL TABLE X
Year One Electricity (kgCO2e)

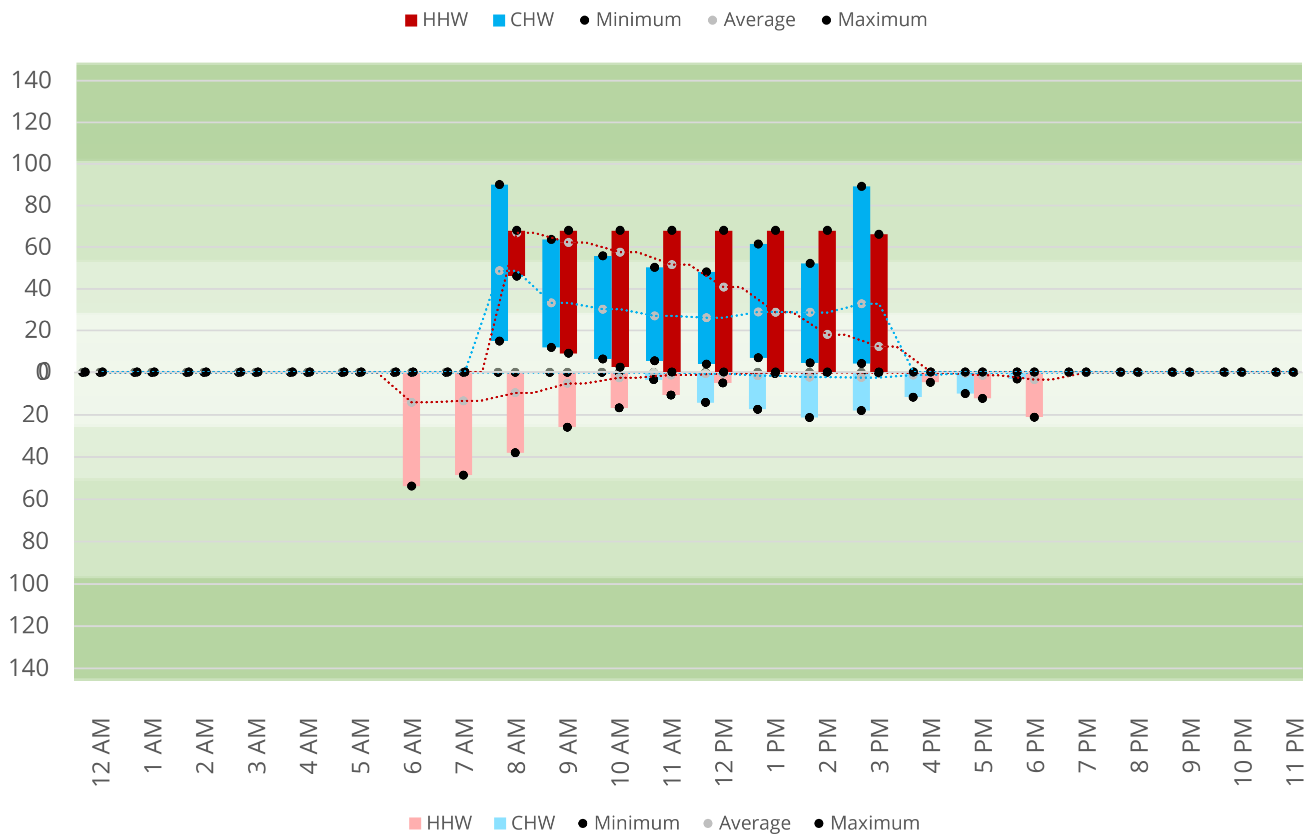
	Baseline Scenario (Steel + VRF) (kgCO2e)	Clark Pacific (Precast + Radiant) (kgCO2e)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Fans	136,096	42,998	*93,098*	*68.4%*
Pumps	0	8,715	*-8,715*	*0.0%*
Cooling	72,171	25,827	*46,344*	*64.2%*
Heating	14,987	10,380	*4,606*	*30.7%*
DHW	12,680	12,680	*0*	*0.0%*
Exterior Lighting	6,557	6,557	*0*	*0.0%*
Interior Lighting	66,997	66,997	*0*	*0.0%*
Plug Loads	143,907	143,907	*0*	*0.0%*
Total Electricity Year 1 (kgCO2e)	**453,395**	**318,062**	***135,333***	***29.8%***
HVAC Subtotal	**235,934**	**100,601**	***135,333***	***57.4%***

DETAIL TABLE Y
Electricity B6 Whole Life Emissions

	Baseline Scenario (Steel + VRF) (kgCO2e)	Clark Pacific (Precast + Radiant) (kgCO2e)	*Savings vs. Baseline (magnitude)*	*Savings vs. Baseline (%)*
Heating	390,476	270,461	*120,016*	*30.7%*
Cooling	1,880,417	672,927	*1,207,491*	*64.2%*
Fans	3,545,982	1,120,318	*2,425,664*	*68.4%*
Pumps	0	227,066	*-227,066*	*0.0%*
DHW	330,379	330,379	*0*	*0.0%*
Interior Lighting	1,745,610	1,745,610	*0*	*0.0%*
Exterior Lighting	170,834	170,834	*0*	*0.0%*
Plug Loads	3,749,509	3,749,509	*0*	*0.0%*
Total Electricity (kgCO2e)	**11,813,207**	**8,287,102**	***3,526,105***	***29.8%***
HVAC Subtotal	**6,147,255**	**2,621,150**	***3,526,105***	***57.4%***
Non-HVAC Subtotal	**5,665,952**	**5,665,952**	***0***	***0.0%***

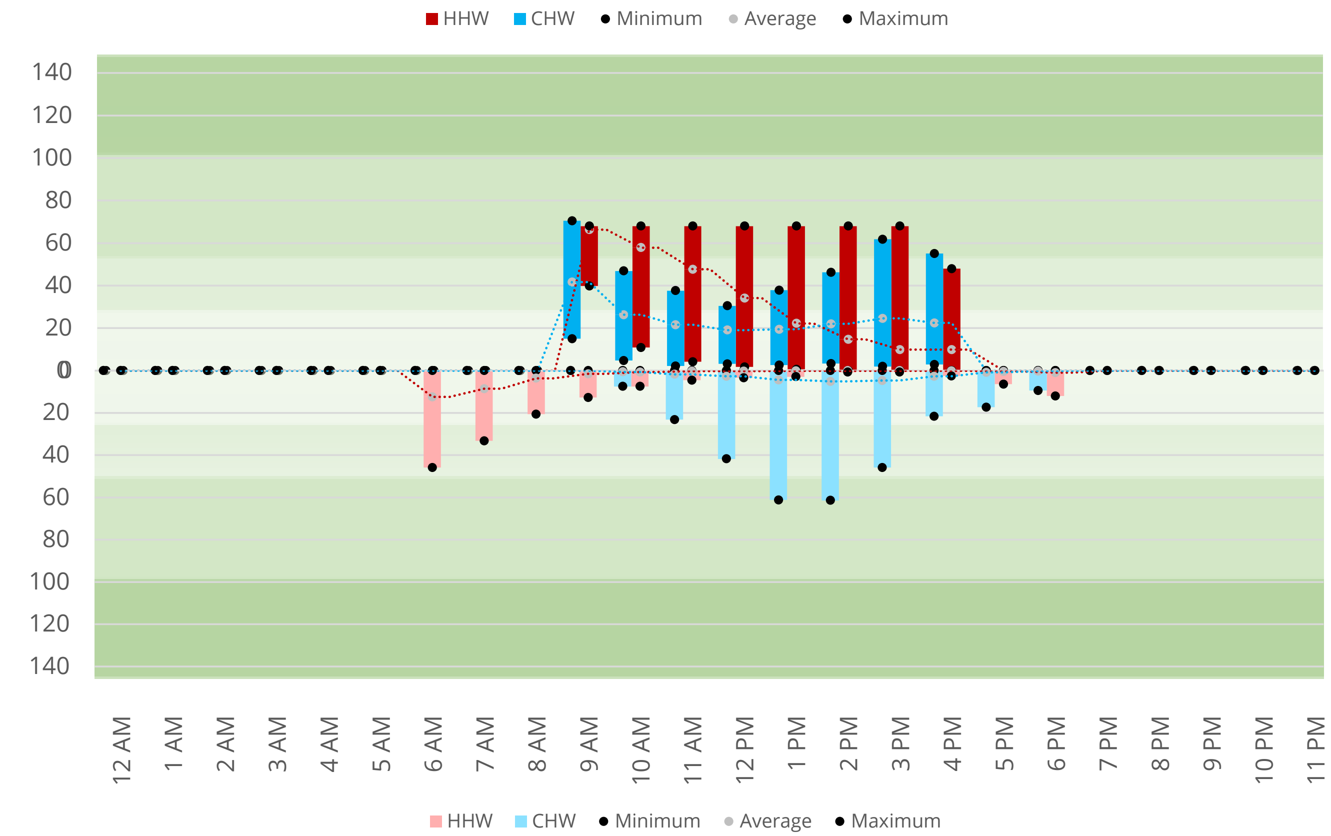
January CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



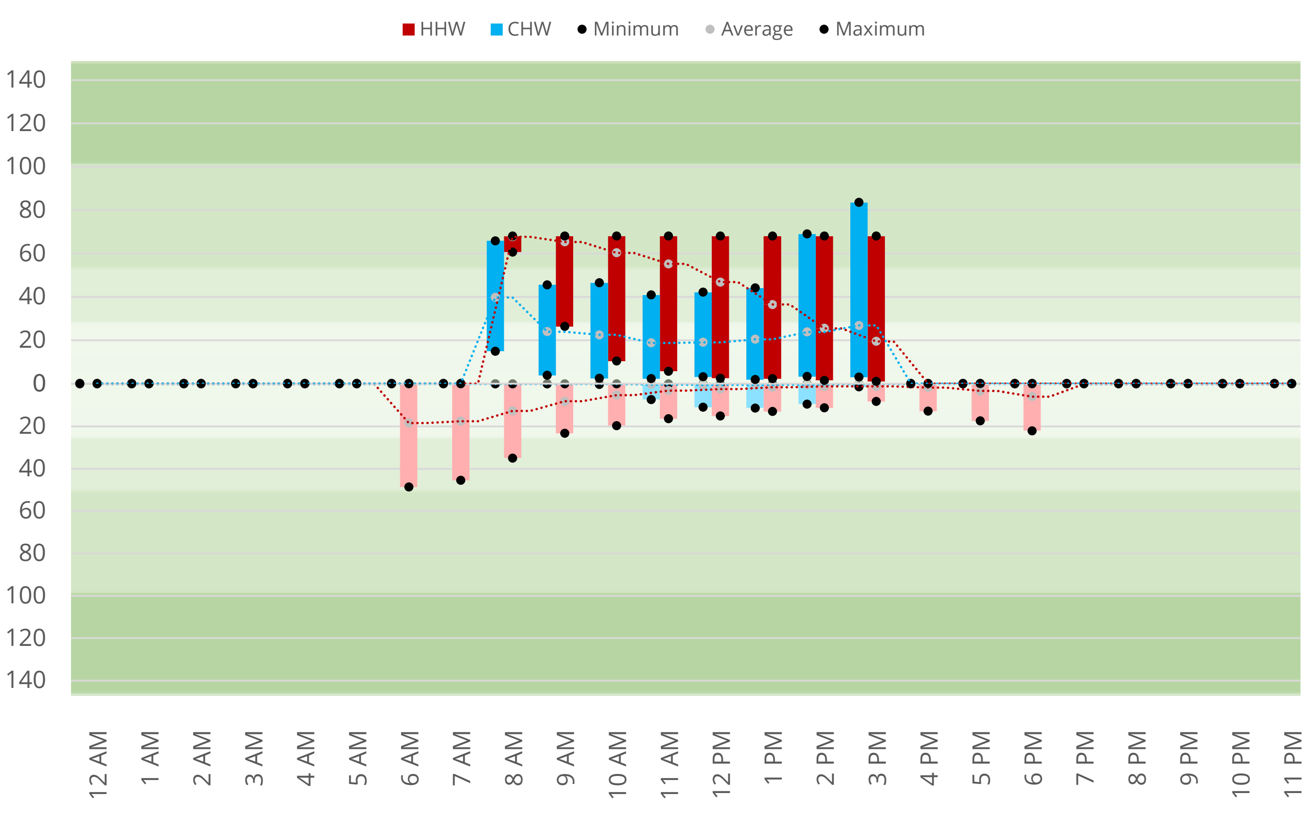
March CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



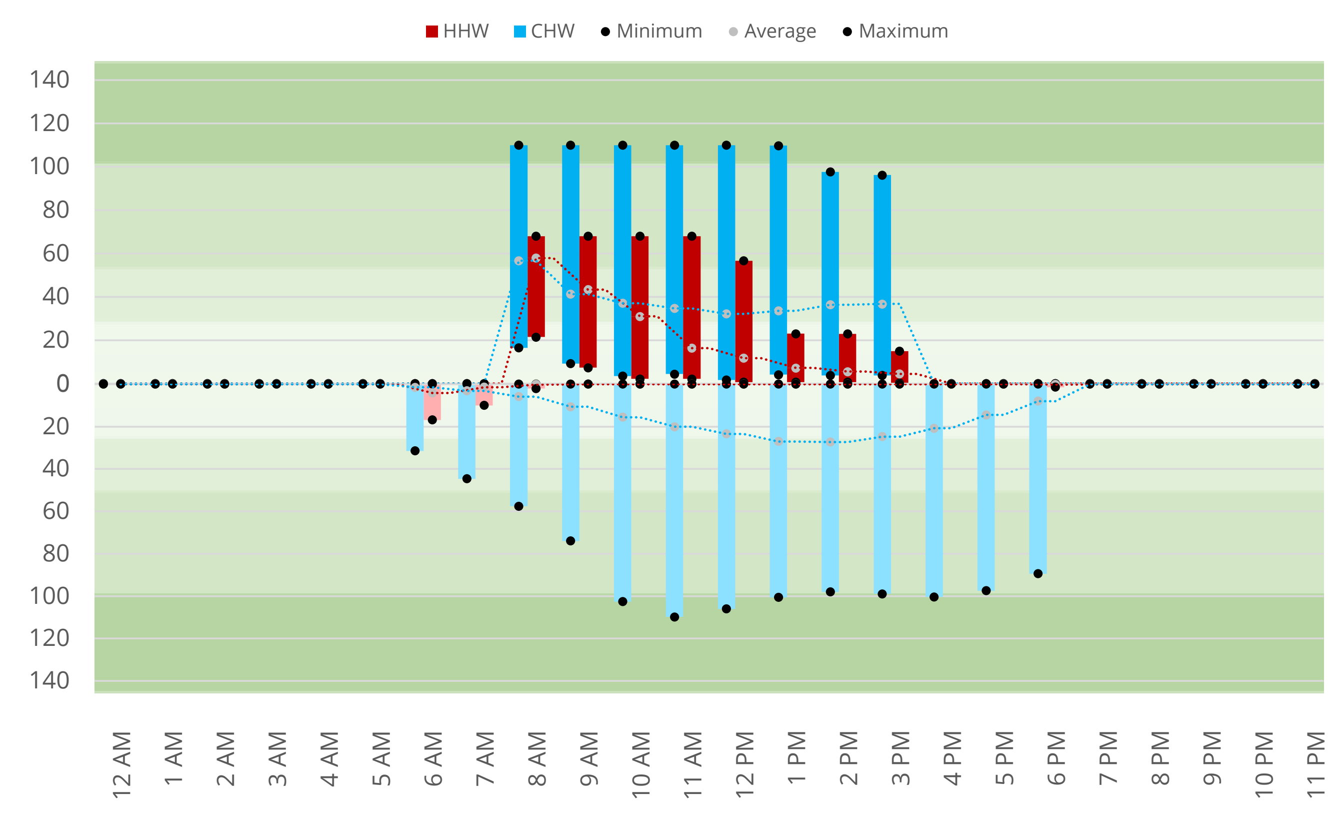
February CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



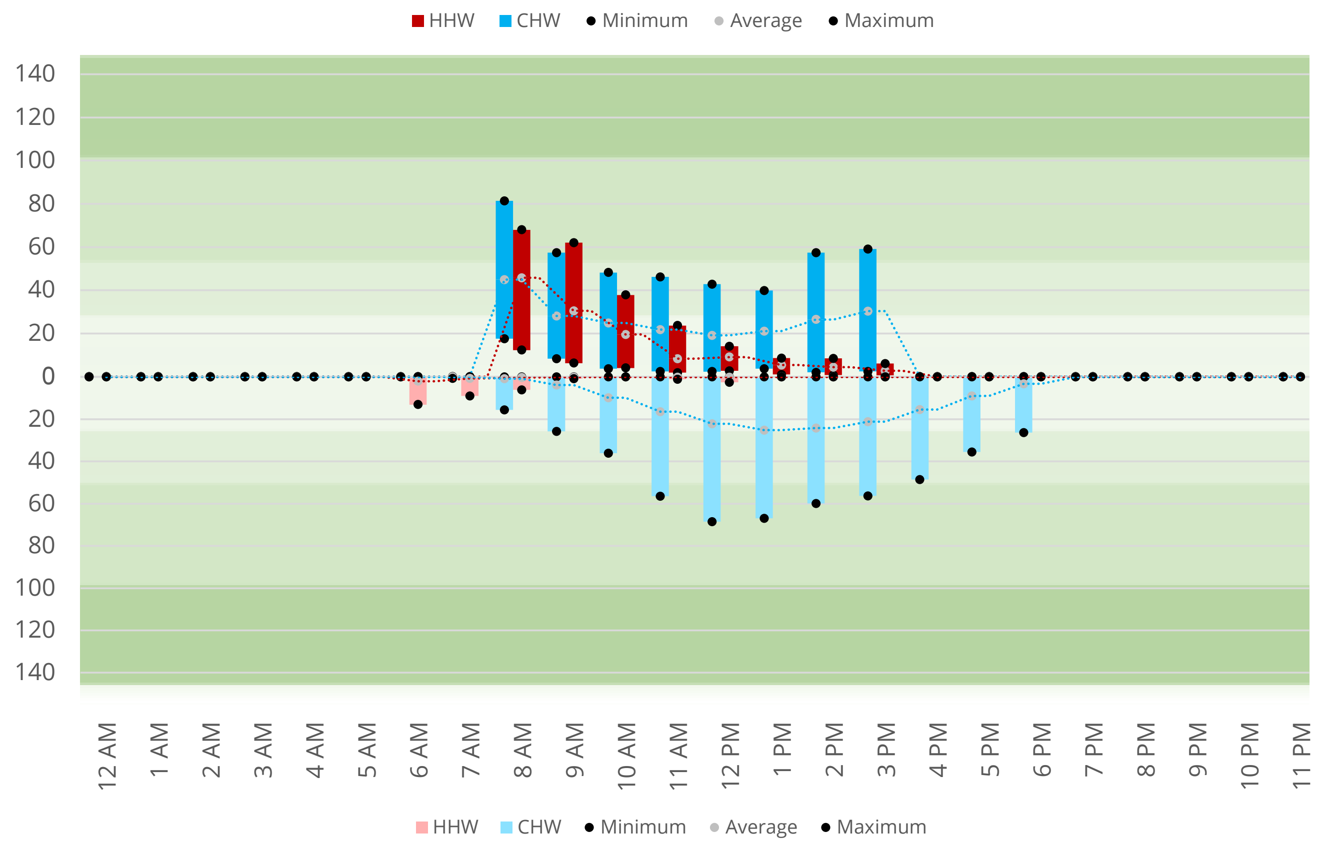
April CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



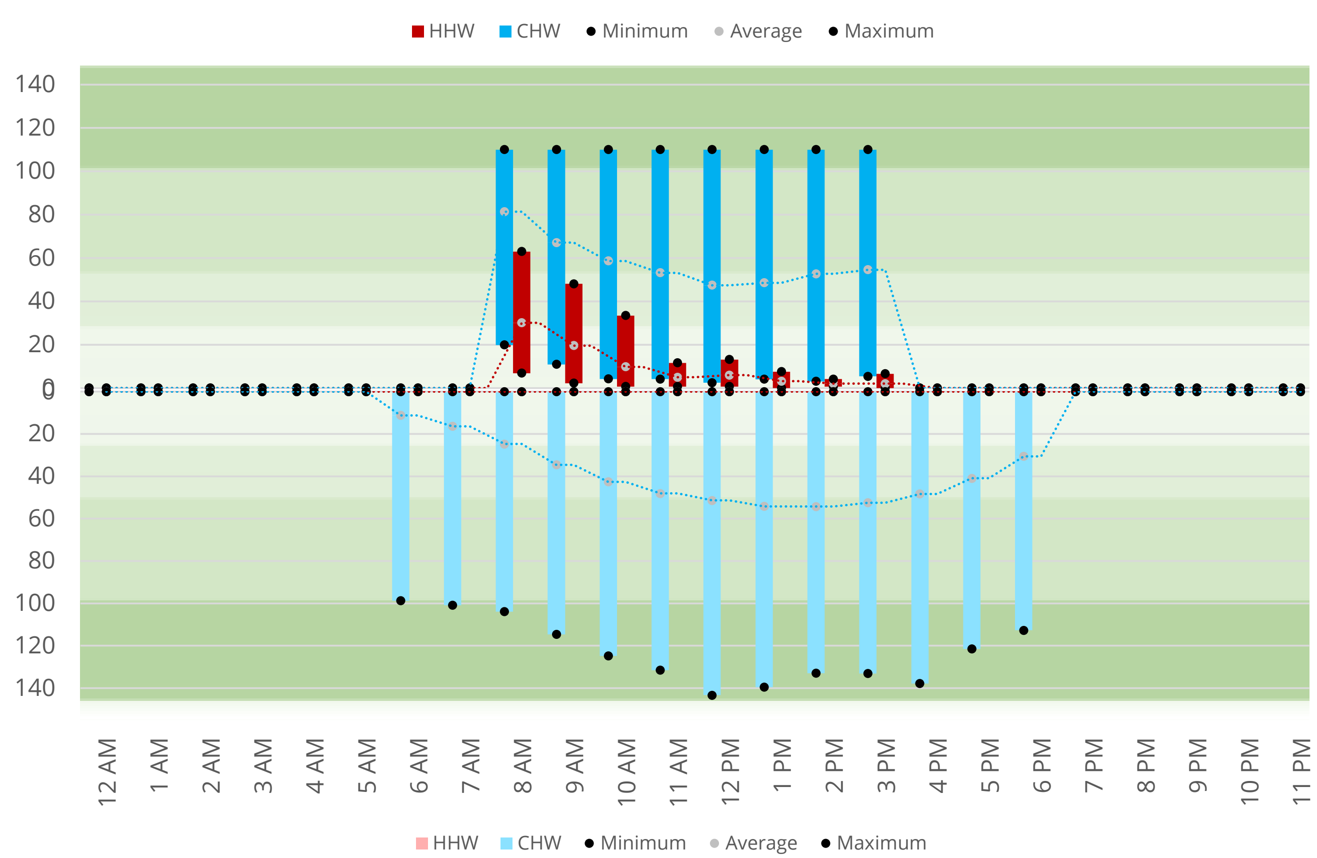
May CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



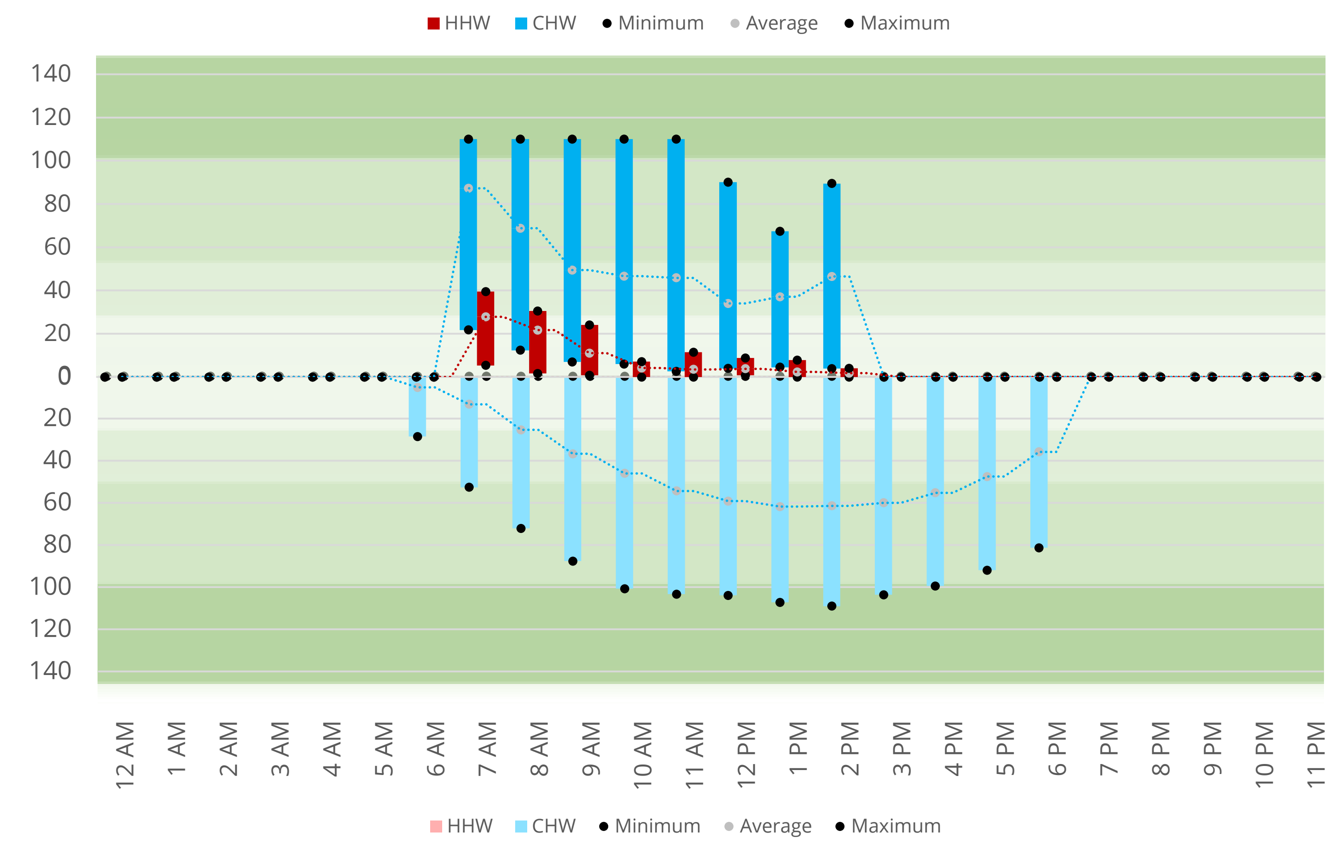
June CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



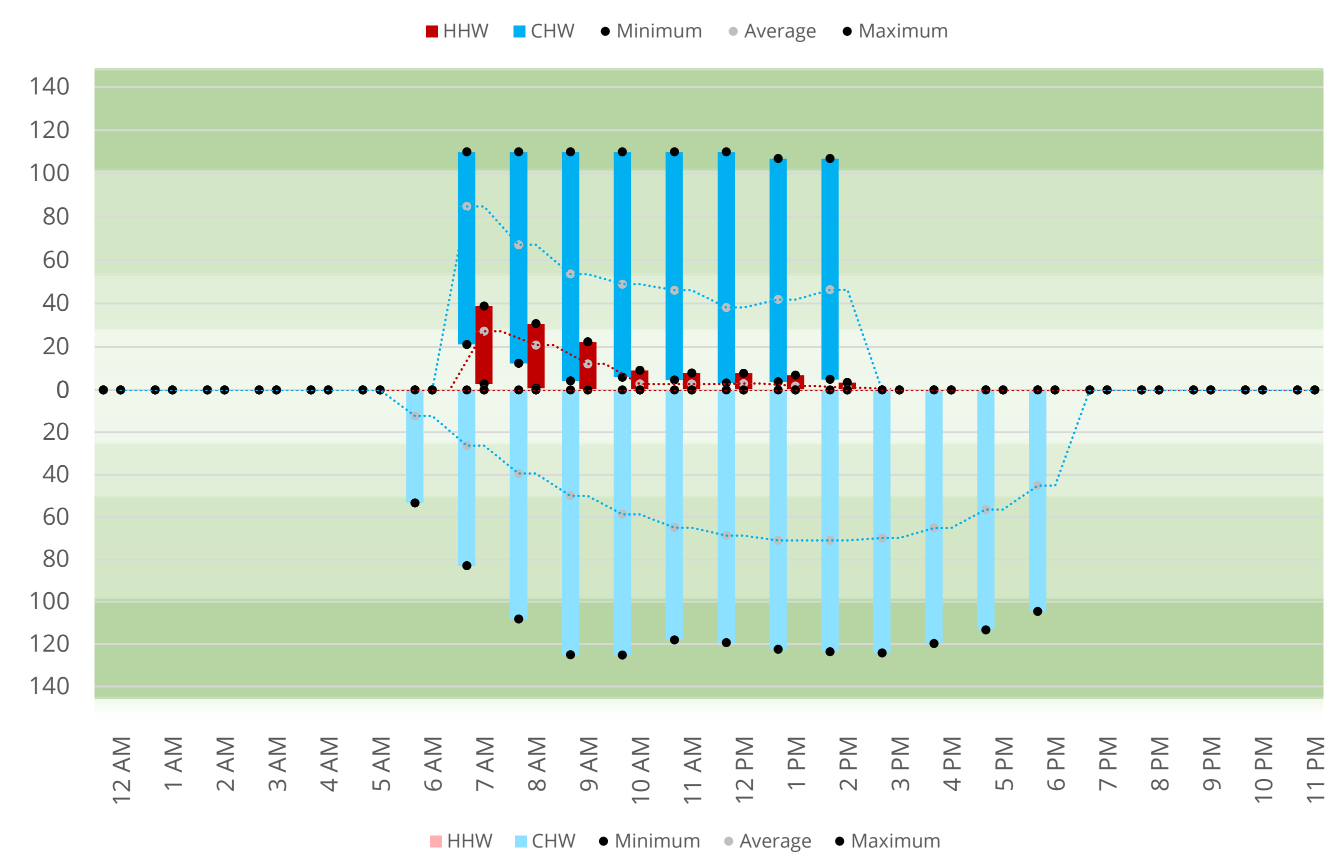
July CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



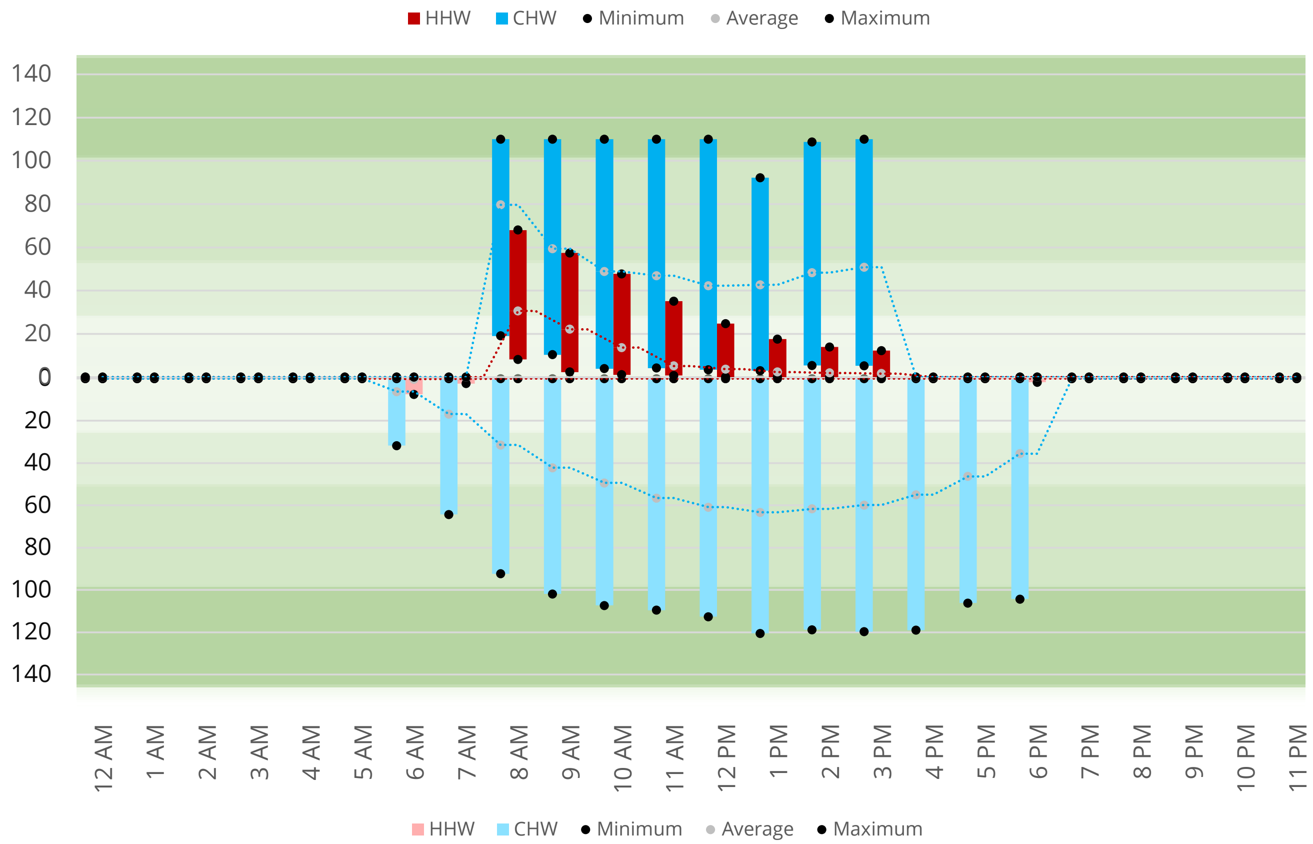
August CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



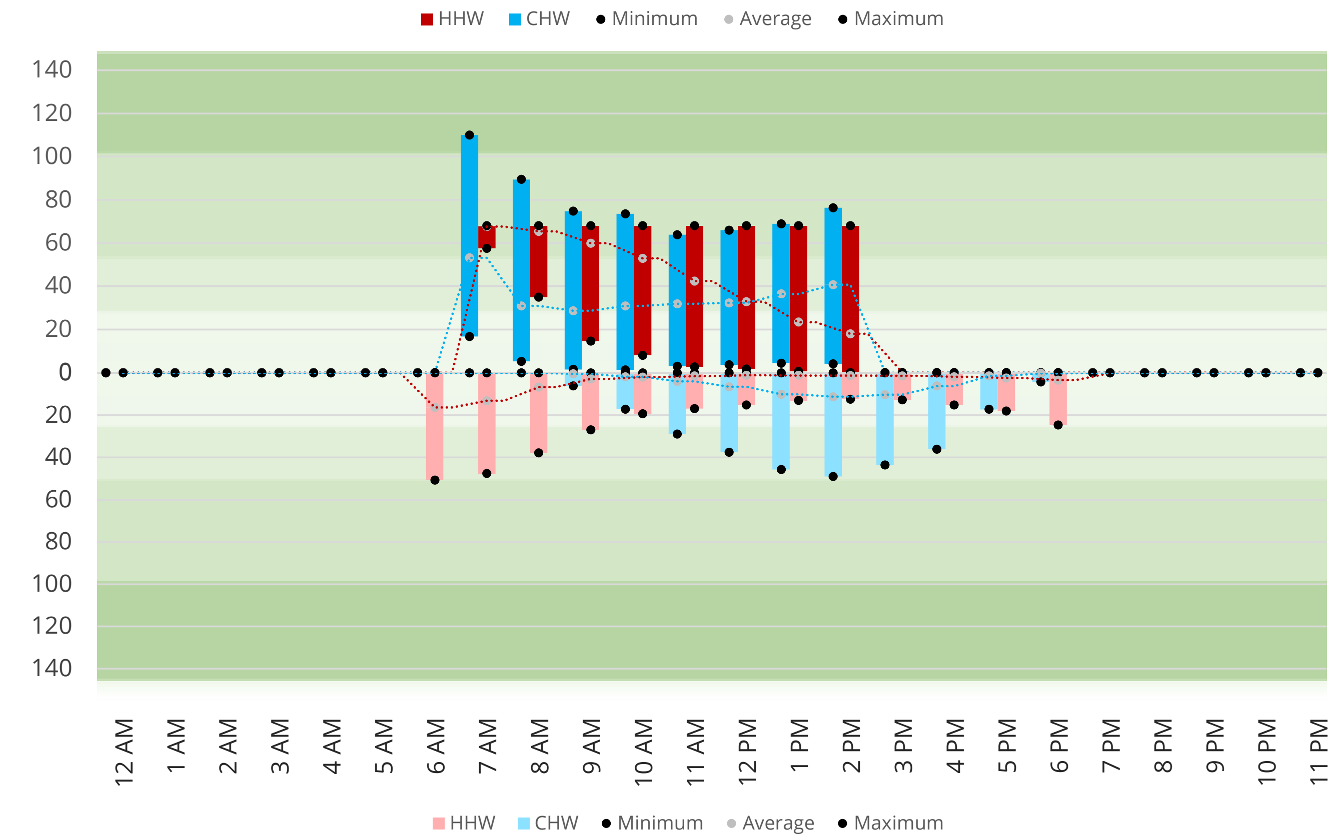
September CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



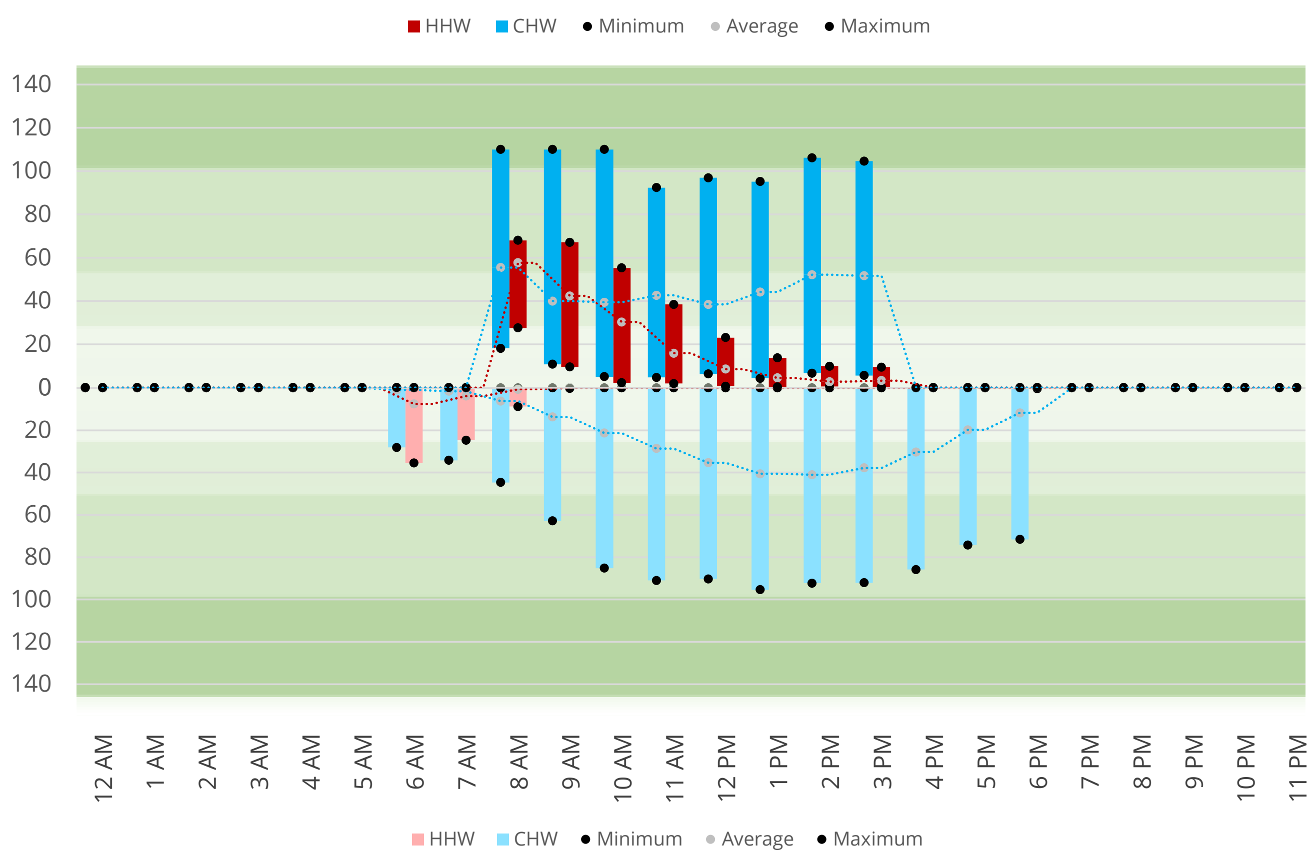
November CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



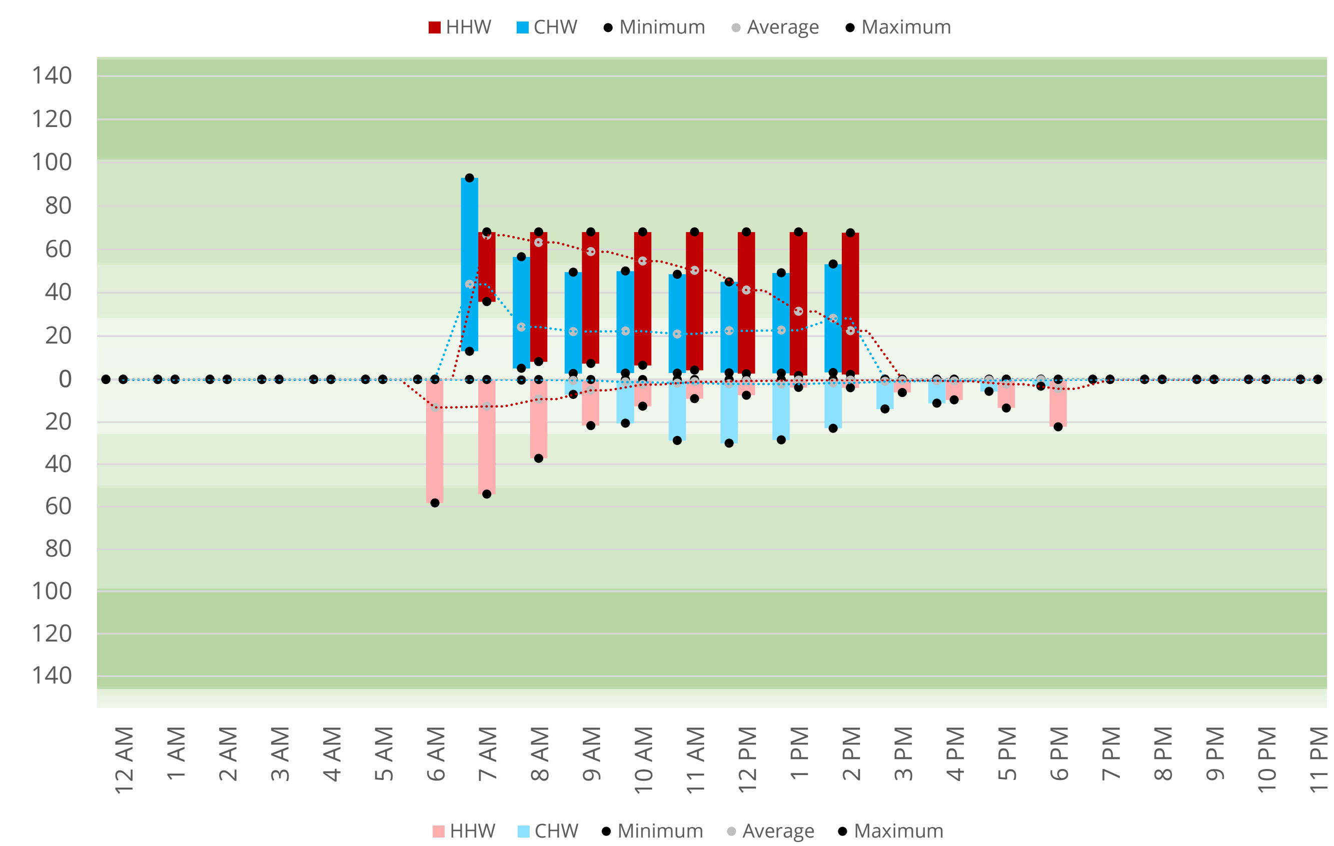
October CHW and HHW Loads (tons)

(Slab Loads on top - DOAS on bottom)



December CHW and HHW Loads (tons)

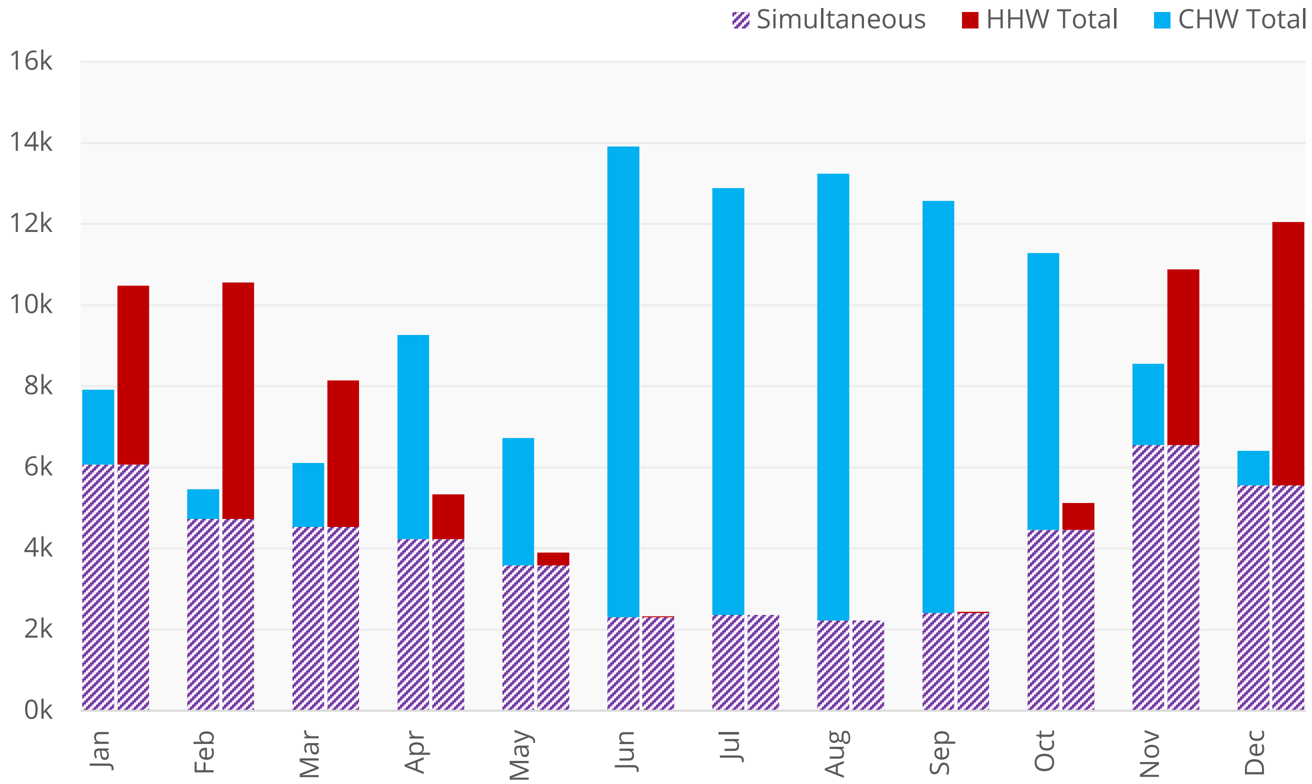
(Slab Loads on top - DOAS on bottom)



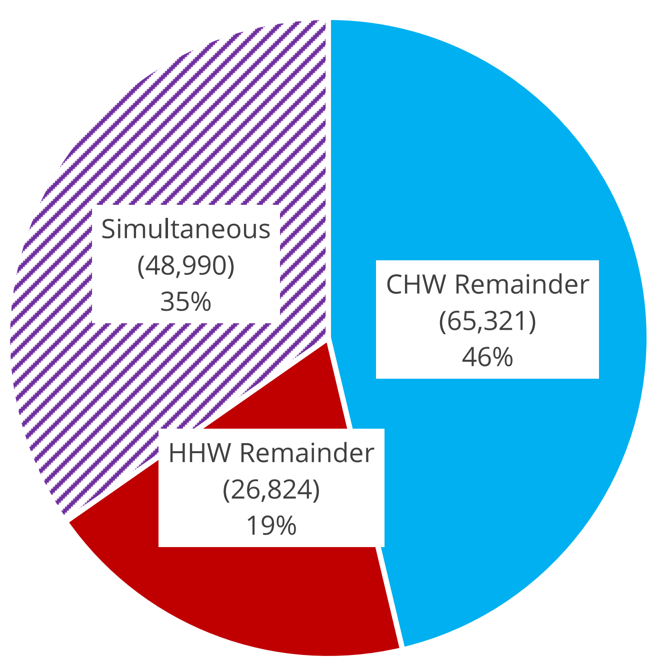
RADIANT SLAB LOAD TOTALS

Slab Heat Pump CHW and HHW Annually

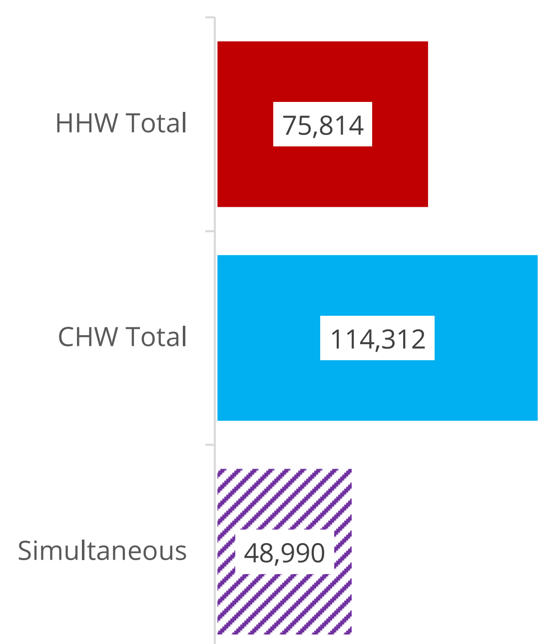
Monthly Ton-Hours



Annual Ton-Hours

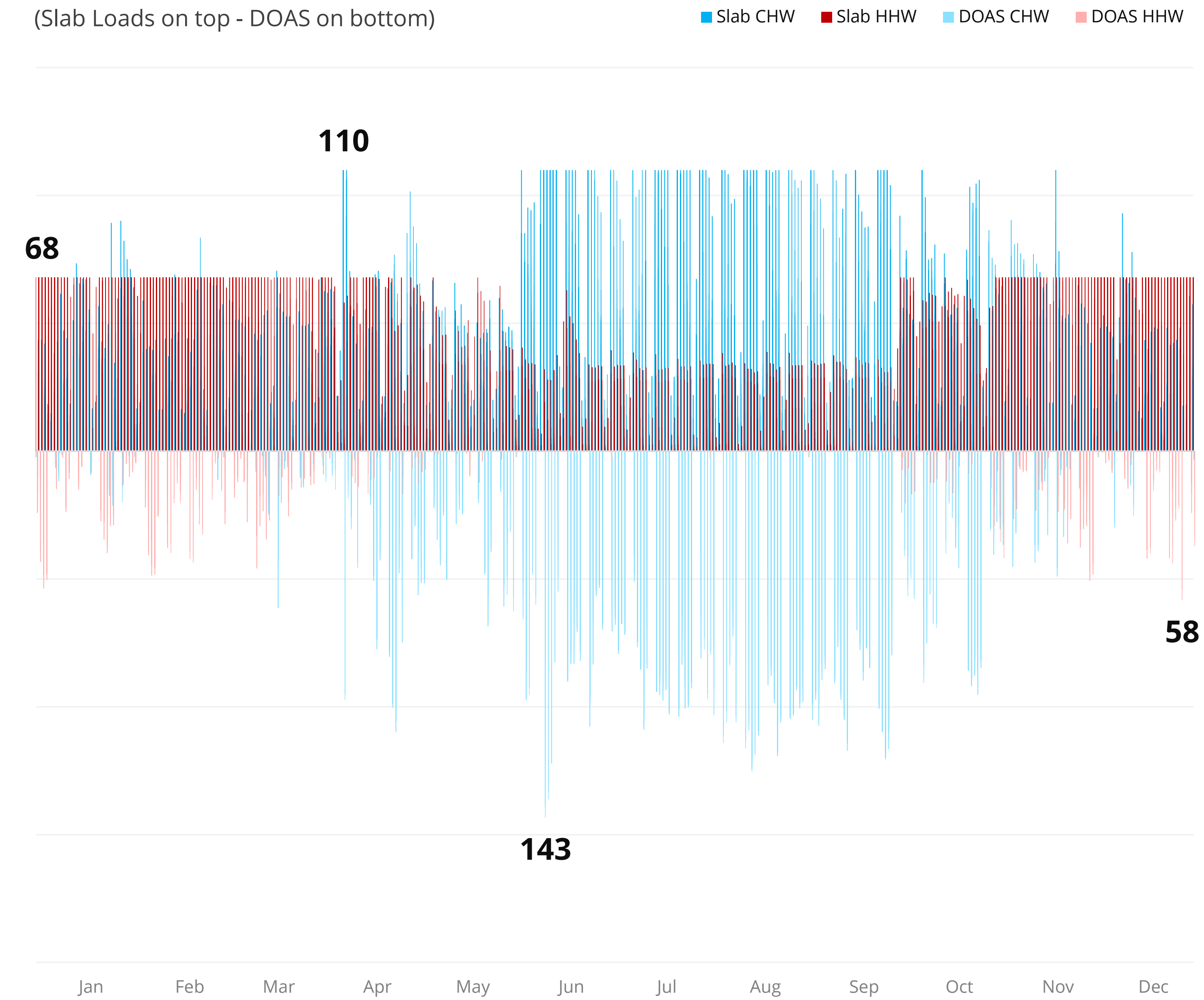


Annual Ton-Hours

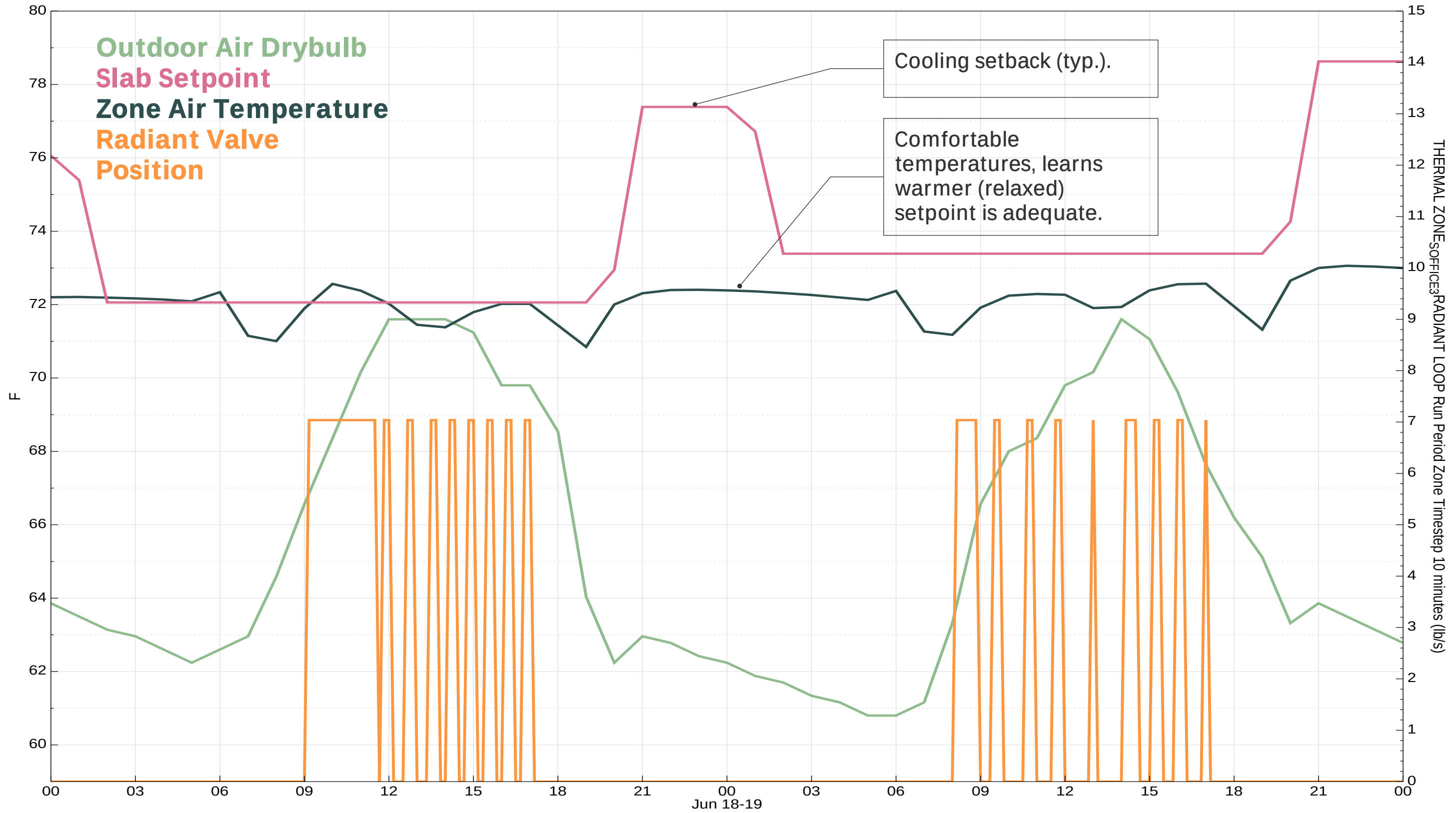


Hourly CHW & HHW Loads (tons)

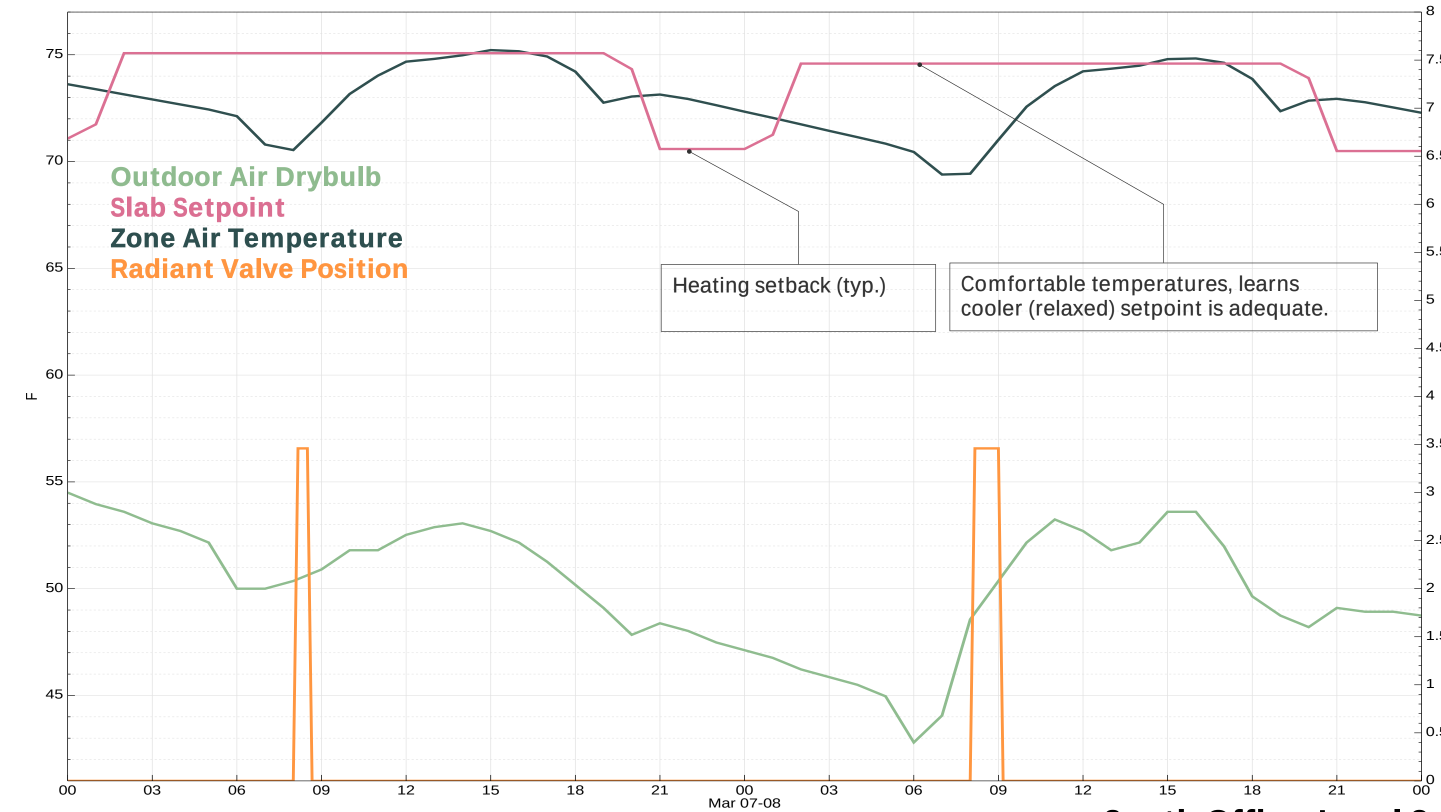
(Slab Loads on top - DOAS on bottom)



COOLING WORKING | LEARNING TO RELAX

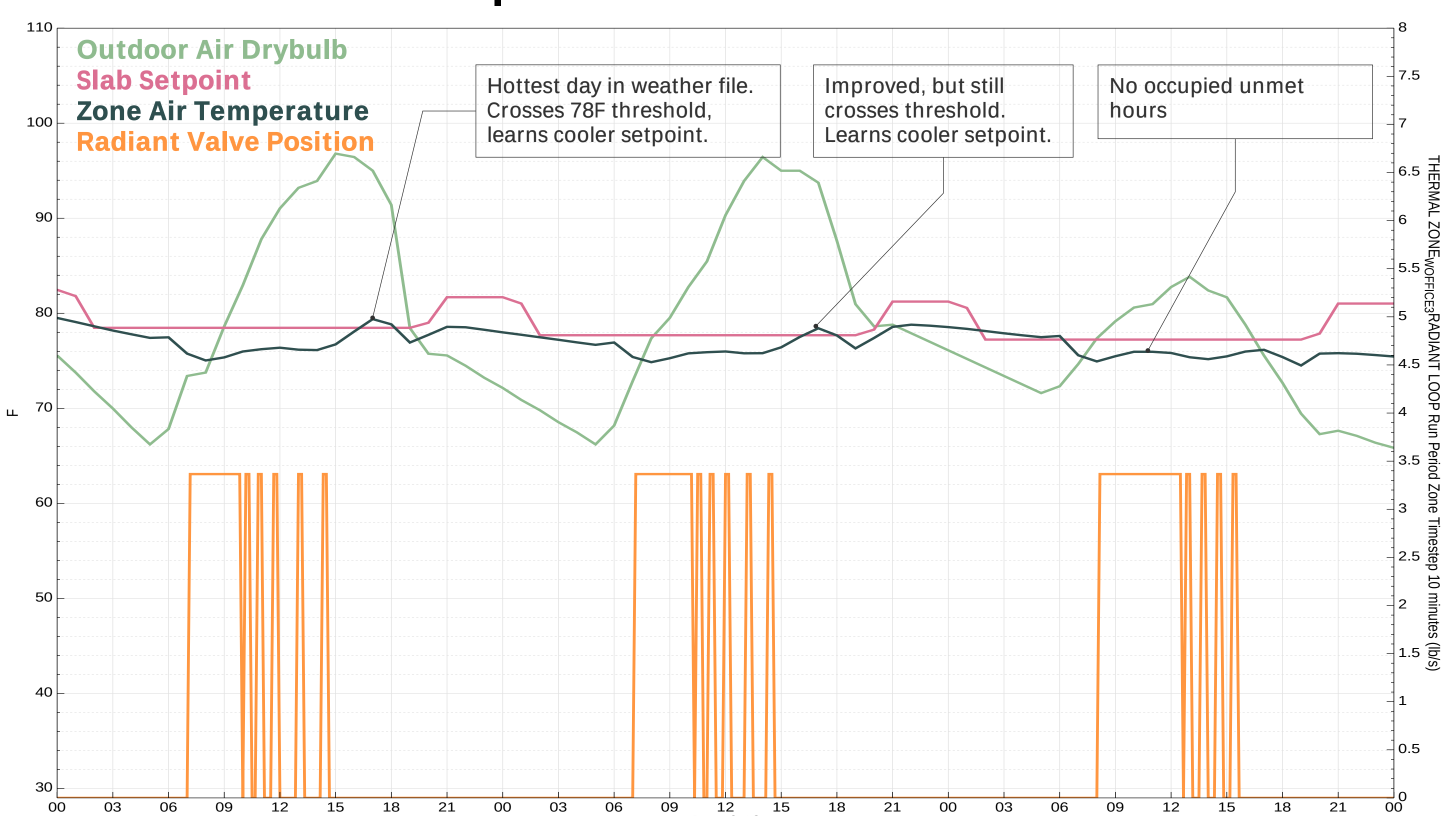


HEATING WORKING | LEARNING TO RELAX



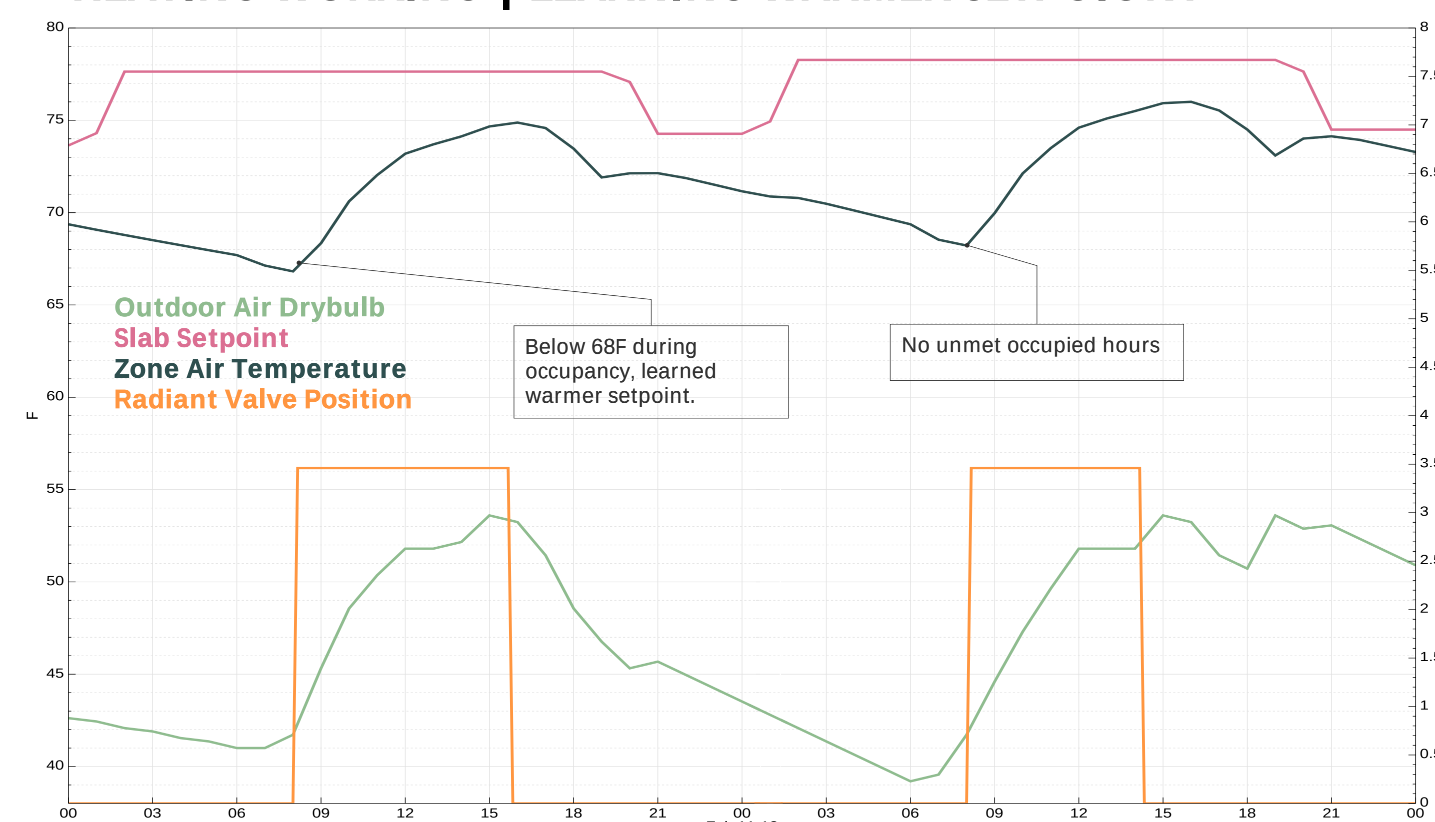
South Office, Level 3

COOLING WORKING | LEARNING COOLER SETPOIONT



West Office, Level 3

HEATING WORKING | LEARNING WARMER SETPOIONT



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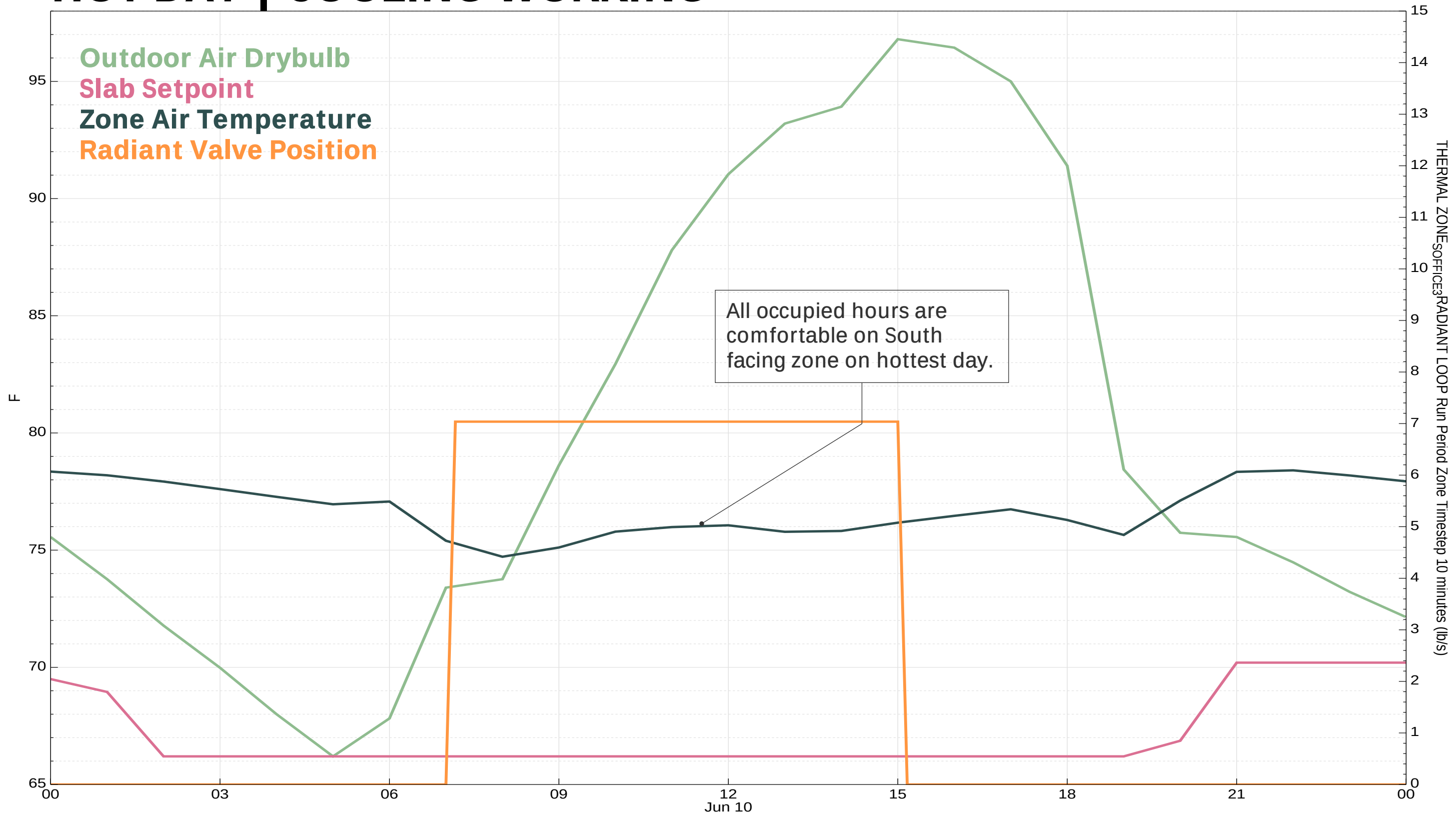
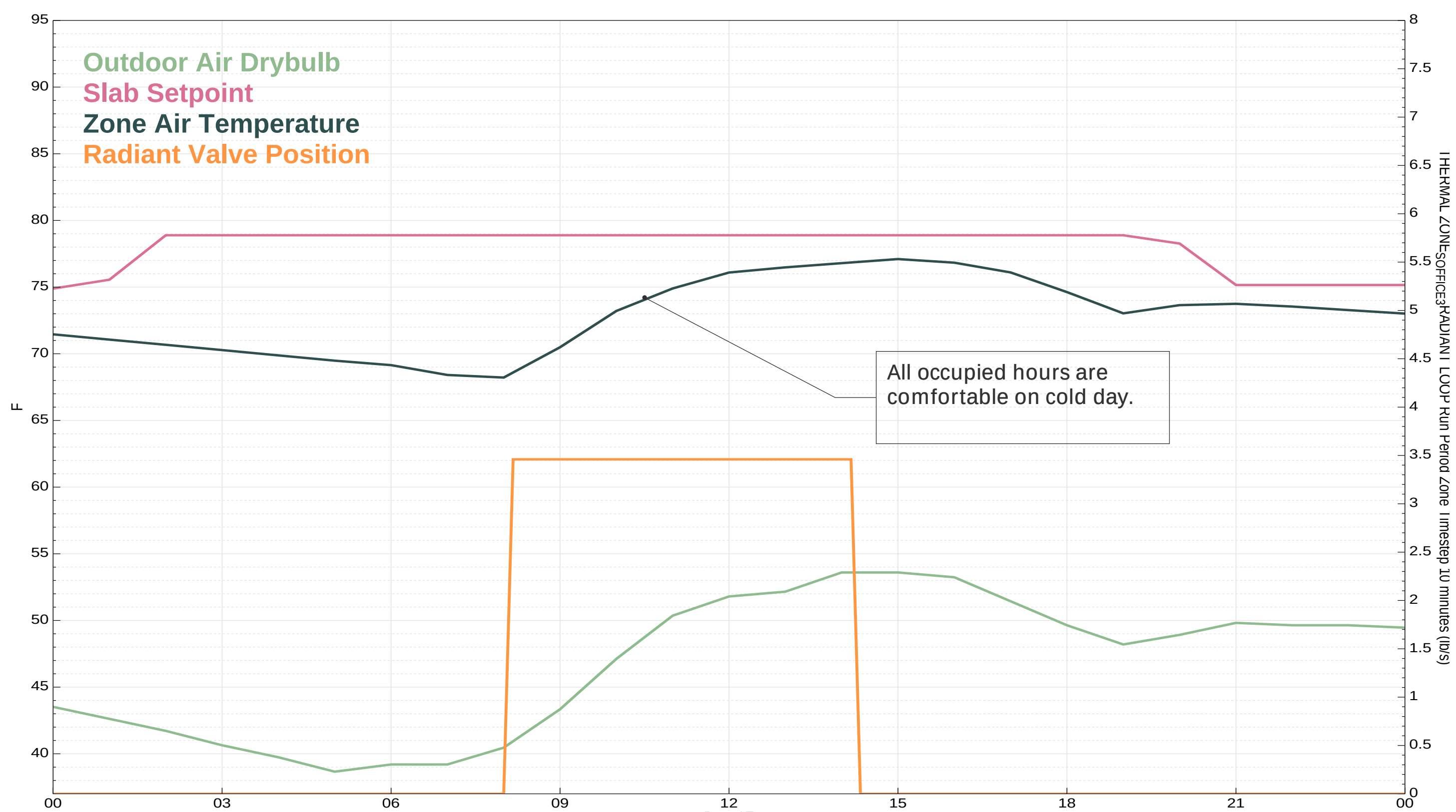
HOT DAY | COOLING WORKING



South Office, Level 3

COLD DAY | HEATING WORKING



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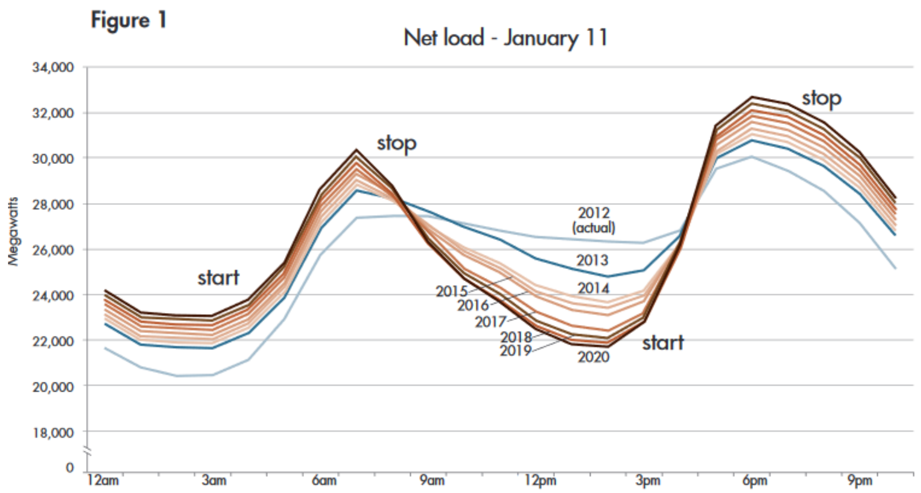
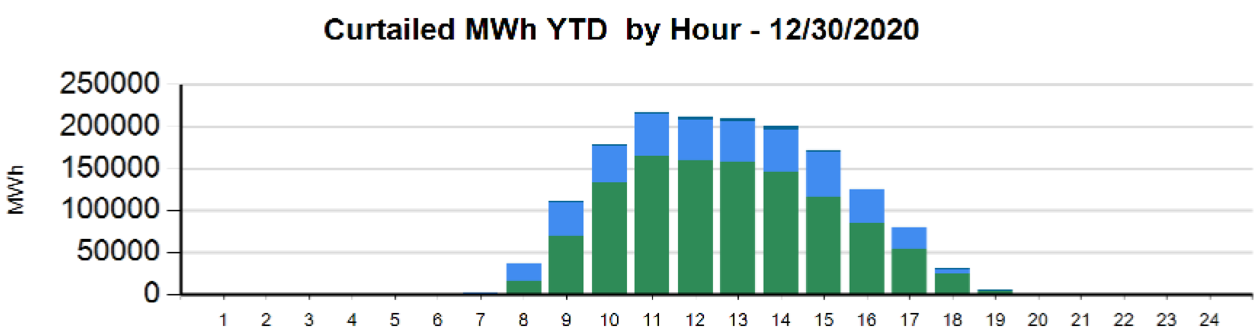
Curtailment and Other Grid Considerations

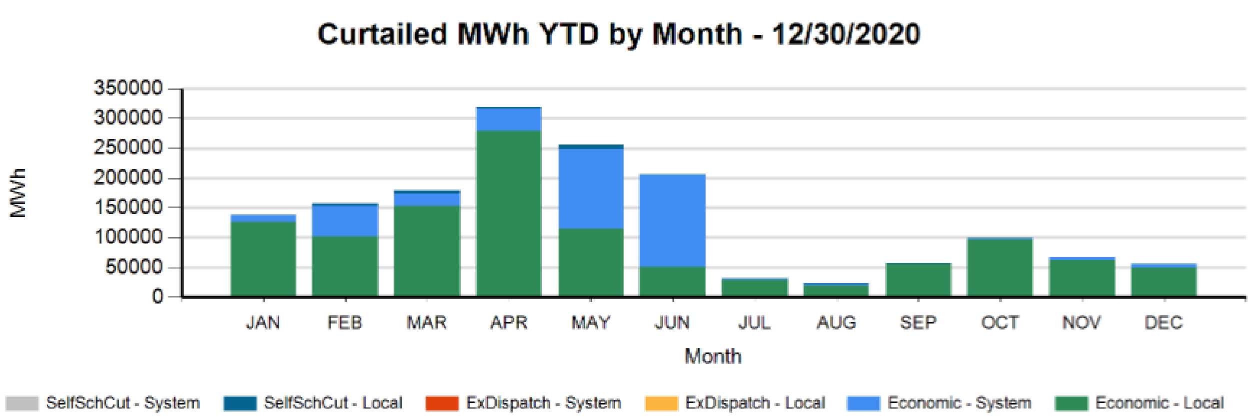
CAISO is targeting 50% renewable energy by 2030. The concept of the 'duck curve' illustrates the utility's challenge in operating the grid of the future. A pronounced valley exists when solar power is significantly contributing to the grid, and is followed by a rapid rise in net load as the sun sets (the duck's back and neck respectively). As more renewables comes online, this is projected to become more pronounced. The Radiant Building System carbon lockout proactively turns off the slab heat pump at times when the duck curve is steepest, while still maintaining comfort the whole day.



http://www.caiso.com/Documents/Flexibleresourceshelprenewables_FastFacts.pdf

Renewable energy curtailment is already significant and occurs when there is a misbalance of supply to demand. Storage, demand response, and flexible resources are all listed by CAISO as solutions to this challenge[14]. The radiant and thermal mass touches each of these categories, by providing an extremely robust, simple, and flexible load shifting in the form of concrete thermal storage.





http://www.caiso.com/Documents/Wind_SolarReal-TimeDispatchCurtailmentReportDec30_2020.pdf

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[14] http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

INTEGRAL