System COP

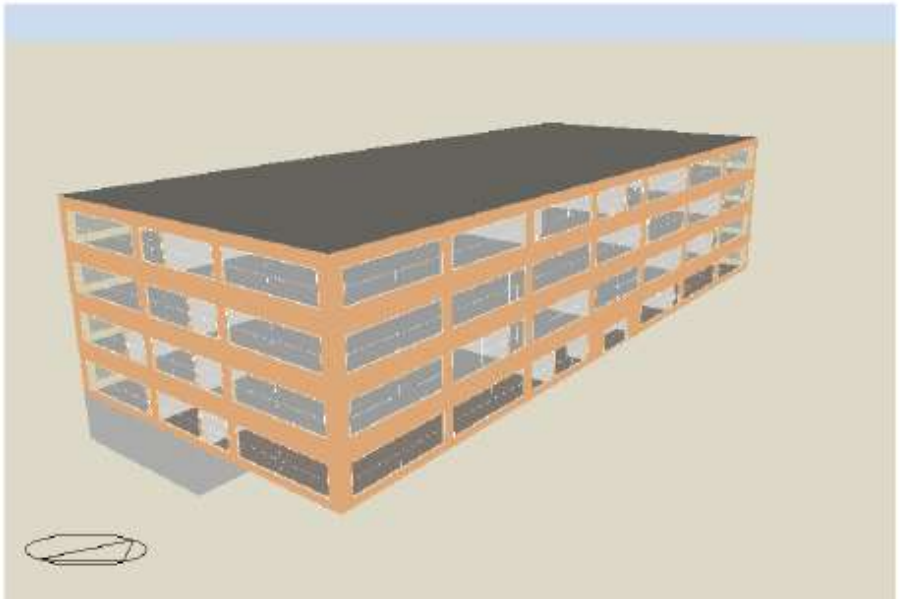
The Future of Energy Efficiency Modeling

Barry Stephens
BE25 – 20 MARCH 2025

TARRYTOWN OFFICE BUILDING

CONVENTIONAL MODELING

- Inputs using AHRI data
- Heat Pumps & VHE ERVs
- Simple Inputs, Simple Results
- Existing Testing & Ratings Procedures



Energy Analysis Report | Project 20044.000
Tarrytown Office Building, 150 White Plains Rd, Tarrytown, NY

CONVENTIONAL MODELING

- Modest Savings
- Simple Payback Not Exciting!
- Incremental Cost Payback Was Worth Proceeding With Project
- Existing Testing & Ratings Procedures

Energy costs, cost savings, and simple payback are calculated based on current energy utility rates (Con Edison April 2018) and estimated incentive rates (Con Edison Commercial and Industrial Energy Efficiency Program Manual 2018, v2.2 March 1st, 2018). Key results are summarized below.

TABLE 0.2 SUMMARY OF SIMPLE PAYBACK

	Code Minimum Retrofit Model	DOAS ERV + VRF Retrofit Model
Simple Payback Over Existing (Including Incentive)		
Total Capital Cost	$1,700,000	$2,000,000
Total Capital Cost with Incentive	$1,657,720	$1,817,760
Total Annual Savings	$15,300	$61,700
Simple Payback	108	29
Simple Payback Over Code Minimum (Including Incentive)		
Incremental Capital Cost	-	$300,000
Incremental Capital Cost with Incentive	-	$160,040
Total Annual Savings	-	$46,400
Simple Payback	-	3

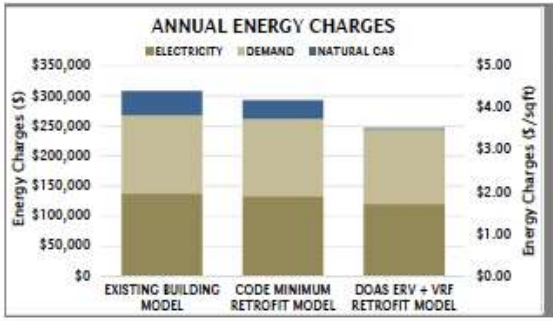


Figure 0.3

Comparison of estimated annual energy charges.

CONVENTIONAL MODELING

- Modest Savings
- Simple Payback Not Exciting!
- Incremental Cost Payback Was Worth Proceeding With Project
- Existing Testing & Ratings Procedures

TABLE 0.1 SUMMARY OF ANNUAL ENERGY SAVINGS		
	CODE MINIMUM MODEL	DOAS ERV + VRF MODEL
Savings Over Existing		
Electricity	43,000 kWh	224,000 kWh
Natural Gas	9,800 Therms	38,800 Therms
Savings Over Code Minimum		
Electricity	-	181,000 kWh
Natural Gas	-	29,000 Therms

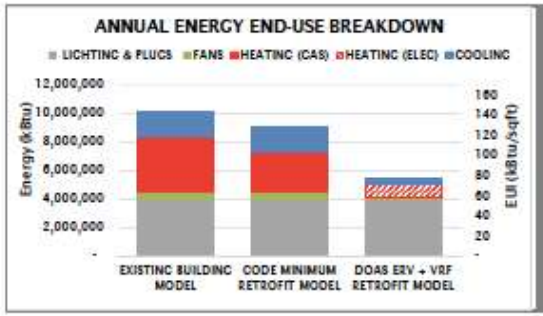


Figure 0.1

Comparison of annual energy consumption.

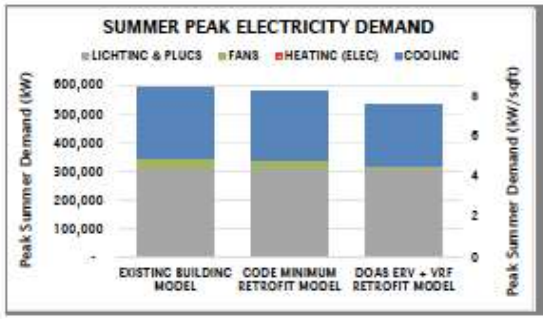


Figure 0.2

Comparison of peak summer demand savings.

MODELED AND ACTUAL PERFORMANCE

Annual *Savings*

	Modeled (TMY)	Actual (not TMY)
Electricity (kWh)	224,000	656,000
Natural Gas (therms)	38,800	52,650
Annual Energy Cost	$61,700	$213,920

SIGNIFICANT SAVINGS EXCEED THE MODEL

- 71,000 Sq ft
- 4 stories + partial basement
- Existing HVAC system based on dual-deck RTUs
- Lots of simultaneous heating & cooling
- Conversion completed (while occupied) in late 2019
- 2018 peak demand 519 kW (June)
- 2020 peak demand 366 kW (November)
- 2020 highest summer peak demand 208 kW (July)

Why did the model Underestimate the savings so significantly?

THE SOLUTION

CSA SPE-07:23

Load-based and climate-specific testing and rating procedures for heat pumps and air conditioners

CSA SPE-18:24

Load-based and climate-specific testing and rating procedures for seasonal performance of heat recovery and energy recovery ventilators (HRVs and ERVs)

HEAT PUMPS

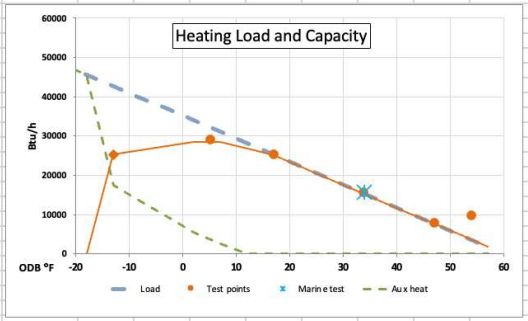
Manufacturer	SUPERHP
OutModelNum	DHP24-X
InModelNum	DHP24-I
AhriNumber	00000001
CommentOrTradeName	SUPER PLUS
OutRatedCap47Heat	28400
OutRatedInput47Heat	2700
OutRatedCap95Cool	28000
OutRatedInput95Cool	2480
RatedHSPF	9
RatedSEER	18
RatedEER95	10.2
Nominal Tons	2.3
Rating type	Heat Pump

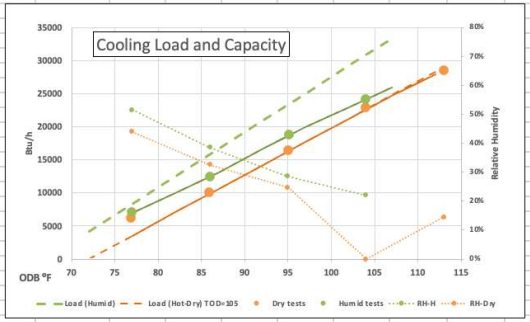
Heating	Subarctic	Very Cold	Cold/Dry	Cold/Humid	Marine	Mixed	Hot/Humid	Hot/Dry
SCOPs	1.88	2.55	3.19	2.90	4.17	3.57	4.00	3.88
w/Standby	1.87	2.52	3.14	2.86	4.02	3.48	3.72	3.69

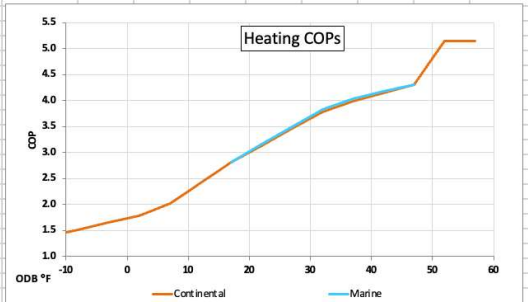
Cooling	Very Cold	Cold/Dry	Cold/Humid	Marine	Mixed	Hot/Humid	Hot/Dry
SCOPs	4.62	4.46	4.60	4.22	4.55	4.67	3.96
w/Standby	2.10	3.52	3.69	1.40	4.23	4.48	3.72

Cooling test indoor RH @ outdoor temp condition

77	86	95	104	113	°F
51%	39%	29%	22%	n/a	Humid
44%	33%	25%	#VALUE!	14%	Dry

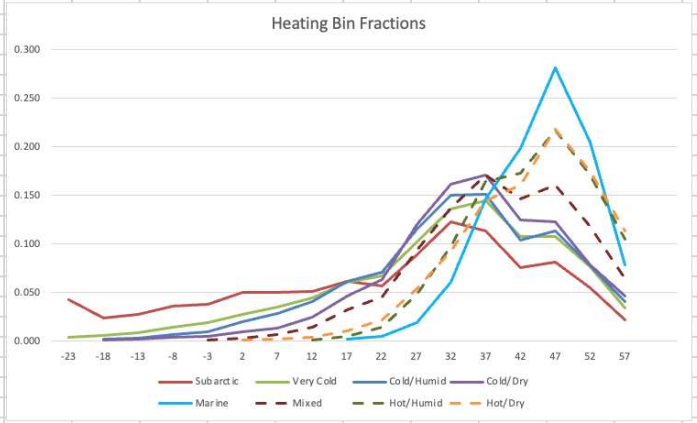


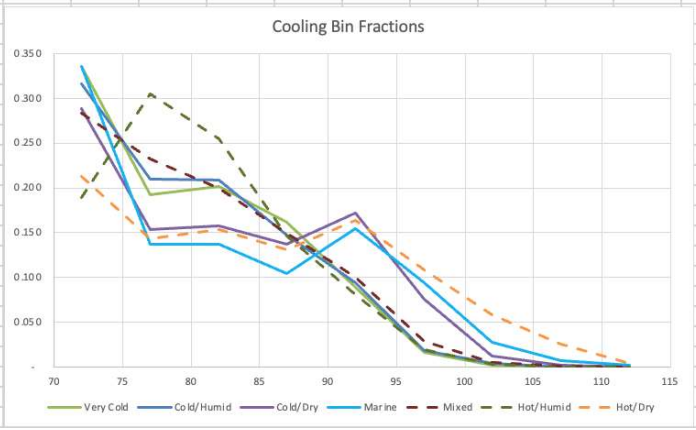




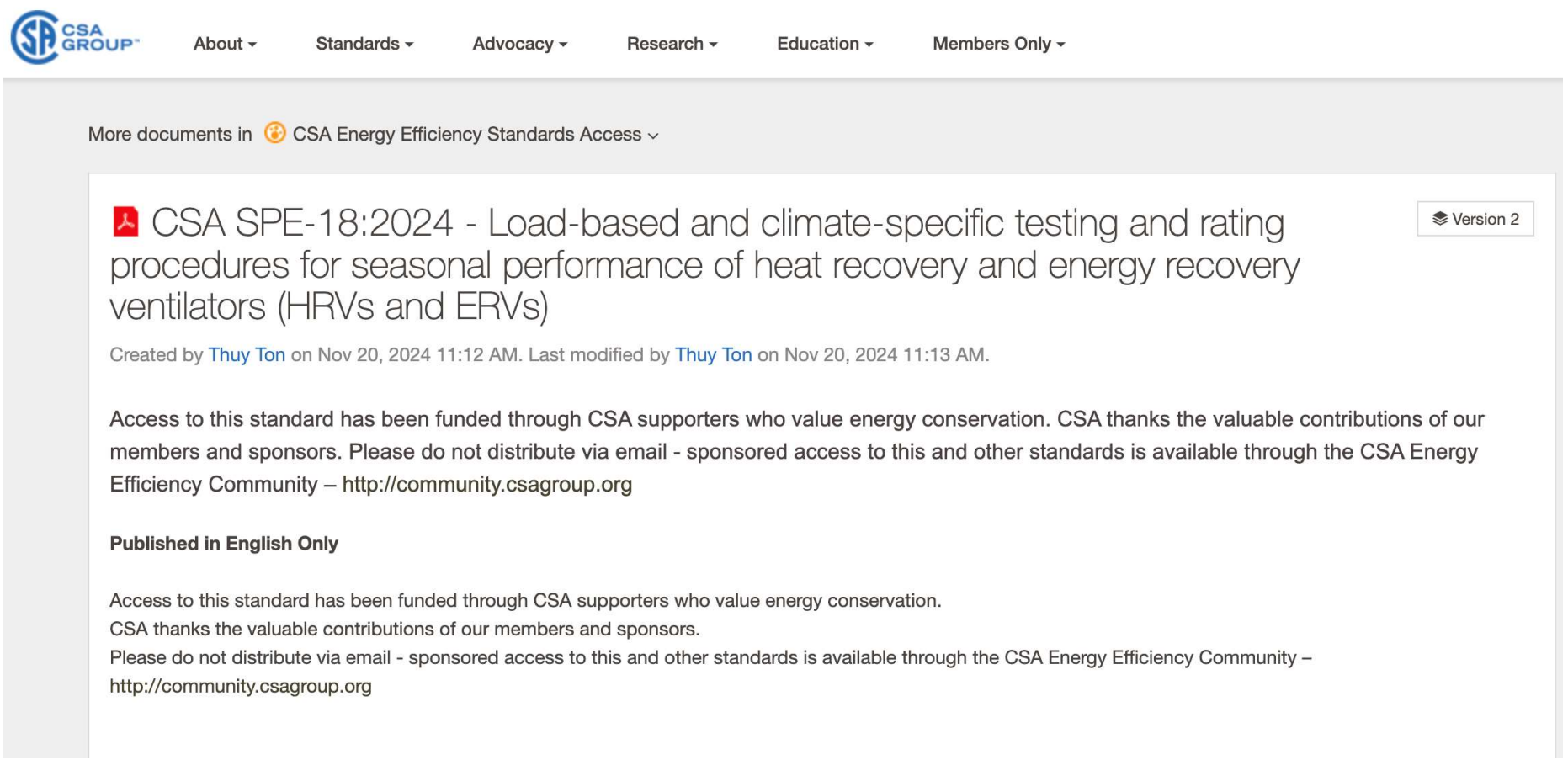
HEAT PUMPS

Tj (°F)	Subarctic	Very Cold	Cold/Dry	Cold/Humid	Marine	Mixed	Hot/Humid	Hot/Dry
Table B.11								
Heating Season Temperature Bins								
Tj	Subarctic	Very Cold	Cold/Dry	Cold/Humid	Marine	Mixed	Hot/Humid	Hot/Dry
-23	0.043	0.004						
-18	0.024	0.006	0.001	0.002				
-13	0.028	0.009	0.002	0.003				
-8	0.036	0.015	0.004	0.007				
-3	0.038	0.019	0.005	0.010		0.001		
2	0.050	0.028	0.010	0.020		0.003		0.001
7	0.050	0.035	0.014	0.029		0.007		0.002
12	0.051	0.045	0.025	0.041		0.015	0.001	0.004
17	0.062	0.061	0.047	0.062	0.002	0.033	0.005	0.011
22	0.057	0.067	0.064	0.071	0.005	0.046	0.015	0.022
27	0.089	0.102	0.120	0.116	0.019	0.094	0.049	0.054
32	0.123	0.136	0.162	0.150	0.061	0.137	0.098	0.093
37	0.114	0.145	0.171	0.151	0.147	0.171	0.165	0.145
42	0.076	0.108	0.125	0.104	0.199	0.147	0.173	0.161
47	0.082	0.108	0.123	0.114	0.282	0.161	0.217	0.218
52	0.055	0.077	0.079	0.078	0.205	0.118	0.171	0.175
57	0.022	0.034	0.047	0.041	0.079	0.065	0.105	0.114
N	7758	6340	5017	4808	4630	3299	1199	2162
Odb	**-25**	**-13**	**5**	**0**	**30**	**15**	**30**	**25**
FLH	**3267**	**2526**	**2267**	**2175**	**2337**	**1564**	**580**	**1219**
HHE	5050	3353	2267	2373	1275	1279	369	665
Table B.10								
Cooling Season Temperature Bins								
Tj	Subarctic	Very Cold	Cold/Dry	Cold/Humid	Marine	Mixed	Hot/Humid	Hot/Dry
72	-	0.336	0.289	0.316	0.335	0.284	0.190	0.213
77	-	0.192	0.154	0.210	0.137	0.232	0.305	0.143
82	-	0.202	0.157	0.209	0.137	0.199	0.255	0.154
87	-	0.162	0.138	0.147	0.104	0.150	0.146	0.131
92	-	0.089	0.172	0.095	0.154	0.100	0.081	0.163
97	-	0.016	0.076	0.019	0.094	0.029	0.019	0.109
102	-	0.002	0.013	0.005	0.028	0.006	0.003	0.058
107	-	-	0.002	-	0.007	0.001	-	0.025
112	-	-	-	-	0.002	-	-	0.004
Nc	-	**58**	**467**	**560**	**52**	**1694**	**3611**	**1965**
Odbc								
FLHc								





H/ERVs


CSA GROUP
About
Standards
Advocacy
Research
Education
Members Only
More documents in CSA Energy Efficiency Standards Access
CSA SPE-18:2024 - Load-based and climate-specific testing and rating procedures for seasonal performance of heat recovery and energy recovery ventilators (HRVs and ERVs)
Version 2
Created by Thuy Ton on Nov 20, 2024 11:12 AM. Last modified by Thuy Ton on Nov 20, 2024 11:13 AM.
Access to this standard has been funded through CSA supporters who value energy conservation. CSA thanks the valuable contributions of our members and sponsors. Please do not distribute via email - sponsored access to this and other standards is available through the CSA Energy Efficiency Community – http://community.csagroup.org
Published in English Only
Access to this standard has been funded through CSA supporters who value energy conservation.
CSA thanks the valuable contributions of our members and sponsors.
Please do not distribute via email - sponsored access to this and other standards is available through the CSA Energy Efficiency Community – http://community.csagroup.org

AHRI 1060/CSA 439 vs CSA SPE18

AHRI

- Allows for mass flow imbalance
- Primarily testing core/wheels
- Limited to 70% & 100% flows
- Two data points for temperature

CSA439

- Allows for mass flow imbalance
- Two or Three data points for temperature
- Very high failure rate for challenge testing

CSA SPE18

- Six (6) data points for temperature
- Accounts for climate zones
- Accounts for frost control in cold climates
- Accounts for economizing in cooling mode
- Mass Flow Balance flows within 5%
- Indoor ***and*** Outdoor testing

AHRI HAS “ALLOWANCES”

MEASUREMENTS	SUMMER		WINTER	
	Outdoor (OA)	Room (RA)	Outdoor (OA)	Room (RA)
Flow Rate **scfm**	1400	1110	1400	1110
Dry Bulb **°F**	82	75	23	70
Wet Bulb **°F**	63	62.6	22	54.4
Enthalpy (H) **BTU/lb**	28.4	28.1	7.8	22.7
Moisture Ratio (MR) **grains/lb**	55.5	64.7	15.0	38.0
	Exhaust (EA)	Fresh (FA)	Exhaust (EA)	Fresh (FA)
Flow Rate **scfm**	-	1400	-	1400
Dry Bulb **°F**	-	77.3	-	54.6
Wet Bulb **°F**	-	62.4	-	44.8
Enthalpy (H) **BTU/lb**	-	27.9	-	17.5
Moisture Ratio (MR) **grains/lb**	-	60.0	-	28.1

	SUMMER	WINTER
Fresh Air - External Static Pressure **w.g.**	1.4	1.4
Exhaust Air - External Static Pressure **w.g.**	1.4	1.4
Sensible effectiveness **%**	84.9	84.9
Total effectiveness **%**	74	81.7
Load savings ratio **%**	58.7	64.8
Moisture removed **grains/lb**	-4.5	-13.1

	Sen	Lat	Tot	Sen	Lat	Tot
Original load **BTUH [T]**	10584 [0.9]	8850 [0.7]	19434 [1.6]	71064	22921	93985
Load w/ RenewAire **BTUH [T]**	3461 [0.3]	4566 [0.4]	8027 [0.7]	23239	9862	33102
Total energy saved **BTUH [T]**	7123 [0.6]	4284 [0.4]	11407 [1]	47825	13059	60883

TRUTH IN ADVERTISING?

1. OA = 23F
2. RA = 70F
3. FA = 54.6 F

AHRI = 70-23 (47)
54.6-23 (31.6)

= 31.6/47 - 67%

CLAIM SENSIBLE 84.9% ?

WHAT IS VERY HIGH EFFICIENCY?

VENTACITY SYSTEMS
ALWAYS HEALTHY • ALWAYS EFFICIENT

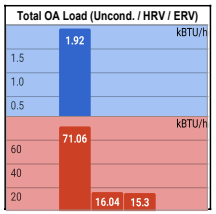
Project Information

Project Name:	Example Project Name
City:	Portland
State/Province:	SFO
Org Name:	Customer Co, Inc.
Org Contact Name:	John Doe
Org Contact Phone:	800-555-1212
Org Contact Email:	john@buildingowner.com
Created By:	BST
Created On:	6/4/2019

Quick Selector

Ventacity HRV / ERV

Ventacity Model	VS3000	
Altitude	100	ft
Supply Flow	1400	CFM
Exhaust Flow	1110	CFM



HRV	ERV	REDUX
-8.28	-2.3	kBTU/h
-55.03	-55.8	kBTU/h

Project Conditions

Summer Conditions Cooling

Outside DBT	82.0	°F
Outside WBT	63.0	°F
or Outside RH		% 34.2
Design Inside DBT	75.0	°F
Design Inside WBT		°F
or Design Inside RH	50.0	% 50.0

Unconditioned OA Cooling Load		
Supply DBT	82.0	°F
Supply WBT	63.0	°F
Supply RH	34.2	%
Total Load	**1.92**	**kBTU/h**
Sensible Load	10.58	kBTU/h
Latent Load	-8.66	kBTU/h

HRV OA Cooling Load		
Supply DBT	76.5	°F
Supply WBT	61.1	°F
Supply RH	40.9	%
Efficiency (S)	78.2	%
Total Load	**-6.36**	**kBTU/h**
Sensible Load	2.31	kBTU/h
Latent Load	-8.67	kBTU/h

ERV OA Cooling Load		
Supply DBT	76.9	°F
Supply WBT	62.5	°F
Supply RH	44.4	%
Efficiency (S)	72.2	%
Efficiency (L)	78.5	%
Total Load	**-0.3**	**kBTU/h**
Sensible Load	2.9	kBTU/h
Latent Load	-3.3	kBTU/h

Winter Conditions Heating

Outside DBT	23	°F
Outside WBT	22	°F
or Outside RH		% 86.4
Design Inside DBT	70	°F
Design Inside WBT		
or Design Inside RH	35	% 35.0

Unconditioned OA Heating Load		
Supply DBT	23.0	°F
Supply WBT	22.0	
Supply RH	86.4	%
Total Load	**71.06**	**kBTU/h**
(Sensible)		

HRV OA Heating Load		
Supply DBT	59.4	°F
Supply WBT	44.9	°F
Supply RH	28.3	%
Efficiency (S)	73.3	%
Total Load	**16.04**	**kBTU/h**
(Sensible)		
Preheater: 7.2F / 36.8F		
Warning: Condensation (1)		

ERV OA Heating Load		
Supply DBT	59.9	°F
Supply WBT	48.8	°F
Supply RH	43.7	%
Efficiency (S)	72.0	%
Efficiency (L)	82.4	%
Total Load	**15.3**	**kBTU/h**
(Sensible)		
Preheater: 10.8F / 36.8F		

TRUTH IN ADVERTISING?

- WINTER

1. OA = 23F
2. RA = 70F
3. FA = 59.9 F

AHRI = 70-23 (47)
59.9-23 (36.9)

= 36.9/47 - **79%**

BALANCED FLOWS ARE IMPORTANT

VENTACITY SYSTEMS
ALWAYS HEALTHY • ALWAYS EFFICIENT

Project Information

Project Name:	Example Project Name
City:	Portland
State/Province:	SFO
Org Name:	Customer Co, Inc.
Org Contact Name:	John Doe
Org Contact Phone:	800-555-1212
Org Contact Email:	john@buildingowner.com
Created By:	BST
Created On:	6/4/2019

Project Conditions

Summer Conditions Cooling

Outside DBT	**82.0**	°F
Outside WBT	**63.0**	°F
or Outside RH		% 34.2
Design Inside DBT	**75.0**	°F
Design Inside WBT		°F
or Design Inside RH	**50.0**	% 50.0

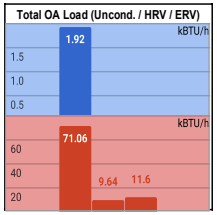
Winter Conditions Heating

Outside DBT	**23**	°F
Outside WBT	**22**	°F
or Outside RH		% 86.4
Design Inside DBT	**70**	°F
Design Inside WBT		
or Design Inside RH	**35**	% 35.0

Quick Selector

Ventacity HRV / ERV

Ventacity Model	**VS3000**	
Altitude	**100**	ft
Supply Flow	**1400**	CFM
Exhaust Flow	**1400**	CFM



HRV	ERV	REDUX
-9.52	-2.8	kBTU/h
-61.42	-59.5	kBTU/h

Unconditioned OA Cooling Load

Supply DBT	82.0	°F
Supply WBT	63.0	°F
Supply RH	34.2	%
Total Load	**1.92**	**kBTU/h**
Sensible Load	10.58	kBTU/h
Latent Load	-8.66	kBTU/h

HRV OA Cooling Load

Supply DBT	75.7	°F
Supply WBT	60.8	°F
Supply RH	42.1	%
Efficiency (S)	89.8	%
Total Load	**-7.60**	**kBTU/h**
Sensible Load	1.08	kBTU/h
Latent Load	-8.67	kBTU/h

ERV OA Cooling Load

Supply DBT	76.3	°F
Supply WBT	62.3	°F
Supply RH	45.8	%
Efficiency (S)	81.8	%
Efficiency (L)	68.0	%
Total Load	**-0.9**	**kBTU/h**
Sensible Load	1.9	kBTU/h
Latent Load	-2.8	kBTU/h

Unconditioned OA Heating Load

Supply DBT	23.0	°F
Supply WBT	22.0	
Supply RH	86.4	%
Total Load	**71.06**	**kBTU/h**
(Sensible)		

HRV OA Heating Load

Supply DBT	63.6	°F
Supply WBT	46.0	°F
Supply RH	21.0	%
Efficiency (S)	85.3	%
Total Load	**9.64**	**kBTU/h**
(Sensible)		

Preheater: 3.6F / 36.8F
Warning: Condensation (1)

ERV OA Heating Load

Supply DBT	62.3	°F
Supply WBT	49.8	°F
Supply RH	39.9	%
Efficiency (S)	81.6	%
Efficiency (L)	74.1	%
Total Load	**11.6**	**kBTU/h**
(Sensible)		

Preheater: 5.4F / 36.8F

TRUTH IN ADVERTISING?

- WINTER

1. OA = 23F
2. RA = 70F
3. FA = 62.3 F

AHRI = 70-23 (47)
62.3-23 (39.3)

= 39.3/47 - **84%**

CSA SPE18

Table 4
Test conditions
(See Clauses 10.1.2, 10.3.2, 10.4.4, 10.4.5, and 10.6.1.)

	Outdoor		Indoor	
Test	**Dry-bulb, °C (°F)**	**Wet-bulb, °C (°F)**	**Dry-bulb, °C (°F)**	**Wet-bulb, °C (°F)**
A	35 (95)	26.1 (78.9)	24 (75.2)	17 (62.6)
B	30 (86)	21.9 (71.4)		
C	10 (50)	4.5 (40.1)	21 (69.8)	11.4 (52.5)
D	0 (32)	−3.4 (25.9)		
E*	−10 (14)	−12 (10.4)		
F†	−25 (−13)	−25.7 (−14.3)		

* *Optional test, if needed to estimate parameters for frost control.*
† *For long-term cold weather test only.*

CSA SPE18

B.2 Climates

The eight climate zones used in this Document are shown in Figure B.1. The prototype cities that correspond with each climate zone are shown in Table B.1, along with approximate correspondence or overlap with IECC climate zones is shown.

Table B.1
Climate zone mapping
(See Clauses B.1 and B.2.)

Climate zone	**Prototype City**	**IECC climate zone equivalents** (approximate)
Subarctic	Ambler, AK	8
Very cold	Presque Isle, ME	6A, 7
Cold/Dry	Rifle, CO	5B, 6B
Cold/Humid	Lansing, MI	4A (north), 5A
Marine	Kelso, WA	3C, 4C, 5C
Mixed/Humid	Wichita, KS	3A, 4A (south)
Hot/Humid	Houston, TX	2A
Hot/Dry	Kingman, AZ	2B, 3B

CSA SPE18

Annex A (informative)
Fixed-bed regenerator performance testing

Notes:

1) *This informative annex has been written in mandatory language to facilitate adoption where users of the Document or regulatory authorities wish to adopt it formally as additional requirements to this Document.*
2) *See Clause 3.*

A.1 General

It is important to consider the alternating discharge and regeneration cycle when testing fixed-bed regenerators (FBRs). Unlike conventional HRV/ERVs, an FBR operating at steady state produces airstreams with periodically fluctuating air properties. Except as specified in this Annex, the same measurement techniques, test conditions, and calculations described in this Document shall be used to determine the performance of FBR units.

A.2 Instrumentation and measurement procedures

A.2.1 General

The instruments used to determine performance shall meet the requirements in Clauses 4.2, 5, and 6.

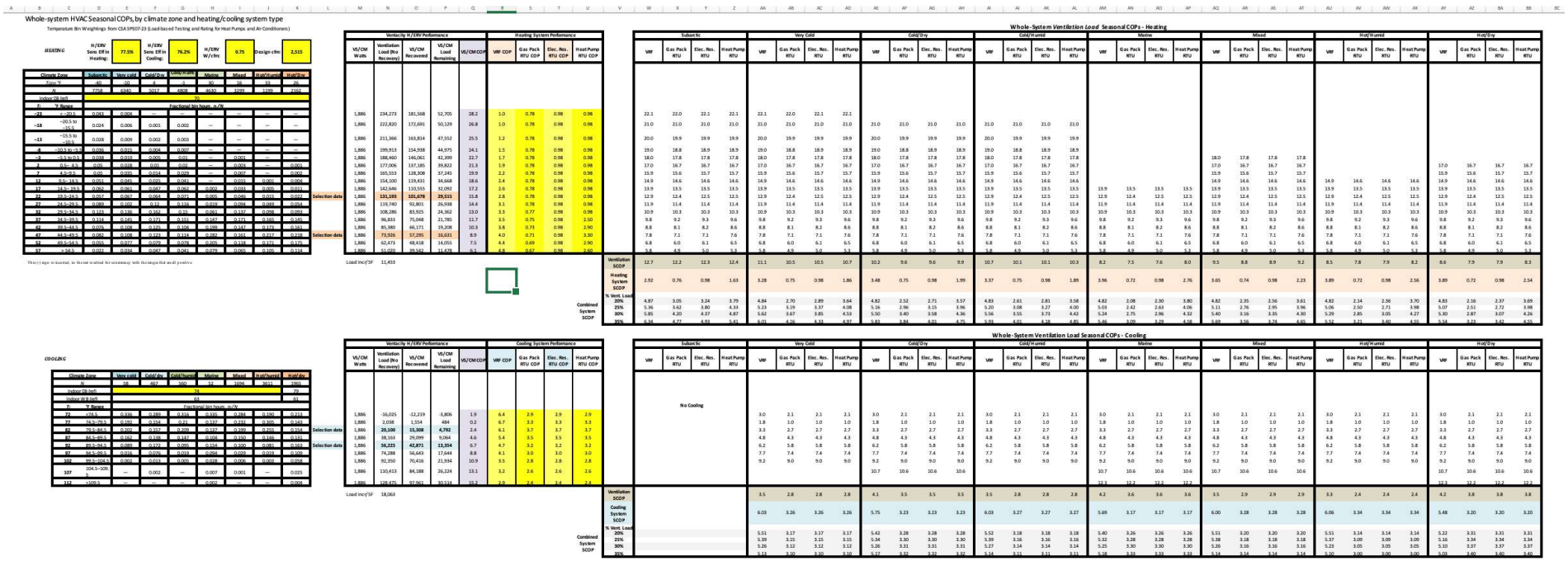
A.2.2 Sampling rate and response time

A.2.2.1 Air sampling

Air properties at the four measuring stations shall be sampled at least 30 times per recovery period, and shall span the entire recovery period using instruments with a response time shorter than the sampling rate.

SYSTEM COP

*



* Modeling Tool Compliments of Charlie Stephens

SYSTEM COP

Whole-system HVAC Seasonal COPs, by climate zone and heating/cooling system type

Temperature Bin Weightings from CSA SPE07-23 (Load-based Testing and Rating for Heat Pumps and Air Conditioners)

HEATING	H/ERV Sens Eff in Heating:	77.5%	H/ERV Sens Eff in Cooling:	76.2%	H/ERV W/cfm:	0.75	Design cfm:	2,515

Climate Zone		Subarctic	Very cold	Cold/Dry	Cold/Humid	Marine	Mixed	Hot/Humid	Hot/Dry
T_{ODH} °F		-40	-10	4	-1	30	16	33	26
N		7758	6340	5017	4808	4630	3299	1199	2162
Indoor DB (ref)		70							
T_j	°F Range	Fractional bin hours, n_j/N							
–23	<–20.5	0.043	0.004	—	—	—	—	—	—
–18	–20.5 to –15.5	0.024	0.006	0.001	0.002	—	—	—	—
–13	–15.5 to –10.5	0.028	0.009	0.002	0.003	—	—	—	—
-8	–10.5 to –5.5	0.036	0.015	0.004	0.007	—	—	—	—
–3	–5.5 to 0.5	0.038	0.019	0.005	0.01	—	0.001	—	—
2	0.5– 4.5	0.05	0.028	0.01	0.02	—	0.003	—	0.001
7	4.5–9.5	0.05	0.035	0.014	0.029	—	0.007	—	0.002
12	9.5–14.5	0.051	0.045	0.025	0.041	—	0.015	0.001	0.004
17	14.5–19.5	0.062	0.061	0.047	0.062	0.002	0.033	0.005	0.011
22	19.5–24.5	0.057	0.067	0.064	0.071	0.005	0.046	0.015	0.022
27	24.5–29.5	0.089	0.102	0.12	0.116	0.019	0.094	0.049	0.054
32	29.5–34.5	0.123	0.136	0.162	0.15	0.061	0.137	0.098	0.093
37	34.5–39.5	0.114	0.145	0.171	0.151	0.147	0.171	0.165	0.145
42	39.5–44.5	0.076	0.108	0.125	0.104	0.199	0.147	0.173	0.161
47	44.5–49.5	0.082	0.108	0.123	0.114	0.282	0.161	0.217	0.218
52	49.5–54.5	0.055	0.077	0.079	0.078	0.205	0.118	0.171	0.175
57	>54.5	0.022	0.034	0.047	0.041	0.079	0.065	0.105	0.114

* Modeling Tool Compliments of Charlie Stephens

SYSTEM COP

		Ventacity H/ERV Performance					Heating System Performance			
		VS/CM Watts	Ventilation Load (No Recovery)	VS/CM Recovered	VS/CM Load Remaining	VS/CM COP	VRF COP	Gas Pack RTU COP	Elec. Res. RTU COP	Heat Pump RTU COP
-18	−20.5 to −15.5	1,886	234,273	181,568	52,705	28.2	1.0	0.78	0.98	0.98
-13	−15.5 to −10.5	1,886	222,820	172,691	50,129	26.8	1.0	0.78	0.98	0.98
-8	−10.5 to −5.5	1,886	211,366	163,814	47,552	25.5	1.2	0.78	0.98	0.98
-3	−5.5 to 0.5	1,886	199,913	154,938	44,975	24.1	1.5	0.78	0.98	0.98
2	0.5– 4.5	1,886	188,460	146,061	42,399	22.7	1.7	0.78	0.98	0.98
7	4.5–9.5	1,886	177,006	137,185	39,822	21.3	1.9	0.78	0.98	0.98
12	9.5– 14.5	1,886	165,553	128,308	37,245	19.9	2.2	0.78	0.98	0.98
17	14.5– 19.5	1,886	154,100	119,431	34,668	18.6	2.4	0.78	0.98	0.98
22	19.5–24.5	1,886	142,646	110,555	32,092	17.2	2.6	0.78	0.98	0.98
27	24.5–29.5	1,886	**131,193**	**101,678**	**29,515**	15.8	2.8	0.78	0.98	0.98
32	29.5–34.5	1,886	119,740	92,801	26,938	14.4	3.1	0.78	0.98	0.98
37	34.5–39.5	1,886	108,286	83,925	24,362	13.0	3.3	0.77	0.98	0.98
42	39.5–44.5	1,886	96,833	75,048	21,785	11.7	3.5	0.75	0.98	2.50
47	44.5–49.5	1,886	85,380	66,171	19,208	10.3	3.8	0.73	0.98	2.90
52	49.5–54.5	1,886	73,926	57,295	16,631	8.9	4.0	0.71	0.98	3.30
57	> 54.5	1,886	62,473	48,418	14,055	7.5	4.4	0.69	0.98	2.90
		1,886	51,020	39,542	11,478	6.1	4.8	0.67	0.98	2.60

* Modeling Tool Compliments of Charlie Stephens

SYSTEM COP

Whole-System *Ventilation Load* Seasonal COPs - Heating

		Cold/Dry				Cold/Humid				Marine				Mixed			
		VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU	VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU	VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU	VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU
		21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0								
		20.0	19.9	19.9	19.9	20.0	19.9	19.9	19.9								
		19.0	18.8	18.9	18.9	19.0	18.8	18.9	18.9								
		18.0	17.8	17.8	17.8	18.0	17.8	17.8	17.8					18.0	17.8	17.8	17.8
		17.0	16.7	16.7	16.7	17.0	16.7	16.7	16.7					17.0	16.7	16.7	16.7
		15.9	15.6	15.7	15.7	15.9	15.6	15.7	15.7					15.9	15.6	15.7	15.7
		14.9	14.6	14.6	14.6	14.9	14.6	14.6	14.6					14.9	14.6	14.6	14.6
		13.9	13.5	13.5	13.5	13.9	13.5	13.5	13.5	13.9	13.5	13.5	13.5	13.9	13.5	13.5	13.5
		12.9	12.4	12.5	12.5	12.9	12.4	12.5	12.5	12.9	12.4	12.5	12.5	12.9	12.4	12.5	12.5
		11.9	11.4	11.4	11.4	11.9	11.4	11.4	11.4	11.9	11.4	11.4	11.4	11.9	11.4	11.4	11.4
		10.9	10.3	10.3	10.3	10.9	10.3	10.3	10.3	10.9	10.3	10.3	10.3	10.9	10.3	10.3	10.3
		9.8	9.2	9.3	9.6	9.8	9.2	9.3	9.6	9.8	9.2	9.3	9.6	9.8	9.2	9.3	9.6
		8.8	8.1	8.2	8.6	8.8	8.1	8.2	8.6	8.8	8.1	8.2	8.6	8.8	8.1	8.2	8.6
		7.8	7.1	7.1	7.6	7.8	7.1	7.1	7.6	7.8	7.1	7.1	7.6	7.8	7.1	7.1	7.6
		6.8	6.0	6.1	6.5	6.8	6.0	6.1	6.5	6.8	6.0	6.1	6.5	6.8	6.0	6.1	6.5
		5.8	4.9	5.0	5.3	5.8	4.9	5.0	5.3	5.8	4.9	5.0	5.3	5.8	4.9	5.0	5.3
	Ventilation SCOP	10.2	9.6	9.6	9.9	10.7	10.1	10.1	10.3	8.2	7.5	7.6	8.0	9.5	8.8	8.9	9.2
	Heating System SCOP	3.48	0.75	0.98	1.99	3.37	0.75	0.98	1.89	3.96	0.72	0.98	2.76	3.65	0.74	0.98	2.23
	% Vent. Load																
	20%	4.82	2.52	2.71	3.57	4.83	2.61	2.81	3.58	4.82	2.08	2.30	3.80	4.82	2.35	2.56	3.61
Combined System SCOP	**25%**	5.16	2.96	3.15	3.96	5.20	3.08	3.27	4.00	5.03	2.42	2.63	4.06	5.11	2.76	2.95	3.96
	30%	5.50	3.40	3.58	4.36	5.56	3.55	3.73	4.42	5.24	2.75	2.96	4.32	5.40	3.16	3.35	4.30
	35%	5.83	3.84	4.01	4.75	5.93	4.01	4.18	4.85	5.46	3.09	3.29	4.58	5.69	3.56	3.74	4.65

SYSTEM COP

)OLING

Climate Zone		Very cold	Cold/dry	Cold/humid	Marine	Mixed	Hot/humid	Hot/dry
N		58	467	560	52	1694	3611	1965
Indoor DB (ref)		74						79
Indoor WB (ref)		63						61
T_j	°F Range	Fractional bin hours, n_j/N						
72	<74.5	0.336	0.289	0.316	0.335	0.284	0.190	0.213
77	74.5–79.5	0.192	0.154	0.21	0.137	0.232	0.305	0.143
82	79.5–84.5	0.202	0.157	0.209	0.137	0.199	0.255	0.154
87	84.5–89.5	0.162	0.138	0.147	0.104	0.150	0.146	0.131
92	89.5–94.5	0.089	0.172	0.095	0.154	0.100	0.081	0.163
97	94.5–99.5	0.016	0.076	0.019	0.094	0.029	0.019	0.109
102	99.5–104.5	0.002	0.013	0.005	0.028	0.006	0.003	0.058
107	104.5–109.5	—	0.002	—	0.007	0.001	—	0.025
112	>109.5	—	—	—	0.002	—	—	0.004

	Ventacity H/ERV Performance					Cooling System Performance			
	VS/CM Watts	Ventilation Load (No Recovery)	VS/CM Recovered	VS/CM Load Remaining	VS/CM COP	VRF COP	Gas Pack RTU COP	Elec. Res. RTU COP	Heat Pump RTU COP
	1,886	-16,025	-12,219	-3,806	1.9	6.4	2.9	2.9	2.9
	1,886	2,038	1,554	484	0.2	6.7	3.3	3.3	3.3
Selection data	1,886	**20,100**	**15,308**	**4,792**	2.4	6.1	3.7	3.7	3.7
	1,886	38,163	29,099	9,064	4.6	5.4	3.5	3.5	3.5
Selection data	1,886	**56,225**	**42,871**	**13,354**	6.7	4.7	3.2	3.2	3.2
	1,886	74,288	56,643	17,644	8.8	4.1	3.0	3.0	3.0
	1,886	92,350	70,416	21,934	10.9	3.5	2.8	2.8	2.8
	1,886	110,413	84,188	26,224	13.1	3.2	2.6	2.6	2.6
	1,886	128,475	97,961	30,514	15.2	2.9	2.4	2.4	2.4

SYSTEM COP

		Cold/Dry				Cold/Humid				Marine				Mixed			
		VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU	VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU	VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU	VRF	Gas Pack RTU	Elec. Res. RTU	Heat Pump RTU
		3.0	2.1	2.1	2.1	3.0	2.1	2.1	2.1	3.0	2.1	2.1	2.1	3.0	2.1	2.1	2.1
		1.8	1.0	1.0	1.0	1.8	1.0	1.0	1.0	1.8	1.0	1.0	1.0	1.8	1.0	1.0	1.0
		3.3	2.7	2.7	2.7	3.3	2.7	2.7	2.7	3.3	2.7	2.7	2.7	3.3	2.7	2.7	2.7
		4.8	4.3	4.3	4.3	4.8	4.3	4.3	4.3	4.8	4.3	4.3	4.3	4.8	4.3	4.3	4.3
		6.2	5.8	5.8	5.8	6.2	5.8	5.8	5.8	6.2	5.8	5.8	5.8	6.2	5.8	5.8	5.8
		7.7	7.4	7.4	7.4	7.7	7.4	7.4	7.4	7.7	7.4	7.4	7.4	7.7	7.4	7.4	7.4
		9.2	9.0	9.0	9.0	9.2	9.0	9.0	9.0	9.2	9.0	9.0	9.0	9.2	9.0	9.0	9.0
		10.7	10.6	10.6	10.6					10.7	10.6	10.6	10.6	10.7	10.6	10.6	10.6
										12.3	12.2	12.2	12.2				
	Ventilation SCOP	4.1	3.5	3.5	3.5	3.5	2.8	2.8	2.8	4.2	3.6	3.6	3.6	3.5	2.9	2.9	2.9
	Heating System SCOP	5.75	3.23	3.23	3.23	6.03	3.27	3.27	3.27	5.69	3.17	3.17	3.17	6.00	3.28	3.28	3.28
	% Vent. Load																
Combined System SCOP	20%	5.42	3.28	3.28	3.28	5.52	3.18	3.18	3.18	5.40	3.26	3.26	3.26	5.51	3.20	3.20	3.20
	25%	5.34	3.30	3.30	3.30	5.39	3.16	3.16	3.16	5.32	3.28	3.28	3.28	5.38	3.18	3.18	3.18
	30%	5.26	3.31	3.31	3.31	5.27	3.14	3.14	3.14	5.25	3.30	3.30	3.30	5.26	3.16	3.16	3.16
	35%	5.17	3.32	3.32	3.32	5.14	3.11	3.11	3.11	5.18	3.33	3.33	3.33	5.14	3.14	3.14	3.14

MODELING HVAC WITH SYSTEM COP – VRF & H/ERV

67% H/ERV – 1.2 Watts/cfm

Heating COP -	3.37
Cooling COP -	6.03
Ventilation COP h -	6.7
Ventilation COP c -	3.4
System COP h -	**4.38**
System COP c -	**5.24**

82% H/ERV – 0.6 Watts/cfm

Heating COP -	3.37
Cooling COP -	6.03
Ventilation COP h -	14.4
Ventilation COP c -	4.0
System COP h -	**6.68**
System COP c -	**5.43**

Nearly 50% Increase in COP

Based on 70% Heating and Cooling Load, 30% Outside Air (Ventilation) Load

MODELING HVAC WITH SYSTEM COP ELECTRIC HEATING, NO COOLING & H/ERV IN A HIGH PERFORMANCE BUILDING

67% H/ERV – 1.2 Watts/cfm

Heating COP - 3.37

Cooling COP - 6.03

Ventilation COP h - 6.7
Ventilation COP c - 3.4

System COP h - 5.04

System COP c - 4.72

82% H/ERV – 0.6 Watts/cfm

Heating COP - 3.37

Cooling COP - 6.03

Ventilation COP h - 14.4
Ventilation COP c - 4.0

System COP h - 8.89

System COP c - 5.0

Nearly 50% Increase in COP

Based on 50% Heating and Cooling Load, 50% Outside Air (Ventilation) Load

MODELING HVAC WITH SYSTEM COP
ELECTRIC HEATING, NO COOLING & H/ERV

67% H/ERV – 1.2 Watts/cfm

Heating COP - 0.98

Cooling COP - N/A

Ventilation COP h - 2.5

System COP h - 1.44

82% H/ERV – 0.6 Watts/cfm

Heating COP - 0.98

Cooling COP - N/A

Ventilation COP h - 14.0

System COP h - 4.88 — **Over 300% Increase in COP**

Based on 70% Heating and Cooling Load, 30% Outside Air (Ventilation) Load

MODELING HVAC WITH SYSTEM COP ELECTRIC HEATING, NO COOLING & H/ERV IN A HIGH PERFORMANCE BUILDING

67% H/ERV – 1.2 Watts/cfm

Heating COP - 0.98

Cooling COP - N/A

Ventilation COP h - 2.5

System COP h - 1.74

82% H/ERV – 0.6 Watts/cfm

Heating COP - 0.98

Cooling COP - N/A

Ventilation COP h - 14.0

System COP h - 7.49 — **Over 400% Increase in COP**

Based on 50% Heating and Cooling Load, 50% Outside Air (Ventilation) Load

SIGNIFICANT ROI

Ventacity Comparison: North Beach Elementary
ERV-1 @ 3000CFM, 1"W.C.

Assumption	Parameter	Competitor	Ventacity
	Fan Power (W)	6114	3421
	Delivered (SA) Temperature Deg F	53.4	57.8
	Heat Recovered (W)	30785	34956
	Heat Recovered (BTU/h)	104976	119200
•	Hours per day	***10***	***10***
•	Days per month	25	25
•	Months per year	9	9
	Heat Recovered per month (kW.h)	7696	8739
	Heat Recovered per year (kW.h)	69266	78651
	HRV/ERV CoP	**5.0**	**10.2**
	Heat Load from fresh HRV/ERV air (W)	15772	11613
	Heat Load from fresh HRV/ERV air (BTU/h)	53784	39600
•	heat Pump CoP (heating)	1	1
	Heat pump power to heat HRV/ERV SA (W)	15772	11613
	Power: Heat Pump Plus fan (W)	21886	15034
•	Electrical rate $/kWh	0.15	0.15
	Monthly electric bill HRV/ERV Power plus		
	Power to heat fresh air. $	$ 821	$ 564
	Annual electic bill to heat fresh air $	$ 7,387	$ 5,074

Savings Per Unit	$	**2,313**
Savings for 6 Units	$	**13,876.37**
Savings for 6 Units over 10 Years	$	**138,763.75**

- **BIGGER VOLUMES EQUALS BIGGER SAVINGS**
- **SCHOOL USED TEN YEAR BOND – SAVINGS MORE THAN COVERED INCREASED COST OF PROJECT OVER LIFE OF LOAN**
- **COP IS *DOUBLE* THAT OF CONVENTIONAL ERVS**

TWO KEY COMPARISON PERFORMANCE DRIVERS

HVAC whole-system COP

At average heating conditions in one floor of a New York highrise:				
ERV recovery efficiency:		70	85	0
Ventilation rate:	cfm	1,000	1,000	1,000
ERV fan power:	W	600	390	510
Heating hours per year:	hrs	3,650	3,650	3,650
OAT:	F	35	35	35
IAT:	F	70	70	70
delta T:	F	35	35	35
Energy recovered:	Btu/hr	26,460	32,130	0
Energy not recovered:	Btu/hr	11,340	5,670	37,800
Vent. fraction of total load	%	19.4	10.8	44.6
Fan energy used:	Btu/hr	2,047	1,331	1,740
Heating COP:		0.75	3.00	0.75
Ventilation Gas Energy use :	therms	355		1,183
Ventilation Fan Energy use:	kWh	3,154	10,283	3,066
At average conditions:				
Ventilation System COP:		12.9	24.1	na
Whole System COP:		3.1	5.3	0.75
(Assuming envelopel heating load of 3.9 tons)				

Designing for “off”

SYSTEM COP COMPARISON

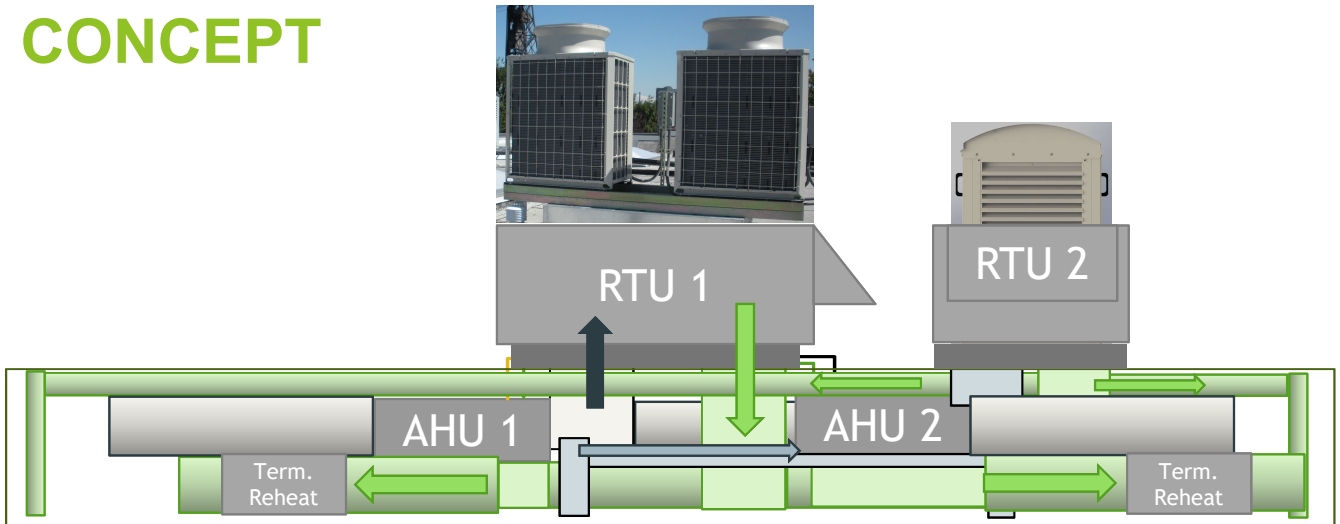
SYSTEM COP = 1.02

- High Fan Power
- Modest H&C COP
- Tempering Outside Air
  "Always On"

SYSTEM COP = 4.94

- High H&C COP w/Heat Pumps
- Low Fan Power
- Extremely Low OA Load
- Design for Off

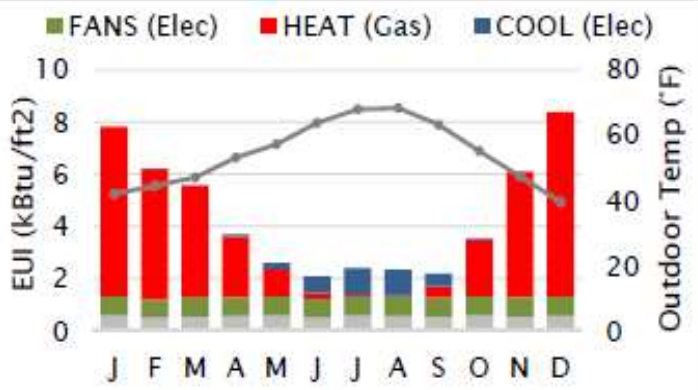
CONCEPT



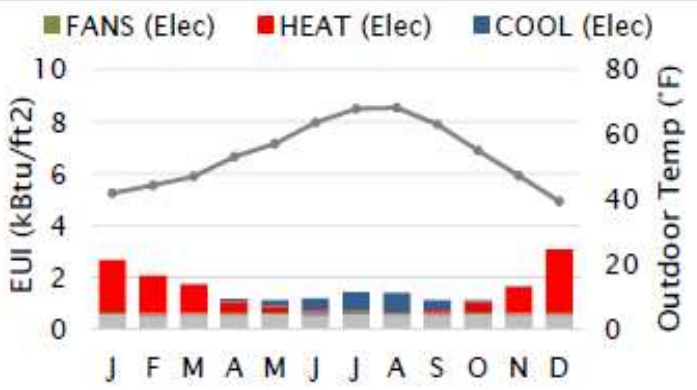
Typical System $SCOP_h$: 5.6

Typical System $SCOP_c$: 5.3

LAW OFFICE RESULTS
71% HVAC ENERGY SAVINGS

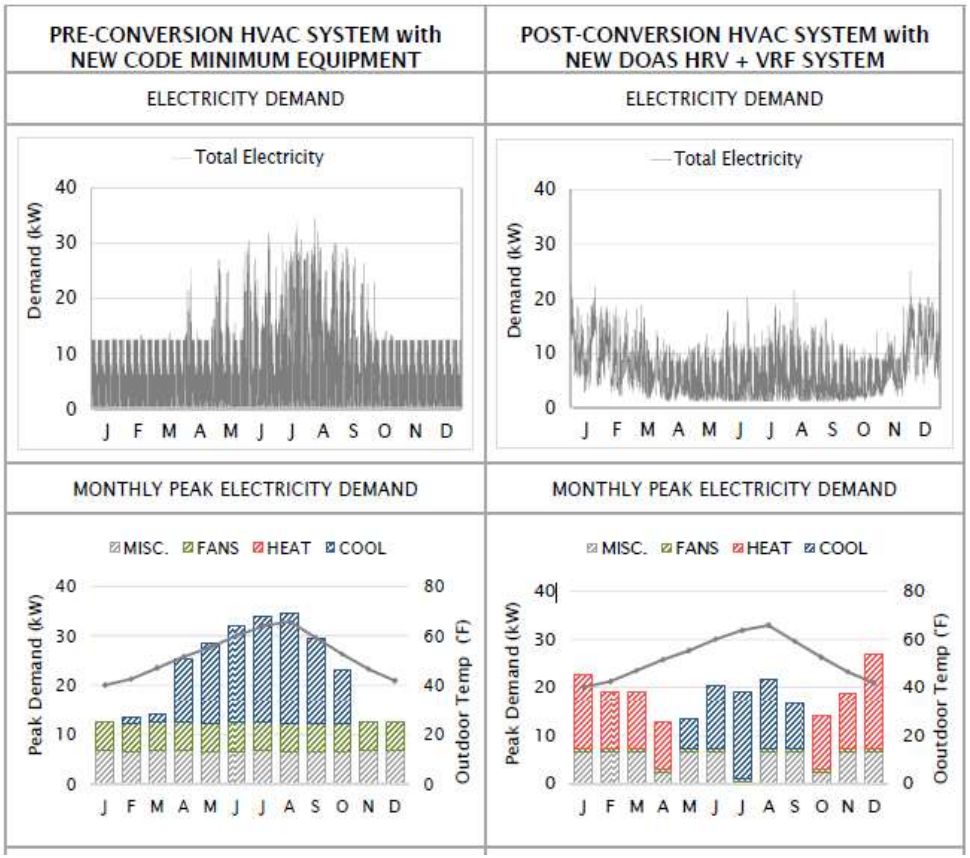


	ANNUAL EUI	---
Total:[2]	51.4 kBtu/ft²	---
Fans:	8.7 kBtu/ft²	---
Heating:	32.5 kBtu/ft²	---
Cooling:	3.4 kBtu/ft²	---
HVAC:	44.6 kBtu/ft²	---
Electricity:	18.9 kBtu/ft²	---
Gas:	32.5 kBtu/ft²	---

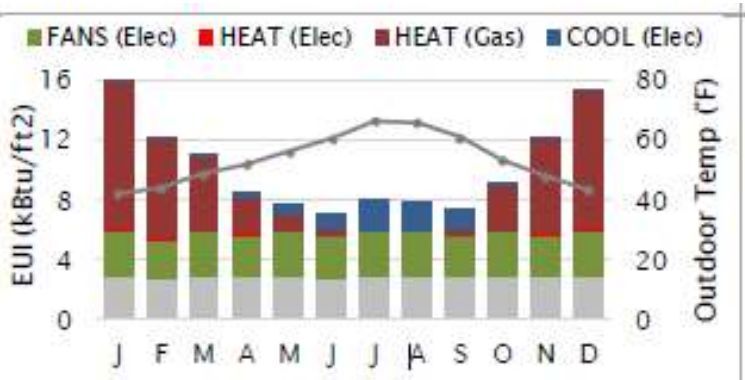


	ANNUAL EUI	ANNUAL SAVINGS
Total:	19.1 kBtu/ft²	32.3 kBtu/ft²
Fans:	1.0 kBtu/ft²	7.6 kBtu/ft²
Heating:	8.4 kBtu/ft²	24.1 kBtu/ft²
Cooling:	2.8 kBtu/ft²	0.6 kBtu/ft²
HVAC:	12.3 kBtu/ft²	32.3 kBtu/ft²
Electricity:	19.1 kBtu/ft²	-0.2 kBtu/ft²
Gas:	0.0 kBtu/ft²	32.5 kBtu/ft²

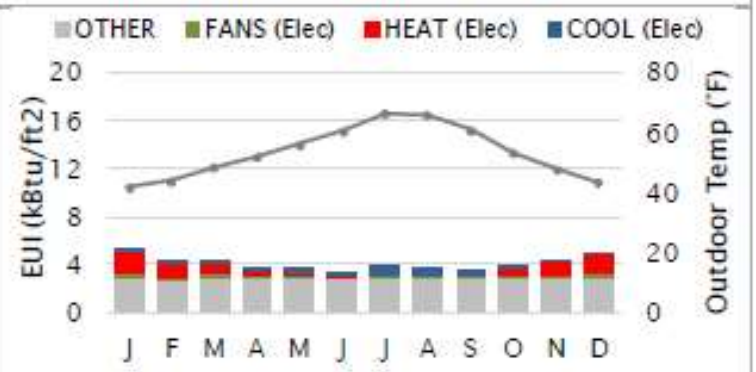
LAW OFFICE RESULTS
DEMAND REDUCTION



AIRPORT TERMINAL RESULTS
84% HVAC ENERGY SAVINGS



ANNUAL EUI		---
Total:	122.0 kBtu/ft²	---
Fans:	33.9 kBtu/ft²	---
Heating:	45.5 kBtu/ft²	---
Cooling:	7.9 kBtu/ft²	---
HVAC:	87.3 kBtu/ft²	---
Electricity:	76.8 kBtu/ft²	---
Gas:	45.3 kBtu/ft²	---

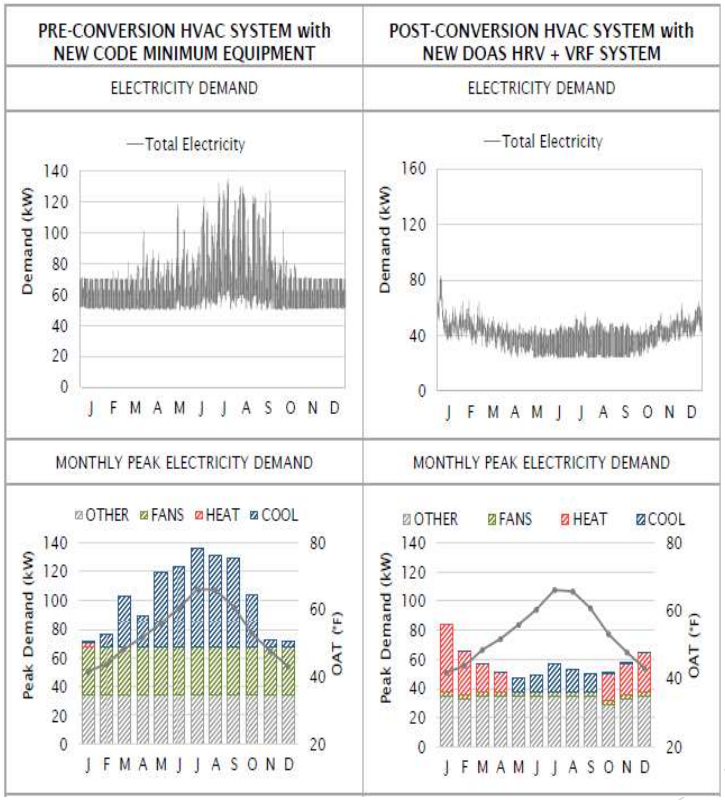


ANNUAL EUI		ANNUAL SAVINGS
Total:	48.1 kBtu/ft²	73.9 kBtu/ft²
Fans:	2.8 kBtu/ft²	31.2 kBtu/ft²
Heating:	8.1 kBtu/ft²	37.3 kBtu/ft²
Cooling:	2.4 kBtu/ft²	5.5 kBtu/ft²
HVAC:	13.3 kBtu/ft²	73.9 kBtu/ft²
Electricity:	47.4 kBtu/ft²	29.4 kBtu/ft²
Gas:	0.7 kBtu/ft²	44.6 kBtu/ft²

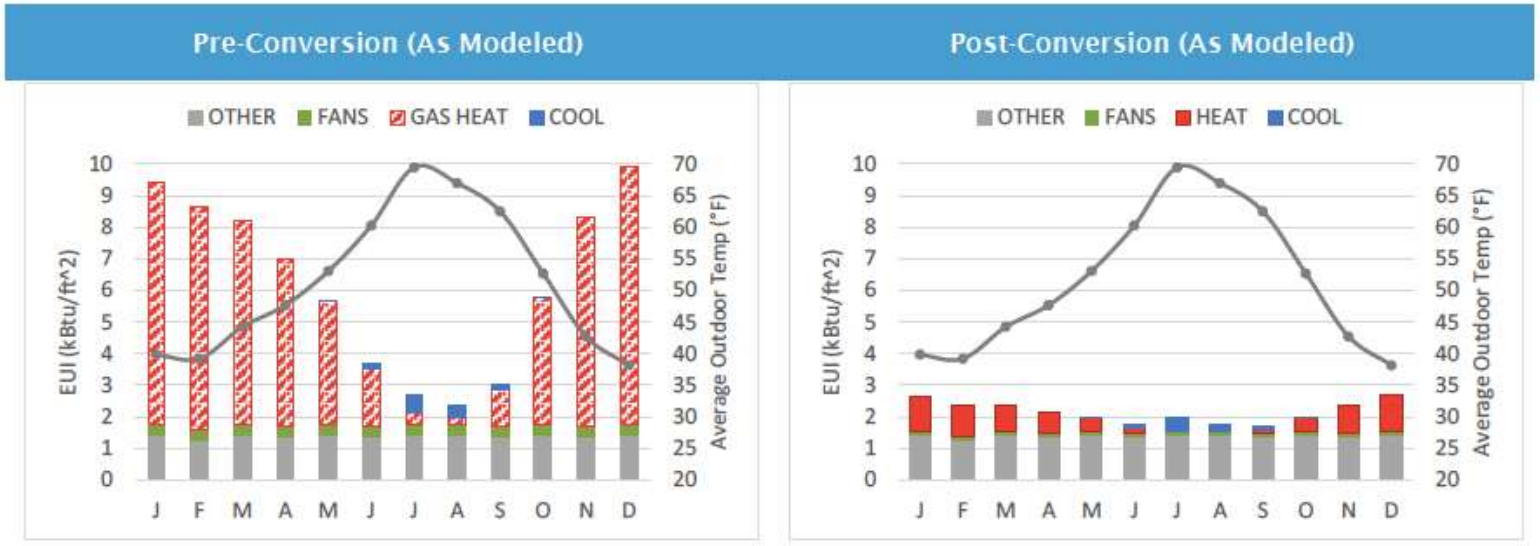
1 Minor additive discrepancies are due to rounding.

AIRPORT TERMINAL DEMAND REDUCTION

- Peak January Demand (highest post-conversion month): ~72 kW to 83 kW (15% increase)
- Peak July Demand (highest pre-conversion month): ~138 kW to 58 kW (58% reduction)
- Overall, demand is essentially flattened, with average summer demand slightly lower than average winter demand.



OFFICE IN PORTLAND, OR
84% HVAC ENERGY SAVINGS



GREAT RESULTS

PROJECT	HVAC SAVINGS %	WHOLE BUILDING SAVINGS %
Seattle airport/office	85%	61%
Portland engineering office	84%	66%
Portland office	79%	64%
Portland law office #2	75%	53%
Portland law office #1	73%	63%
Portland restaurant	73%	20%
Corvallis office	71%	39%
Seattle office	69%	42%
Net Zero preschool	58%	50%
Tacoma office	57%	40%
Montana dorms	52%	24%
Rural school	50%	35%
Montana office	45%	29%
Corvallis restaurant	43%	8%