A Compartmentalization & Ventilation System Retrofit Strategy for High-Rise Residential Buildings in Cold Climates

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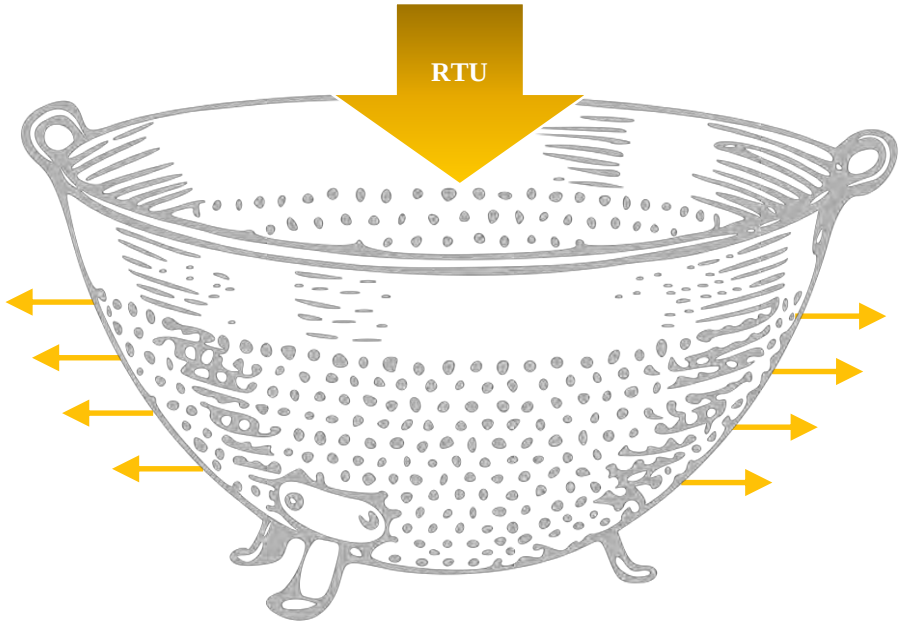
Problem

Pressurized corridor ventilation strategy

Inefficient – wasteful

- Ventilation through exhaust & exfiltration
- Often oversized
- Always on

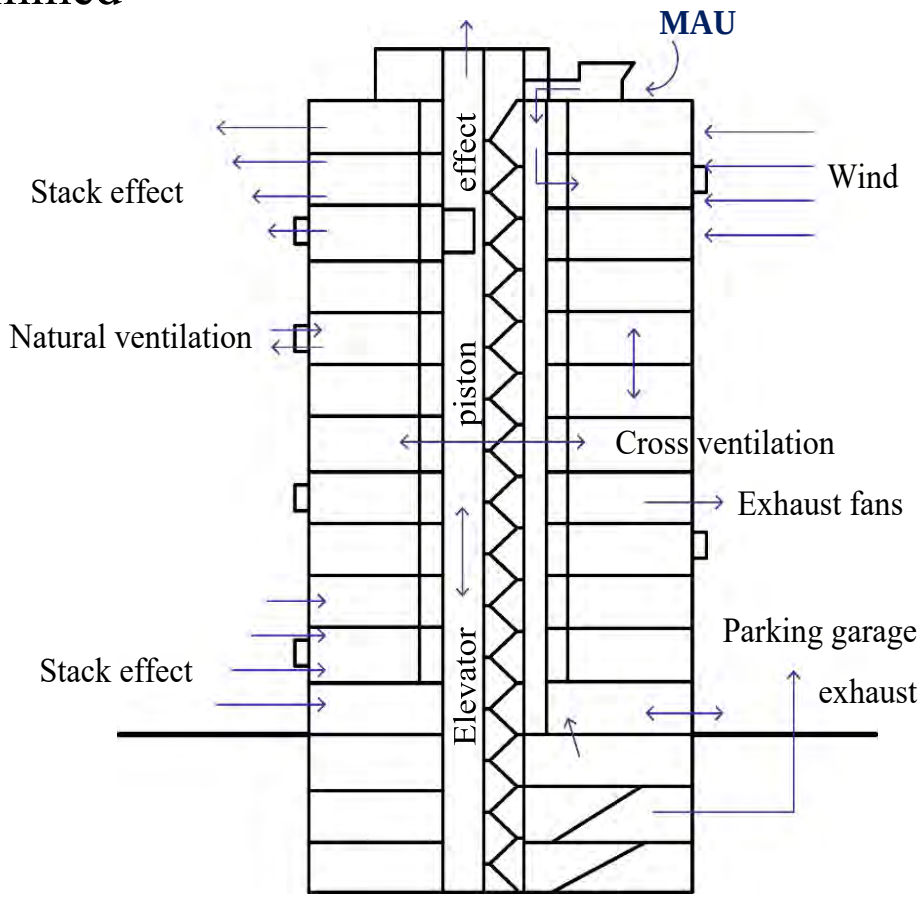


Problem

Pressurized corridor ventilation strategy

Ineffective – constantly undermined

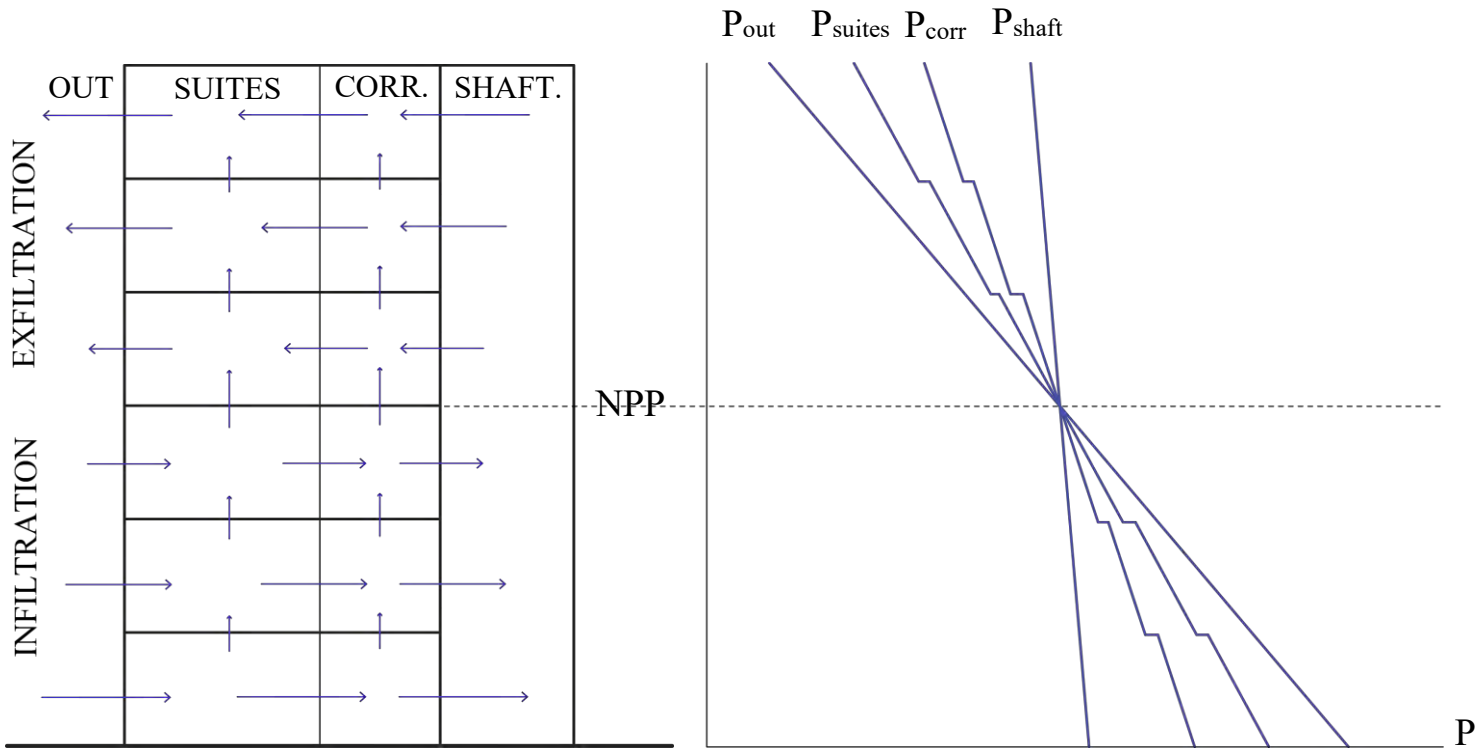
- Stack effect
- Wind pressures
- Window operation
- Duct/other losses
- Elevator operation
- Enclosure retrofits



Background

Stack effect

- Upper floors receive recycled air from lower floors
- Lower floors experience infiltration
- CO from parking garage can be drawn into lower suites



Background

Case study building

- Vancouver (1983)
- 13-storey MURB
- Pressurized corridor ventilation
- Electric baseboard heaters

Background

- Envelope retrofit 2012
- Improved thermal performance & air-tightness
- *Space heating load decreased*
- *Ventilation performance poor (probably worse)*

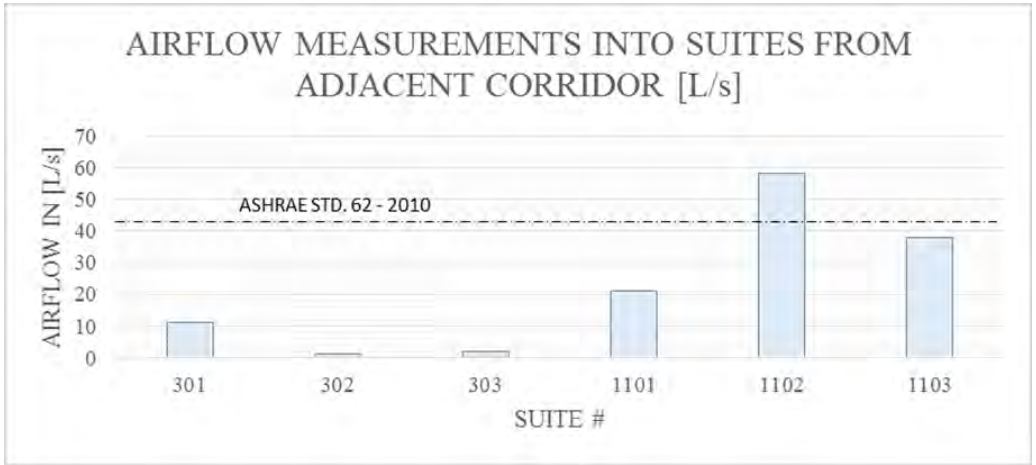
Background

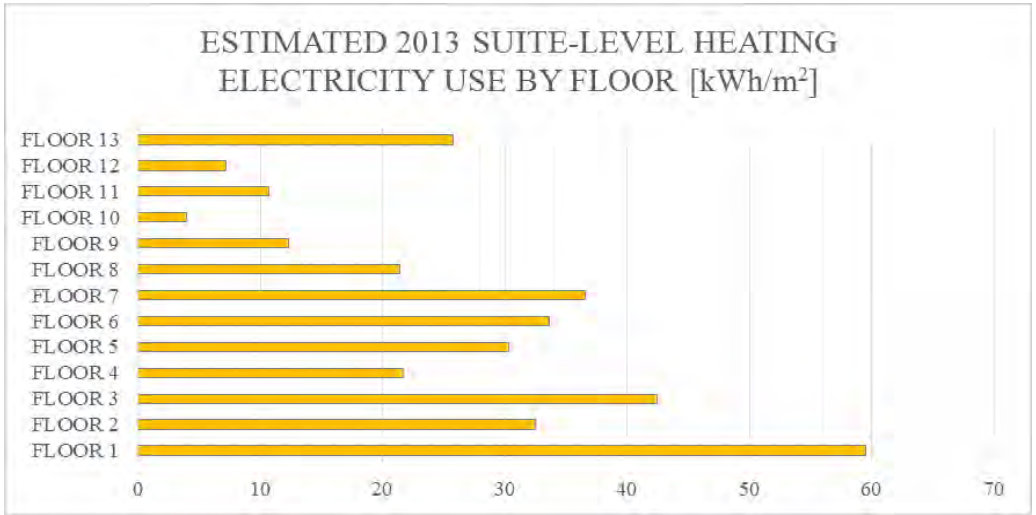
Post-retrofit testing:

- MAU made up 69% of all heating energy
- 92% of supply air lost to duct leakage & vertical shafts

Background

Overall performance





Objective

Research question:

1. For the case study building, what is the impact of a compartmentalization & in-suite ventilation system (ISVS) retrofit, on:

    - Heating energy & fuel mix
    - GHG emissions?

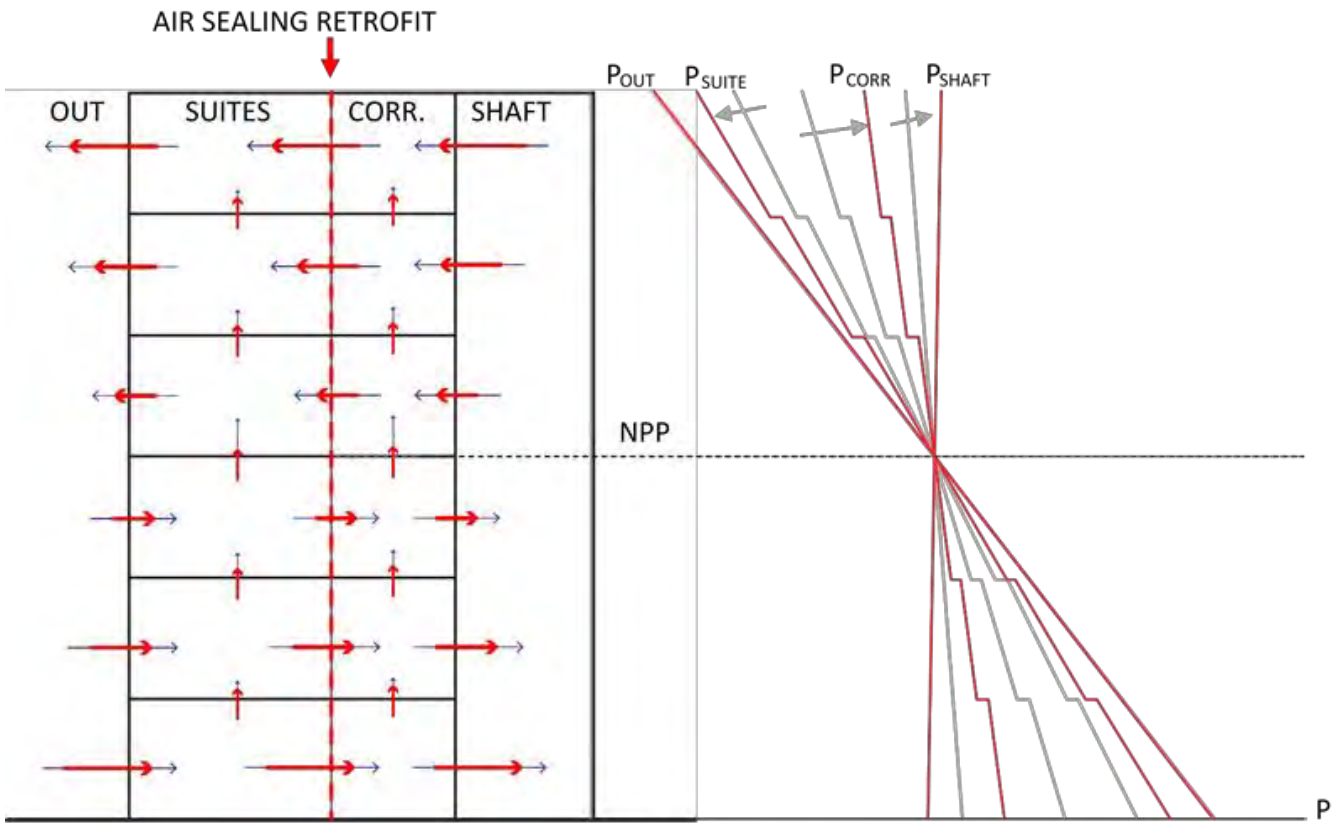
Background

Retrofit proposal

1. Compartmentalize suites
2. Install ISVS (HRVs)
3. Reduce supply air to corridors

Background

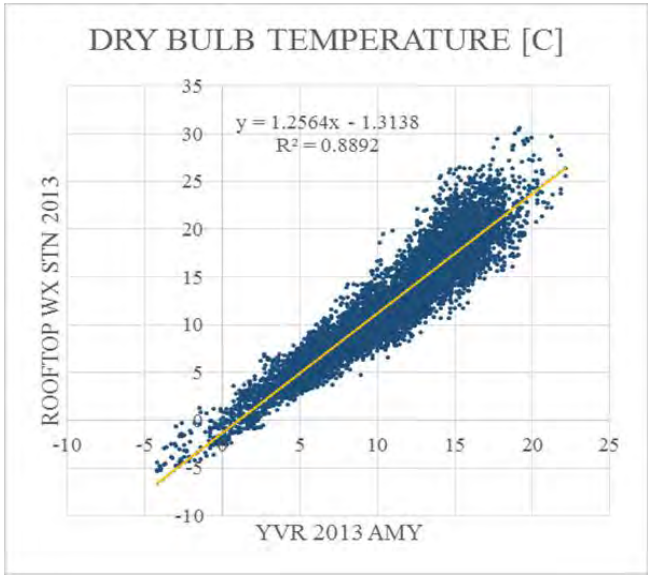
Retrofit proposal - compartmentalization



Methodology

Weather file - 2013

DateTime	TEMP - WS	Tsfc_C	RH - WS	Rh_PCT	DP - WS	Tdew_C	Wind Speed - WS [m/s]	Spd_[m/s]	Wind Direction - WS [Ã°]	Dir_DEG	BARO PRES - WS [kPa]	Psfc_KPA	SOLAR - WS [W/m2	DnSol_Wsq M
2013-01-01 0:00	1.2	2	85.9	88	0.5	0.1	2.9	0.5	157	50	103.14	102.6	0	0
2013-01-01 1:00	0.9	1.8	85.9	88	0.4	0	2.9	0.5	161	60	103.21	102.7	0	0
2013-01-01 2:00	0.7	1.6	86.6	89	0.4	0	2.6	0.0	165	70	103.21	102.6	0	0
2013-01-01 3:00	0.3	1.3	87.3	90	0.3	-0.1	3.2	1.0	165	70	103.21	102.7	0	0
2013-01-01 4:00	0.1	1.1	87.3	90	0.1	-0.3	2.9	0.5	161	60	103.17	102.7	0	0
2013-01-01 5:00	0.1	1.1	87.3	90	0.1	-0.3	2.9	0.5	236	260	103.21	102.7	0	0
2013-01-01 6:00	-0.1	1	87.3	90	0.0	-0.4	2.6	0.0	262	330	103.17	102.7	0	0
2013-01-01 7:00	-0.1	1	87.3	90	0.0	-0.4	2.6	0.0	139	0	103.24	102.8	0	0
2013-01-01 8:00	0.2	1.2	87.3	90	0.1	-0.3	2.6	0.0	161	60	103.27	102.8	76	14
2013-01-01 9:00	-0.2	0.9	87.3	90	-0.2	-0.6	2.9	0.5	266	340	103.31	102.9	155	92
2013-01-01 10:00	0.4	1.4	86.6	89	0.1	-0.3	3.2	1.0	258	320	103.34	102.8	248	173
2013-01-01 11:00	0.9	1.8	85.9	88	0.4	0	3.2	1.0	243	280	103.27	102.7	308	193
2013-01-01 12:00	1.5	2.2	85.9	88	0.8	0.3	3.5	1.5	243	280	103.21	102.7	232	187
2013-01-01 13:00	1.6	2.3	86.6	89	1.1	0.6	3.5	1.5	247	290	103.21	102.6	141	148
2013-01-01 14:00	1.6	2.3	86.6	89	1.2	0.7	3.5	1.5	247	290	103.14	102.6	111	93
2013-01-01 15:00	0.3	1.3	87.3	90	0.3	-0.1	3.5	1.5	258	320	103.1	102.7	62	28
2013-01-01 16:00	0.8	1.7	85.9	88	0.4	0	3.5	1.5	262	330	103.1	102.6	14	0
2013-01-01 17:00	1.3	2.1	84.4	86	0.4	0	3.5	1.5	258	320	103.04	102.5	0	0
2013-01-01 18:00	1.7	2.4	82.2	83	0.3	-0.1	3.5	1.5	258	320	102.97	102.5	0	0
2013-01-01 19:00	2.0	2.6	81.5	82	0.2	-0.2	3.2	1.0	262	330	102.93	102.4	0	0
2013-01-01 20:00	2.1	2.7	81.5	82	0.3	-0.1	3.2	1.0	266	340	102.93	102.4	0	0
2013-01-01 21:00	1.7	2.4	83.0	84	0.4	0	3.2	1.0	143	10	102.9	102.5	0	0
2013-01-01 22:00	1.7	2.4	83.0	84	0.4	0	3.5	1.5	146	20	102.87	102.4	0	0
2013-01-01 23:00	1.8	2.5	82.2	83	0.3	-0.1	3.5	1.5	146	20	102.87	102.3	0	0
2013-01-02 0:00	2.0	2.6	80.8	81	0.1	-0.3	3.2	1.0	146	20	102.87	102.3	0	0
2013-01-02 1:00	2.1	2.7	80.1	80	0.0	-0.4	2.9	0.5	146	20	102.8	102.3	0	0
2013-01-02 2:00	2.2	2.8	79.3	79	-0.1	-0.5	2.9	0.5	150	30	102.77	102.2	0	0
2013-01-02 3:00	1.6	2.3	82.2	83	0.0	-0.4	3.5	1.5	154	40	102.73	102.3	0	0
2013-01-02 4:00	1.6	2.3	81.5	82	-0.1	-0.5	3.5	1.5	157	50	102.7	102.2	0	0
2013-01-02 5:00	1.5	2.2	81.5	82	-0.2	-0.6	2.6	0.0	176	100	102.66	102.2	0	0
2013-01-02 6:00	1.6	2.3	80.8	81	-0.2	-0.6	2.6	0.0	139	0	102.63	102.2	0	0
2013-01-02 7:00	1.8	2.5	80.1	80	-0.3	-0.7	2.9	0.5	143	10	102.6	102.2	0	0
2013-01-02 8:00	2.2	2.8	79.3	79	-0.1	-0.5	2.9	0.5	154	40	102.6	102.1	58	16
2013-01-02 9:00	2.2	2.8	81.5	82	0.4	0	2.9	0.5	154	40	102.63	102.2	178	97
2013-01-02 10:00	2.7	3.2	81.5	82	0.8	0.3	2.6	0.0	180	110	102.63	102.1	297	136
2013-01-02 11:00	3.1	3.5	81.5	82	1.1	0.6	2.9	0.5	198	160	102.63	102	424	155
2013-01-02 12:00	3.2	3.6	81.5	82	1.2	0.7	2.9	0.5	221	220	102.56	102	394	151
2013-01-02 13:00	3.3	3.7	80.8	81	1.2	0.7	3.2	1.0	236	260	102.49	102	288	126
2013-01-02 14:00	3.5	3.8	78.6	79	0.6	0.2	3.2	1.0	247	290	102.46	102	152	81



Site Name: Belmont rooftop wx stn
Latitude [degrees]: 49.24 Longitude [degrees]: -123.16
Time Zone: -8 Elevation [m]: 134.3

Header Chart

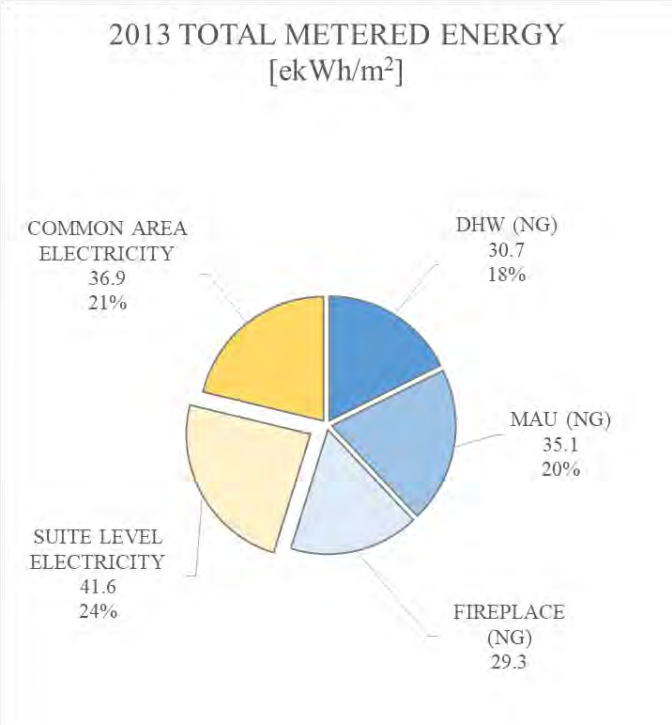
Tools: Offset Scale Normalize Normalize By Month

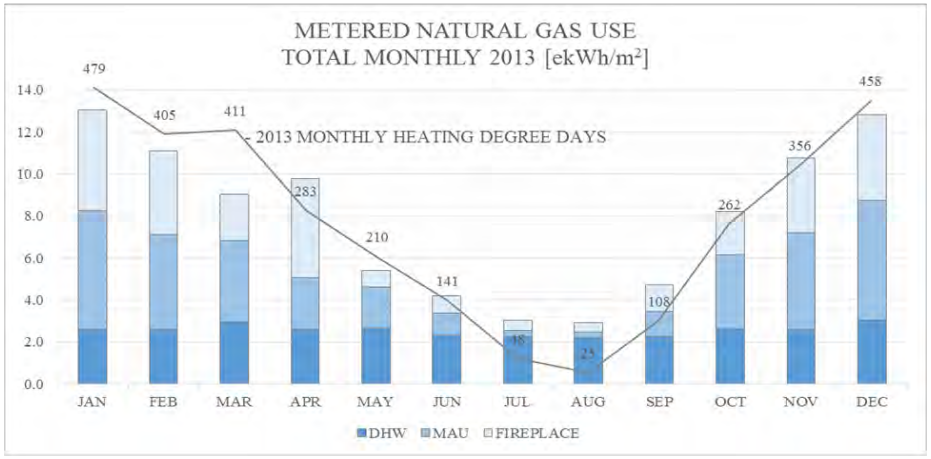
Variables to Hold Constant:

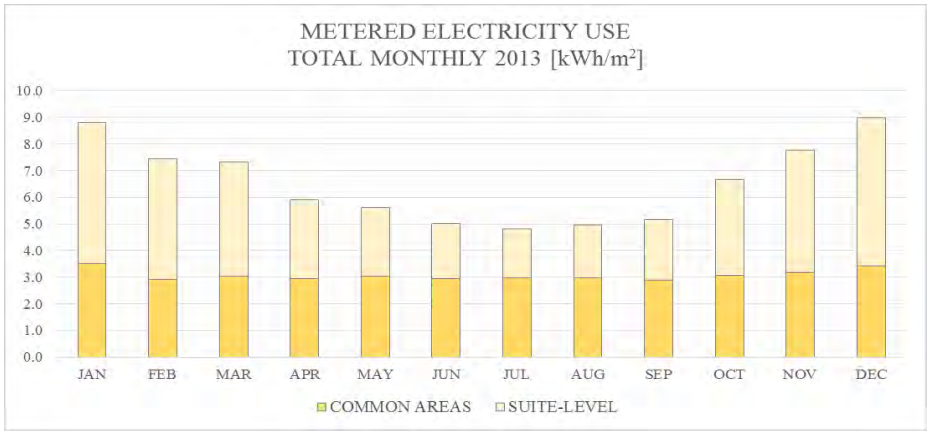
Date/Time	Dry Bulb Temperature [C]	Wet Bulb Temperature [C]	Atmospheric Pressure [kPa]	Relative Humidity %	Dew Point Temperature [C]	Global Solar [Wh/m2]	Normal Solar [Wh/m2]	Diffuse Solar [Wh/m2]	Wind Speed [m/s]
2013/01/01 @ 00:00:00	1.2	0.37	103.14	86	-0.77	0	0	0	2.9
2013/01/01 @ 01:00:00	0.9	0.09	103.21	86	-1.03	0	0	0	2.9
2013/01/01 @ 02:00:00	0.7	-0.05	103.21	87	-1.07	0	0	0	2.6
2013/01/01 @ 03:00:00	0.3	-0.41	103.21	87	-1.41	0	0	0	3.2
2013/01/01 @ 04:00:00	0.1	-0.6	103.17	87	-1.59	0	0	0	2.9
2013/01/01 @ 05:00:00	0.1	-0.6	103.21	87	-1.59	0	0	0	2.9
2013/01/01 @ 06:00:00	-0.1	-0.83	103.17	87	-1.77	0	0	0	2.6
2013/01/01 @ 07:00:00	-0.1	-0.83	103.24	87	-1.77	0	0	0	2.6

Methodology

Energy use analysis – 2013







Methodology

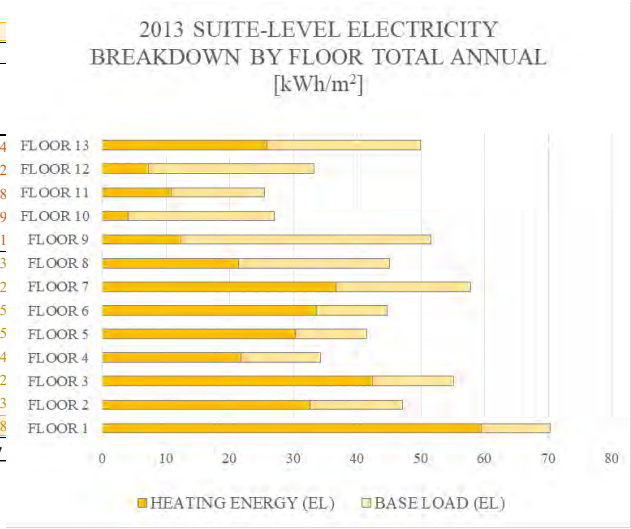
Energy use analysis – 2013

Monthly Suite Electricity Consumption by Floor 2013 [kWh]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Floor 13	1941	2001	2079	1359	949	762	**740**	764	904	1562	2293	3057	18409
Floor 12	1477	1144	1102	901	839	**799**	860	880	819	1038	1121	1286	12266
Floor 11	812	1072	1430	889	624	518	**453**	727	730	732	698	706	9391
Floor 10	1013	835	834	776	770	**708**	731	761	766	824	881	1063	9959
Floor 9	3247	1770	1773	1278	1219	**1207**	1264	1375	1399	1698	1760	2025	19015
Floor 8	1680	1402	1401	1105	1556	1466	1024	**931**	942	1350	1746	2010	16612
Floor 7	3059	2529	2141	1377	1095	867	**855**	941	1186	1813	2406	3042	21312
Floor 6	2026	1725	1750	1279	903	667	581	**543**	744	1385	2083	2784	16470
Floor 5	2101	1754	1839	1204	900	656	**549**	700	770	1357	1571	1912	15312
Floor 4	1356	1089	1108	890	810	621	**590**	749	806	1356	1553	1715	12642
Floor 3	3343	2617	1980	1182	922	698	609	**596**	863	1787	2623	3130	20351
Floor 2	2394	1885	1698	1141	963	757	**651**	728	892	1584	2201	2464	17359
Floor 1	3929	3628	3194	2007	1699	1035	547	**536**	778	2217	2776	3591	25938
TOT kWh	**27378**	**23450**	**22328**	**15388**	**13250**	**10761**	**9451**	**10232**	**11599**	**18703**	**23711**	**28784**	**215037**

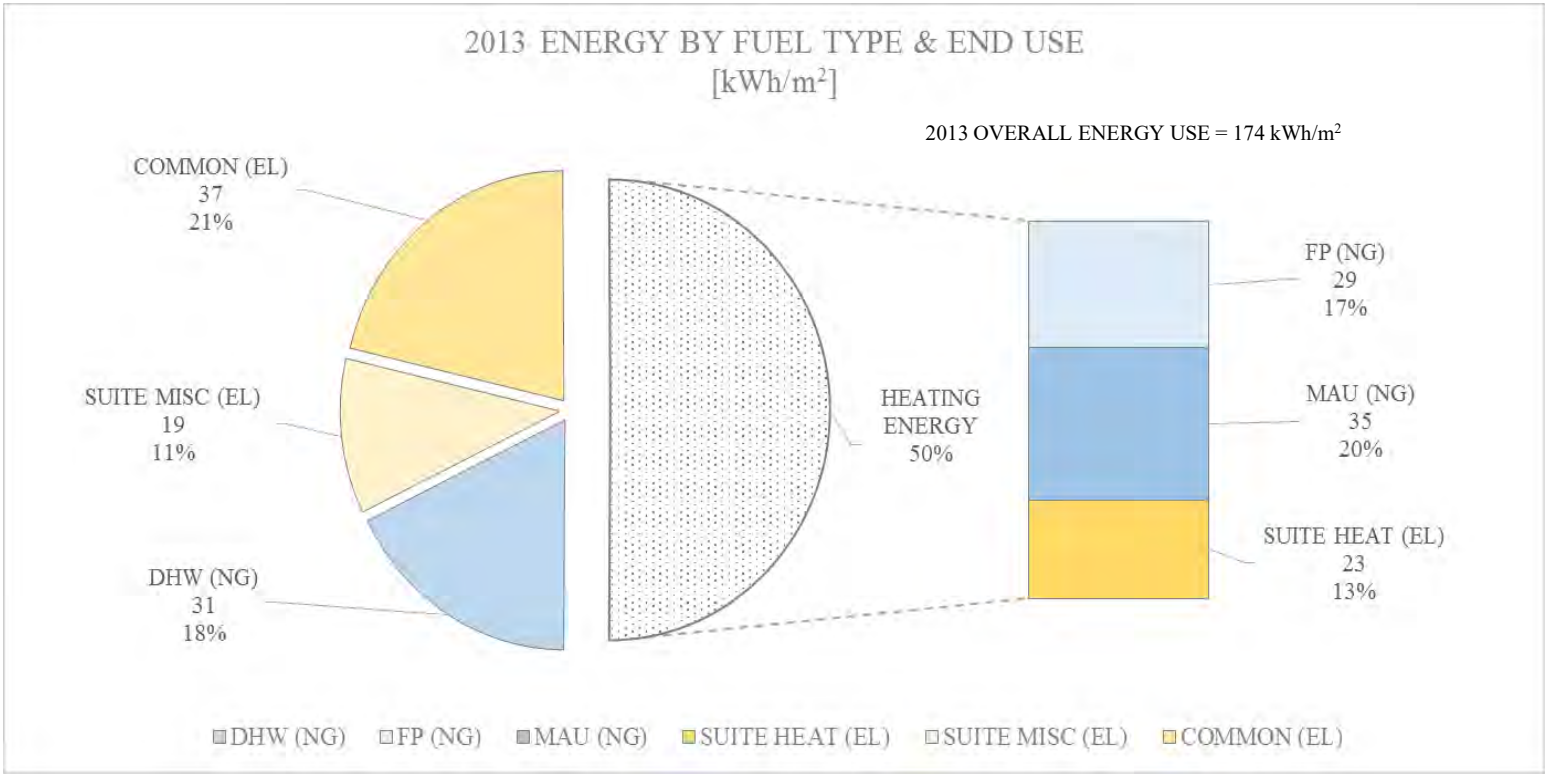
Monthly Heating Electricity by Floor 2013 [kWh]

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Total El. Htg Energy
Floor 13	1201	1260	1338	618	208	21	**0**	24	163	821	1552	2316	9524
Floor 12	677	344	302	101	39	**0**	61	81	20	239	322	486	2672
Floor 11	359	619	977	437	171	66	**0**	274	277	279	246	253	3958
Floor 10	305	128	126	68	63	**0**	23	53	58	116	173	355	1469
Floor 9	1040	563	566	71	12	**0**	56	168	192	491	553	818	4531
Floor 8	749	470	470	174	625	535	92	**0**	11	419	815	1079	7893
Floor 7	2205	1675	1286	523	241	12	**0**	87	332	959	1552	2187	13512
Floor 6	1483	1182	1207	735	360	124	38	**0**	201	841	1539	2240	12405
Floor 5	1553	1206	1290	656	352	107	**0**	152	222	808	1023	1363	11185
Floor 4	766	498	517	299	220	30	**0**	159	216	766	963	1125	8014
Floor 3	2747	2021	1384	586	326	102	12	**0**	267	1191	2027	2534	15652
Floor 2	1744	1234	1047	490	313	106	**0**	77	241	933	1550	1814	12003
Floor 1	3392	3092	2658	1470	1163	499	11	**0**	242	1681	2240	3054	21958
TOT kWh	18220	14292	13170	6230	4092	1603	**293**	1074	2441	9545	14553	19626	**124,777**



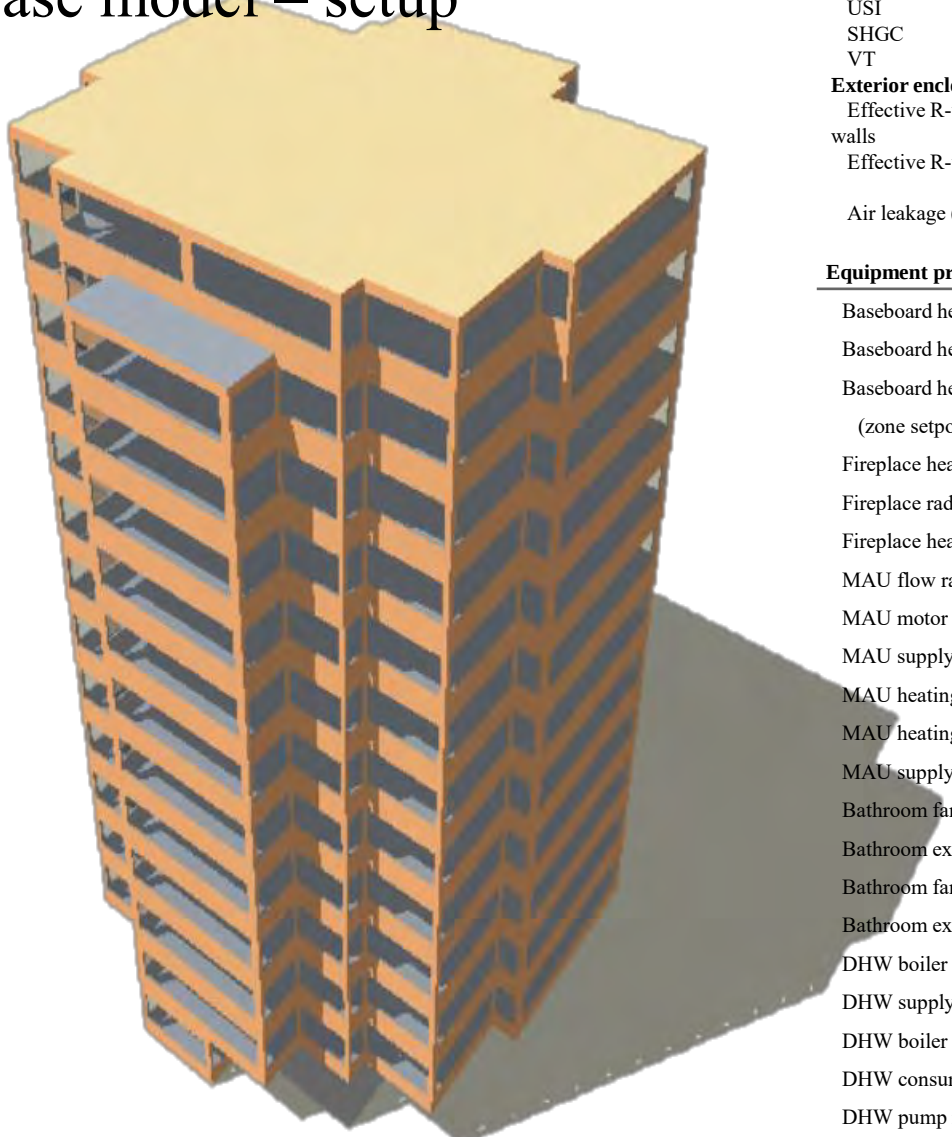
Methodology

Energy use analysis – 2013



Methodology

Base model – setup

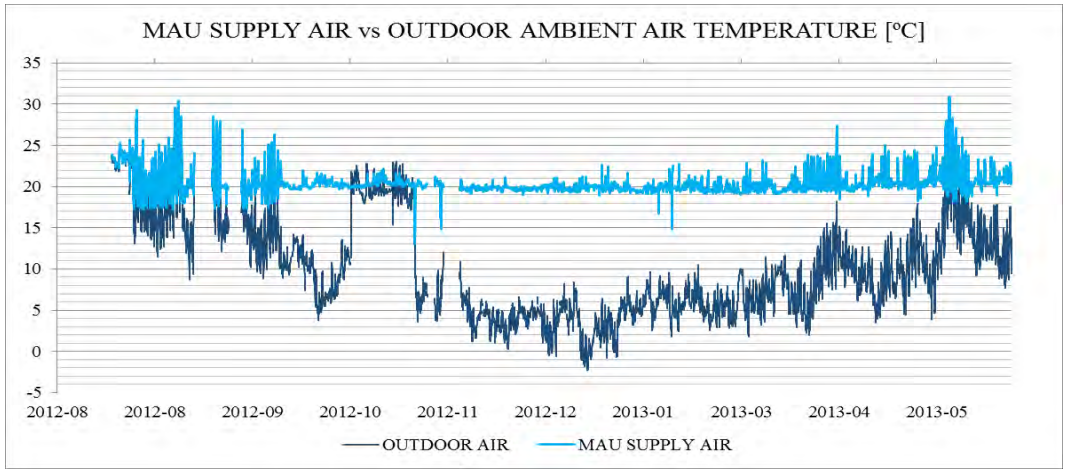


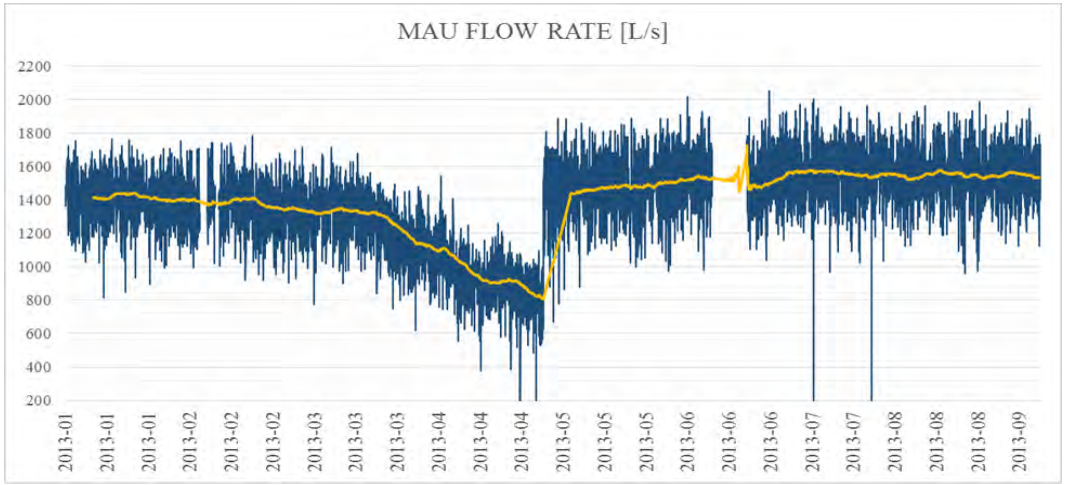
Performance characteristic	Value	Source
Windows & balcony doors		
USI	1.57 W/m²-K	ASHRAE
SHGC	0.2	ASHRAE
VT	0.7	ASHRAE
Exterior enclosure		
Effective R-value - walls	RSI-2.84 m²-K/W (R-16.1 °F-ft²-hr/Btu)	RDH
Effective R-value - roof	RSI-3.5 m²-K/W (R-19.9 °F-ft²-hr/Btu)	RDH
Air leakage (avg.)	1.81 L/s/m² @75 Pa	RDH

Equipment property	Value	Source
Baseboard heater capacity (-01 suites)	11.0 kW	RDH
Baseboard heater capacity (-02 suites)	7.0 kW	RDH
Baseboard heater capacity (-03 suites)	10.5 kW	RDH
(zone setpoint temperature)	23 C	RDH
Fireplace heating capacity	8.8 kW	RDH
Fireplace radiant fraction	0.4	RDH
Fireplace heat fraction lost	0.6	RDH
MAU flow rate	1440 L/s (avg.)	Airflow testing (RDH)
MAU motor	1.12 kW (1.5 hp)	RDH
MAU supply fan efficiency	60%	Engineered Air
MAU heating coil capacity	73.2 kW	RDH
MAU heating coil efficiency	80%	Engineered Air
MAU supply air temperature	20.7 C	Test data (RDH)
Bathroom fan exhaust rate	33 L/s	RDH
Bathroom exhaust fan power	60W	RDH
Bathroom fan efficiency	60%	RDH
Bathroom exhaust fan static pressure	50 Pa	assumed
DHW boiler capacity	178.7 kW	RDH
DHW supply temperature	55 C	RDH
DHW boiler efficiency	82%	RDH
DHW consumption	2.75 L/m²-day	RDH
DHW pump rated power	250 W	RDH

Methodology

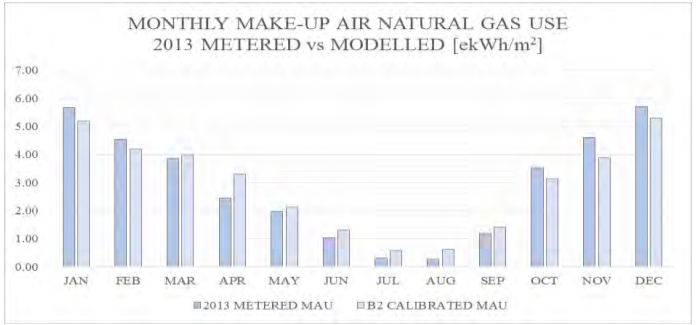
Base model - 2013 calibration

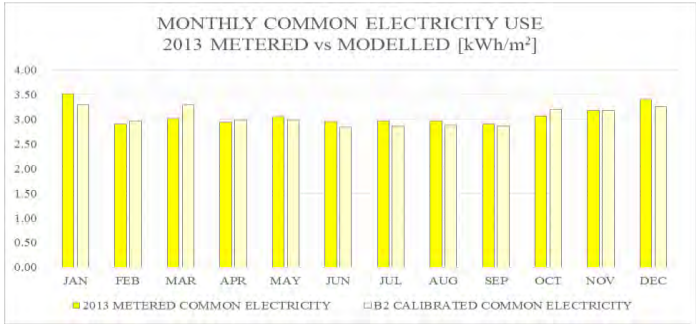


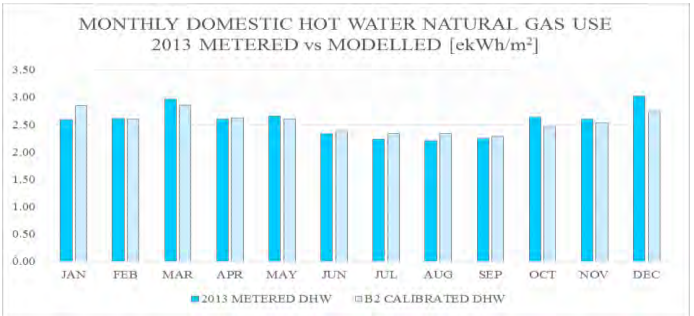


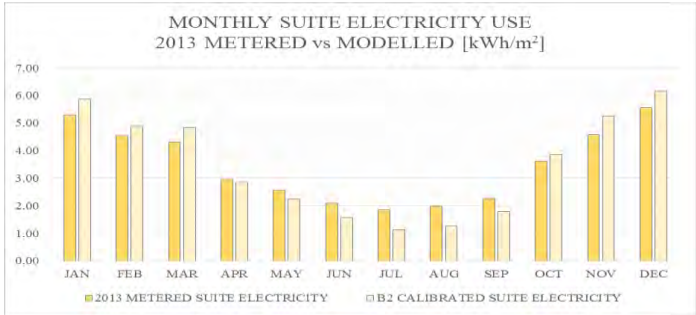
Methodology

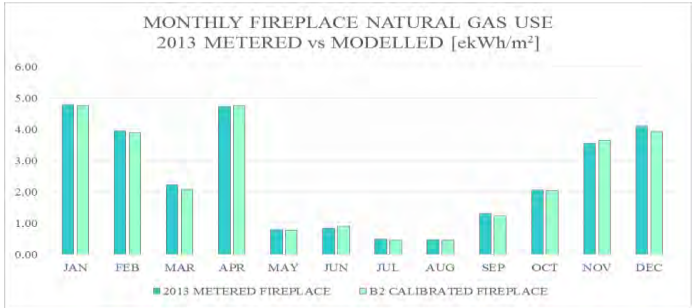
Base model - 2013 calibration

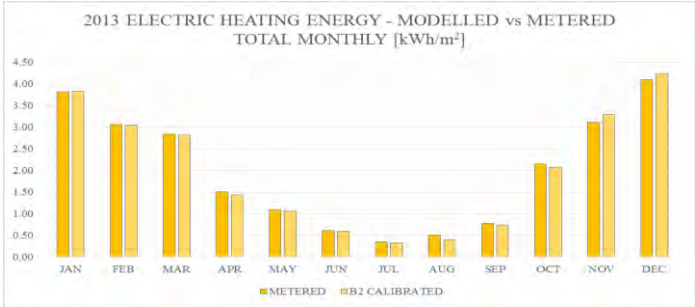






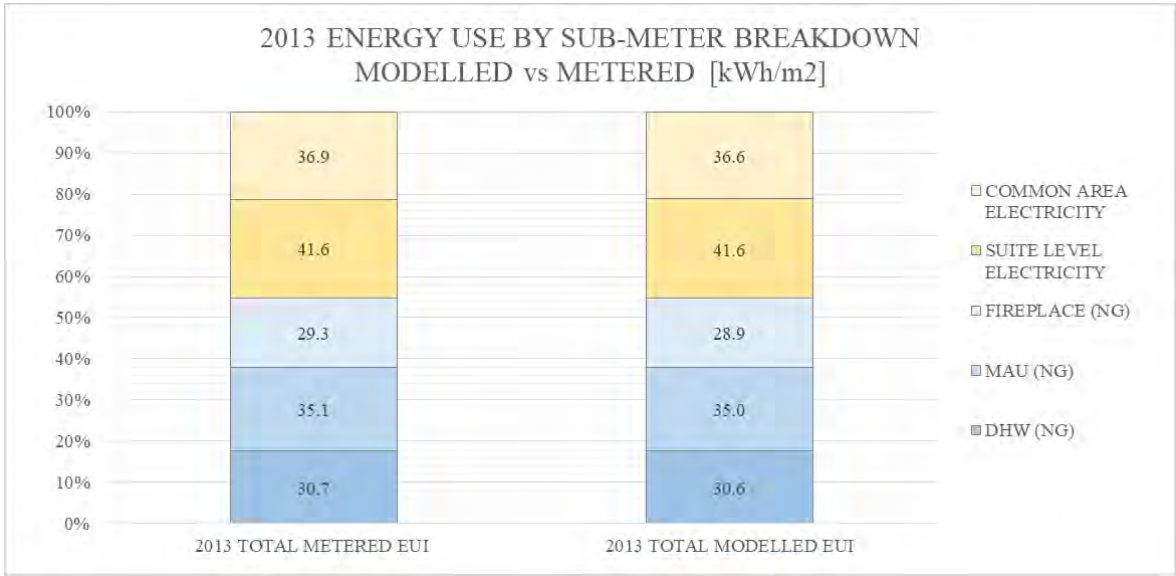






Methodology

Base model - 2013 calibration



	NMBE (+/- 5%)	CV(RMSE) (+/- 15%)
Overall natural gas	**0.7%**	**6.8%**
NG for DHW	0.3%	5.6%
NG for MAU	1.6%	14.9%
NG for fireplaces	1.4%	3.3%
Overall electricity	**0.3%**	**8.9%**
Common areas	0.7%	4.5%
Suite-level heating electricity	0.5%	4.3%
Suite-level total electricity	-1.6%	13.8%

Methodology

Retrofit model

Compartmentalization

- Eliminate MAU supply air to suites – corridors only

ISVS

- Add HRV to each suite
- Remove bathroom exhaust fans

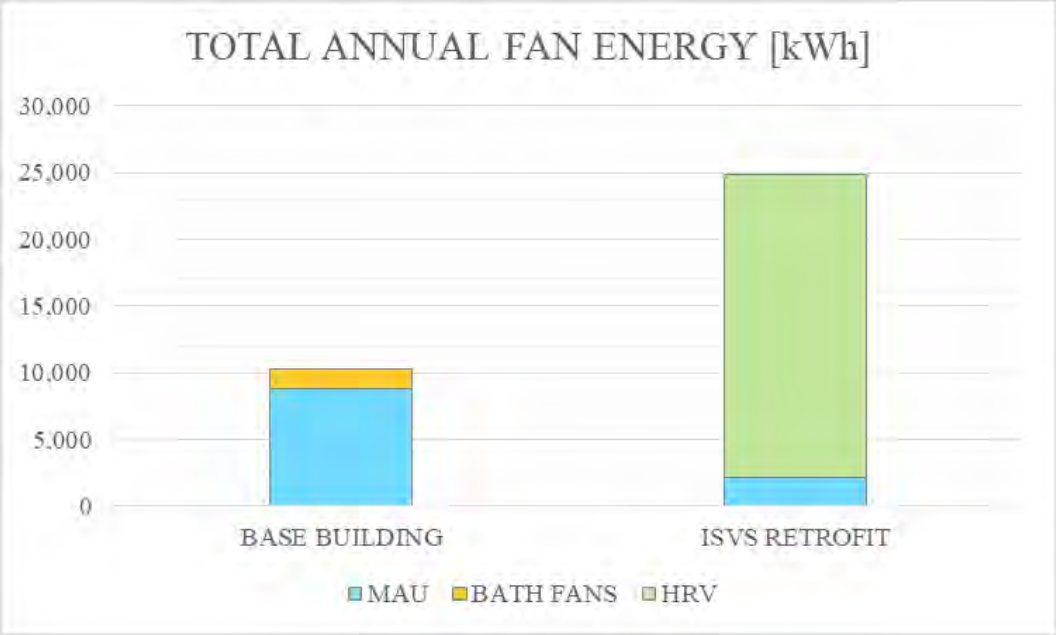
Also

- Reduce MAU supply airflow as per ASHRAE 62 for corridors
- Reduce infiltration

Results

Retrofit – fan energy

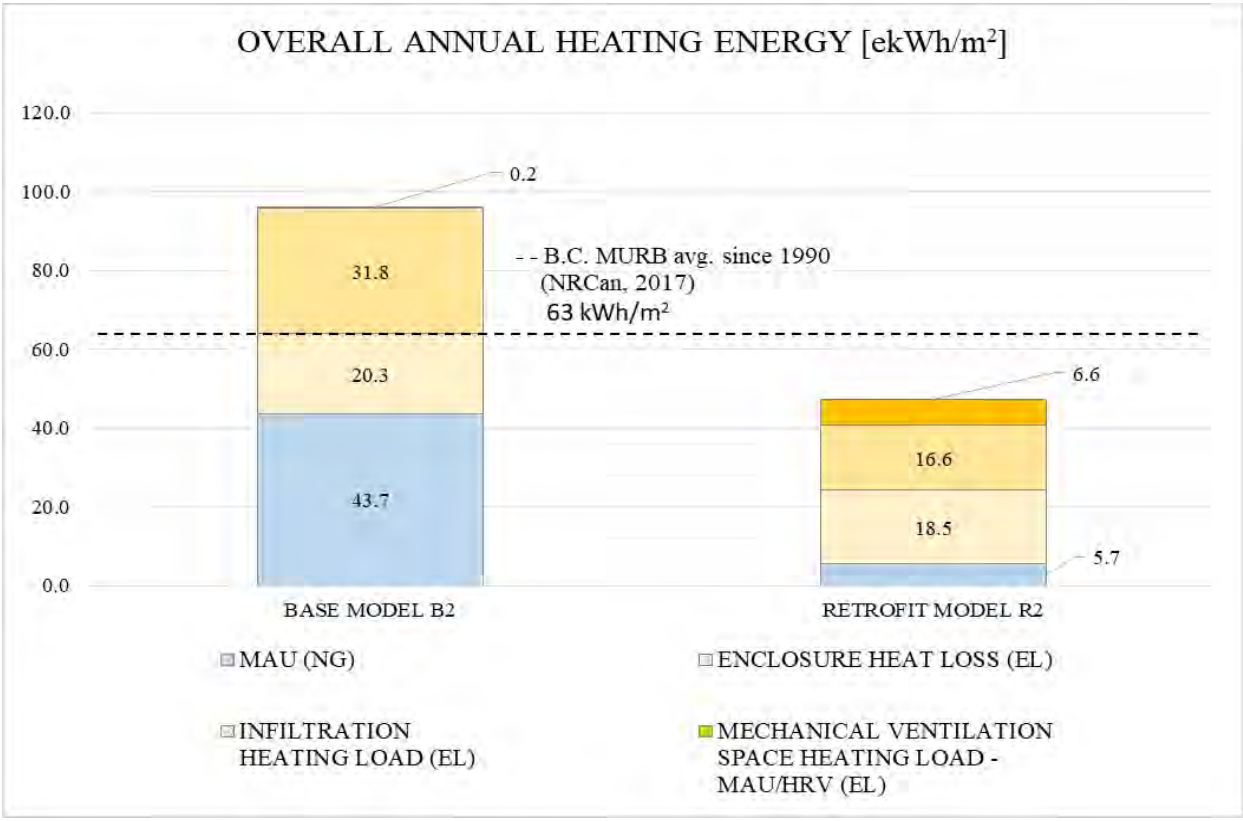
- 141% increase in total fan energy



Results

Retrofit – overall heating energy

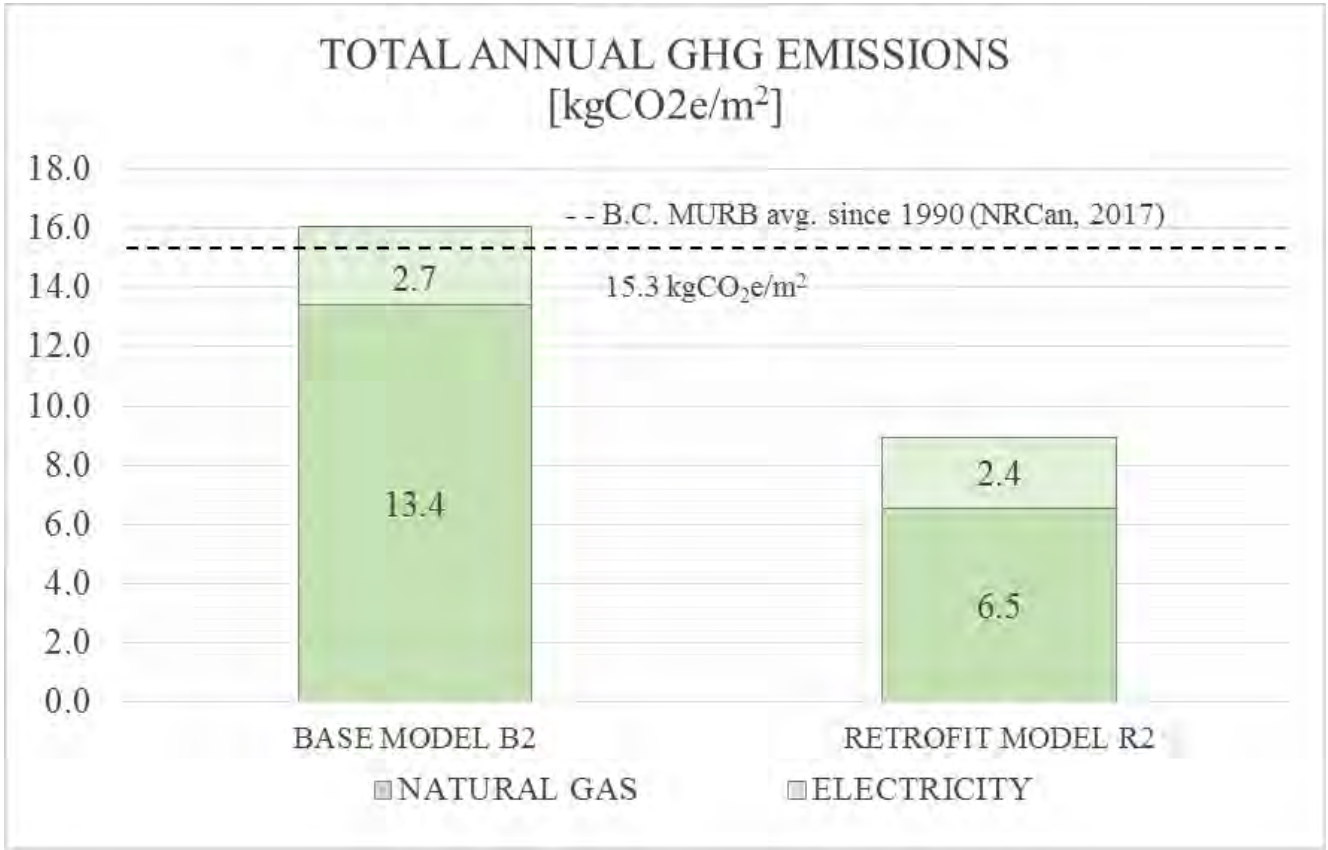
- 51% reduction in total annual heating energy (87% NG, 20% electricity)
- 48% decrease in infiltration heat loss



Results

Retrofit – GHG emissions

- 29% reduction (20.2 tCO2e) in total annual GHG emissions



Conclusion

For existing high-rise MURBs, the proposed retrofit can:

- Reduce overall heating energy
- Reduce GHG emissions
- Improve mechanical ventilation distribution effectiveness

Collateral benefits

- Reduce airborne pollutants from parking garage
- Facilitate natural ventilation
- Reduce heating bill inequities
- Increase passive surviveability duration (thermal resilience)

➢ A compartmentalization retrofit should be considered together with – or before – an enclosure retrofit

Context

In British Columbia (2013):

- 33% of all natural gas in B.C. was consumed by residential buildings.

  (Of that, 58% for space heating)
- apartment buildings alone accounting for 17% of all residential GHG emissions

In Canada (2013):

- residential buildings accounted for 15% of Canada's overall GHG emissions
- Space heating was 64% of the total residential building sector GHG emissions. Of that:
  - Apartments = 15%
  - Natural Gas = 56%

Source: (NRCan, 2017)

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