Final Project

CIV576| Sustainable Buildings
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Introduction

The following document serves to outline the modelling, analysis and evaluation of a single-detached residential home. Using HOT2000, mass balance models, as well as building science strategies and concepts, the team has calibrated and provided recommendations for the home in order to achieve reduced heating energy use and indoor ozone concentrations.

1.0 Calendarization

Table 1 Calendarization of house bills.

2019 Calendarization			
Months	Natural Gas (m^3)	Water Consumption (m^3)	Electricity (kWh)
Jan	481.05	14.22	403.22
Feb	441.92	13.91	357.14
Mar	401.67	15.4	431.39
Apr	258.66	16.53	301.15
May	159.34	16.57	307.26
Jun	99.67	20.22	381.12
Jul	104.84	21.2	670.45
Aug	91.48	26.95	376.09
Sep	84.1	26.08	314.37
Oct	193.28	26.95	351.32
Nov	326.61	26.08	469.47
Dec	366.56	24.57	513.8
Total	3009.18	248.68	4876.78

1.1 Normalization

Electricity Normalization Equation: $Y = 1.8277X + 558.19$, with $R^2 = 0.7403$ (Appendix 2)

Table 2: Electricity Normalization

Month	HOT2000 Temperature	Billing Period Temperature	HOT2000 CDD	Billing Period CDD	HOT2000 Electricity Usage Estimate (kWh)	Normalized Electricity (kWh)	Billing Period Electricity Usage (kWh)
Jan	-5.8	-5.9	0	0	0	558	0
Feb	-5.7	-5	0	0	0	558	0
Mar	-0.7	-0.3	0	0	0	558	0

Apr	5.7	6.3	0	0	0	558	0
May	12.0	13.1	0	0	0	558	0
Jun	17.7	18.1	0	3	0	564	0
Jul	20.8	21.1	87	96	0	734	0
Aug	19.8	20	56	62	0	672	0
Sep	15.0	15.5	0	0	0	558	0
Oct	8.5	9	0	0	0	558	0
Nov	3.5	3.3	0	0	0	558	0
Dec	-2.5	-2.6	0	0	0	558	0

Gas Normalization Equation: $Y = 0.3772X + 21.873$, $R^2 = 0.9785$ (Appendix 2)

Table 3: Natural Gas Normalization

Month	HOT2000 Temperature	Billing Period Temperature	HOT2000 CDD	Billing Period CDD	HOT2000 Natural Gas Usage Estimate (kWh)	Normalized Natural Gas (kWh)	Billing Period Natural Gas Usage (kWh)
Jan	-5.8	-5.9	738	741	314	301	481.1
Feb	-5.7	-5	664	690	274	282	441.9
Mar	-0.7	-0.3	580	567	231	236	401.7
Apr	5.7	6.3	369	351	147	154	258.7
May	12.0	13.1	186	152	76	79	159.3
Jun	17.7	18.1	9	0	40	22	99.7
Jul	20.8	21.1	0	0	38	22	104.8
Aug	19.8	20	0	0	37	22	91.5
Sep	15.0	15.5	90	75	43	50	84.1
Oct	8.5	9	295	279	107	127	193.3
Nov	3.5	3.3	435	441	186	188	326.6
Dec	-2.5	-2.6	636	639	280	263	366.6

1.2 Calibration

Air Exchange Rate:

From Liu, Koutrakis, Leech and Broder (1995), average air exchange rates were measured for homes in Toronto which are summarized below [1]. Using the values below, the upper bound air exchange rate was calculated = 1.04 + 1.28 = 2.32 h^{-1}. The default value was set as 3.04 h^{-1}.

Table 4: Summary of AER Information From Literature.

Season	Average Mean AER (h^{-1})	50% homes had AER less than (h^{-1})
Winter	0.69 ± 0.88	0.41
Summer	1.04 ± 1.28	0.52

Table 5.0 shows that the optimum AER is 1.04 h^{-1} because decreasing beyond that did not have a significant impact on the results. There is still a significant base load for electricity (higher than actual) and natural gas (lower than actual). The design team reconfirmed the parameters and tried calibrating the equipment that would impact both electricity and natural gas. More detail on how each parameter was calibrated is provided in the Appendix 2. The graphical representation of the calibration of AER and its impact on gas and electricity usage is given in Appendix 2. Since residents live for varying time in the house, the occupancy could not be completely accurate however a reasonable estimate was used and that may have impacted the base load for electricity and gas.

Table 5: Results of Calibration for AER for Model.

Month	Air Exchange Rate (h^{-1})															
	3.04		2.32		1.57		3.2		10		1.04		0.69		0.41	
	Elec (kWh)	Gas (m^3)	Elec (kWh)	Gas (m^3)	Elec (kWh)	Gas (m^3)	Elec (kWh)	Gas (m^3)	Elec (kWh)	Gas (m^3)	Elec (kWh)	Gas (m^3)	Elec (kWh)	Gas (m^3)	Elec (kWh)	Gas (m^3)
Jan	558	301	557	289	556	276	558	304	572	188	555	269	555	265	554	262
Feb	558	282	557	270	556	259	558	285	572	177	555	252	555	248	554	246
Mar	558	236	557	226	556	217	558	238	572	150	555	211	555	208	554	207
Apr	558	154	557	149	556	143	558	156	572	104	555	140	555	138	554	137
May	558	79	557	77	556	75	558	80	572	60	555	74	555	74	554	73
Jun	564	22	562	23	561	24	564	22	577	27	561	24	560	24	560	25
Jul	734	22	734	23	734	24	734	22	733	27	734	24	734	24	734	25
Aug	672	22	671	23	671	24	672	22	676	27	671	24	671	24	670	25
Sep	558	50	557	50	556	49	558	50	572	44	555	49	555	49	554	49
Oct	558	127	557	123	556	119	558	128	572	88	555	116	555	115	554	114
Nov	558	188	557	181	556	174	558	190	572	123	555	170	555	167	554	166
Dec	558	263	557	252	556	241	558	265	572	166	555	235	555	231	554	230

2.0 Mass Balance

The increase in the level of ozone concentrations has been associated with an increase in health-related issues among people [3]. A substantial amount of ozone exposure takes place indoors and that is of great concern as people spend the majority of their time in built environments [4] [5]. According to ASHRAE, the indoor level of ozone is recommended to be "as low as reasonably achievable" and as stated by The World Health Organization, the 8-h average of the ozone concentration should not exceed 0.1 mg/m^3 [6] [7].

To calculate the concentration of ozone, and investigate the interventions that improve Indoor Air Quality, the design team has developed a mass balance for the house. The input parameters used in this equation are calculated according to the specification sheets and literature. In the calculation of mass balance, it is important to note that the indoor ozone concentration depends on different factors such as outdoor ozone concentration, indoor air change rate, indoor ozone sources, and removal by indoor surfaces and gaseous chemicals [7].

2.1 Mass Balance Input Parameters

The parameters used in the mass balance equation are summarized in Table 6.

<u>Notes</u>

1. There are no portable or central air cleaners in the house.
2. There are no HRV/ERV systems in the house. Therefore,it is assumed that no indoor-outdoor air exchange occurs through the mechanical system.
3. It is assumed that the emission from different activities/sources is well spread around the whole volume of the house. The common scenario is the scenario where no laser printer is used in the house, and the worst scenario includes two laser printers operating continuously.
4. Calibrated AER from HOT2000 results is used for the infiltration air exchange rate because it is closer to reality.
5. The amount of ozone filtration through the filter for this house is assumed to be negligible since the current filter does not contain activated carbon and would not be as effective in removing ozone particles [11].

Table 6: Mass Balance Parameters

Parameter	Definition	Values	Comments
E	Whole Building Emission rate	67.8 [mg/h] [8] --*Typical* 69.4 [mg/h] [8] --*Maximum*	Refer to calculations below
V	Whole Building Volume	519.74 [m^3]	See Appendix 3.
λ_i	Infiltration air exchange rate	1.04 [h^{-1}]	See Note 4.
p	Penetration	0.54 [9]	-
C_{out}	Outdoor concentration	27 [ppb] [10]--*Typical*	See Appendix 3.

		35 [ppb] [10]--*Maximum*	
λ_m	Mechanical ventilation air exchange rate	0	See Note 2.
η_m	Filter efficiency	0	See Note 2..
β	Deposition loss rate	3 [h^{-1}] [12]	-
λ_r	Recirculation air	2.18 [h^{-1}]	Q = 314.9 L/s = 1133.64 m^3/h (from HOT2000 model) V= 519.74 [m^3]
η_{HVAC}	Filter efficiency	0	See Note 5.
t	Run time	0.3	See Appendix [3]

2.2 Calculations

Average ozone emission rate: [8]:

In-duct air cleaner = 62.8 [mg/h]
Room air purifiers= 4.6 [mg/h]
Laser printer = 0.8 [mg/h]
Other small devices = 0.4 [mg/h]
$E_{typical}$ = 62.8 + 4.6 + 0.4 = 67.8 [mg/h]
E_{high} = 62.8 + 4.6 + 0.4 + 2 * 0.8 = 69.4 [mg/h]

Mass balance equation (steady-state):

$$C_{ss} = \frac{\frac{E}{V} + \lambda_i p C_{out} + \lambda_m (1 - \eta_m) C_{out}}{\lambda_i + \lambda_m + \beta + \lambda_r \eta_{HVAC} t + \frac{CADR}{V}}$$

Assuming temperature of 20 °C and P= 0.75 atm, the outdoor concentration of ozone is calculated as follows:

$$1\,ppb = 1 * 10^{-9} * \frac{MWi * P}{R*T} = \frac{1 * 10^{-9} * (48\ g/mol) * 0.75\ atm}{82.05 * 10^{-6}\ (atm.m^3/mol.k) * 293.15\ K} = 1.49\ \mu g/m^3$$

$C_{out,\ typical}$ = 27 ppb * $1.49\ \mu g/m^3$ = 40.23 $\mu g/m^3$

$C_{out,\ maximum}$ = 35 ppb * $1.49\ \mu g/m^3$ = 52.15 $\mu g/m^3$

Plugging in the input parameters in the mass balance equation, the typical and maximum hourly concentrations are calculated as follows:

$$C_{ss,\ typical} = \frac{\frac{67800\ \mu g}{519.75\ m^3} + 1.04*0.8*40.23\frac{\mu g}{m^3}}{1.04\ h^{-1} + 3\ h^{-1}} = 40.57\frac{\mu g}{m^3}$$

For the maximum concentration, the maximum outdoor concentration is considered and it is assumed that two laser printers are working continuously

$$C_{ss,\ maximum} = \frac{\frac{69400\ \mu g}{519.75\ m^3} + 1.04*0.8*52.15\frac{\mu g}{m^3}}{1.04\ h^{-1} + 3\ h^{-1}} = 43.79\frac{\mu g}{m^3}$$

3.0 Outcomes

Outcome #1: Primarily significantly reduces heating energy use

Based on the model, between space heating and domestic hot water heating, space heating uses 68.30% of the total heating energy use as shown in Table 7. The home currently uses a relatively new tankless water heating system which is energy efficient because they heat water on demand, that uses natural gas to power the water heater. For these reasons, the focus will be placed on space heating which is energy intensive during the winter months. In addition, the home is relatively new and is unlikely to go under any major renovation in terms of increasing the R-Value of the entire home or changing windows. As well, there is adequate caulking and sealing on the home, maintained by the homeowner. In an effort to significantly reduce heating energy use, the recommendation is to add insulation to the attached garage ceiling where there is a bedroom directly over top in the arrangement as shown in Appendix 4. The bedroom experiences significantly colder temperatures than in the other bedrooms during the heating months. The thermostat and thermostat sensor is placed in the main floor hallway. The set temperature is a nighttime heating setpoint of 20ºC and indoor design temperature of 22ºC to accommodate the colder bedroom that has a slightly lower temperature. Accordingly, there is an opportunity to set the temperature lower if the bedroom floor (garage ceiling) were to be insulated as it would experience the same temperature throughout the home.

To evaluate this in the model, two approaches were taken. Approach 1 is that Bedroom 2's floor and wall values were increased. The RSI value is now 5.13 from 3.85. The input is shown in Table 9. These values were determined using the City of Saskatoon Energy Efficiency Handbook, in "*Floor Over Attached Garage Assemblies*", shown in Figure A4.1 [16]. Approach 2 is the reduction of night time heating set point and indoor design temperature from 20ºC and 22ºC to 19ºC and 21.5ºC, respectively. The results are summarized in Table 8.

Table 7: Energy Use Values From HOT2000 Model

	Heating (MJ)				**Other (MJ)**		
	Space Heating		*DHW Heating*		*Lights &*	*HRV &*	*Air*
Month	**Primary**	**Secondary**	**Primary**	**Secondary**	**Appliances**	**FANS**	**Conditioner**
Annual	41604.3	0	19308.7	0	21881	1222.6	1887.2

Percentage Breakdown	48.43%		22.48%		25.47%	1.42%	2.20%
	68.30%		46.88%				

Table 8: Model Results From Implementing Recommendation

	Annual Energy Consumption				
	Original	**Reduced night time heating set point and indoor design temperature**		**Increased R-Value for the bedroom (walls and floor)**	
	Energy Consumption (MJ)	Energy Consumption (MJ)	Change (%)	Energy Consumption (MJ)	Change (%)
Space Heating	41604.3	40452.9	-2.77%	41443.9	-0.39%
DHW Heating	19308.7	19308.7	0%	19308.7	0%
Lights & Appliances	21881	21881	0%	21881	0%
HRV & FANS	1222.6	1199.3	-1.91%	1219.4	-0.26%
Air Conditioner	1887.2	1877	-0.54%	1886.5	-0.04%

Table 9. Floor Values Input

Insulation Layer1	RSI 3.87 @ 140 mm (R 22 @ 5.5”) batt
Insulation Layer 2	50 mm (2 in) EPS II

In both cases, it showed a reduction in heating energy use for space heating and HRV and Fans. The reduction is not significant. In regards to the garage insulation recommendation, this may be because it is only affecting a single bedroom in the home. In addition, it may not be captured properly in the HOT2000 Model since we cannot change the conditions of the unconditioned space and therefore, focus on increasing insulation of the bedroom walls and floors. The secondary consequences are installation and costs associated. Other concerns would be installation errors should the homeowners do it themselves. They need to ensure to comply with fire-codes and leave an air space to prevent mold or mildew.

Outcome #2: Primarily reduces the indoor concentrations of indoor ozone.
To reduce the indoor concentration of indoor ozone, it is important to note the main sources of ozone. It is an unstable O3 molecule; a product of a photochemical reaction under sunlight and concentration are higher outside than inside. Indoor sources include air cleaners containing UV lamps that can generate ozone as well as office equipment such as photocopiers and printers. For our residence, our focus will be on the removal of ozone itself rather than its sources. Another option considered was passive removal materials but due to the limited space of the walls in the home, it was not feasible for this residence, The solution mentioned in the IAQ Guide are sorbent-based filtrations. In our case, we will consider the use of activated carbon filters. The filters are evidently effective at removing ozone. Filters with pre filters containing activated carbon were able to reduce ozone concentration significantly by about 60% to 70%

[13]. With continuous operation, carbon filters can remove between 60% and 90% of ozone, depending on the companion filter (e.g. particle, pre-filters) after ranges of 5 to 8 years [14].

Secondary consequences from activated carbon is that there is uncertainty in how often to change the filter since it can saturate quickly. In the case that it is replaced too early or too often, it can generate poor benefit-cost ratios. It is to be used as a complementary filter in addition to the MERV filter already used in the home. Acknowledging that the family is often busy, it will be a challenge to ensure the additional filter is replaced when required.

As can be seen from the calculation below, by using activated carbon filters with an efficiency of 60% , the hourly concentrations decreased by 8.9% [17]. This is different from the values shown in the literature of 60% to 90% due to the span of time. The studies are for continuous years for 5 to 8 years while our calculation below does not have input for time [14].

$$C_{ss} = \frac{\frac{E}{V} + \lambda_i p C_{out} + \lambda_m (1 - \eta_m) C_{out}}{\lambda_i + \lambda_m + \beta + \lambda_r \eta_{HVAC} t + \frac{CADR}{V}}$$

$$C_{ss,\ typical} = \frac{\frac{67800\ \mu g}{519.75\ m^3} + 1.04*0.8*40.23 \frac{\mu g}{m^3}}{1.04\ h^{-1} + 3\ h^{-1} + 2.18\ h^{-1} * 0.6*0.3} = 36.98 \frac{\mu g}{m^3}$$

$$C_{ss,\ maximum} = \frac{\frac{69400\ \mu g}{519.75\ m^3} + 1.04*0.8*52.15 \frac{\mu g}{m^3}}{1.04\ h^{-1} + 3\ h^{-1} + 2.18\ h^{-1} * 0.6*0.3} = 39.9 \frac{\mu g}{m^3}$$

4.0 Conclusion

Based on the HOT2000 model and the mass balance, we decided on the two different approaches that are specific and appropriate to the home. To reduce heating energy use, the team recommends adding insulation and for reducing ozone, activated carbon filters are to be put in place. The reductions are not as high as expected but it may be due to the limits of the model and the lack of time input for the mass balance. In the future, the residents may consider a renovation to increase R-value or more significant upgrades to improve the efficiency and indoor air quality of the home.

The appendix are supplementary and provide supporting references, calculations, parameters and inputs used to create the HOT2000 Model. It mainly consists of data retrieved from the home that was calibrated to conform to the required formats and units of the model.

Appendix 1: Model Input Parameters

The parameters used in the model were primarily obtained through field observations and are noted below. There were no overall significant assumptions that were made other than R-value for roof and wall where due to the inability to access inner layers and/or house architectural drawings we could not verify materials. Based on its year, style and location, we did assume typical R-values, the calculation for which is done in Part A. Any other assumptions or calibrations for a specific parameter are noted, explained and justified below, as needed.

Roof Data:
Construction: Attic/Gable
Roof R-Value = 4.17 m^2K/W (calculations in Part A)

Wall Data:
North/South Wall Length: 12.5 m
East/West Wall Length: 8.96 m
Basement Height: 2.29 m
Main Floor Height: 2.44 m
Second Floor Height: 2.75 m
Floor Area: 12.5 m x 8.96 m = 112 m^2
Floor Perimeter: 12.5 m + 12.5 m + 8.96 m + 8.96 m = 42.92 m

Wall R-Value = 4.8 m^2K/W (calculations in Part A)

Floor Data:
The floor headers were automatically inserted by HOT2000 once the house wizard was complete and so the values were kept as default.

Door and Window Data: obtained by field, physical observations

All windows are vinyl and double-glazed. The R-Values and SHGC were calculated by inputting in a window type that had features most closely related to the ones in the house. (Low-e, double glazed on one side from field observations). The window dimensions were measured physically.

Front Door is fibreglass, polystyrene core and Back Door is a sliding door so it was modelled as a window.

Table A1.0: Main Input Parameters

Main Floor			
Location	**Direction**	**Height (mm)**	**Width (mm)**
Family Room	South	1701.8	736.6

Family Room	South	1701.8	736.6
Family Room	South	558.8	1219.2
Kitchen (Door)	South	2032	1524
Kitchen	South	1016	1168.4
Dining Room	East	1701.8	1346.2
Dining Room	East	1701.8	1346.2
Entrance (Door)	North	1625.6	2032
Second Floor			
Location	**Direction**	**Height (mm)**	**Width (mm)**
Hallway	North	1397	736.6
Bedroom 2	North	1397	1346.2
Bedroom 2	North	1397	736.6
Bedroom 3	East	1219.2	1219.2
Bedroom 4	South	1219.2	1219.2
Master Bedroom	South	1219.2	1219.2
Master Bedroom	South	1219.2	1219.2
Ensuite	West	609.6	1219.2
Bathroom	East	609.6	1219.2
Basement			
Location	**Direction**	**Height (mm)**	**Width (mm)**
Basement	East	600	500
Basement	West	600	500
Basement	South	600	500
Basement	South	600	500

TEMPERATURE:
Default values were kept except for main floor and basement set points which were obtained from users:

Daytime and Nighttime Heating Set Point: 22 and 20 degrees Celsius respectively
Cooling Set Point: 25 degrees Celsius

Basement Heating Daytime Setpoint: 20 degrees Celsius

BASELOADS:

Baseloads:

There are 7 occupants in the house, however 3 live away from home during weekdays.

Therefore, 4 occupants live 100%, 3 occupants live 100% during the summers and 28.6% (2 days of a week) during the rest of the year.

(100% * 16 weeks + 28.6% * 36 weeks)/52 weeks = 50.57%

(4 * 100% + 3 * 50.57%)/7 occupants = 78.81%

Adults: 7 occupants at 78.81%

Water Usage:

Most of the variables were set as default except the following:

Average number of showers/occupant/week: The default was set as 5.2 and there are 7 total occupants in the house. However, 3 of the occupants tend to spend weekdays away from the house so the average was used.

5.2 * 1 week/7 days = 0.7428 showers per occupant per day

(0.7428 * 4 occupants * 7 days + 0.7428 * 3 occupants * 2 days)/(7 occupants) = 3.607 showers per occupant per day.

Number of Dishwasher Cycles: while there is a dishwasher installed, it is never used. Therefore, this was set as 0.

Electricity Usage:

Dryer:

Dryer's source is natural gas and it is located on the main floor. This was confirmed through field observations. The residents dry all their laundry in the dryer so the percentage of washer loads dried was also set as 100%.

The dryer's value was set as default of 916 kWh/year, however it was doubled since there are two dryers in the house. Therefore, it was set to 1832 kWh/year.

Stove:
Rating: 19000 BTU/h however HOT2000 sets 565 kWh/year as default. This parameter varied from 0 to 2000 (maximum allowed by HOT2000) and it did not have a significant impact on the value. However, since there are two natural gas stoves in the house that are regularly used, the default value was doubled and so the rated annual energy consumption was set as 1130 kWh/year.

Refrigerator:
This was set as the default value (639 kWh/year). This was multiplied by 2 since there are two fridges so it was set as 1278 kWh/year.

Lighting:
All lights in the house are LED which was confirmed through field observations.

Miscellaneous:
This parameter was observed to make a significant impact on the electricity use of the house. The default value was 9.7 kWh/day and when this was run, the electricity load was almost double that of the house which seemed incorrect. Since electricity can be impacted by multiple parameters, all parameters were double checked and this was the one that was considered too high.

The residents only have one main electrical load not outlined above which is a TV. The TV uses 386 kWh/year so that is 386/365 = 1.06 kWh/day. Other loads include laptops but laptops typically use less than 1 kWh/day (100 kWh/year = 0.27 kWh) [2]. Additionally, the majority of the laptop owners are away at school during most of the week. As a result, this value was considered a severe over-estimation and so was reduced.To keep it conservative however, the value was kept at 5 kWh/day.

Exterior Electricity Loads:
The house does not have any additional lights outside other than a porch light and two of either side of the garage, as a typical house so the default was not changed.

<u>POWER GENERATION</u>:

There are no power generation systems in the house.

<u>NATURAL AIR INFILTRATION</u>:

House Volume was calculated as 519.7 m^3 as shown below.

Table A1.2: House Volumes

Volumes (m^3)	
Main Floor	188.90
Second Floor	189.42
Basement	141.43
Conditioned Volume (m^3)	519.74
Above Grade (m^3)	378.31
Below-Grade (m^3)	141.43

Above Grade Height was calculated using heights of Main and Second Floor:

$$2.44 \text{ m} + 2.75 \text{ m} = 5.19 \text{ m}$$

The average ceiling for the basement, main floor and second floor is 2.29m, 2.44m and 2.75m, respectively.

All other values are set as default.

VENTILATION:

The house has a forced-air distribution system. The values were kept as default.

There is no whole-house component

The supplemental components are as follows:

Table A1.3: Ventilation Components

Component	Location	Manufacturer/ Model	Exhaust (L/s)	Time Used (min/Day)
Rangehood	Main Floor	Kitchen Aid/ KWCU405SSS	283.5	19.2
Rangehood	Basement	Air King/ AV1303	84.5	38.5

Bathroom Fan	Main Floor	Broan EC50	23.6	45
Bathroom Fan	Second Floor	Broan EC50	23.6	45
Bathroom Fan	Second Floor	Broan EC50	23.6	45
Bathroom Fan	Basement	Broan EC50	23.6	45

HEATING/COOLING SYSTEMS:

Main: There is a furnace and an air conditioner

Season: AC is typically run from May - September. Default design month set as July. This was obtained from residents.

Fans/Pumps: Kept as default.

Furnace:
Manufacturer/Model: Lennox - G43UF-24B-070-08 - Energy Star [18]
Output Capacity: Set as calculated (2 tons = 24000 BTU/h as capacity)
Energy Source: Natural Gas
Equipment Type: Condensing
Sizing Factor: Set as default
AFUE: 92.1% (Obtained from label)

A/C:
Manufacturer/Model: Lennox - 13ACD-024-230
Central Equipment System: Central Split System
Output Capacity: Set as calculated (2 tons = 24000 BTU/h as capacity)
Efficiency: 13 SEER (Obtained from label)
Openable Window Area: 100%
All other values are set default.

DOMESTIC HOT WATER:
Manufacturer/Model: Napien - NPE 240A - NG - Energy Star
Energy Source: Natural gas
Tank Type: Tankless
Energy Factor: 0.97
Location: Basement
All other values are set as default. No secondary system.

Appendix 2: Normalization and Calibration Graphs

This appendix shows the graphs and data used for electricity and gas normalization as well as AER calibration.

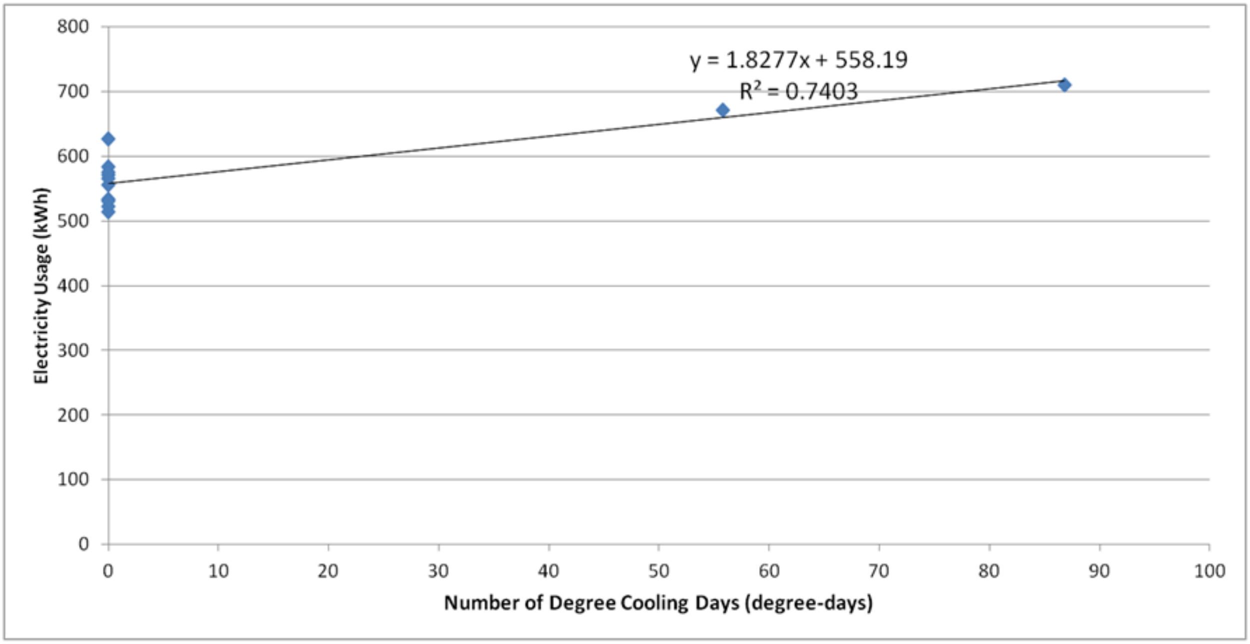


Figure A2.0 shows the equation used for electricity normalization

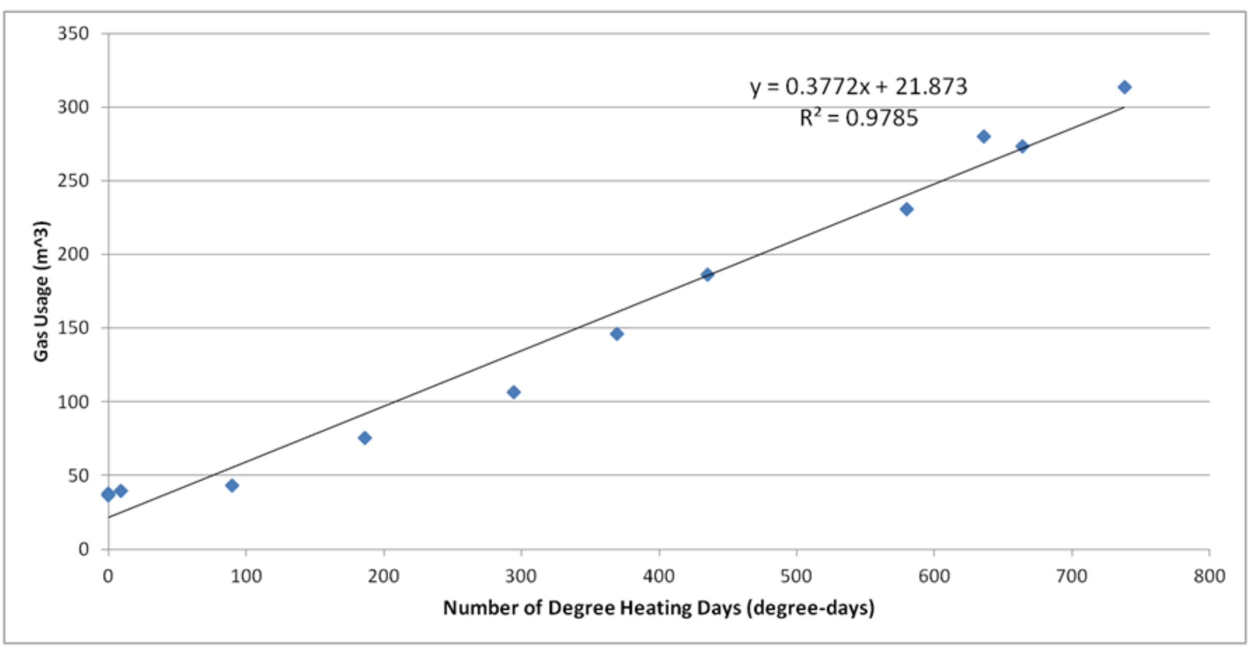


Figure A2.1 shows the equation used for natural gas normalization.

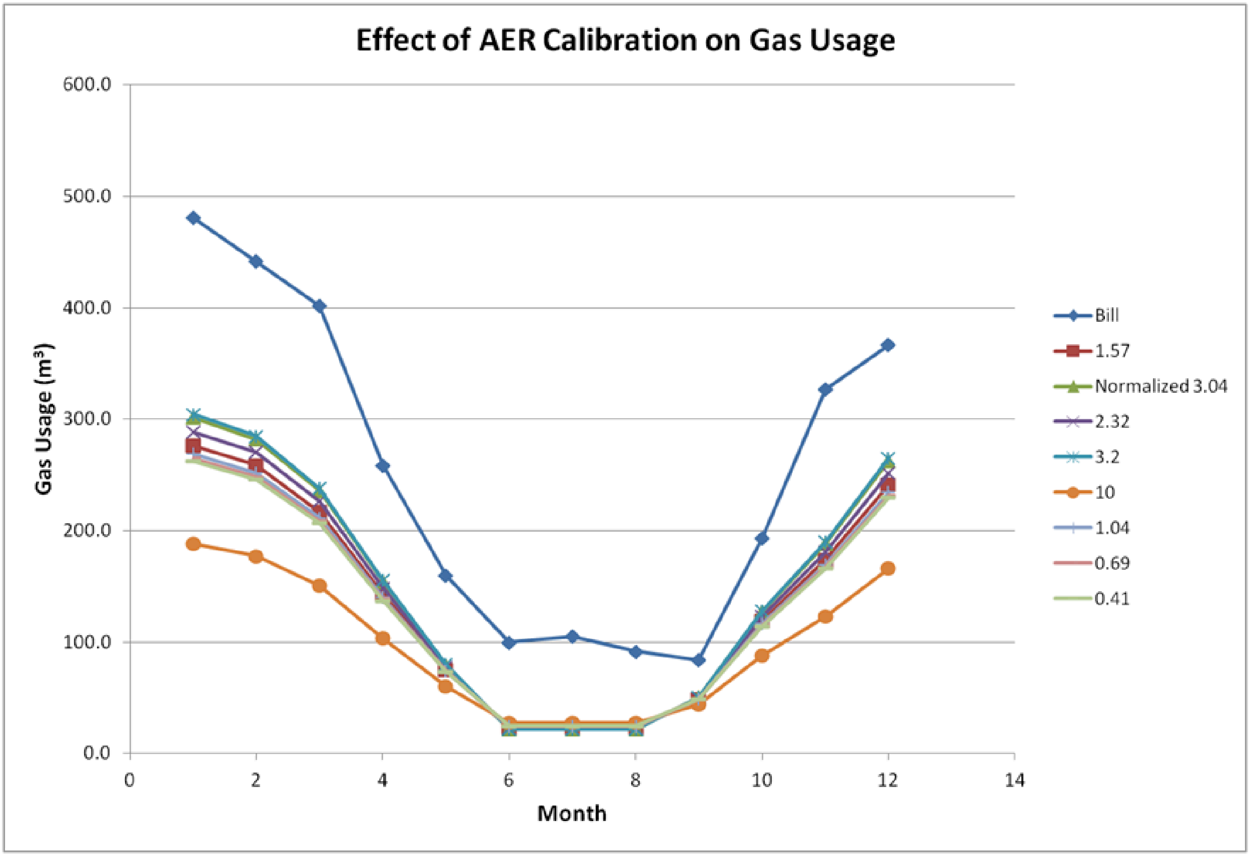


Figure A2.3 shows graphical results from the AER gas calibration

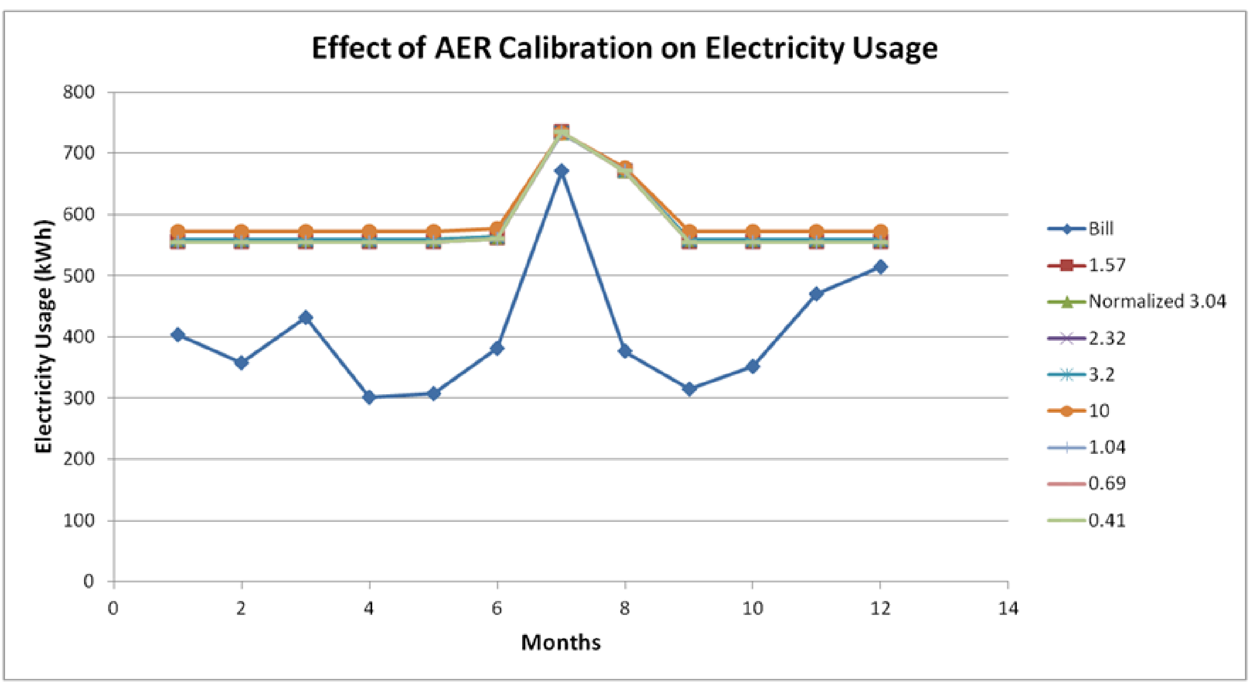


Figure A2.4 shows graphical results of the electricity AER calibration

Appendix 3 Mass Balance Parameter Information

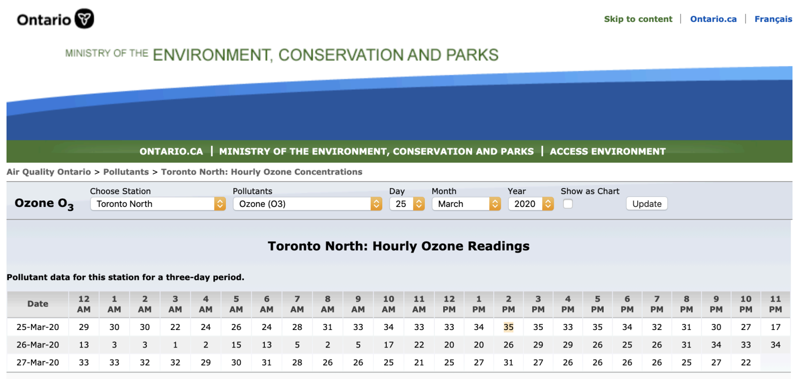
Outdoor Concentration:

Station Data for Toronto North

Station Information	
Station Name:	Toronto North
Address:	4905 Dufferin St., Eccc
Latitude:	43.78047
Longitude:	-79.467372
Station Type:	Urban
Height of Air Intake:	4 m
Elevation ASL:	186 m
Pollutants Measured:	O_3, $PM_{2.5}$, NO_2, SO_2

Measured Pollutants at Toronto North

Pollutant	Measured 1-Hour Concentration
O_3	27 ppb
$PM_{2.5}$	11 µg/m^3
NO_2	10.1 ppb
SO_2	0 ppb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ONTARIO.CA | MINISTRY OF THE ENVIRONMENT, CONSERVATION AND PARKS | ACCESS ENVIRONMENT

Air Quality Ontario > Pollutants > Toronto North: Hourly Ozone Concentrations

Ozone O_3 — Choose Station: Toronto North — Pollutants: Ozone (O3) — Day: 25 — Month: March — Year: 2020 — Show as Chart — Update

Toronto North: Hourly Ozone Readings

Pollutant data for this station for a three-day period.

Date	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	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
25-Mar-20	29	30	30	22	24	26	24	28	31	33	34	33	33	34	35	35	33	35	34	32	31	30	27	17
26-Mar-20	13	3	3	1	2	15	13	5	2	5	17	22	20	20	26	29	29	26	25	26	31	34	33	34
27-Mar-20	33	33	32	32	29	30	31	28	26	26	25	21	25	27	31	27	26	26	26	26	25	27	22	

Figure A3.0: Station Data and Information [10]

Source: http://www.airqualityontario.com/history/station.php?stationid=34021

Emission Rate:

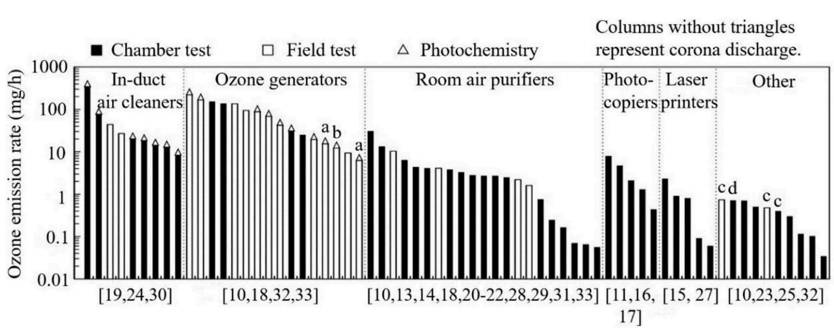


Fig. 7. OERs of IOEDs presented in the literature [10,11,13–25,27–33]. Mean value of the OER is chosen if there are multiple sets of experiments for the same device in one investigation. a: fruit and vegetable washers, b: shoe sanitizers, c: car (dashboard) ionizer purifiers, d: pet brushes. Other data in the "Other" group are for wearable air purifiers.

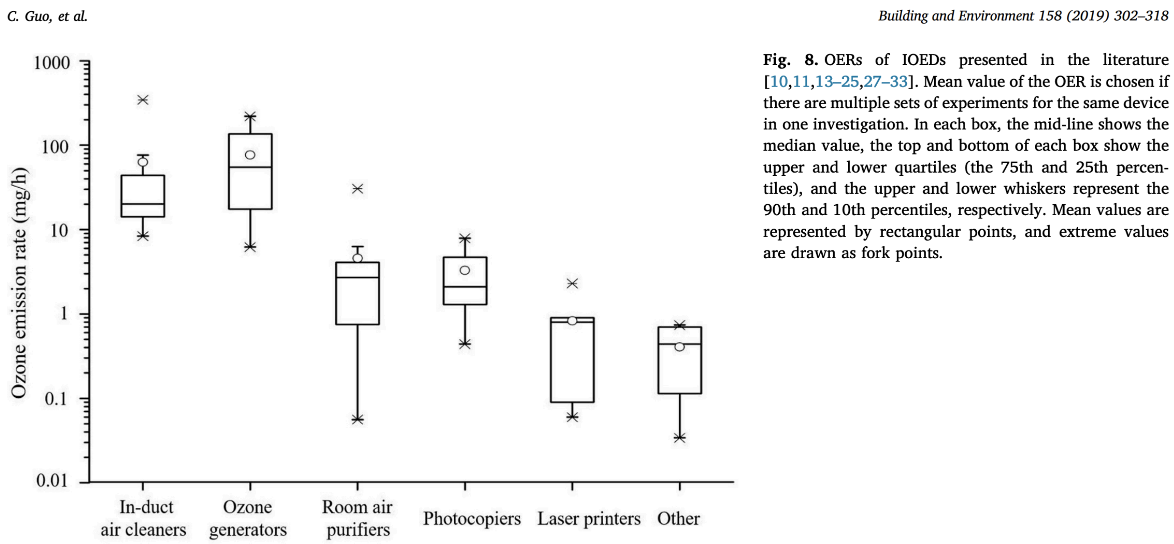


Figure A3.1: Ozone Emission Rate from household equipment [8].

House Volume

Table A3.0: House Volumes

Volumes (m^3)	
Main Floor	188.90
Second Floor	189.42
Basement	141.43
Conditioned Volume (m^3)	519.74
Above Grade (m^3)	378.31
Below-Grade (m^3)	141.43

Runtime

Runtime was calculated based on observations shown in Table 6.0. The method of observing whether the fan was operating was by feeling airflow at a supply register in the main floor powder room (aural cues). From 6:50, I switched it to 21.1ºC. Fans were operating consistently when they ran from 7:15-7:30 and 8:35-8:50. The system was set to heating and the fan was auto. The temperature outside was -5ºC.

$$Runtime = \frac{40\ minutes}{120\ minutes} = 0.3$$

Appendix 4 Insulation References for Model

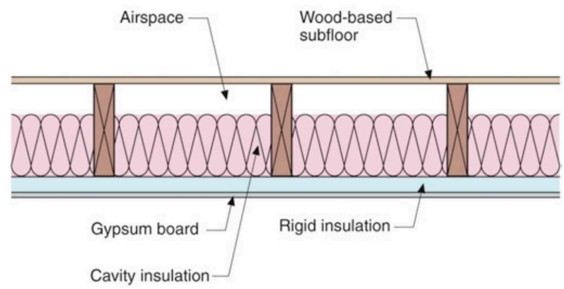


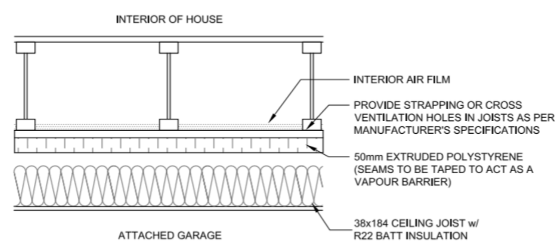
Figure 1: Hot Stuff – Best way to construct a warm floor. Continuous rigid insulation coupled with an airspace above cavity insulation.

Figure A4.0: Recommended construction of floor [15]

SAMPLE **CALCULATIONS**

Floor Over Attached Garage Assemblies

BONUS ROOM FLOOR w/ 50mm EXTRUDED POLYSTYRENE
AND A 38x184 CEILING JOIST w/ R22 FIBREGLASS BATT INSULATION
(w/HRV RSI OF 4.86 (4) REQUIRED)
(w/o HRV RSI OF 4.86 (4) REQUIRED)



SECTION

I-JOIST FLOOR w/ 38x184 CEILING JOIST : 5.14 RSI (R=5.678 x RSI)		
COMPONENT	RSI CALCULATION	RSI FOR COMPONENT
OUTSIDE AIR FILM	0.03 (1)	0.03
12.7mm GYPSUM BOARD	12.7 x 0.0061 (1)	0.0775
38x184 CEILING JOIST @ 406 o.c. w/ R22 FIBREGLASS BATT INSULATION	100/ [(13/1.19*) + (87/3.87*)] (2) *1.19 = 140 x 0.0085 (CEILING JOIST S.P.F.) (1) *3.87 = RSI FOR R22 BATT (1)	2.99
AIR CAVITY (44mm)	0.20 (1)	0.20
EXTRUDED POLYSTYRENE (50mm)	1.68 (1)	1.68
INTERIOR AIR FILM	0.16 (1)	0.16
AIR CAVITY	NOT APPLICABLE (3)	–
19.1mm T&G OSB	NOT APPLICABLE (3)	–
TOTAL		5.14

(1) VALUES FROM NBC 2015 TABLE A-9.36.2.4.(1) - D

(2) VALUES FROM NBC 2015 TABLE A-9.36.2.4.(1) - A

(3) MATERIALS INSTALLED TOWARDS THE INTERIOR OF A CONDITIONED AIR SPACE CANNOT BE INCLUDED IN THE CALCULATION OF EFFECTIVE THERMAL RESISTANCE OF THE ASSEMBLY.

(4) WHERE COMPONENTS OF THE BUILDING ENVELOPE IS PROTECTED BY AN ENCLOSED UNCONDITIONED SPACE, SUCH AS A SUN PORCH, ENCLOSED VERANDA, VESTIBULE OR ATTACHED GARAGE, THE REQUIRED EFFECTIVE THERMAL RESISTANCE OF THE BUILDING ENVELOPE COMPONENT BETWEEN THE BUILDING AND THE UNCONDITIONED ENCLOSURE IS PERMITTED TO BE REDUCED BY 0.16 ($m^2 \cdot K$)/W.

Figure A4.1. City of Saskatoon Guide on floor over attached garage assemblies [16]

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