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Final Draft: Infiltration Rate of the Energy Technology Center

Introduction:

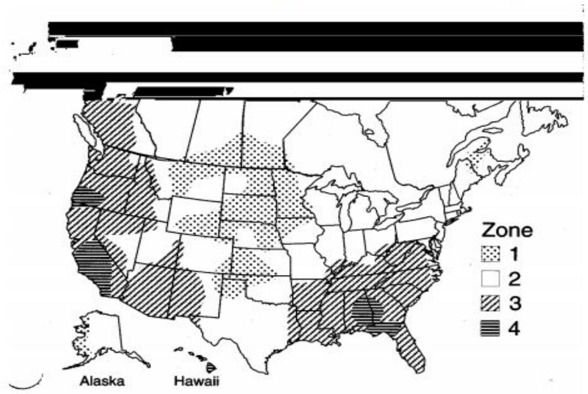
Effectively managing ventilation is important for the health, well-being, and productivity of building occupants. People on average spend 87% of their time within buildings so it becomes imperative that they be designed to optimize infiltration and ventilation operation with continuous efficiency. The Environmental Technology Center at Sonoma State University is one such building that was designed with multiple sustainable features, but has experienced wear and tear that lead our team to question its effectiveness in regards to how well its air is circulated. Our objective is to use the ETC's rate of CO_2 decay and air tightness using a blower door and NetAtmo data in order to compare and contrast our findings to our predictions, and to the expectations the building had during its design phase. On average adults exhale 40-50 grams of CO_2 per hour. In a room full of people there will be a dramatic spike in the ppm of CO_2. This abundance of CO_2 can be used as a tracer gas to calculate the infiltration rate of the ETC. Measuring concentration decay to determine the air change rate comes with two distinct advantages: it does not rely on obtaining the building's volume for airflow measurements and it can be used to measure the entire building (AIHA). However, we decided to measure the airflow anyway by using a blower door to evaluate the building's tightness in order to compare it to industry standards. By conducting these two different testing methods we would be able to measure how fast CO_2 was leaving the building and how fast outside air was replacing it by bridging measurements in CO_2 parts per million with air changes per hour.

We expected to find that the blower door test results would prove the building to be performing at a high standard of energy efficiency, meaning a lower level of air changes per hour. This was assumed because when a building is certified as energy efficient, developers use best practices to ensure envelope tightness. By building standards, this would mean the envelope has been built to resist inward or outward air leakage to a builder's best effort, thus, the air changes in the room would be minimal. As for the CO_2 data, we assumed the air changes to be similar to what we saw from the blower door due to the degradation in CO_2 levels as classes come and go.

Assumptions:

From the figure below, we assume that the ETC is located in Zone 3 and is normally shielded from the wind. Because the ETC is an irregular shape, we will use the Lawrence Berkeley Lab (LBL) factor for a 1-story building (21.5) and the LBL factor for a 2-story building (17.2) to get the range of ACH.

Table 4: LBL Factor to convert ACH_{50} to Natural Air Changes per Hour (ACH_{nat})



Zone	# of stories ➜	1	1.5	2	3
1	Well-shielded	18.6	16.7	14.9	13.0
	Normal	15.5	14.0	12.4	10.9
	Exposed	14.0	12.6	11.2	9.8
2	Well-shielded	22.2	20.0	17.8	15.5
	Normal	18.5	16.7	14.8	13.0
	Exposed	16.7	15.0	13.3	11.7
3	Well-shielded	25.8	23.2	20.6	18.1
	Normal	21.5	19.4	17.2	15.1
	Exposed	19.4	17.4	15.5	13.5
4	Well-shielded	29.4	26.5	23.5	20.6
	Normal	24.5	22.1	19.6	17.2
	Exposed	22.1	19.8	17.6	15.4

$$ACH_{nat} = \frac{ACH_{50}}{LBL\ Factor}$$

Using the ETC blueprints, we calculated the ETC volume to roughly: 41,000 ft^3.

Methods:

Blower Door Summary

In order to find the infiltration rate of the ETC, we used a blower door which is a standard tool used by home energy raters. For the test to be effective we had to limit the amount of outdoor airflow coming into the building by closing all doors and windows and blocking as many cracks and gaps in the building as possible. Once we sealed the building as best as we could, the blower door was set up by erecting an aluminum frame in an open doorway that would hold the both the tarp and the fan during pressurization. We decided to depressurize the ETC so we could better find compromised areas inside the building from places where outside air was rushing in. This was done using a smoke pen and sensory observations around the perimeter of the building.

Once we marked the places where unwanted infiltration was discovered we connected the fan to the manometer which collects the infiltration rate (CFM) at 50 pascals of pressure. This is the standard unit for measurement because at 50 pascals there is enough pressure difference to obtain an accurate reading without causing problems such as sucking chimney ash into houses. We did the test several times under differing circumstances to reflect reality of the building's use. For our first test we sealed the building as best as possible to show the performance of the building under ideal conditions. The second test was done with ventilation ducts unsealed to represent the infiltration during regular occupancy. And the third test was done with the building's main doors open to represent the infiltration happening during hot days when the building doors are left open intentionally.

After the data was recorded, we converted the infiltration rate given in CFM to air changes per hour (ACH) in order to compare our blower door test results with the CO2 decay rate observed by NetAtmo. In order to do this we used the formula provided in the blower manual:

$$\text{ACH @ 50 pascals} = \text{cfm x } \frac{60\ min}{Volume\ of\ building}$$

Doing this resulted in an answer that was still at 50 pascals, so we implemented a strategy developed by Lawrence Berkeley Labs to convert ACH_{50} to $ACH_{natural}$. The LBL factor takes into account wind speed, shielding of the building, the height of the building, and the climate zone the building is in.

NetAtmo CO_2 Decay Summary

Using the data collection software, NetAtmo, allowed us to track the decay rate of CO2 within the ETC. Every five minutes the level of CO2 is recorded and it was this information that allowed us to compare and contrast our blower door infiltration results with the CO2 decay rate. The units for this are in parts per million (ppm) which was worked around in another conversion to cancel ppm units into a cooperative format, without having to deal with the literal units of (parts/million). The following is our basic method for solving for the aforementioned conversion:

$$\left(\frac{\Delta ppm}{\Delta seconds}\right) \times \left(\frac{1}{ppm\ in\ ETC}\right) \times \left(\frac{3600\ seconds}{1\ hour}\right)$$

We initially wanted to use CO2 data after EMD forum on Wednesdays of every week for 2017 in order to have some form of uniformity in the analyzed data, but upon inspection of the few months of data we did have, there is almost no discernible decay trends to be observed immediately after the hours of 4-6 pm that EMD forum would presumably have NetAtmo recording. In a rerun of the study, we would suggest the use of the most recent data possible.

Thus, we resorted to a technique of using Python 3 in Sage Math Cloud to create a code that was able to sift through the archived CO_2 data from 2016. The exact coding can be found in our report's appendix, but what follows is the transcribed translation of what we had done conceptually:

The first thing we did with the NetAtmo data was calculate a concentration slope. This was accomplished by finding an average difference between individual measurements of CO_2 ppm and then put this over the 300 seconds -- equivalent to five minutes -- time interval difference that the NetAtmo automatically gathered. Next, in order to sift through all of the concentration slopes generated, we set a couple of parameters for the select slopes we wanted to be indicative of a decaying slope. The first of the two parameters set were to make sure the slope was below zero, indicating a slope that was decreasing/decaying. The second of the two parameters set was to only take into account a minimum of 450 ppm starting concentrations. This second parameter accounted for a minimum of at least one occupant's exhaled CO_2 content that could be used for a decaying concentration slope. With concentration slopes of 450 ppm or more resembling a decaying trend over the five minute interval (**Δ** concentrations/**Δ** time), we moved to the second and final parts of our equation to calculate the infiltration rate.

Our appendix shows that we combined the second and last parts of our calculations into one coded equation, however we will break it down as the equation in our results resembles. In order to account for the eventual equalizing of the CO_2 concentrations inside the ETC with the 400 ppm CO_2 global baseline concentrations found outside the ETC, we divided the found difference of our average indoor concentrations and the aforementioned outside CO_2 ppm with an absolute value stipulation. This was an assumption we made because of the presumable occurrence of a slowing CO_2 decay reaching a flatlining of ppm between the ETC's inside concentration and the outside's concentration of the tracer gas. The addition of this assumption not only served the purpose mentioned above, but it also helped us to eliminate the ppm units in the CO_2 concentrations without having to incorporate later stoichiometry delving into the innate CO_2 units of parts per million. Finally, to convert the infiltration rate to an hourly rate from the seconds timeframe we had, a simple multiplying of 3600 seconds -- sixty seconds times sixty minutes equals the seconds count of an hour -- got us to our final resultant figures for air changes per hour. We now had our ACH figure derived from the NetAtmo CO_2 data that we could compare to the blower door test's measured figures.

Results:

The blower door results showed that the average infiltration rate the ETC experienced was 0.111 air changes per hour. This would mean that about 11% of the ETC's air is replaced by fresh air every hour which is considered to be normal. The results of the seven blower door tests we ran are shown in Chart 1. Chart 2 is a manipulation of the data using the ACH formula in the blower door manual.

Test using 17.2 in LBL Formula

Chart 1

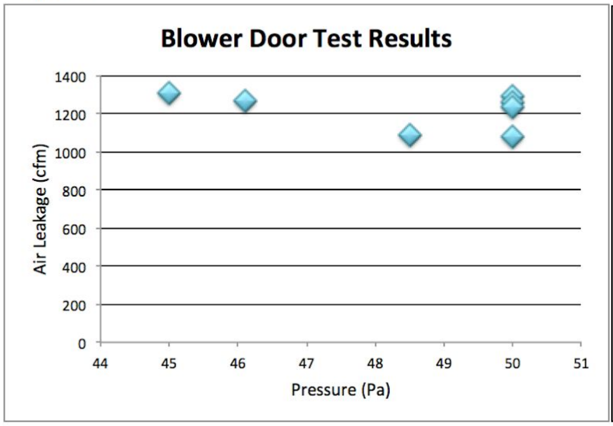
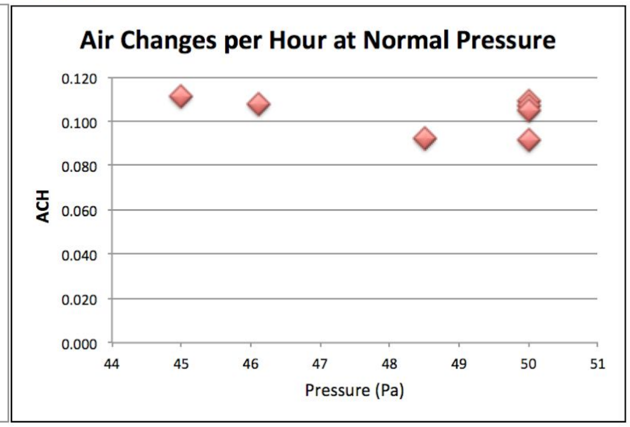


Chart 2



Test using 21.5 in LBL Formula

Chart 1

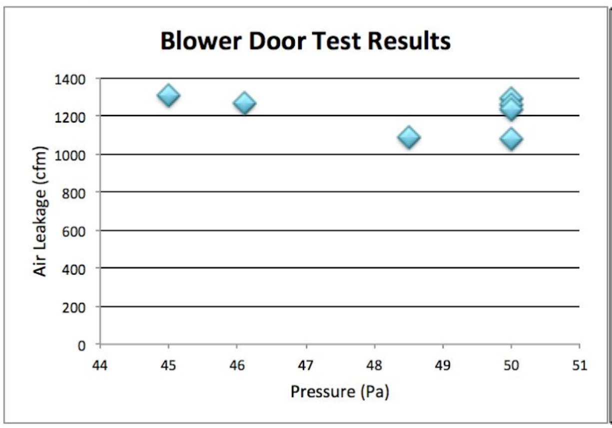
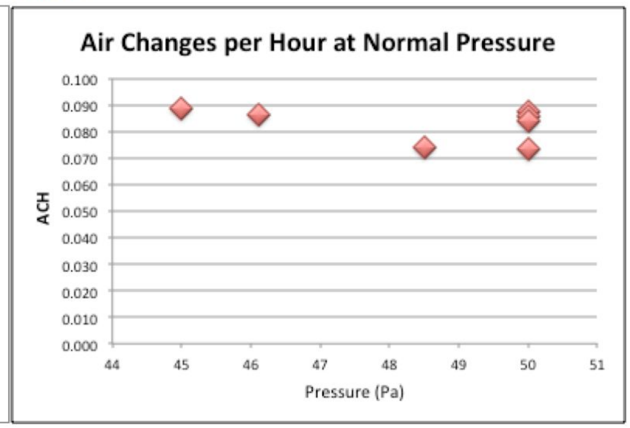
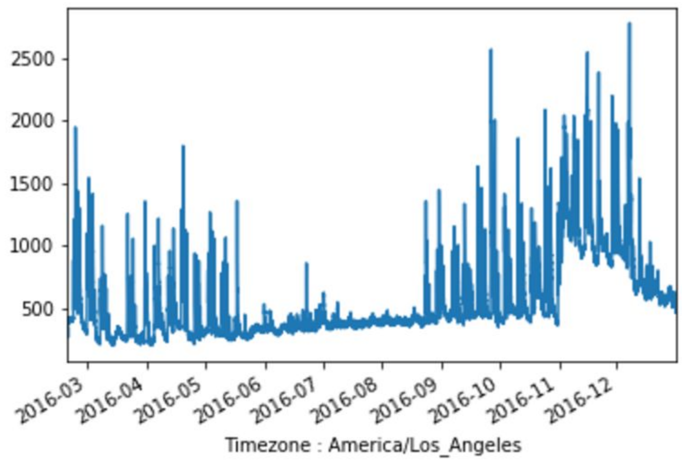


Chart 2



We believed this to be close to the correct amount being that the ETC was built to be an extremely “tight”, energy efficient building. In order for this to happen, it would need to have a minimal amount of leakage making it difficult for air to enter or leave the building.

Although the NetAtmo is currently not working we do have data from 2016.



This graph above shows the PPM of CO_2 in the ETC between March 2016 and January 2017. Using the formula from Matt's 2016 Science Symposium project, we determined that the ETC has a mean infiltration rate of .117. Because of our absolute value parameter, as seen in the appendix, the order of "outside concentration - inside concentration" was negligible.

$$\frac{\Delta\, concentration}{\Delta t} \cdot \frac{1}{outside\ concentration - inside\ concentration} * 3600$$

```
count    89756.000000
mean         0.116603
std          0.437253
min          0.000000
25%          0.000000
50%          0.000000
75%          0.000000
max         25.341272
dtype: float64
```

Discussion:

After reviewing the blower door and NetAtmo results, we found very similar numbers between the two tests. The closest comparable building to the ETC had an LBL factor of 20 which is what our testing was based on. For buildings similar to the ETC a reasonable test range would be from 17.2 to 21.5 so assigning an LBL factor of 20 falls within that range. Our analysis of the blower door data included an initial factor of 20 that helped our equation account for the blower door pressurization at 50 pa, against the non-pressurized ETC figures that were calculated without a base 50 pa of pressure. Further discussion of what the factors of climate region, the wind sheltering, and number of stories for the LBL factor would be encouraged as to how the sub-factors came to be calculated as are presented in Energy Star's Table 4. Currently, efforts to find further explanation of the mathematical reasoning behind the LBL factor have proven unsuccessful.

Our approach may not be applicable to every type of building despite how general the blower door approach is. This means that buildings that have been designed and constructed with unique characteristics like the ETC will likely experience unidentical results to more uniformly designed buildings; so it is important to note that while using a blower door to obtain building CFM is a universal method, the results will vary in accordance to the features of the building. Further peer review of our approach and calculations are advised if additional testing is to be done along the same topic.

Conclusion

Our blower door test results indicate that there is significant leakage in several areas throughout the ETC. Areas that increased the leakiness of the building envelope would be a window in a back office that cannot be shut, double doors leading out to the garden that have a large hole at the top, and the double doors in the foyer. We have two sets of double doors at the ETC's main entrance that are not properly weather stripped. Our initial Blower Door Test was done on a door without weather stripping that clearly affected our results. We expected there to be less leakage than we measured with the blower door based on observations of CO_2 and stale air that accumulate during periods where large numbers of occupants were present. Comparing and contrasting the CO_2 decay with the blower door test results has shown that the relationship between infiltration and CO_2 decay are not immediately interchangeable, but correlating conclusions can be drawn from the data given the conceptual similarities. Once ACH is measured through both CO_2 decay and blower door testing the resulting findings indicate that the testing was extremely accurate, giving confidence to our conclusions. It is our hope that our findings and calculations lead to a simpler explanation of how the two measurements are related.

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