Abstract

- This manuscript explores the effectiveness of determining a building's air changes per hour by monitoring indoor CO2 concentrations.
- Specifically, experiments involving the measure of infiltration and exfiltration were conducted using a NetAtmo indoor Weather-Station.
- The results of these experiments were then compared to the traditional method of blower-door tests.
- Through this comparison, the effectiveness of this new and easier method was determined.
- Using decay rates of tracer gases can significantly impact the cost, time, and frequency of measuring and quantifying a building's efficiency.
- All measurements and data collected were on site at Sonoma State University's Environmental Technology Center (ETC)

Introduction

- Energy efficiency is at the forefront of building science. Buildings make up -- percent of the total energy use in America.
- A building envelope, whether effective or ineffective, is the physical separator between the inside and outside environment.
- A building's ability to passively control the indoor climate is fundamentally linked to the temperature, energy efficiency, and air quality of the building.
- A successful building envelope is one that can generally maintain comfortable temperatures and high air quality.
- Ventilation rates serve as quantitative measure of a building's envelope.
- Air-tightness can have positive and adverse effects.
- The blower door test is the current standard for measuring a building's air changes per hour (ACH).
- This test requires specific equipment that requires some level of training.
- In addition to tetious equipment, the blower-door test requires a completely controlled system. Typically, it requires the building to be out of use.
- *Air Exchange rates.
- As an alternative to the blower door test, cheap and easy data loggers can incorporate simple calculations to determine ACH.
- By measuring the concentrations and decay rate of tracer gases, data loggers have the potential to measure ACH.
- Data loggers provide a significantly less intrusive, cheaper, and more reliable alternative to measuring ACH.

- This method allows for repeated measurements, which add to the precision of the determined ACH calculations.
- offer a less labor-intensive approach to analyzing a building's envelope.
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- This manuscript aims at determining the legitimacy of measuring CO_2 decay rates in order to receive the same quality of measurements from blower-door tests.
- By exploring the associated mathematics and unit analysis of both the blower-door test and the extrapolated ventilation rates from CO_2 decay, relations can be drawn.
- The relationship of these measurement methods should, in theory, allow for a modified tracer-gas decay equation. This equation can be used to determine various ventilation measurements (air changes per hour).

- Research question: Can the implementation of simple calculations provide considerably more reliable measurements of a building's ventilation rates?
- When beginning, we expected a generally easy comparison.

Limitations

- Our blind spot → only measuring ETC. what we are unsure able: is the ETC even "useful". This is a clear weakness.
- The ETC is a well-used building with occupancies that are nearly impossible to model.

Materials

How, what, when, where, why.

- NetAtmo Weather Station (indoor), used to record CO_2 concentrations (ppm).
- Data every ,x, minutes. From this data..(Methods). What are we looking at? Measuring directly, and then what are we inferring.

- Blower Door: measures pressure delta, flow rate, and exchange rate.
- Sagemath Cloud/ Jupyter Notebook / python softwares

Data/Methods (methods here for now)

- CO_2 concentration is measured approximately every 3 minutes.
- We use linear interpolation to get X minute samples
- We observe an increase in CO_2 concentration while students are present in the lecture hall
- We observe a decrease in CO_2 concentration after students leave and the room is ventilated by passive infiltration.

- By measuring the rate of decrease in the CO_2 concentration, we can infer the rate of fresh air entering the building stale CO_2-rich air leaving the building.
- We select periods of CO_2 decrease that are "amenable to analysis"

- Assumptions: I have many.. Need to pin-point what's most important. Listed below are just a few.
- gas concentrations are the same for entire building
- Gases are stable and inert(doesn't react/change)
- Exchange rates are assumed to be constant over time interval
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- Preliminary data: Using simple proportions to look at exchange rates from CO_2.
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- I'll need standard deviation from various days of NetAtmo CO_2 decay
- Linear least squares regression, to find air exchange rate.. (R kernel in SMC?)
- For CO_2 decay, I will need to go from ppm to total volume of CO_2 inside ETC. Then from decay rate/NetAtmo slope I'll determine the CO_2 CFM. Next, CFM to ACH (times 60 mins divided by total volume of ETC). (I want to take a look at pressure delta, from before and after decay, to further analyze). Then from ACH of CO_2, ACH of all gases needs to be extrapolated.
- I'll need all pertinent measurements from Blower-Door Tests. Outside/inside pressures, CFM.
- From blower door test, I'll need all data. With measured CFM at controlled pressure, I need extrapolated CFM at 1 atm (or whatever pressure it was outside) in pascals. (system of extrapolation needs to be flushed out). Once at CFM at non-controlled pressures, it will be easy to determine ACH of building.

Results

- Need a comparison. (Just how easy can I make the comparison)
- Will need to boil-down ppm-->ACH into hopefully 1 or two algebraic equations.
- Need to test equation(s) with data from blower-door test day(s).

Conclusion/Discussion

- Measuring CO_2 concentrations in a building can be easily transformed into monitoring a building's ventilation rates. With only a monitoring device, architects, carpenters, and energy-saving building owners can analyze a building's envelope more often and with greater ease.

References

- Have 4+ articles in pdf form. (ask Soto if he'd like to see/ How to best share these here without links)

Brainstorming:

-What are the current Ventilation standards? (Email from Beeler).

A large part any building envelope is,
-infiltration rate: the volumetric flow-rate of air **INTO** the building.
-exfiltration rate: the flow-rate of air **OUT** of the building
-Stack effect: The flow-rate of air **INTO and OUT** of the building.

“ETC’s Green Design”

(intro or abstract)
...can be the deciding factor of whether comfortable temperatures, suitable air quality, and energy efficiency.

In regions with climate extremes, the measurement and effectiveness of a building’s envelope can become increasing important.

Questions for data (to be determined):

-For every m^3 of CO2, how many m^3 of other gases are leaving?(least squares application seems like best approach)

- Go to graphing for R : GG plot

Notes from Soto:
“Outlining is 80% of your time.” - on the topic of

Find simple proportions of CO2 exchange and room exchange.

- It seems comparing the Blower-Door ACH and decay-rate-determined ACH is my main focus. The units check out.

Nomenclature

- CO2 decay:
- CFM = ft^3 per min.
- ACH = Air Changes per Hour
- ppm= parts per million (volumetric)
- m^3 = volume in meters cubed
- Pa = pascals (Newton per square meter)

- V_dc = volumetric decay (exfiltration)

Converting from ppm to CFM then to total air exchange rate

$$Rp = \frac{ACPH * D * h}{60}$$

- Blower Door
- CFM
- ACH
- Pa
- V_T = total volume of building
- V_in = volume into building (infiltration)

- Ideal gas law
- PV = nRt = NkT
- n = number of moles
- R = universal gas constant (8.3145 J/mol K)
- k = Boltzmann constant = 1.38066E-23 J/K; k= R/N_A
- N_A - Avogadro’s number (6.0221E23 per mol)