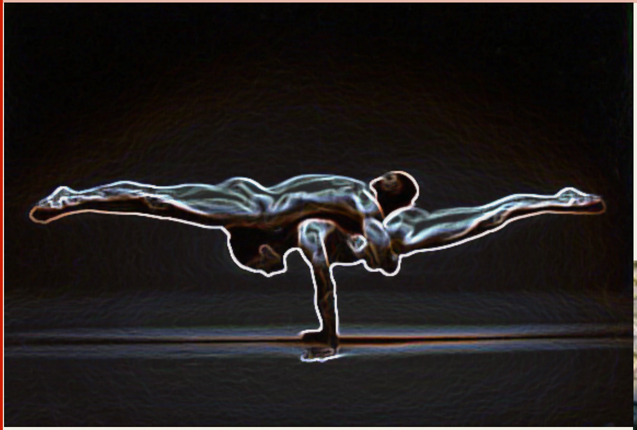
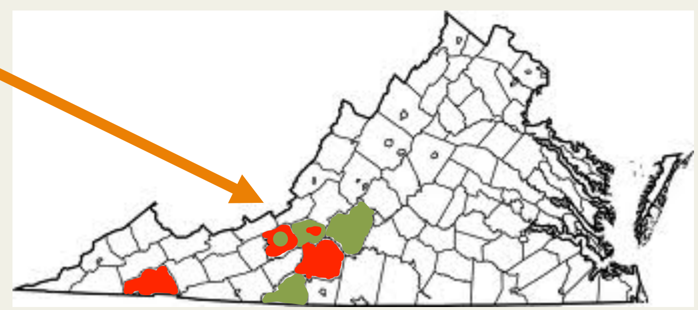
Four Completed Commercial Passive Building Projects – Lessons Learned

Presented by Adam J. Cohen, Architect, CPHC NA & EU, LEED AP



Virginia?

What, Where??



Center for Energy Efficient Design

Project Summary

Location: Rocky Mount, Virginia

Client: Franklin County School Board

The First US public school building built to Passivhaus Standards

Size: 3,600 GSF ~ 3,053 TFA

Construction: 5B, non-sprinkled

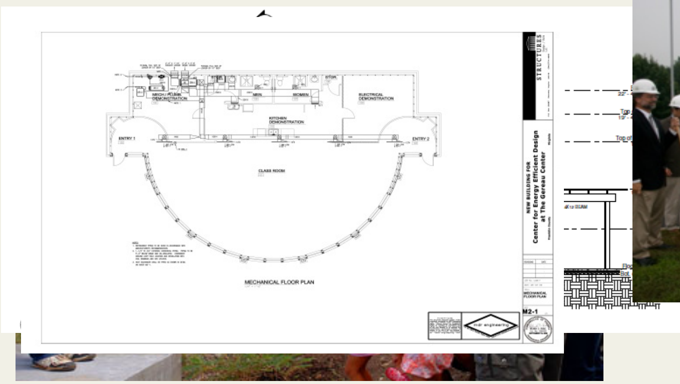
Final air test: 0.59 ACH_{50}

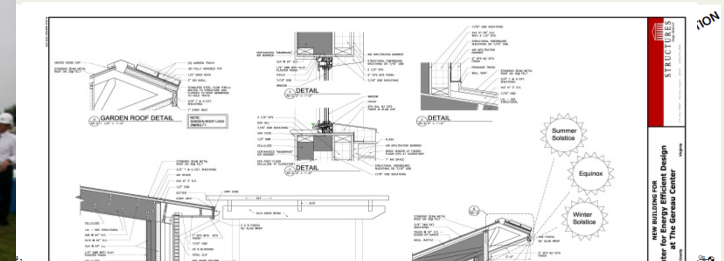
Modeled heat demand: 3.69 kBTU/(ft^2yr) (TFA)

Modeled Specific Primary Energy Demand: 32.2 kBTU/(ft2yr) (TFA)

Center for Energy Efficient Design

Brief Project History





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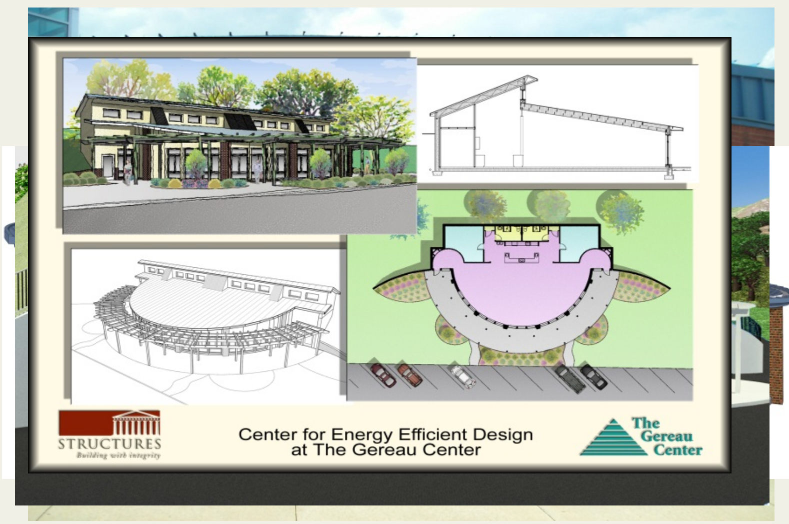


Center for Energy Efficient Design

Construction Assemblies

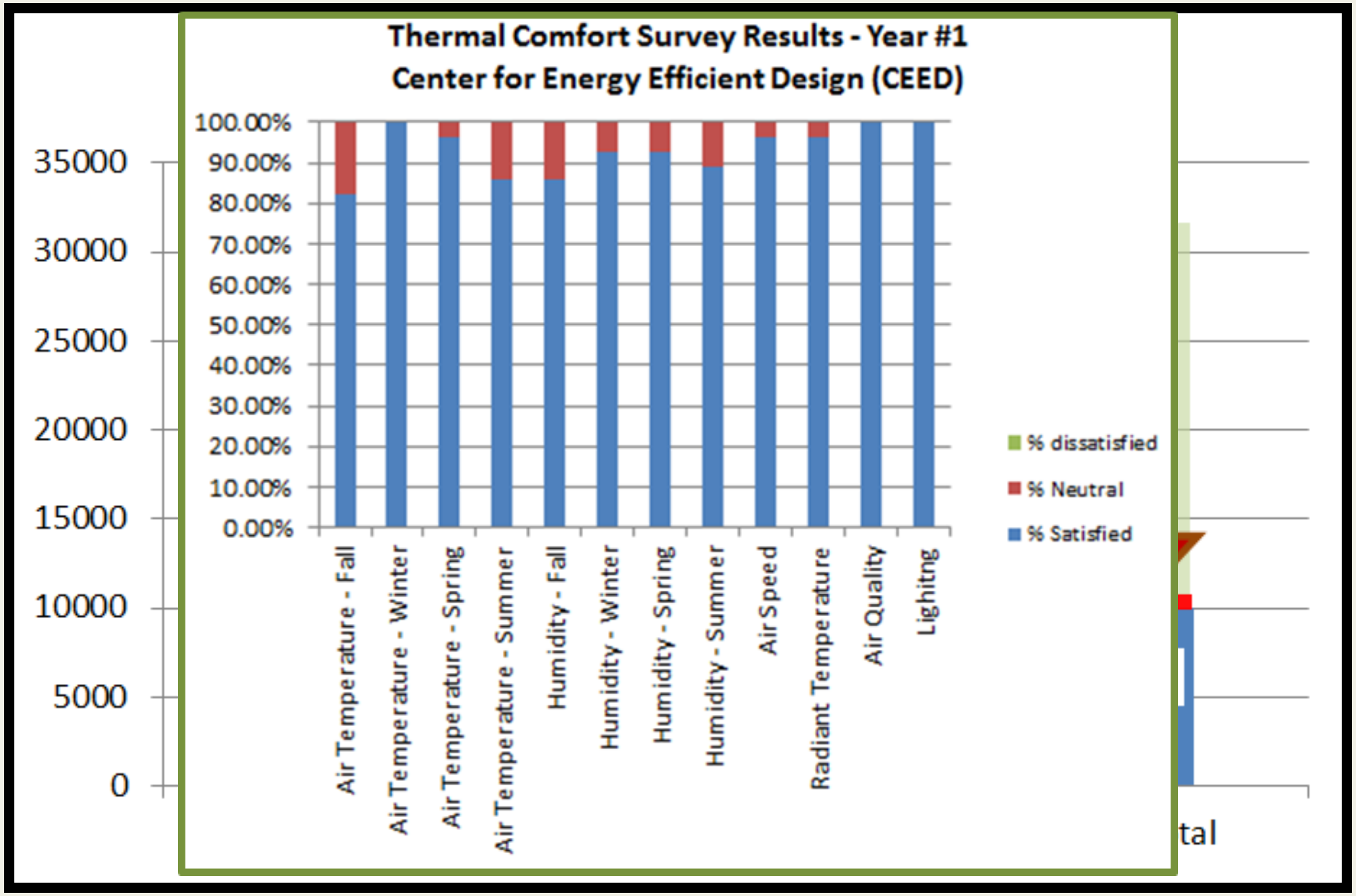
	R value (hr. ft^{2}F/BTU)	U value (W/m^{2}K)
Slab	39.3	0,144
Concrete walls	33.4	0,170
Frame walls with brick	33.5	0,169
Frame walls with EIFS and windows	42.3	0,134
Frame walls with EIFS no windows	45.5	0,125
North Roof	68.0	0,084
South Roof	59.6	0,095

Specific heat demand	3.69	kBTU/(ft²yr)	12	kWh/(m^{2}a)
Specific Cooling demand	1.00	kBTU/(ft²yr)	4	kWh/(m2a)
Specific Primary Energy Demand	32.2	kBTU/(ft²yr)	102	kWh/(m2a)
Pressurization Test Result:	0.6	ACH_{50}	0,6	h^{-1}

SHGC	0.542		SHGC	0,542	
R_{cog}	7.41	(hr. ft^{2}F/BTU)	U_{cog}	0,77	(W/m^{2}K)
R frame	3.47	(hr. ft^{2}F/BTU)	U frame	1,63	(W/m^{2}K)
Y_{Spacer}	3.20	(hr.ft^{2}F/BTU.in)	Y_{Spacer}	0,045	(W/mK)
$Y_{Installation}$	2.88	(hr.ft^{2}F/BTU.in)	$Y_{Installation}$	0,050	(W/mK)

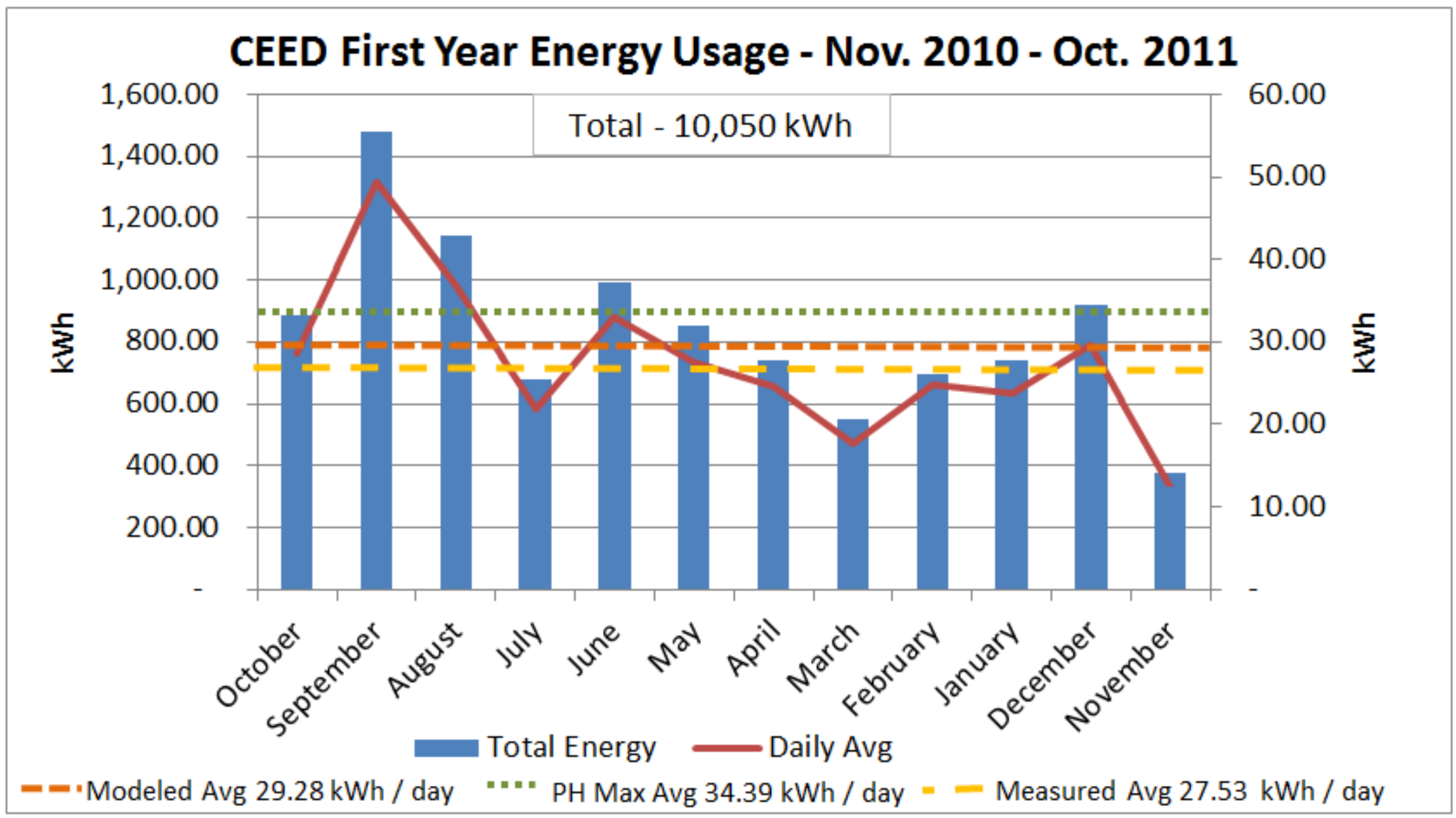
Center for Energy Efficient Design

Year #1 Performance Summary



Center for Energy Efficient Design

Performance in detail



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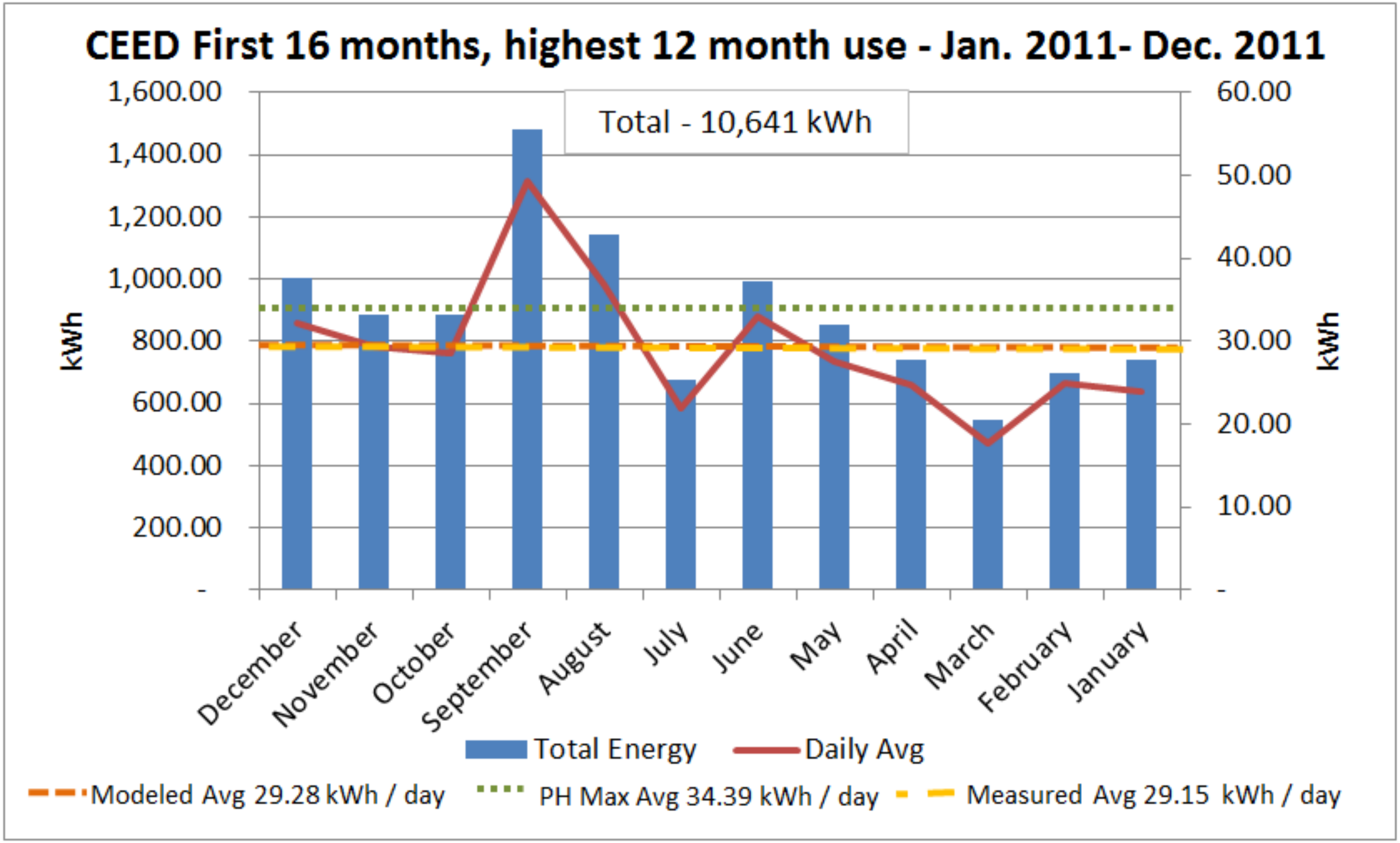
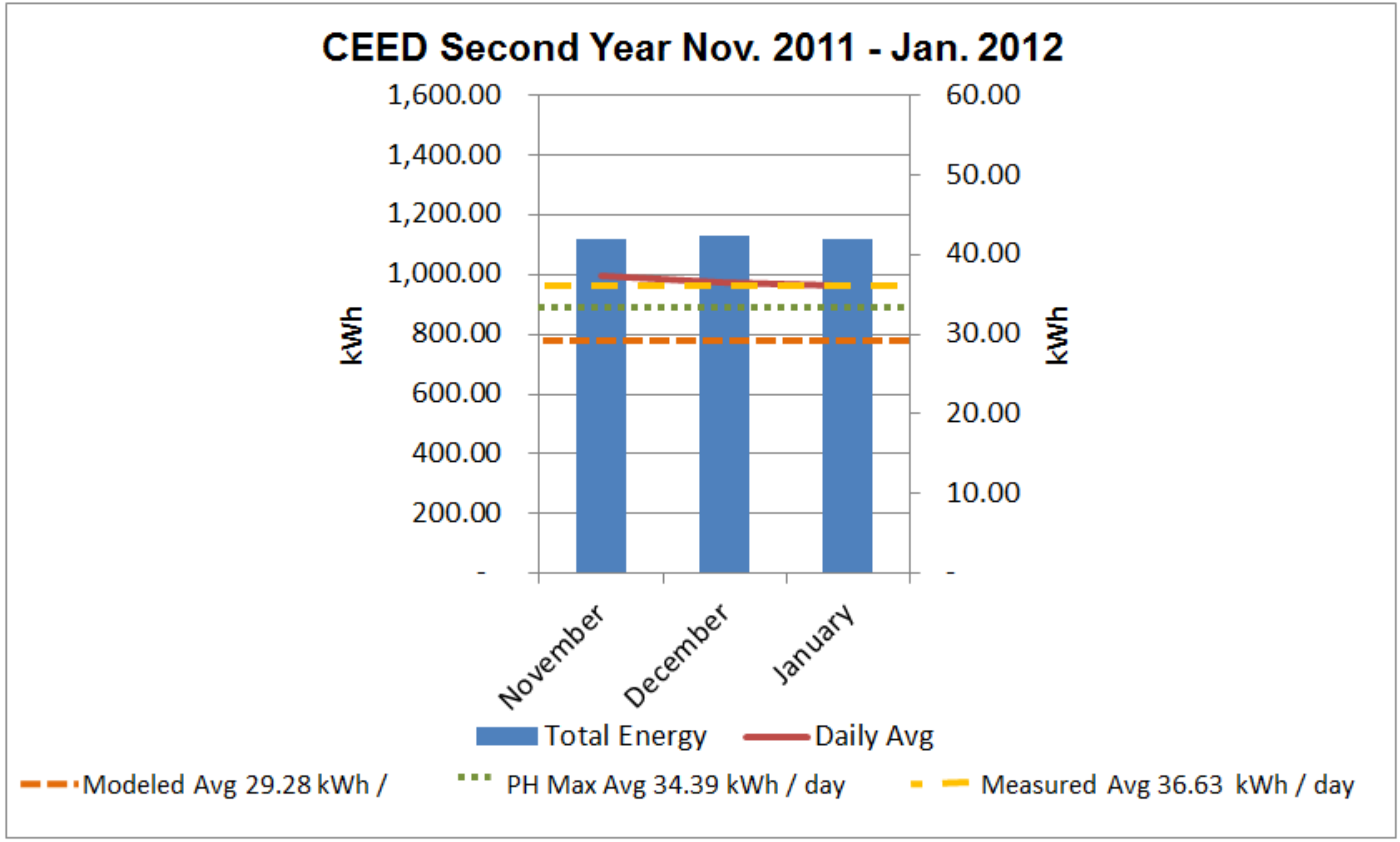
Performance in detail



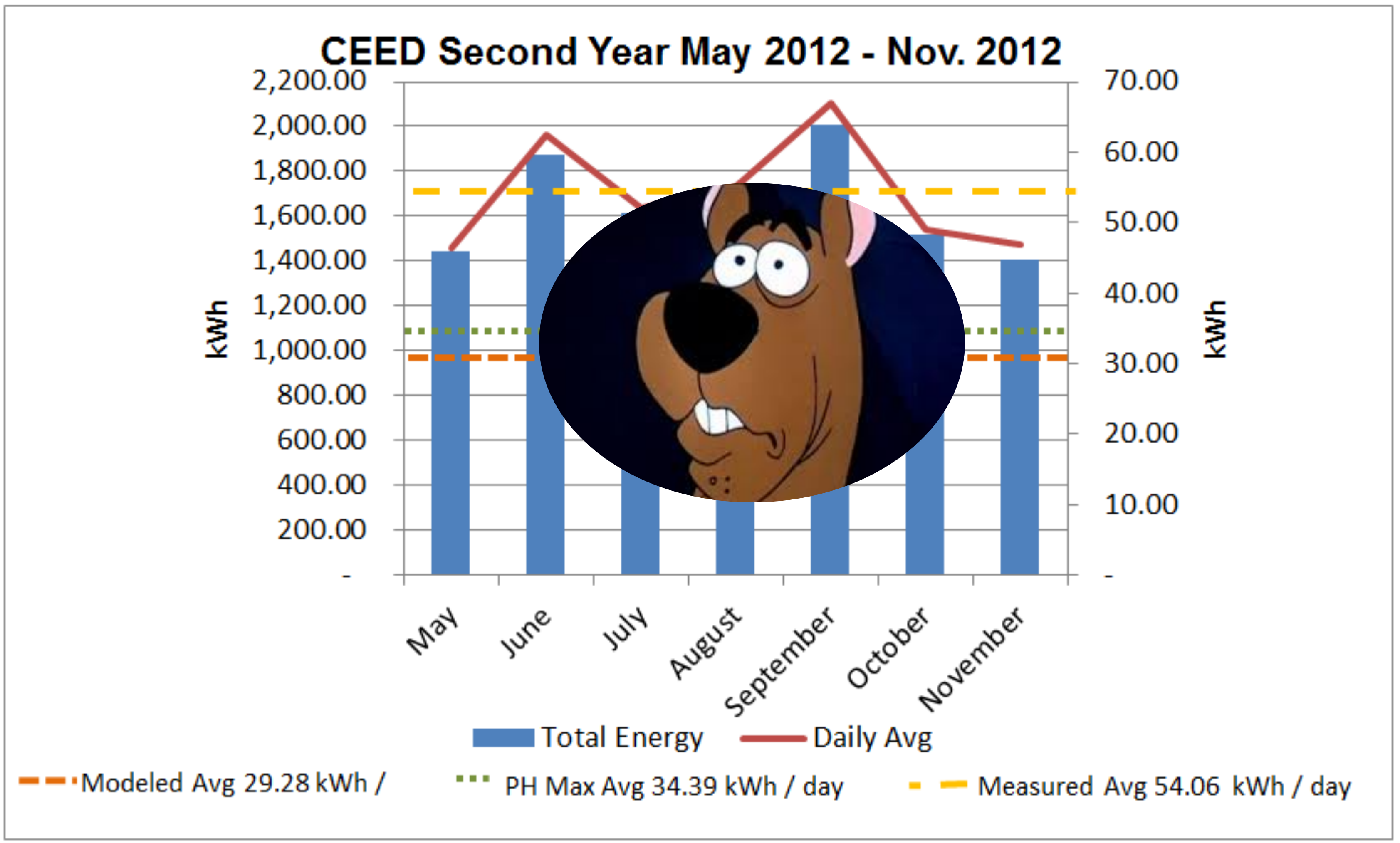
Center for Energy Efficient Design

Performance in detail



Center for Energy Efficient Design

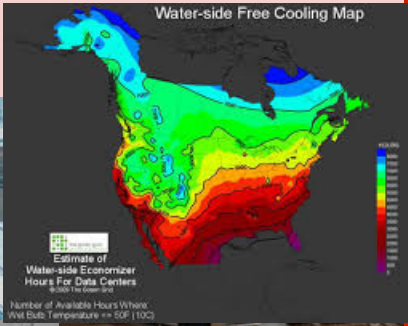
Performance in detail



Center for Energy Efficient Design

Energy Sleuth

- After the first year, the school administration doubled the number of classes in the building.
- When the PHPP was adjusted for the new occupancy periods, it was very close to the actual increase of approximately 100 kWh per month in energy for the first three months of occupancy.
- Over the course of the following six months, though, we observed a steady increase in the energy usage.
- When examined through remote energy observation, we saw that the building's systems including ERV control and lighting control were not operating as designed.
- The ERV was designed to be off when non-occupied and come on for a flush out 1 hour prior to occupancy. The energy readings showed that the ERV was running continuously.
- The summer economizer function was operating in the fall and winter.
- The daylight harvesting controls were not operating as designed.
- The shading system was not in use during the summer.



Center for Energy Efficient Design

So What Happened?

- The teacher that had envisioned this project and whose passionate burning soul had seen it come to reality and was the occupant of the building for the first 15 months, retired.
- Another teacher took over the classroom. This teacher was not given a systems orientation.
- Not only was that overlooked by the school administration and maintenance personnel, but the building systems operation and maintenance (O&M) manual was missing.
- When we investigated at the site, we found that at some point, the building power had been lost and no one had reset the timers on the ERV system.
- The economizer function which was to be manually engaged at the start of the cooling season and manually disengaged when the season was over was never disengaged.
- While on site we discovered that during a solar panel installation in 2011, the installer had uncapped the conduit meant for future solar installations, installed the cabling required but had not followed through with the air tightening measures as proscribed in the O&M manual for future work.
- It was through the remote monitoring system that we were able to detect the problems, but the causes of the issues required site investigation.
- We recommended in November 2012 that the administration re-commission the building, as was recommended in the O&M manual and retrain the new occupants.
- As of September, some 10 months later, this has not been done!

Malcolm Rosenberg Center for Jewish Life

Project Summary

Location: Blacksburg, Virginia

Client: Hillel @ Virginia Tech

The First US assembly building built to Passivhaus Standards

Size: 8,000 GSF ~ 7,243 TFA

Construction: 5B, non-sprinkled

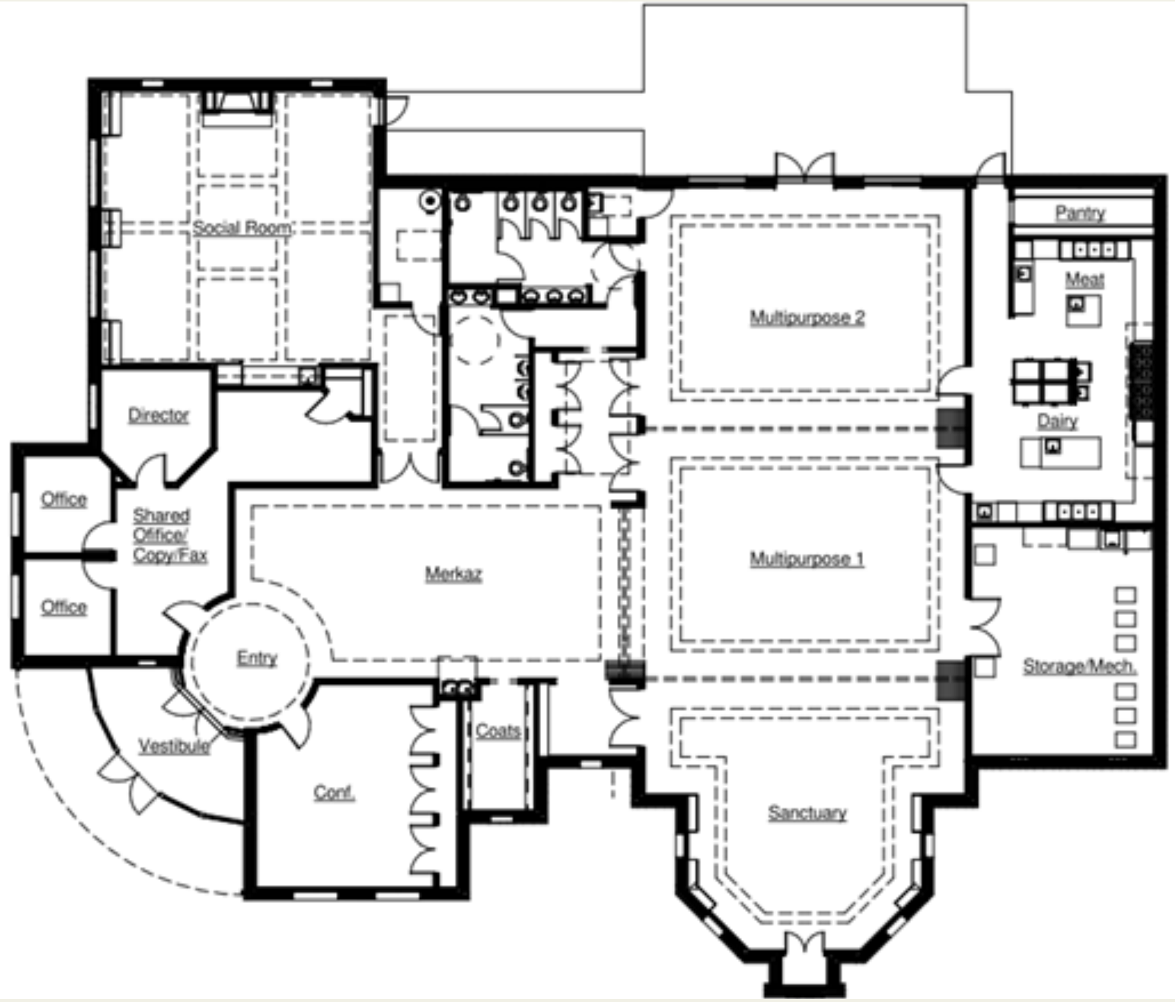
Final air test: 0.54 $ACH_{50\ (kitchen\ dampers\ closed)}$, 2.08 $ACH_{50\ (kitchen\ dampers\ open)}$

Modeled heat demand: 4.30 kBTU/(ft^2yr) (TFA)

Modeled Specific Primary Energy Demand: 35.3kBTU/(ft2yr) (TFA)

Malcolm Rosenberg Center for Jewish Life

The Basics

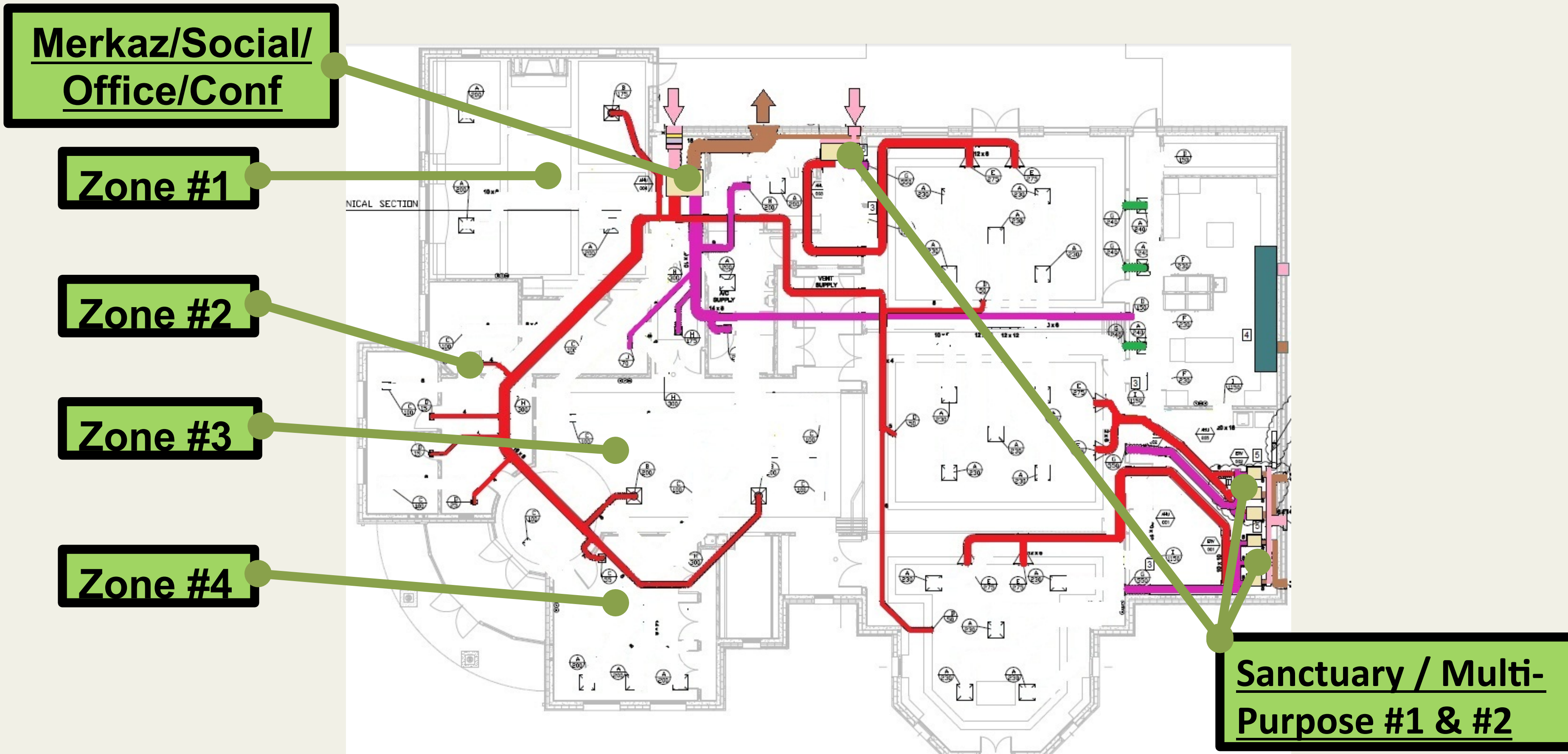


- Light timber construction
- Complex usage pattern
- Significantly different zoning requirements
- Two commercial kitchen exhaust hoods
- Mixed humid climate
- Restricted budget of a non-profit organization
- Slab – R 17.8
- Wall (Stone) – R 40.6
- Wall (EIFS) - R 46.7
- Ceiling – R 67.0
- Window Average – R 6.5, SHGC 0.6

Malcolm Rosenberg Center for Jewish Life

Ventilation Learning Opportunities – THE CONCEPT

- Initially designed three single zone demand control systems (CO_2 based)
- A Single four zone demand control system that would be maintained through static duct pressure.



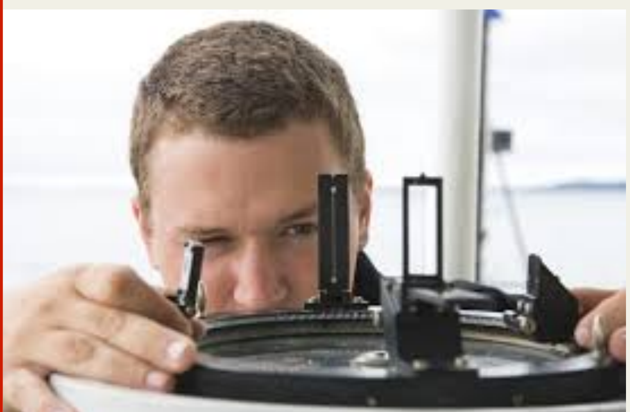
Passive House Institute US

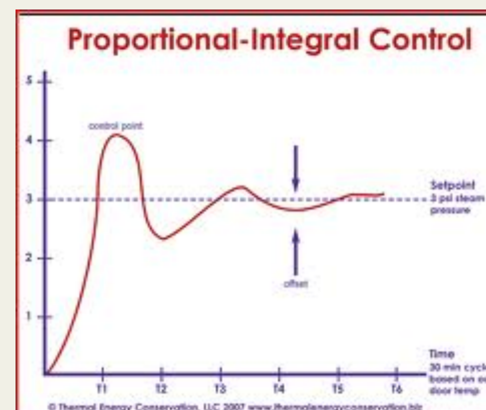
PASSIVSCIENCE Knowledge saves power

Malcolm Rosenberg Center for Jewish Life

Ventilation Learning Opportunities – THE REALITY

- In practice we found getting this instrumentation correct proved very difficult.
- Because we had four zones each with a multi-point damper, there was in essence an almost unlimited series of damper combination settings and we found after many attempts to reprogram the control algorithms, that we were unable to find a group of settings that would not end up with a “hang up” point.
- We reverted to a simpler proportional control of the ERV ECM motor. This system while not as elegant as a static pressure controlled system does the job very well and is simple to design and install.



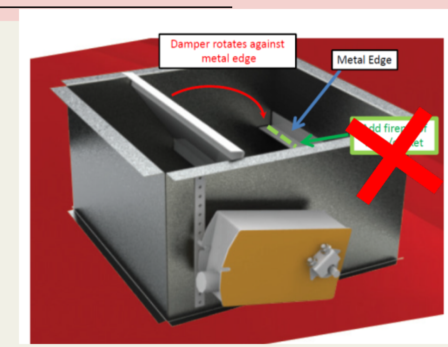


Malcolm Rosenberg Center for Jewish Life

Commercial Kitchen Exhaust Hood

- Finding a UL listed damper for the system was a project in itself.
- UL requirement that we not modify the damper in any way
- The damper was specified by our firm with very tight tolerances, but when the unit was delivered the specifications were not followed.
- Led to a remanufacture of the damper and a delay in the installation of the damper in the project. Without the damper units though we could only guess at how leaky it would be. To solve this, we created a wooden mockup of the damper and air tested it.
- We determined that there would be significant air leakage. Moving on with the project without the actual damper and only the mockup air tightness results, we decided to require an air test with the damper openings blocked off of .30 ACH50 maximum. We achieved .27 ACH50 and waited for the damper. Once the dampers were installed the following results were achieved:

	Kitchen Hood - Dampers Closed	Kitchen Hood - Dampers Open
Pressurized	.54 ACH_{50}	2.06 ACH_{50}
Depressurized	.53 ACH_{50}	2.08 ACH_{50}



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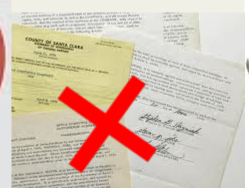
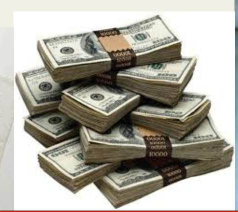
Oh and one other thing . . .

- The design and calculations for the building with the kitchen modeled as finished
- Original contract the kitchen was going to remain unfinished, because of budget
- Our original contract did not include the hood system
- During the initial construction phase, money was raised to complete the kitchen
- Our bid for the hood system was equal to another solicited by the director, she chose not to have the kitchen hood in our contract
- The hood installer was not at all concerned with the air tightness of the building and not being contracted to our team, felt no obligation to follow our instructions
- The director proved to be of little help and this created constant friction between our team, the hood contractor and the director
- Our team ended up putting quite a bit of uncompensated work into the hood as the hood contractor had ignored our directions to make the installation air tight
- Any future contracts will specify that all aspects of construction that affect airtightness shall be made part of our contract, even oversight and consultation of future construction






	MAIN	PILOT
R_{Series}	3.4Ω (R1)	22Ω (R2)
$I_{LED} = \frac{(V_{BATT} - V_{LED})}{R_{Series}}$ $Life(Hours) = \frac{BattCap(AmpHours)}{I_{LED}(Amps)}$	$I_{LED} = \frac{(4.8-3.3)}{3.4} = 441mA$ $Life = \frac{2.7}{0.441} = 6.1hours$	$I_{LED} = \frac{(4.8-2.8)}{22} = 91mA$ $Life = \frac{2.7}{0.091} = 29.7hours$
$P_{LED} = V_{LED} \times I_{LED}$ $P_{TOTAL} = V_{BATT} \times I_{LED}$ $P_{RESISTOR} = P_{TOTAL} - P_{LED}$	$P_{LED} = 3.3 \times 0.441 = 1.45W$ $P_{TOTAL} = 4.8 \times 0.441 = 2.12W$ $P_{RESISTOR} = 2.12 - 1.45 = 0.67W$	$P_{LED} = 2.8 \times 0.091 = 0.25W$ $P_{TOTAL} = 4.8 \times 0.091 = 0.44W$ $P_{RESISTOR} = 0.44 - 0.25 = 0.19W$
$Efficency = \frac{P_{LED}}{P_{TOTAL}}$	$Efficency = \frac{1.45}{2.12} = 68\%$	$Efficency = \frac{0.25}{0.44} = 57\%$
$LightOutput(Lumens)$	~120L	~25L

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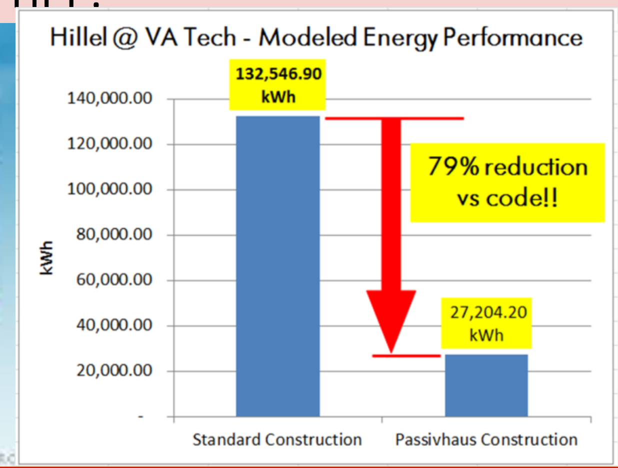
Energy

- Extensive discussions with Director and Board during design about occupancy and energy
- Only gross limited data is available on the energy use of the building because the board of directors elected not to install the monitoring system as we had requested
- The energy use is fairly close to the predicted amount ranging between +5% - +15% per month over the PHPP predicted amount
- While on an information gathering trip, our staff found that the Director of the center had elected not to follow the energy use guidelines outlined in our O&M manual.
- We had directed that all electrical plug loads be switched off when the building was non-occupied. While agreeing to this during the initial design, once occupied, the director decided that to switch off the computers and the TVs was “too much trouble” so there is a phantom load being maintained that was not modeled in the PHPP.

Drs. Lynch, Dickey and Singleton Dental Clinic

Project Summary

Location: Roanoke, Virginia

Client: Drs. Lynch, Dickey and Singleton

The First in the world dental clinic built to Passivhaus Standards

Size: 5,000 GSF ~ 4,460 TFA

Construction: 5B, non-sprinkled

Final air test: 0.29 $ACH_{50\ (Pressurized)}$, 0.25 $ACH_{50\ (Depressurized)}$

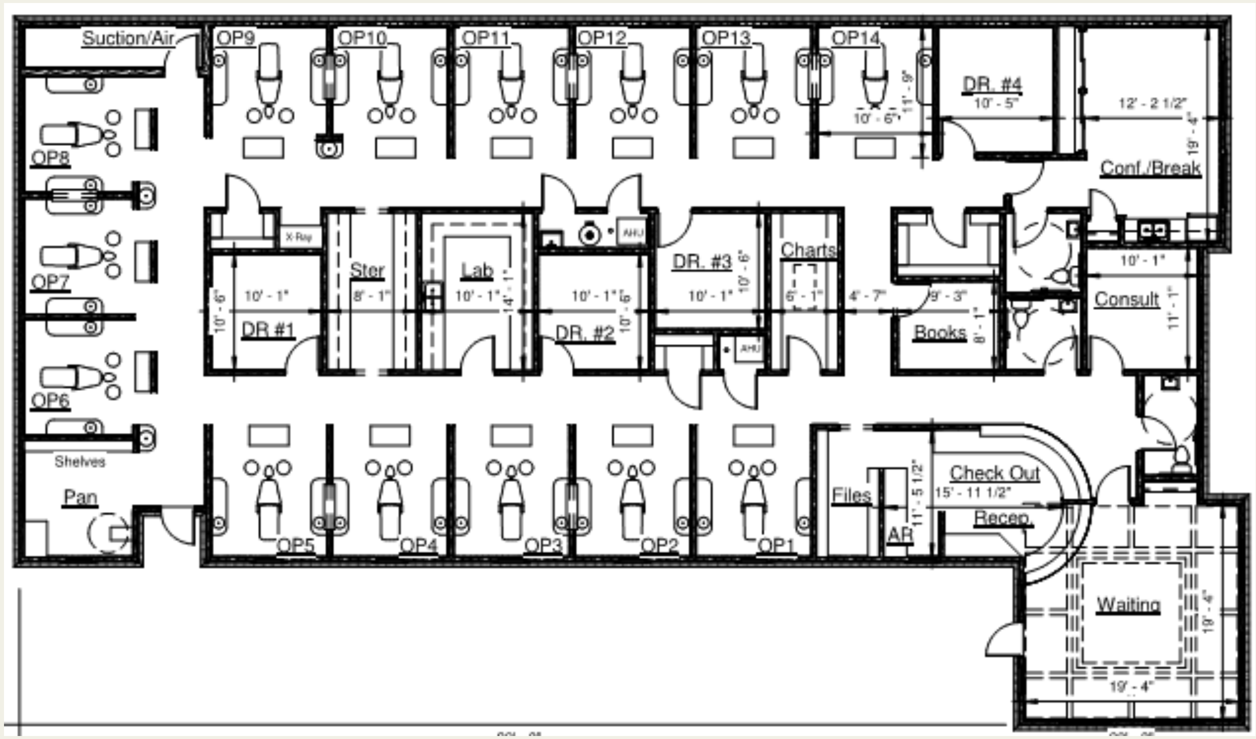
Modeled heat demand: 0.86 kBTU/(ft^2yr) (TFA)

Modeled cooling demand: 8.84 kBTU/(ft2yr) (TFA)

Modeled Specific Primary Energy Demand: 67.1 kBTU/(ft2yr) (TFA)

Drs. Lynch, Dickey and Singleton Dental Clinic

The Basics

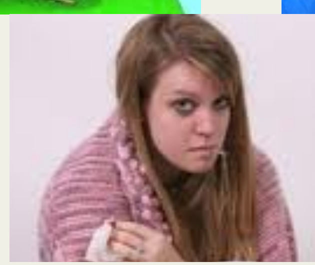


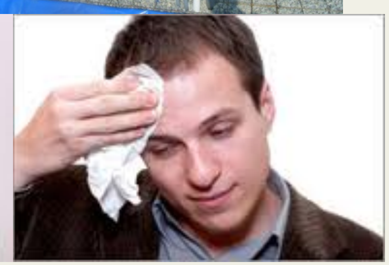
- Light timber construction
- Simple usage pattern
- Significant thermal comfort requirements
- Mixed humid climate
- Slab – R 18.0
- Wall (Brick) – R 37.3
- Wall (Siding) – R 36.5
- Wall (EIFS) - R 42.4
- Ceiling – R 66.3
- Window Average – R 6.8, SHGC 0.6
- Glass Block Assem. – R 4.9, SHGC 0.66

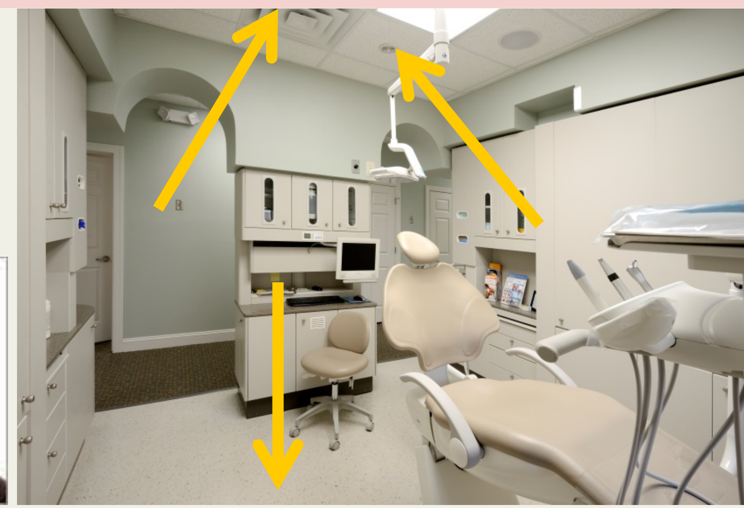
Drs. Lynch, Dickey and Singleton Dental Clinic

#1 Focus THERMAL COMFORT

- One consistent area of concern in all clinics is the thermal comfort of the doctor and patient
- Doctors generally complain of being too hot and often patients complain of being too cold
- When one has a dental procedure, one typically has a nervous patient, a working doctor, an assistant and a dental light. When calculating the heat load in the small work area it becomes clear that the heat generated by the people and light is significant
- Three Pronged Strategy:
  - Preconditioned fresh air along the ceiling of each operatory space at a very low velocity
  - Separate low velocity forced air conditioning system directed behind the dental chair
  - 100 ft2 passive cooling loops around each dental chair to take radiant heat from the bodies in the space



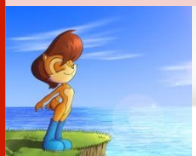




Drs. Lynch, Dickey and Singleton Dental Clinic

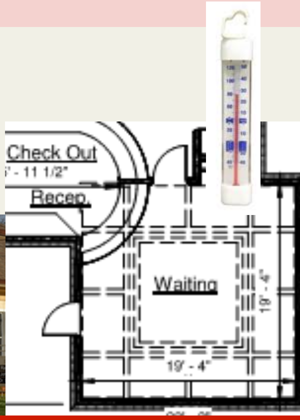
Results – Intended and Unintended

- The doctors report that the operatory thermal comfort is exceptional
- The doctors report that the fresh air exchange has eliminated the “dental clinic smell”
- The waiting room was overheating in the summer
    - West facing reception room rose as high as 76°F, well above the 72°F set point
    - The 80% reduction solar screens that we designed for the glazing in the waiting room were not being used
        - The doctors said that they did not like the look of the screens
    - Good amount of fresh air supply to this space (60 CFM)
        - The very low velocity the warm air felt stagnant
    - The ceiling in this area is 14 ft. while the balance of the space is 9 ft.
    - A ceiling fan was installed in the waiting room which sufficiently mixed the air to alleviate the problem





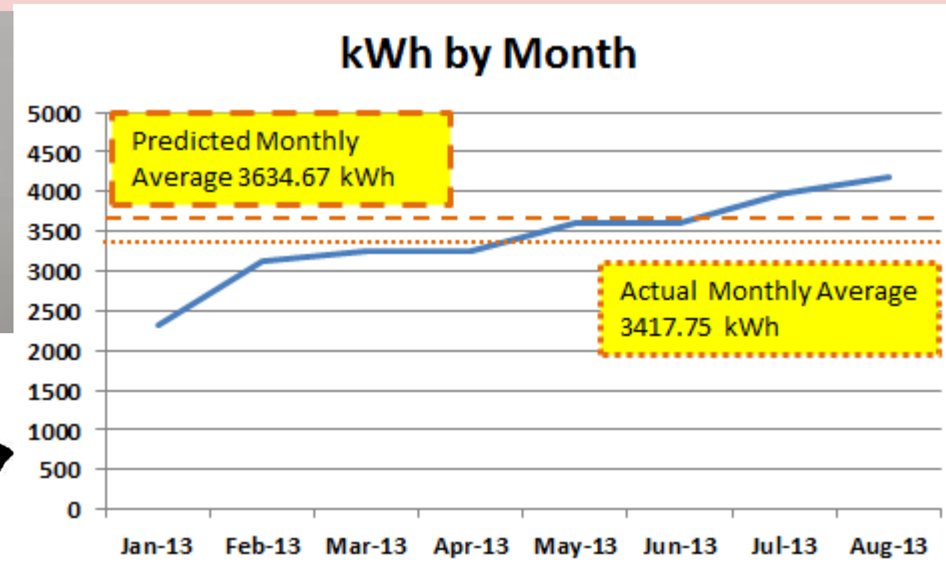


Drs. Lynch, Dickey and Singleton Dental Clinic

Energy

- Building energy use is approximately 5% - 10% below predicted
- Expected results, as 3 of the 14 operatories were left unfinished with the anticipation of adding a fourth partner in the future.
- Fairly easy building to predict the energy use
  - Existing practice and we were able to set up energy monitoring on the existing dental equipment prior to running our models.
  - Did not have to depend on the plate rated energy usage of the equipment for our models.
  - Very consistent occupant usage



Hickory Hall Dormitory

Project Summary

Location: Emory, Virginia

Client: Trustees of Emory & Henry College

The largest US building built to Passivhaus Standards

Size: 40,000 GSF ~ 29,248 TFA

Construction: 5B, sprinkled

Final air test: 0.34 $ACH_{50\ (Pressurized)}$, 0.32 $ACH_{50\ (Depressurized)}$

Modeled heat demand: 0.97 kBTU/(ft2yr) (TFA)

Modeled cooling demand: 1.70 kBTU/(ft2yr) (TFA)

Modeled Specific Primary Energy Demand: 37.4 kBTU/(ft2yr) (TFA)

Hickory Hall Dormitory

The Twin Study

Hickory Hall
Completed March 2013

Elm Hall
Completed August 2010

Hickory Hall

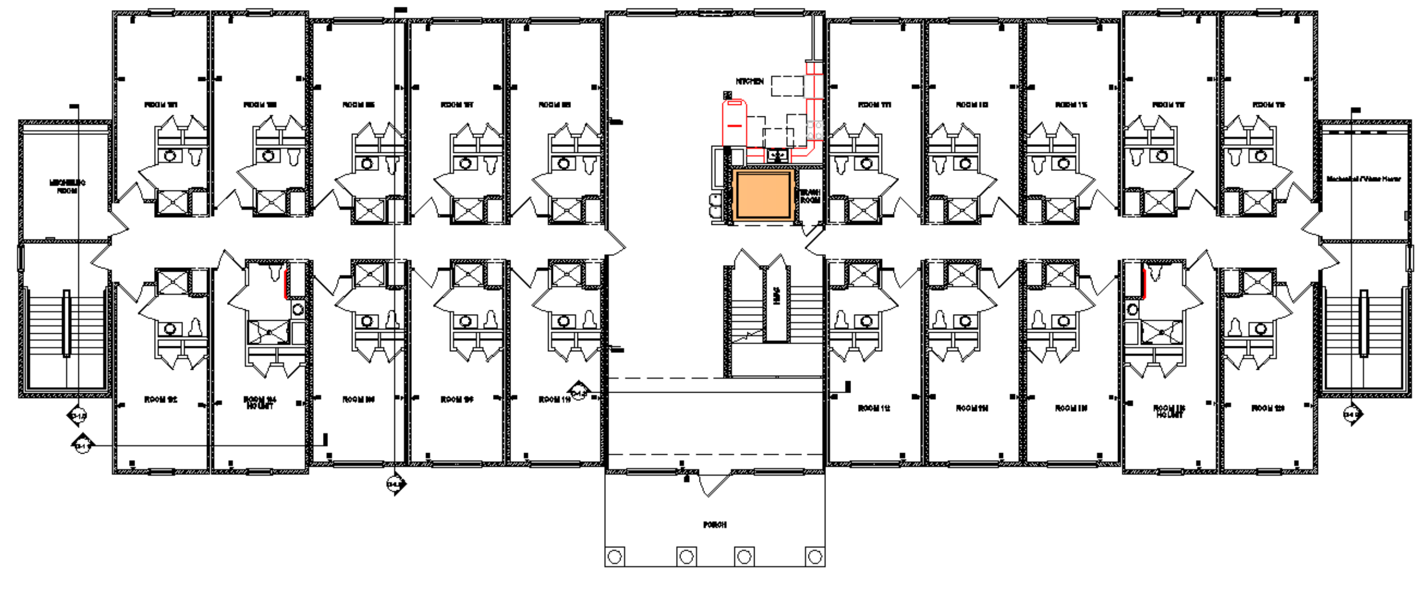
- 40,000 sq ft
- 117 beds
- Modular wooden construction (3 floors)
- Full concrete basement
- Passivhaus & LEED

Elm Hall

- 36,000 sq ft
- 116 beds
- Modular wooden construction (3 floors)
- Partial CMU basement (balance crawl space)
- LEED

Hickory Hall Dormitory

The Basics – Comparison to Elm Hall

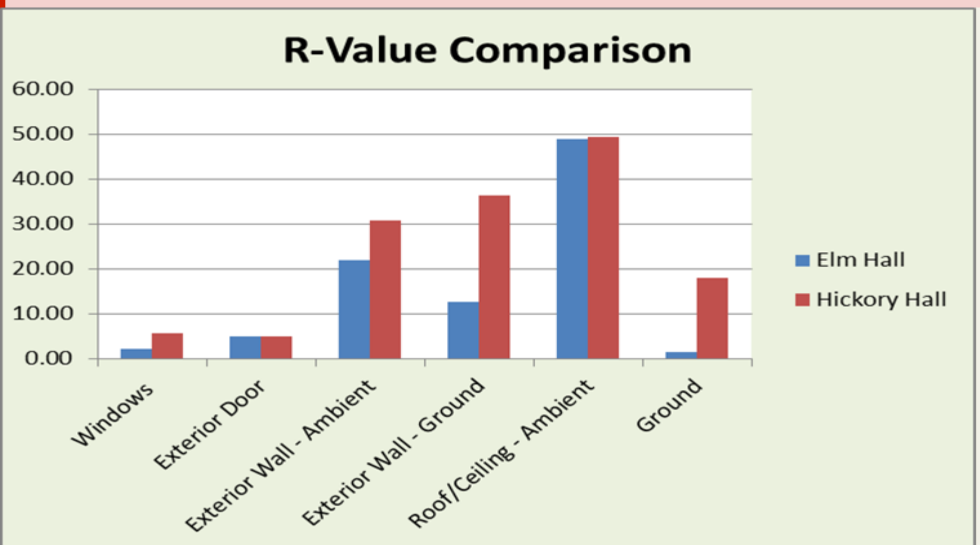


System	Elm Hall	Hickory Hall
Ventilation	Raw Outside Air	Passivhaus Compliant ERVs
HVAC System	PTAC & Ducted Heat Pumps	Integrated Hydronic Geothermal System with Fan Coil Units
Design Heating Load	570,000 BTU/Hr	50,000 BTU/Hr
Installed Heating Capacity	818,430 BTU/Hr	142,000 BTU/Hr (includes 50% DHW load)
Design Cooling Load	32 Tons	14 Tons
Installed Cooling Capacity	68 Tons	14 Tons
Elevator	Hydraulic	Traction

Hickory Hall Dormitory

The Basics – Comparison to Elm Hall

- Airtightness:
  - Hickory Hall - current test .30 ACH50
  - Elm Hall - measured 3.20 ACH75 – (Army Corp protocol)
- Slab - Added 4” termite treated EPS
- Walls:
  - Concrete – Changed to insulated precast with interior insulated wire chase (2x4)
  - Walls added 2 ½” Roxul Cavity Rock exterior insulation
- Roof – Added 2” cellulose
- Windows - Changed to PH certified windows (25% reduction in heat demand!)



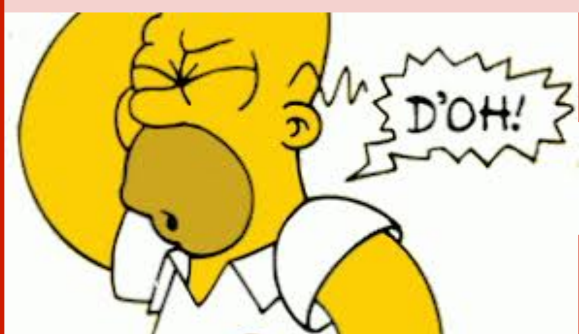
R- Value Comparison

	Elm Hall	Hickory Hall
Windows	2.28	5.66
Exterior Door	5.00	5.00
Exterior Wall - Ambient	21.97	30.70
Exterior Wall - Ground	12.56	36.45
Roof/Ceiling - Ambient	48.83	49.45
Ground	1.53	18.03

Hickory Hall Dormitory

The Good, The Bad and The Ugly ~ mostly Bad and Ugly!

- The design was dictated by the design of Elm Hall, as all buildings on the quad had to match
- The first project that we worked on that we were not the design/builder
  - Contracted to the modular company as **CPHC, LEED AP** and a **construction air tightness** consultant only
  - Restricted by the modular company in that our access to the College personnel had to be through the modular company
  - Instructed the modular company on how to commission, monitor and operate the building but were not involved in the process of commissioning the building or training the personnel
  - Unable to monitor the buildings energy usage as the LEED specified monitoring system had not yet been installed
  - Unable to remotely monitor the building automation system (BAS) as it had been installed but not networked

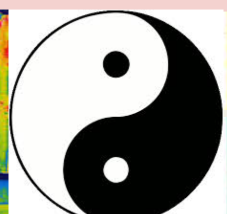




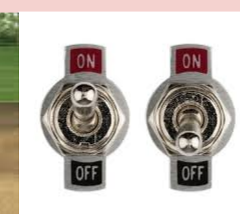
Hickory Hall Dormitory

How it is supposed to work

- Dormitory building type is an interior heat gain dominated building, meaning that the building's mechanical system load is driven primarily by the occupants and electronic loads and only secondarily by the load on the thermal envelope
- Fresh air systems in Hickory Hall are designed to operate when the building is occupied either on or off. (gathering room are demand controlled)
- The ground loop heat pump system is designed to balance the heating and cooling load into the earth
- One heat pump create hot water for the dorm, one heat pump create chilled water for cooling and dehumidification and one act as a heat or cool supplement as needed
- Holistic system design, assumes that when the building is occupied and demand on the cooling systems is increased there will be a corresponding increase in the hot water demand thus creating a roughly balanced condition in the ground exchange fluid
- Systems are designed to cool and dehumidify the building to a 78°F when the building is empty based on the minor amount of load created by the envelope heat transfer and minimal infiltration





Hickory Hall Dormitory

"The difference between fiction and reality? Fiction has to make sense."

- Dorm finished March 2013
- Written commissioning and testing and balancing reports, the third party commissioning agent and balancing technicians appeared to do have the building operating at peak efficiency when they finished in March 2013
- No communication March 2013 – August 2013 (not for lack of trying)
- Mid-August we were notified of complaints from the college regarding comfort and energy use in Hickory Hall
- After a site visit, we found that the discomfort issues were not related to Passive building
    - Related to a number of coincidental factors that combined to create the problem over the course of several months
- **There was a basic lack of understanding of how the building was designed to function by the college maintenance personnel**

Hickory Hall Dormitory

The Comedy of Errors – Not Understanding the Basics

- The dorm remained basically unoccupied from the time of completion until the students moved in mid-August
- The fresh air system was operated at full capacity during the summer while unoccupied
  - If the BAS or energy monitoring system was networked this would have been evident
- Not only was energy used unnecessarily, but the building was “loaded up” with water vapor
  - Every porous hygroscopic material, the surfaces of the pore system accumulate water molecules until a specific equilibrium moisture content corresponding to the humidity of the ambient air is reached
- The systems are designed to cool and dehumidify the building when the building is empty based on the minor amount of load created by the envelope heat transfer
  - If the system was designed for this, a simple humidistat control would have been installed on the systems to allow the building to cool and dehumidify when in a condition of no occupancy and full fresh air intake
    - It makes no sense in a low energy building to do, as the fresh air is only required when occupied

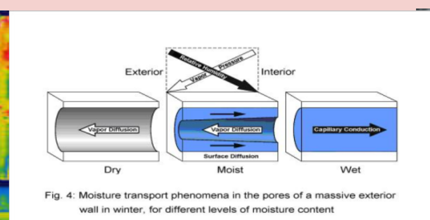
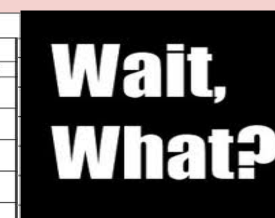


Fig. 4: Moisture transport phenomena in the pores of a massive exterior wall in winter, for different levels of moisture content



PHIUS
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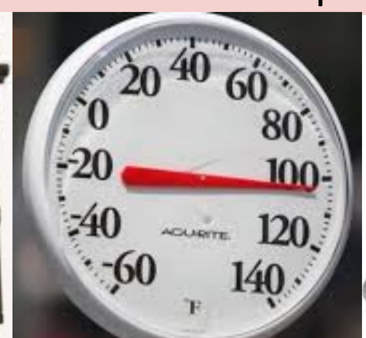
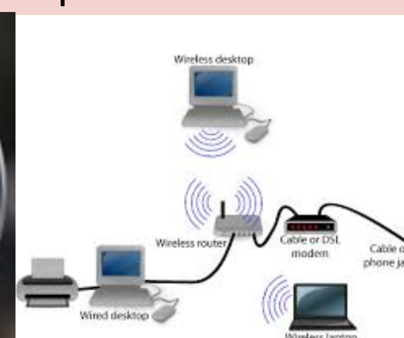
PASSIVSCIENCE
Knowledge saves power

Hickory Hall Dormitory

The Comedy of Errors – More Basic Mistakes in Operation

- In July, the modular company was alerted that the building was "hot" and found that the heat pumps breakers were off (did not contact us)
  - If the BAS or energy monitoring system was networked this would have been evident
- At August site visit:
  - Found that two of the three heat pumps were tripped off and the ground loop temperature was in excess of 100°F
  - Discovered that the main heat pump that is designated for hot water has a bad control module
  - The chilled water loop, (designed to circulate @ 50°F) was 58°F
  - Students in an effort to cool the rooms had the units set on high
  - Humidity in rooms in excess of 60% (summer design RH 50% - 60% max)
  - Maintenance staff knew "something" was not right and just turned down the thermostats, but did not check operation of heat pumps



Hickory Hall Dormitory

Energy Sleuth

- Maintenance did not get the big picture
- Fresh air left on, building unocupied, no hot water load
- The heat pump designed for chilling had been working but the faults experienced by two heat pumps were in the units designated for hot water supply, thus eliminating the ability to offset the heating of ground fluid.
- As the ground loop temperature increased, the temperature of the chilled water to the fan coil units rose from the design temperature of 50°F to almost 60°F
- As the temperature of chilled water rose, it reduced the ability of the cooling system to dehumidify. This in essence created a problem where the sensible cooling function was reduced but the latent removal (dehumidification) function was almost eliminated
- Reduced ability to dehumidify increased the moisture load on the building, by allowing the new students belongings (clothes, furniture, etc.) to also store moisture thus increasing the moisture load that needed to be removed from the building to reach a stable state

Hickory Hall Dormitory

Solution

- The two heat pump units were reset and bad control module replaced
- Temporarily reduced the outside air flow in all the rooms to from 30 CFM to code minimum 20CFM to reduce the load on the cooling and dehumidification system while the building returns to a stable state
- Set all fan coil fans to 68°F and low speed and locked out the occupant control of the thermostat fan function until the dry out function is completed
- Temporarily installed dehumidification to speed drying
- Installed temporary temperature and humidity monitoring
- Results:
  - The ground exchange fluid temperature began to decrease and the chilled loop temperature returned to the design temperature of 50°F and the fan coil units were cooling and dehumidifying as designed
  - RH decreasing

68°F

Low Speed

30 CFM

20 CFM

Hickory Hall Dormitory

What If's

- All this could have been avoided if:
  - If the energy monitoring and BAS system had been installed and networked as initially specified, the building performance could have been monitored remotely by the mechanical engineer, our firm and the college
  - If the "hot and sticky" message had been brought to our attention earlier a dry out of the building could have accomplished prior to students moving in. The fan coils could have been set to 55°F and as long as there was consistent draining of the hot water tank to keep the system in balance, the dry out procedure could have been completed prior to student move in
  - A more deliberate training of the maintenance personnel that included my team may have helped in their understanding of the holistic nature of the design

Hickory Hall Dormitory

One Last, Bigger Concern

- The students do not seem to have been educated as to their responsibility as good stewards of the energy use of this building
  - We observed rooms with no occupants:
    - TV's and computers left running
    - Thermostats that had artwork hung over them
    - Occupancy controls with tape and furniture over them that resulted in unoccupied rooms with the lights on
- Imperative that the college engage the students in an energy awareness campaign to achieve the potential performance of this building
- The initial energy readings from the idle elevator seem significantly higher than the manufacturer represents





Conclusions

"Experience is simply the name we give our mistakes." Oscar Wilde

- In institutional projects, it is imperative that ongoing user education be instituted. Unlike the dental clinic which has a core group of consistent users, the other projects all have a revolving "door" of personnel which must be educated as to the correct operations of a Passive Building. There should be public signage explaining the fact that this is a Passive Building and basic simplified instructions as to use. Users should have access to the building's O&M manual.
- In project that will be used by students, it should be specified as part of the initial consulting contract that the CPHC be allowed to engage in ongoing consultation with the students until such time that there is sufficient institutional memory of the stewardship of the building.
- I recommend remote system monitoring and data logging on all projects. It should be a requirement in institutional projects. Remote monitoring allows personnel to be alerted when equipment is malfunctioning potentially before the issues become critical. Data logging allows the building's systems and interior environment to establish baseline performance norms. These norms can be used to detect small changes in interior conditions or energy use that will give early indication that there may be something changing that needs attention. If the specified Hickory Hall monitoring system or BAS had been installed as specified, it is likely that the initial issues experienced would have been avoided.

Conclusions

"Mistakes are always forgivable, if one has the courage to admit them." Bruce Lee

- Re-commissioning of systems should be a standard part of all O&M manuals and is best done by the original commissioning team.
- As a Passive Building contractor, one should keep all aspects of construction that affect airtightness a part of one's contract.
- The Passive Building consultant should specify that in any future construction affecting the envelope they be hired for project oversight and consultation.
- Simplified mechanical controls are less expensive, more robust and easier to commission and maintain. Mechanical systems and controls should be "dumbed" down and simplified whenever possible.
- The CPHC should be involved in the review of the O&M manual of all projects and the training of the maintenance personnel.
- As a CPHC, access to the owner is critical. We have elected to make it a requirement of our contract.

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