American Concrete Institute®
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# The Art of Thermal Mass Modeling for Energy Conservation in Buildings, Part 2

ACI Spring 2012 Convention
March 18 – 21, Dallas, TX

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## Cost Effective Energy Efficient School Design

**ACI Convention**
**March 19, 2012,**

W. Mark McGinley, Ph. D., PE
FASTM

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**Overview**

- Recently completed a project investigating cost effective – energy efficient/sustainable school design, including both first cost and life cycle costs for KY.

WE WERE ASKED THE QUESTION

*"If I had a dollar to spend for energy efficiency where should I send it first?"*

*ie. "Best Bang for the Buck"*

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**Acknowledgments**

- Most of the work on this project was performed by Kevin Muldoon and Chad Riggs
- Primary funding was provided by the Kentucky Renewable Energy Consortium

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**Overview**

- Study focused on conventional systems with input from design/school community
- Used the range of climates in Kentucky – Climate Zone 4
- Develop relationships between costs and energy efficiencies to allow optimization of both- Holistic approach used.

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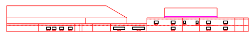
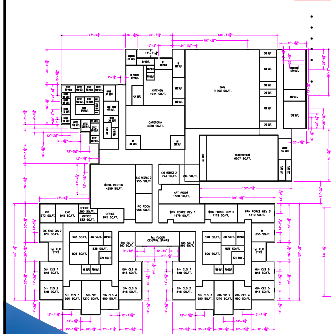
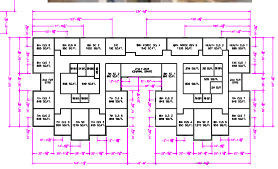
## Designed a Base Prototype Middle School –



- Base: Design met Min ASHRAE 90.1
- Most Lights T 12- 2 and 4 lamp systems
- HVAC VAV - Gas boilers and Chillers
- Typical school use schedules.
- Minimum Envelope U and R values ~ R 22 Roof, ~R 9.8 Walls
- Base EUI - ~132





Base –(www.schoolclearing house.org) ~158,000 ft$^2$    Second Story- Prototype

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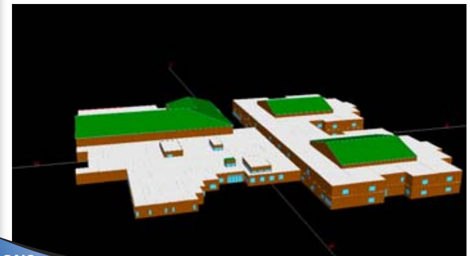
## Analyzed School Building

Analyzed prototype configuration to establish base performance using eQuest (DOE2).

5 KY cities – Corbin, Covington, Louisville, Lexington, Paducah



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## Analysis Results Collated – Base line–

| Rerun status | Energy Efficiency Measure | Construction Data | multiplier | Corbin/Williamsburg | Covington | Lexington | Lou[illegible] | |
|---|---|---|---|---|---|---|---|---|
| | | | 3.412 | kWh | kWh | kWh | kWh | |
| | | | | kW | kW | kW | kW | |
| CM # | description1 | Changes | 1 | kBtu | kBtu | kBtu | kBtu | kBtu |
| Baseline | Baseline Ewall: 9.09 BURoof: 26.3 Siding Roof: 22.22 Ceiling: 1.95 Iwall: 3.08 | Exterior walls R=9.09, layers: outside air film, 4" brick, air space, 1-1/4" polystyrene 8"CMU MW hollow, air film; Pitched Roof R-22.22, layers: outside air film, steel siding, Bldg paper felt, 3" polyiso, steel siding, inside air film Built Up Roof R-26.3, layers: outside air film, Built up roof, 3" polyiso, 5/8" plywood, metal decking Ceilings R-1.95, layers: 1/2" Acoustic tile; Interior walls R-3.75, layers: inside air film, 8"CMU MW hollow, inside air film; | Electric | 2,324,765 | 2,155,194 | 2,186,284 | 2,253,991 | 2,312,572 |
| | | | Demand | 5,630 | 5,272 | 5,36[illegible] | | ,688 |
| | | | | 11,080,212 | 12,327,792 | 12,216,[illegible] | | [illegible]16,435 |

| Rerun status | Energy Efficiency Measure | Construction Data | Louisville |
|---|---|---|---|
| | | | kWh |
| | | | kW |
| CM # | description1 | Changes | kBtu |
| Baseline | Baseline Ewall: 9.08 BURoof: 22.72 Siding Roof: 22.22 Ceiling: 1.95 Iwall: 3.08 Ground Floor: Afloor: | Exterior walls R=9.80, layers: outside air film, 4" brick, air space, 1-1/4" polystyrene 8"CMU MW hollow, air film; Roof R-22.72, layers: outside air film, steel siding, Bldg paper felt, 3" polyiso, steel siding, inside air film Ceilings R-1.95, layers: 1/2" Acoustic tile; Interior walls R-3.75, layers: inside air film, 8"CMU MW hollow, inside air film; Interior floor R=1.94, layers: inside air film, 6" HW Conc, stone 1"; Ground floor R-2.59, layers: inside air film, linoleum, 6" HW conc, inside air film Afloor R-16.67, layers: AFlr Cons Mat 1, Acoustic tile | 2,253,991 |
| | | | 5,622 |
| | | | 11,645,294 |
| | | | 132 |
| | | | 2,253,298 |
| | | | 5,620 |
| | | | 11,610,529 |
| | | | 132 / .2 % |

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## Investigated Energy Conservation Measures

Based on input from

- design community
- facility managers
- Contractors
- literature, etc.

Mature alternative energy conservation measures ECM's) (technologies) were identified and incorporated into the building.

Prototype building re-analyzed eQuest (DOE2) for Each ECM singly and in groups - 5 KY cities

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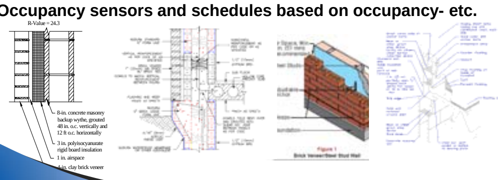
## Evaluated Select Alternatives (ECM's):

- T8 lights – HO instead of Halides in High bay areas
- More efficient Conventional HVAC systems - Boiler
- Day-lighting controls
- Setback - Fan controls
- ERV's
- VFD Motors
- Ground Source and Water Source Heat Pumps
- Enhanced building envelopes – Both light framed and mass walls, high and low U windows, High R roofs
- tighter envelopes
- Occupancy sensors and schedules based on occupancy- etc.



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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C.1 | Pitched Roof R-25.64 Built Up Roof R-29.41 | Change 3" exterior Polyisocyanurate to 3.5" exterior Polyisocyanurate | Demand | 5,628 | 5,270 | | | |
| | | | Gas | 11,057,305 | 12,280,164 | 12,171,87[illegible] | | |
| | | | C.1 EUI | 130 / .1 % | 134 / .3 % | 134 / .2 % | 132[illegible] | |
| C.2 | Pitched Roof R-29.41 Built Up Roof R-33.33 | Change 3" exterior Polyisocyanurate to 4" exterior Polyisocyanurate | Electric | 2,323,392 | 2,154,063 | 2,185,232 | 2,252,749 | |
| | | | Demand | 5,627 | 5,269 | 5,366 | 5,619 | 5,[illegible] |
| | | | Gas | 11,039,218 | 12,242,390 | 12,136,838 | 11,582,843 | 11,847,062 |
| | | | C.2 EUI | 130 / .2 % | 134 / .5 % | 134 / .4 % | 132 / .3 % | 135 / .4 % |
| C.3 | Pitched Roof R-37.04 Built Up Roof R-40.00 | Change 3" exterior Polyisocyanurate to 5" exterior Polyisocyanurate | Electric | 2,322,535 | 2,153,377 | 2,184,581 | 2,251,926 | 2,310,792 |
| | | | Demand | 5,625 | 5,267 | 5,364 | 5,618 | 5,684 |
| | | | Gas | 11,011,239 | 12,186,213 | 12,083,807 | 11,540,309 | 11,800,659 |
| | | | C.3 EUI | 129 / .4 % | 133 / .8 % | 133 / .7 % | 131 / .6 % | 134 / .6 % |
| C.4 | ICF walls R-21.74 | ICF Wall: air film, 4" brick, air space, 1.5" Polyurethane, 6" 140lb conc., 1.5" Polyurethane, 1/2" gyp board, air film | Electric | 2,324,371 | 2,154,839 | 2,163,009 | 2,253,728 | 2,312,122 |
| | | | Demand | 5,631 | 5,272 | 5,329 | 5,623 | 5,689 |
| | | | Gas | 11,045,692 | 12,151,629 | 12,052,720 | 11,546,113 | 11,798,442 |
| | | | C.4 EUI | 130 / .2 % | 133 / .9 % | 133 / 1.2 % | 131 / .5 % | 134 / .6 % |
| C.5 | CMU walls R-25 | Changed 1-1/4" Polystyrene to 3" ployiso | Electric | 2,324,081 | 2,154,614 | 2,162,782 | 2,253,297 | 2,311,822 |
| | | | Demand | 5,629 | 5,271 | 5,327 | 5,621 | 5,687 |
| | | | Gas | 11,042,519 | 12,133,630 | 12,036,631 | 11,536,908 | 11,791,807 |
| | | | C.5 EUI | 130 / .2 % | 133 / 1.0 % | 133 / 1.3 % | 131 / .6 % | 134 / .6 % |
| C.6 | CMU walls R-18.18 | Changed 1-1/4" Polystyrene to 2" ployiso | Electric | 2,324,223 | 2,154,749 | 2,185,776 | 2,253,456 | 2,311,991 |
| | | | Demand | 5,629 | 5,271 | 5,367 | 5,621 | 5,687 |
| | | | Gas | 11,050,622 | 12,177,489 | 12,081,000 | 11,560,328 | 11,819,560 |
| | | | C.6 EUI | 130 / .2 % | 133 / .8 % | 133 / .7 % | 131 / .4 % | 135 / .5 % |
| C.7 | CMU walls R-13.33 | Changed 1-1/4" Polystyrene to 1 1/2" polyurethane | Electric | 2,324,423 | 2,154,918 | 2,185,999 | 2,253,659 | 2,312,189 |
| | | | Demand | 5,629 | 5,271 | 5,368 | 5,621 | 5,688 |
| | | | Gas | 11,061,140 | 12,233,706 | 12,131,544 | 11,590,998 | 11,855,189 |
| | | | C.7 EUI | 130 / .1 % | 134 / .5 % | 134 / .4 % | 132 / .3 % | 135 / .3 % |
| C.8 | Steel Stud Walls R-34.5 | Steel wall stud layers: air film, 4" face brick, air space, 3.5" polyiso, 2x6 steel wall 16 O.C. R-19 batt insul, gypsum board air film | Electric | 2,324,466 | 2,154,917 | 2,163,217 | 2,253,852 | 2,312,212 |
| | | | Demand | 5,631 | 5,272 | 5,329 | 5,623 | 5,689 |
| | | | Gas | 11,040,827 | 12,117,113 | 12,021,283 | 11,529,392 | 11,781,746 |
| | | | C.8 EUI | 130 / .2 % | 133 / 1.1 % | 133 / 1.4 % | 131 / .6 % | 134 / .7 % |

Ran eQuest on each in Building Config. – 5 Ky [illegible]ties

| | |
|---|---|
| ICF walls R-21.74 | 2,253,728 |
| | 5,623 |
| | 11,546,113 |
| | 131 / .5 % |
| CMU walls R-25 | 2,253,297 |
| | 5,621 |
| | 11,536,908 |
| | 131 / .6 % |

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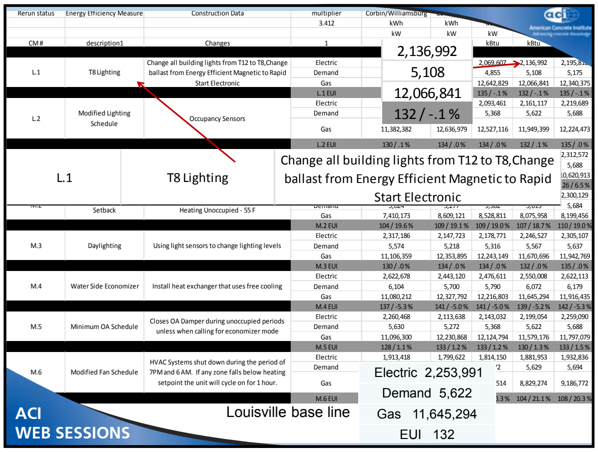


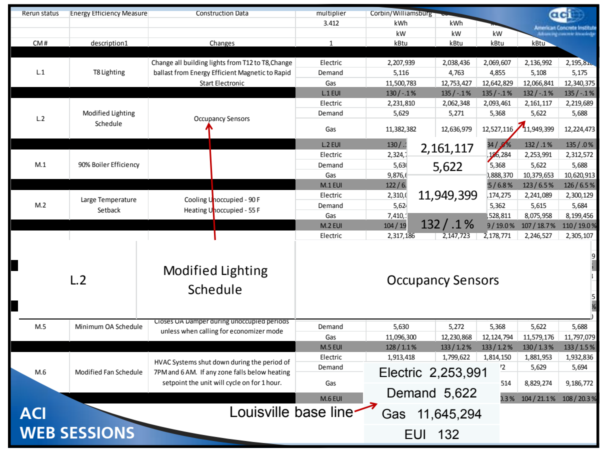


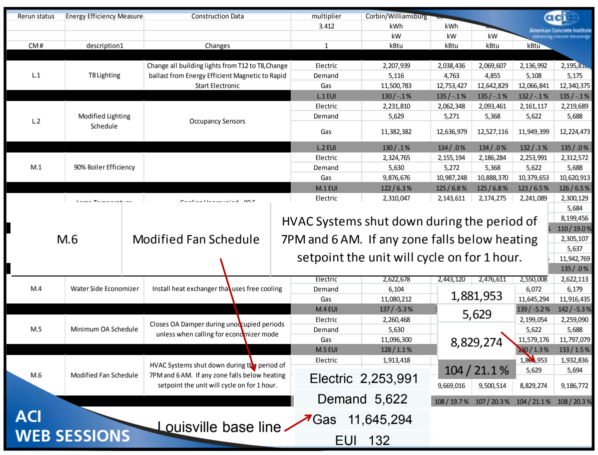


## Select Findings on Energy Savings:

- T8 reduces elect. energy ↓6% but heating ↑3% - EUI almost unchanged –Energy Cost savings ~3%.
- Envelope improvements have generally less than 1% change in EUI.
- Increased boiler efficiency to 90% can save about 9%.
- ERV systems can actually increase overall energy used in certain conditions.

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## Select Findings on Energy Savings:

- Controls have significant effects- 19- 25%
  - Set backs.
  - Modified fan schedule (periodic ventilation.
  - VAV- minimum air flow reduction (close – unoccupied)
- Can get near ↓ 56% EUI -using conventional systems
- Geothermal ↓ 80% EUI

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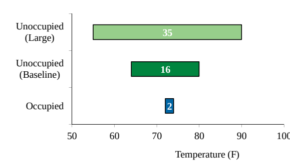
## Controls

- Simple controls can have significant effects
  - Base set backs 64°F and 80°F reduces EUI ~30+%




  - Set-backs 55°F & 90°F reduces EUI another 19%
  - Can use programmable thermostats or DDC of all thermostats – be careful of IAC and Mold

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## Controls

VAV- minimum air flow ~ ↓ 25% reduction in EUI

Allows the damper controlling the minimum air flow in a VAV box to fully close during unoccupied periods if the room temperature is satisfied.

May need modification of VAV boxes in conventional construction– occupancy sensors – DDC system.



## Controls

Modified fan schedule (periodic ventilation) ~↓21% EUI

The air handler units are shut down during the unoccupied periods (7 pm – 6 pm). If any zone falls below the heating set point the unit will cycle on for 1 hour.

For periodic ventilation outside of occupancy periods- energy management/control system of some sort is needed (DDC)

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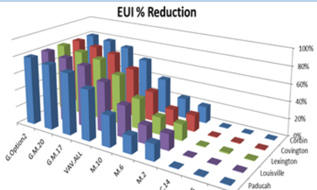


| ECM | Corbi | Covingt | Lexingt | Louisvil | Paduc |
|---|---|---|---|---|---|
| C.3 | 0.4% | 0.8% | 0.7% | 0.6% | 0.6% |
| C.5 | 0.2% | 1.0% | 1.3% | 0.6% | 0.6% |
| C.14 | 0.6% | 0.9% | 0.8% | 0.7% | 0.8% |
| M.2 | 19.6% | 19.1% | 19.0% | 18.7% | 19.0% |
| M.6 | 23.4% | 19.7% | 20.3% | 21.1% | 20.3% |
| M.10 | 41.7% | 35.1% | 35.7% | 37.3% | 36.1% |
| VAV.ALL | 61.0% | 57.6% | 58.1% | 58.5% | 58.5% |
| G.M.17 | 72.6% | 71.6% | 72.1% | 71.9% | 71.6% |
| G.M.20 | 77.2% | 75.9% | 76.3% | 76.2% | 75.9% |
| G.Option2 | 79.9% | 79.7% | 80.1% | 79.7% | 79.5% |

| | |
|---|---|
| C.3 | Change 3" exterior Polyisocyanurate to 5" exterior Polyisocyanurate (Roof) |
| C.14 | Air barrier – 0 .2 Air changes per hour |
| C.5 | Change 1-1/4" Polystyrene to 3" ployisocyanurate (CMU Walls) |
| M.2 | Large Temperature Setbacks |
| M.6 | Modified Fan Schedule – Fans to shut down during unoccupied hours until a space drops below the setpoint temperature. |
| M.10 | VAV Box Minimum Air Flow Schedule – Dampers on the VAV boxes to close if the space temperature setpoint is satisfied. |
| VAV.ALL | Best ECMs for the baseline building modeled as one ECM. Most efficient building design for the VAV system. |
| G.M.17 | Replace the VAV HVAC System with a Geothermal Heat Pump System |
| G.M.20 | Modified Fan Schedule – Fans to shut down during unoccupied hours until a space drops below the setpoint temperature. |
| G.Option2 | Best ECMs for the baseline building modeled as one ECM. Most efficient building design for the geothermal system. |

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## Economic Analysis:

- Determined the cost of the electricity and gas using the LG&E/KU commercial utility rate structure for each analysis
- Estimated cost of Building $17,540,000 – about $111/ft$^2$
- Conducted quantity takeoff on systems that were changed and developed incremental change in capital costs using input from RsMeans – Cert. Construct. Estimator, input from contractors and Energy Enrgs. – For each ECM

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## Economic Analysis:

A. Determined simple payback for each ECM – Capital cost increase / yearly energy savings.

B. Using 4.5 % interest rate and 1.5% estimated increase in energy determined year self funding – for longer periods – 50 to 75 year design lives – included estimated maintenance costs where different from base conditions.

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| ECM | Description | Cost | Savings | SPB (Years) | SF In Year |
|---|---|---|---|---|---|
| A.45 | Varying the Orientation - No Cost | $ - | $ 98.72 | 0.0 | NO Cost ECM |
| A.90 | Varying the Orientation - No Cost | $ - | $ 5.69 | 0.0 | NO Cost ECM |
| A.135 | Varying the Orientation - No Cost | $ - | $ 44.71 | 0.0 | NO Cost ECM |
| A.180 | Varying the Orientation - No Cost | $ - | $ (107.78) | 0.0 | NO IMPROVEMENT |
| A.225 | Varying the Orientation - No Cost | $ - | $ (152.90) | 0.0 | NO IMPROVEMENT |
| A.270 | Varying the Orientation - No Cost | $ - | $ (156.24) | 0.0 | NO IMPROVEMENT |
| A.315 | Varying the Orientation - No Cost | $ - | $ 26.39 | 0.0 | NO Cost ECM |
| C.1 | Change 3" exterior Polyisocyanurate to 3.5" exterior | $ 84,274.71 | $ 330.02 | 255.4 | - |
| C.2 | Change 3" exterior Polyisocyanurate to 4" exterior | $ 94,678.99 | $ 592.28 | 159.9 | - |
| C.3 | Change 3" exterior Polyisocyanurate to 5" exterior | $ 187,277.13 | $ 993.39 | 188.5 | - |
| C.4 | ICF Wall: air film, 4" brick, air space, 1.5" Polyurethane, 6" | $ 252,986.52 | $ 755.20 | 335.0 | - |
| C.5 | Changed 1-1/4" Polystyrene to 3" ployiso | $ 66,031.59 | $ 877.44 | 75.3 | - |
| C.6 | Changed 1-1/4" Polystyrene to 2" ployiso | $ 8,923.19 | $ 686.98 | 13.0 | 17 |
| C.7 | Changed 1-1/4" Polystyrene to 1 1/2" polyurethane | $ - | $ 438.10 | 0.0 | NO Cost ECM |
| C.8 | Steel wall stud layers: air film, 4" face brick, air space, 3.5" polyiso, 2x6 steel wall 16 O.C. R-19 batt insul, gypsum board air film | $ (255,556.89) | $ 868.51 | -294.2 | NO Cost ECM |
| C.9 | Steel wall stud layers: air film, 4" face brick, air space, 2" polyiso, 2x6 steel wall 16 O.C. R-19 batt insul, gypsum board air film | $ (309,542.18) | $ 739.09 | -418.8 | NO Cost ECM |
| C.10 | Steel wall stud layers: air film, 4" face brick, air space, 1.5" Polystyrene, 2x6 steel wall 16 O.C. R-19 batt insul, 1/2" GYP board, air film | $ (326,942.39) | $ 495.87 | -659.3 | NO Cost ECM |
| C.11 | Steel wall stud layers: air film, 4" face brick, air space, 3" Polystyrene, 2x6 steel wall 16 O.C. No batt insul, 1/2" GYP board, air film | $ (313,557.61) | $ 500.51 | -626.5 | NO Cost ECM |
| C.12 | Light Vapor Barrior | $ - | $ (180.49) | 0.0 | NO IMPROVEMENT |
| C.13 | Medium Vapor Barrior | $ 42,385.14 | $ 725.60 | 58.4 | - |
| C.14 | Heavy Vapor Barrier | $ 84,770.28 | $ 1,573.12 | 53.9 | - |
| C.15 | Wall: air film, 4" brick, air space, 1.5" Polyurethane, 6" 140lb conc., 1.5" Polyurethane, 1/2" gyp board, air film; for roof: Changed 3" exterior Polyisocyanurate to 5" exterior Polyisocyanurate | $ 440,263.65 | $ 1,553.44 | 283.4 | - |

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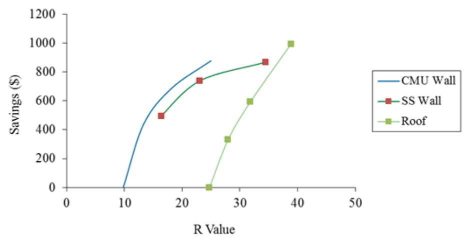
## Effect of Envelope R increases on Yearly Savings






| ECM | Description | Cost | Savings | SPB (Years) | SF In Year |
|---|---|---|---|---|---|
| M.1 | Condensing Boiler | $ 2,264.60 | $ 9,492.31 | 0.2 | [illegible] |
| M.2 | Large Temperature Setbacks | $ - | $ 27,813.53 | 0.0 | NO Cost ECM |
| M.3 | Daylighting | $ 17,113.27 | $ 1,021.24 | 16.8 | 24 |
| M.4 | Water Side Economizer | $ - | $ (27,538.22) | 0.0 | NO IMPROVEMENT |
| M.5 | Minimum OA Schedule | $ 169,990.00 | $ 4,605.77 | 36.9 | - |
| M.6 | Modified Fan Schedule | $ 169,990.00 | $ 48,868.29 | 3.5 | 4 |
| M.7 | VFD on Cooling Tower Fan | $ 11,869.00 | $ 7,123.72 | 1.7 | 2 |
| M.8 | 3-Way to 2-Way Valves and VFD on Pumps Combine with CHW & HW Reset Temps | $ 15,886.20 | $ 28,698.77 | 0.6 | 1 |
| M.9 | ERV on AHUs | $ - | $ (43,919.85) | 0.0 | NO IMPROVEMENT |
| M.10 | VAV Box Minimum Air Flow Schedule | $ 169,990.00 | $ 74,569.17 | 2.3 | 3 |

- Note the lighting ECM's saves some electrical energy but increase heating energy in winter
- More efficient lights and occupancy sensors on lights have lower payback periods for new schools, although aggressive sensor driven daylighting may take a while.

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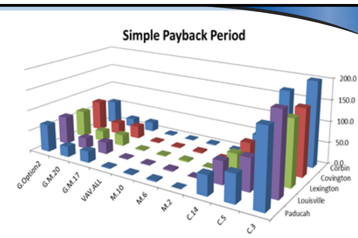


| Simple Payback Period (Years) | | | | | |
|---|---|---|---|---|---|
| ECM | Corbin | Covington | Lexington | Louisville | Paducah |
| C.3 | 218.8 | 156.3 | 151.8 | 188.5 | 174.0 |
| C.14 | 804.5 | 195.3 | 69.9 | 335.0 | 272.2 |
| C.5 | 168.3 | 45.5 | 17.5 | 75.3 | 64.5 |
| M.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| M.6 | 2.8 | 3.8 | 3.4 | 3.5 | 3.4 |
| M.10 | 1.8 | 2.5 | 2.3 | 2.3 | 2.3 |
| VAV.ALL | 2.2 | 2.8 | 2.5 | 2.6 | 2.5 |
| G.M.17 | 23.2 | 31.0 | 27.0 | 28.1 | 27.3 |
| G.M.20 | 21.1 | 28.2 | 24.7 | 25.6 | 25.0 |
| G.Option2 | 57.2 | 73.7 | 64.9 | 67.7 | 66.2 |

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## We looked at typical Kentucky performance:

- We then asked the question - How will the school perform in other climates?
- Ran the base school and critical ECM's in Dallas, Miami, and Madison.
- The following results were obtained

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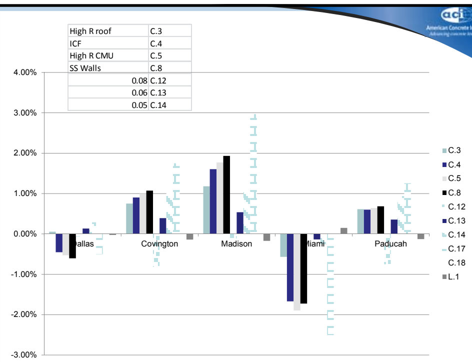


- Envelope improvements helped more in Madison and hurt in Dallas and Miami

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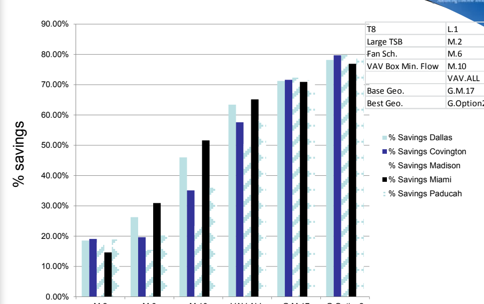


- Mechanical Systems and Controls great effects

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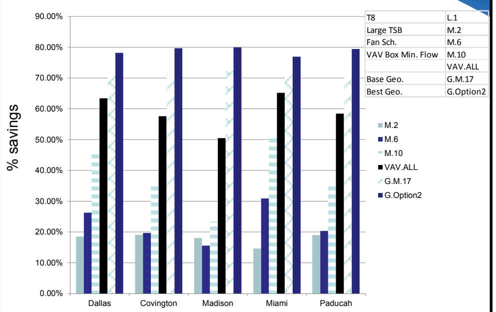


- Mechanical Systems and Controls great effects



## Conclusions

- Over 50% can be saved in typical school configurations using conventional HVAC systems and aggressive control strategies. These improvements generally have aggregate paybacks of less than 3 years.
- Use of ground source heat pumps greatly increase the energy saved but have much higher payback periods, usually in excess of 20 years.



## Conclusions

- Envelope improvements in typical school configurations have a minimal impact on energy used in most Kentucky climates and generally have long payback periods (in excess of 100 years)
- Many of the findings of this investigation can be applied to school retrofits – controls – set backs occupancy controlled ventilation, fans , lights.
- Most of these findings appear applicable to most climates.



# THANK YOU !

# QUESTIONS?