Comparative Analysis of the Life Cycle Costs of Geothermal Heat Pumps and Three Conventional HVAC Systems for an Elementary School in Lincoln, Nebraska

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Project Background

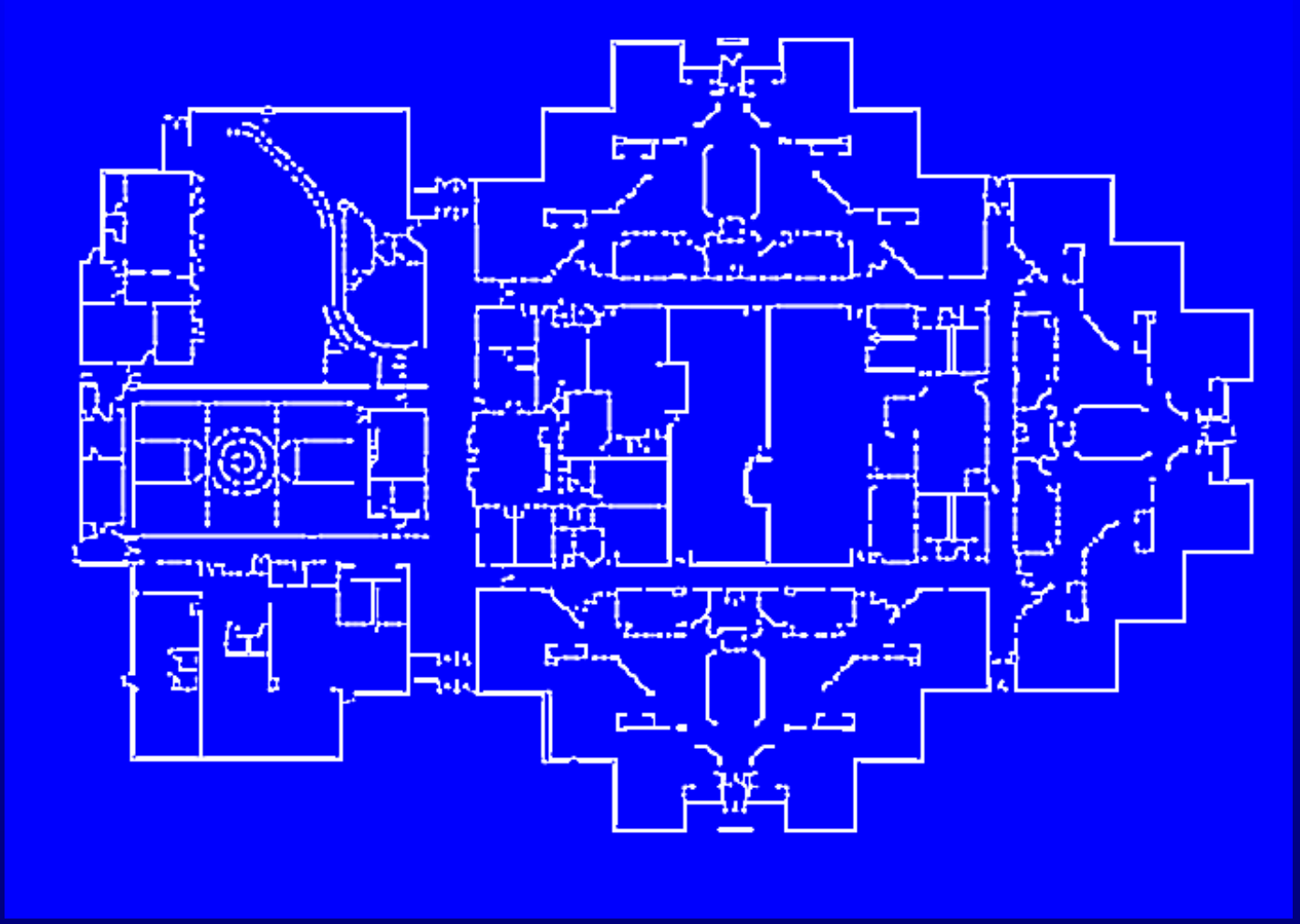
- Four new, identical 69,000 ft^2 elementary schools were built in 1995 in Lincoln, Nebraska
- The decision to use geothermal heat pumps based on life cycle cost comparison using another school in the district
- Pre-construction estimates contain a great deal of uncertainty. Would actual performance would bear out the initial assumptions, and confirm the technology selection?

Objectives of the study

- Use site-monitored energy use data to develop a calibrated simulation model of one of the schools
- Implement GHPs and three alternative HVAC systems to determine annual energy and water use
- Use maintenance data from the school district to estimate annual maintenance cost for each alternative
- Develop estimates of installed costs for each alternative
- Determine life cycle cost of each alternative

Maxey Elementary School

Floorplan of the School



GHP System Design

- Total of 54 GHP units
- 200 tons total nominal cooling capacity
- Peak block loads: 150 tons / 940,000 Btu/hr
- Two 15-ton units provide pre-conditioned OA (ASHRAE 16-1989) with HW coil for cold days
- Gymnasium, cafeteria also introduce OA (40-45%)
- Remaining units (1.4 - 4.5 tons) draw return air from corridors, and supply classrooms, offices, etc.
- Unit heaters in corridors with HW coils
- Four 333,000 BTU/hr gas-fired boilers; gas DHW

Borefield Details

- 120 vertical loops using 1 in. HDPE pipe
- 12 by 10 pattern located under soccer field
- 20 ft. center-to-center spacing between bores
- Bore depth 240 feet (~140 ft/ton)
- Backfilled with fine gravel, bentonite plug top 10 ft.
- Designed for year-round occupation
- 22% (by volume) propylene glycol solution
- Variable speed pump

Extensive 10-min Interval Data Were Available from EMS/Utility

- Total building electrical use
- HVAC electrical use
- Compressor, reversing valve, and fan status for each of the heat pumps
- Flow rate, supply/return temperatures for borefield
- Zone temperatures, outdoor air temperatures
- Monthly natural gas use
- All in varying stages of completeness

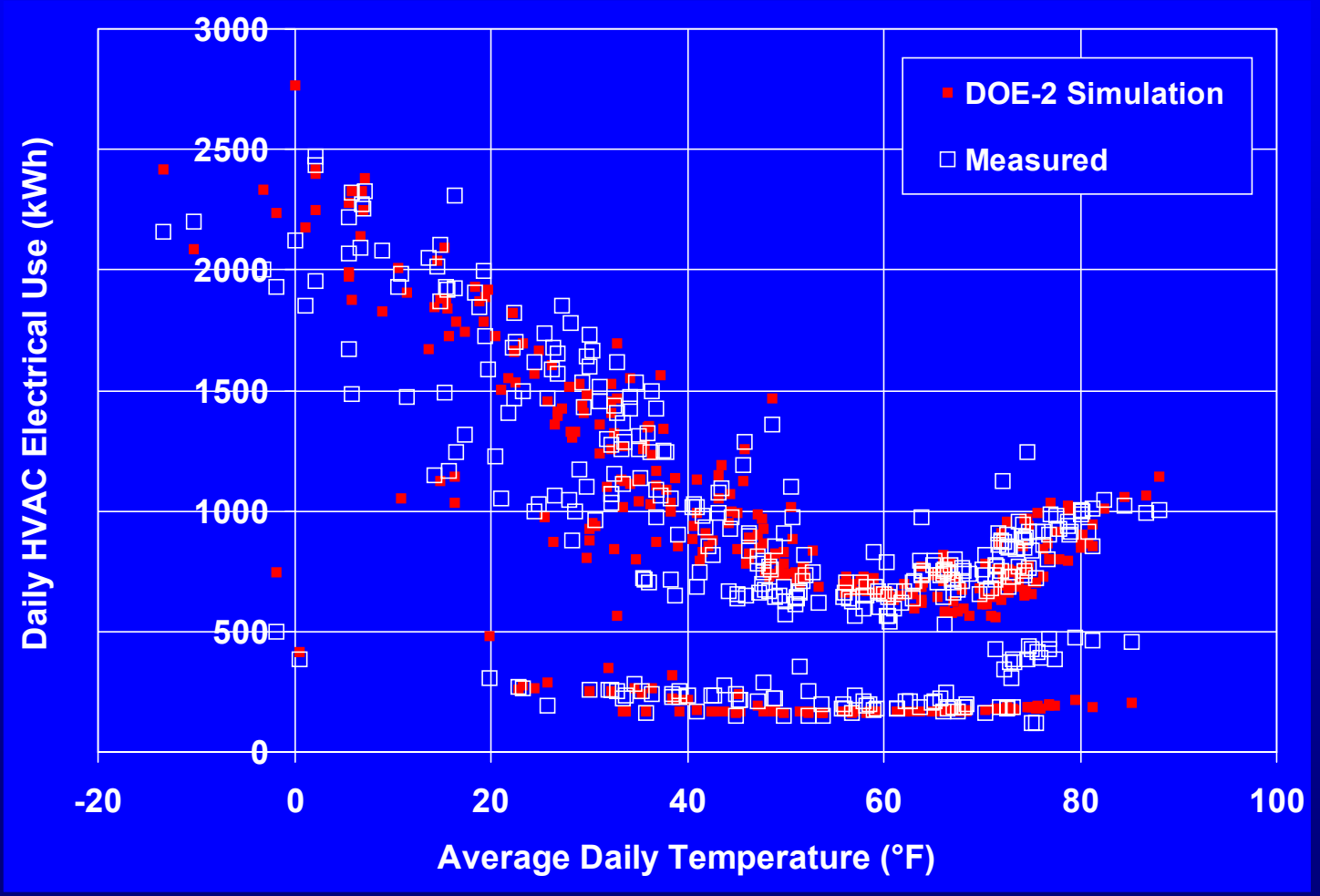
Maintenance Data Available

- Lincoln school district provided access to complete maintenance database (preventive and unplanned)
- 18 schools selected (all with $\geq$ 70% cooled floorspace)
- 4 categories of heating/cooling plants
  - 4 Geothermal heat pumps (GHP)
  - 2 Air-cooled chiller/gas-fired HW boiler (ACC/GHWB)
  - 12 Water-cooled chiller/gas-fired HW boiler (WCC/GHWB) of which 9 were VAV
- Ages of cooling plants: 3 to 32 years
- Ages of heating plants: 3 to 70 years
- Analysis of this data presented in two ASHRAE papers

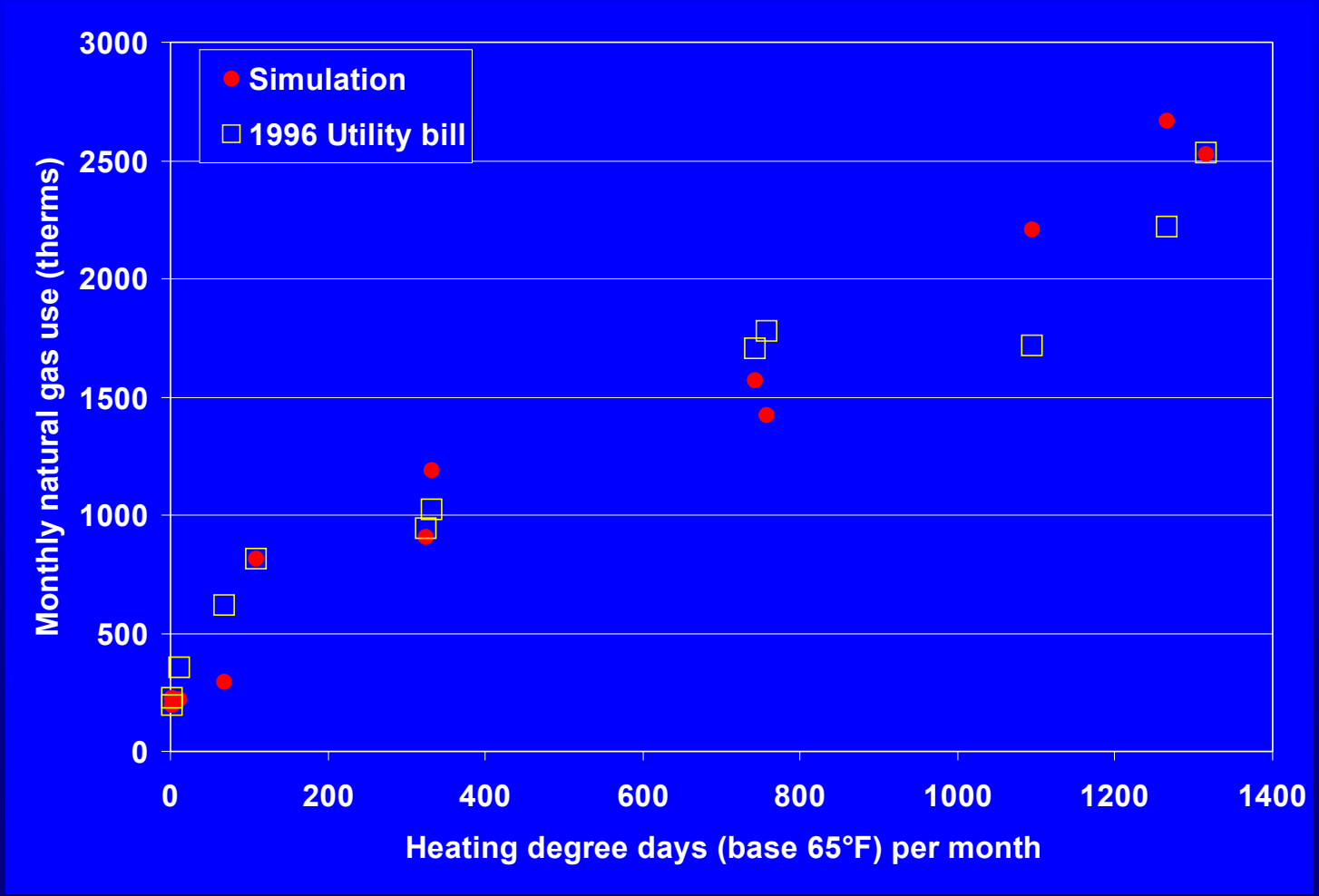
Study is based on a calibrated simulation

- Developed simulation model beginning with as-built construction plans
- Estimated internal loads from occupancy, fixture counts
- Developed occupancy schedule based on school calendar
- “Tweaked” the model (adjusting infiltration) until performance matched site-monitored data (daily electrical use, monthly gas use)

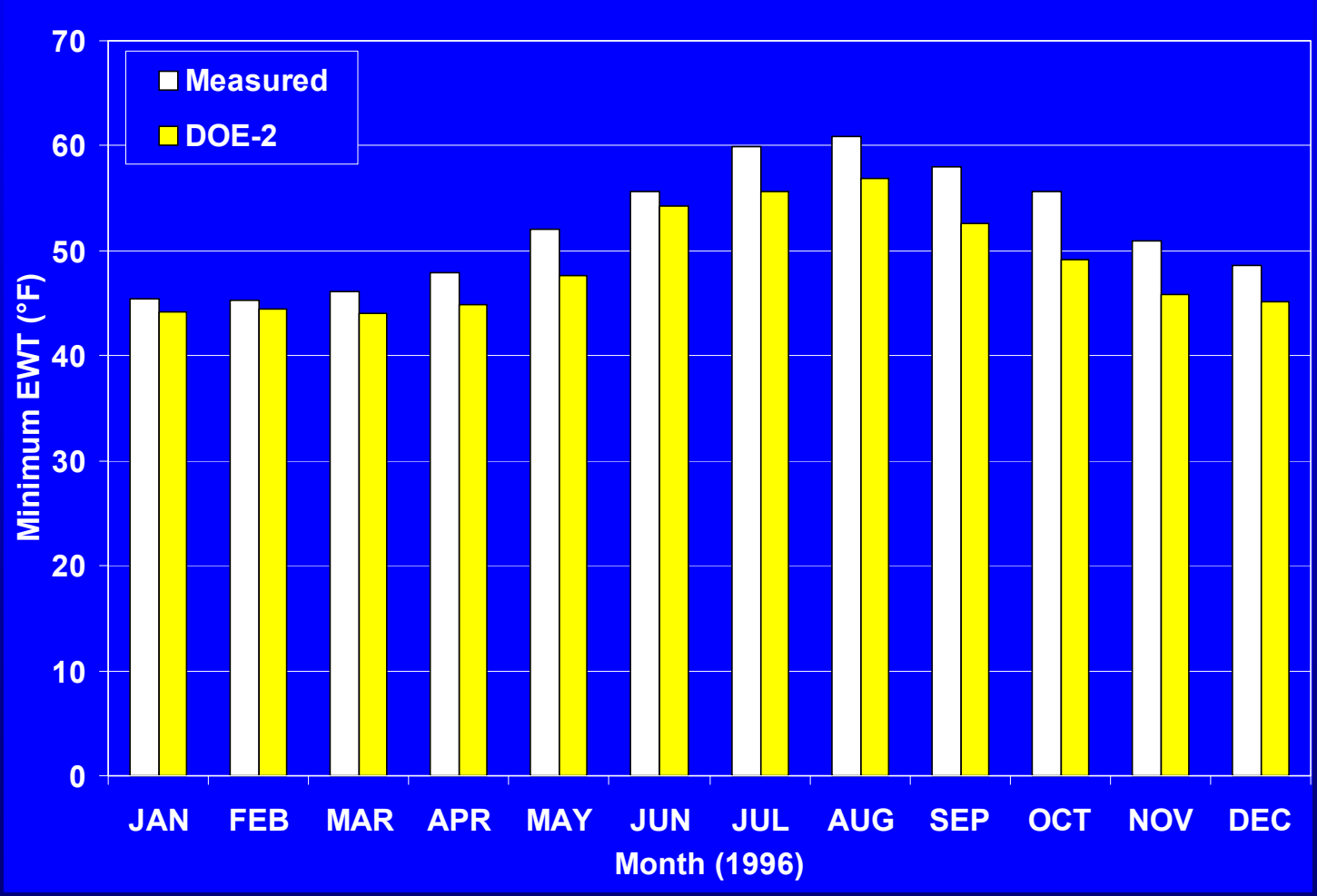
Simulated and monitored daily HVAC electrical use



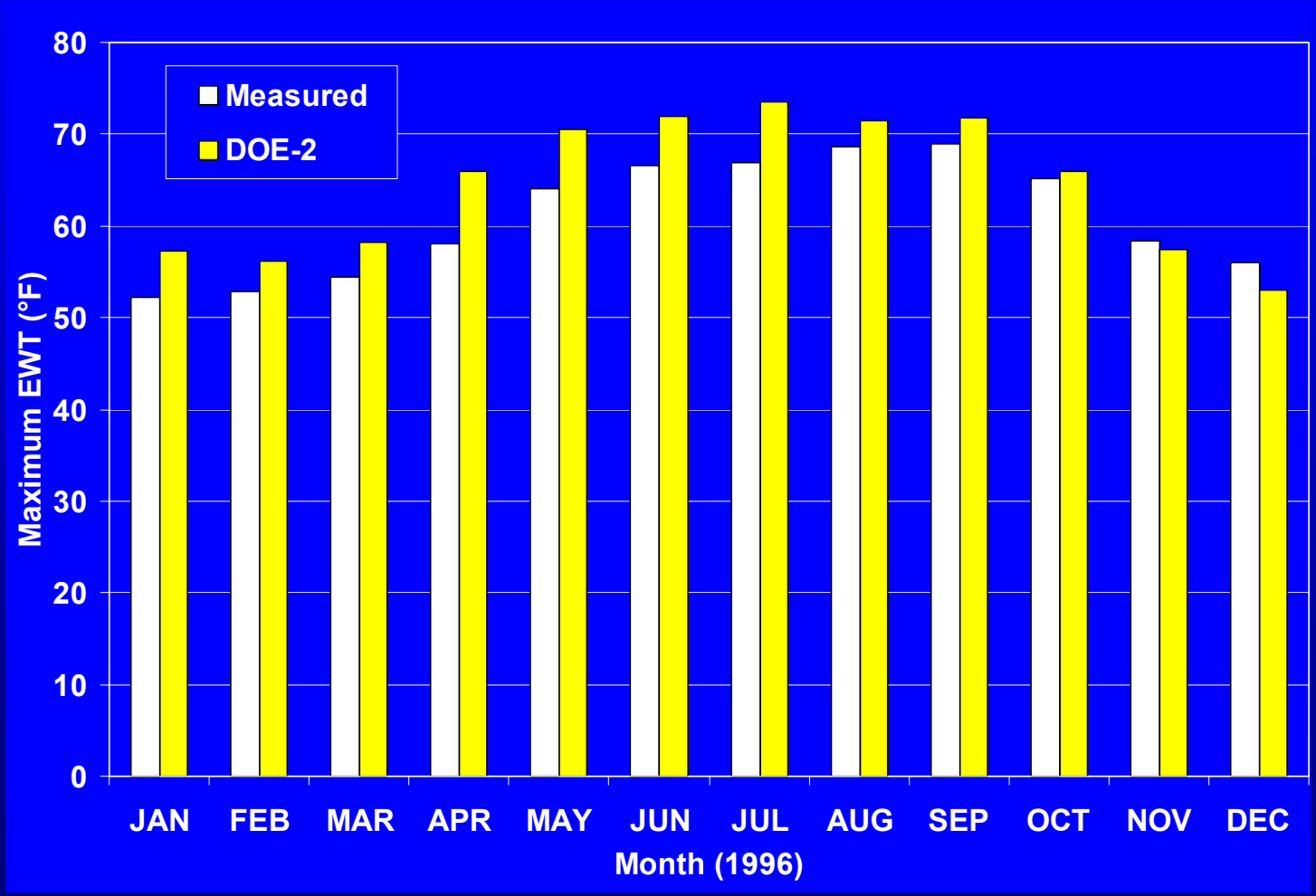
Simulated and monitored monthly total natural gas use



Predicted and Monitored Minimum Monthly EWT



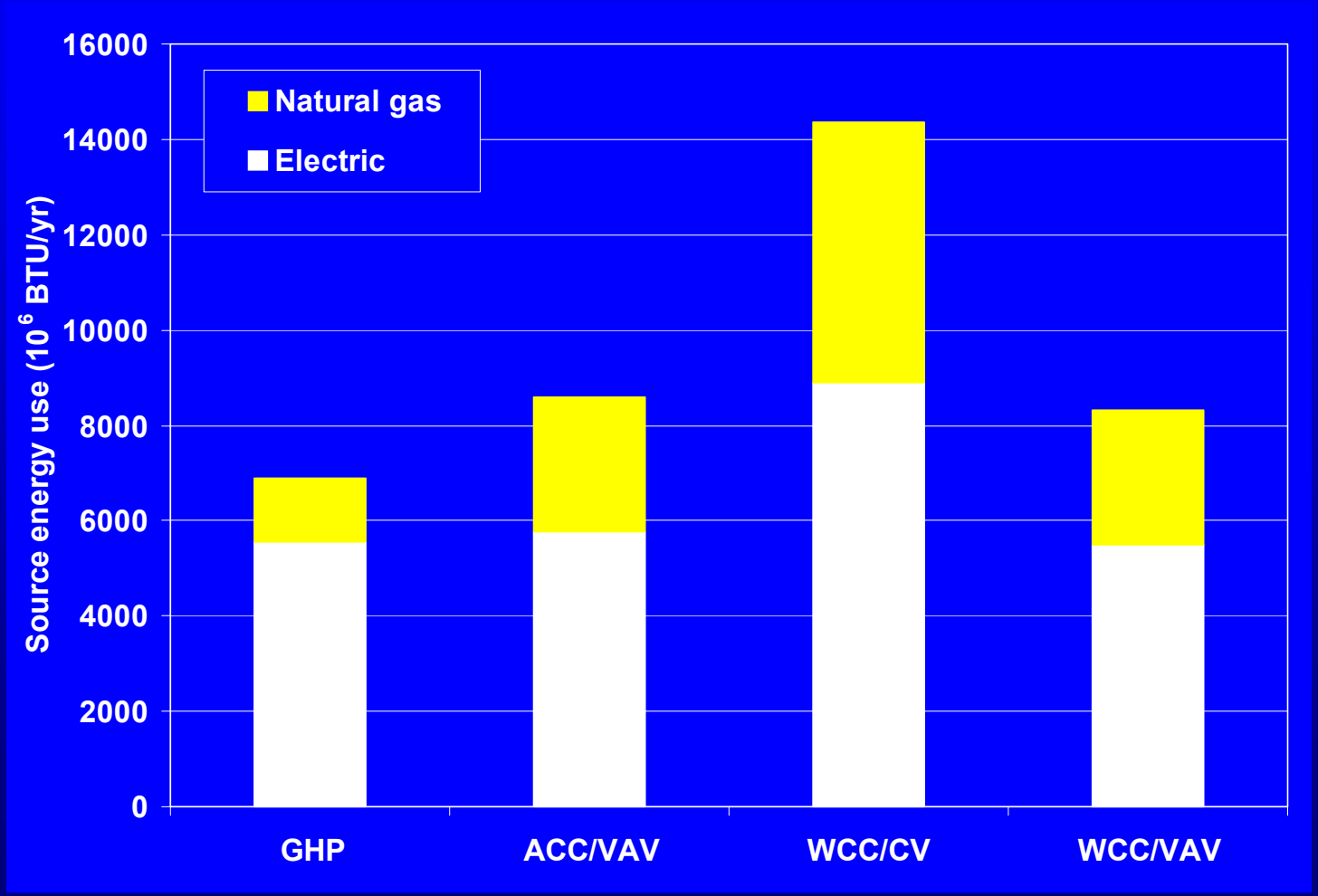
Predicted and Monitored Maximum Monthly EWT



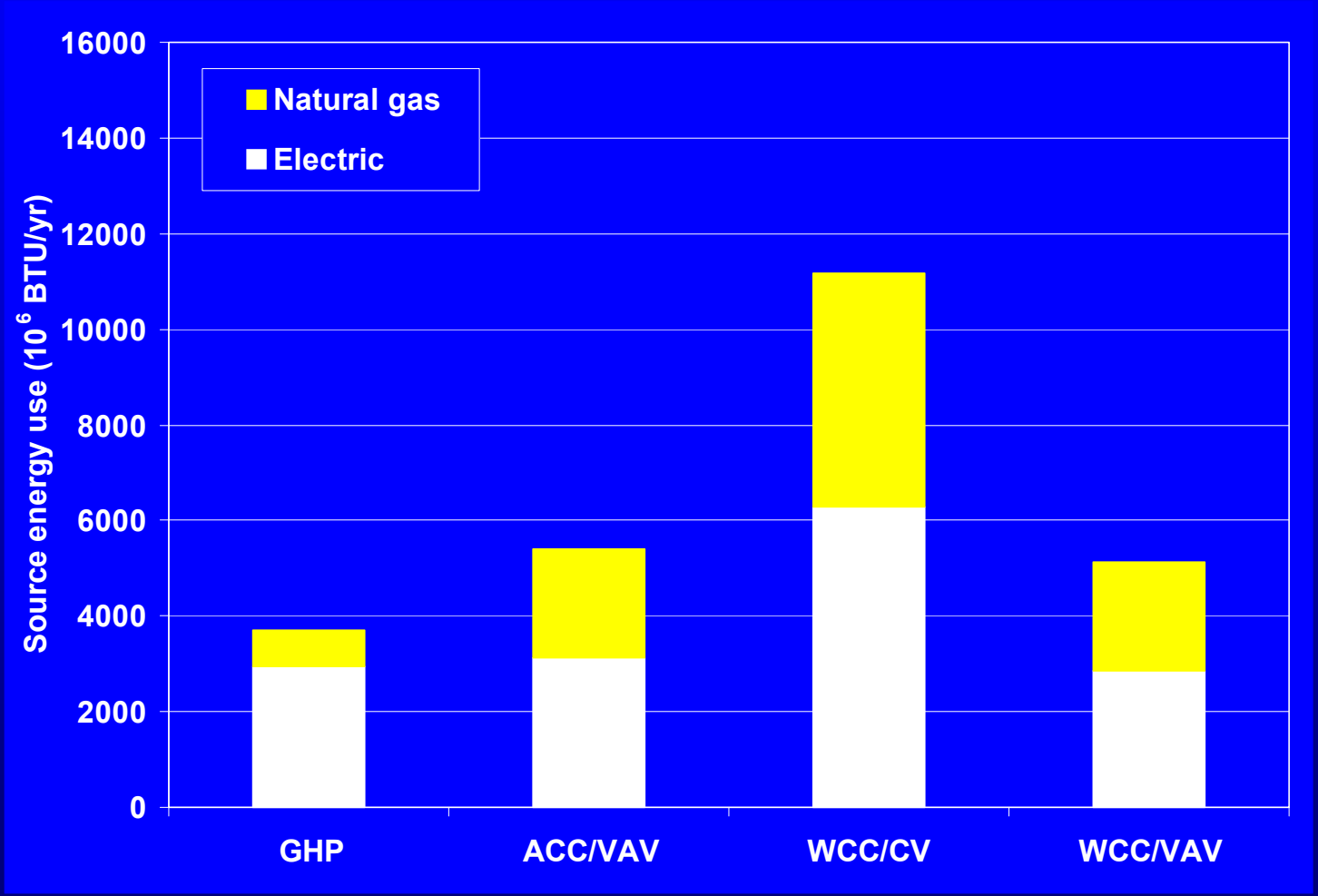
Alternative systems were dictated by available maintenance data

- Air-cooled chiller, VAV air handling system, gas-fired hot water boiler
- Water-cooled chiller, VAV air handling system, gas-fired hot water boiler
- Water-cooled chiller, constant volume air handling system, gas-fired hot water boiler (unlikely to be installed in a new school)

Comparison of total energy use



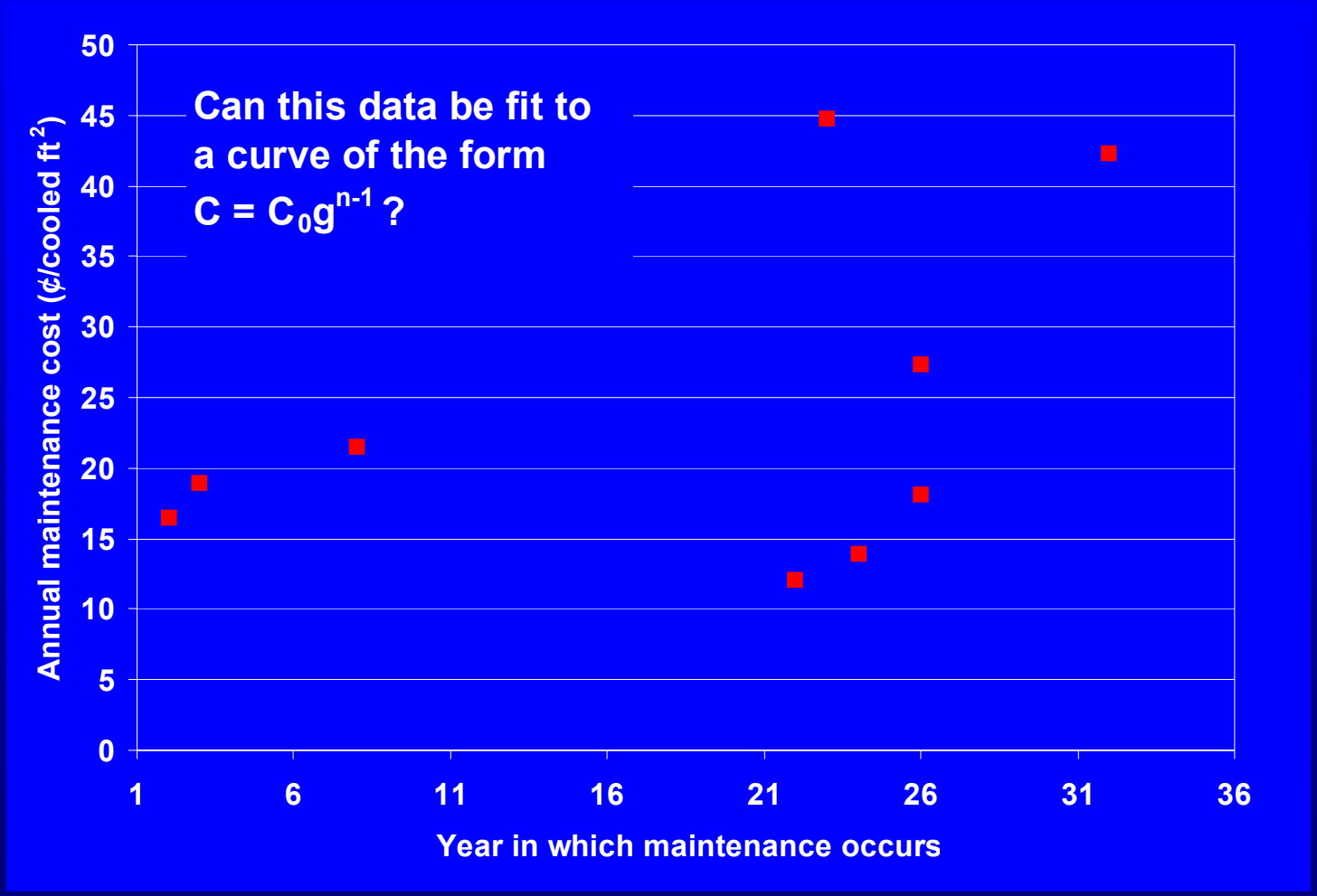
Comparison of HVAC energy use



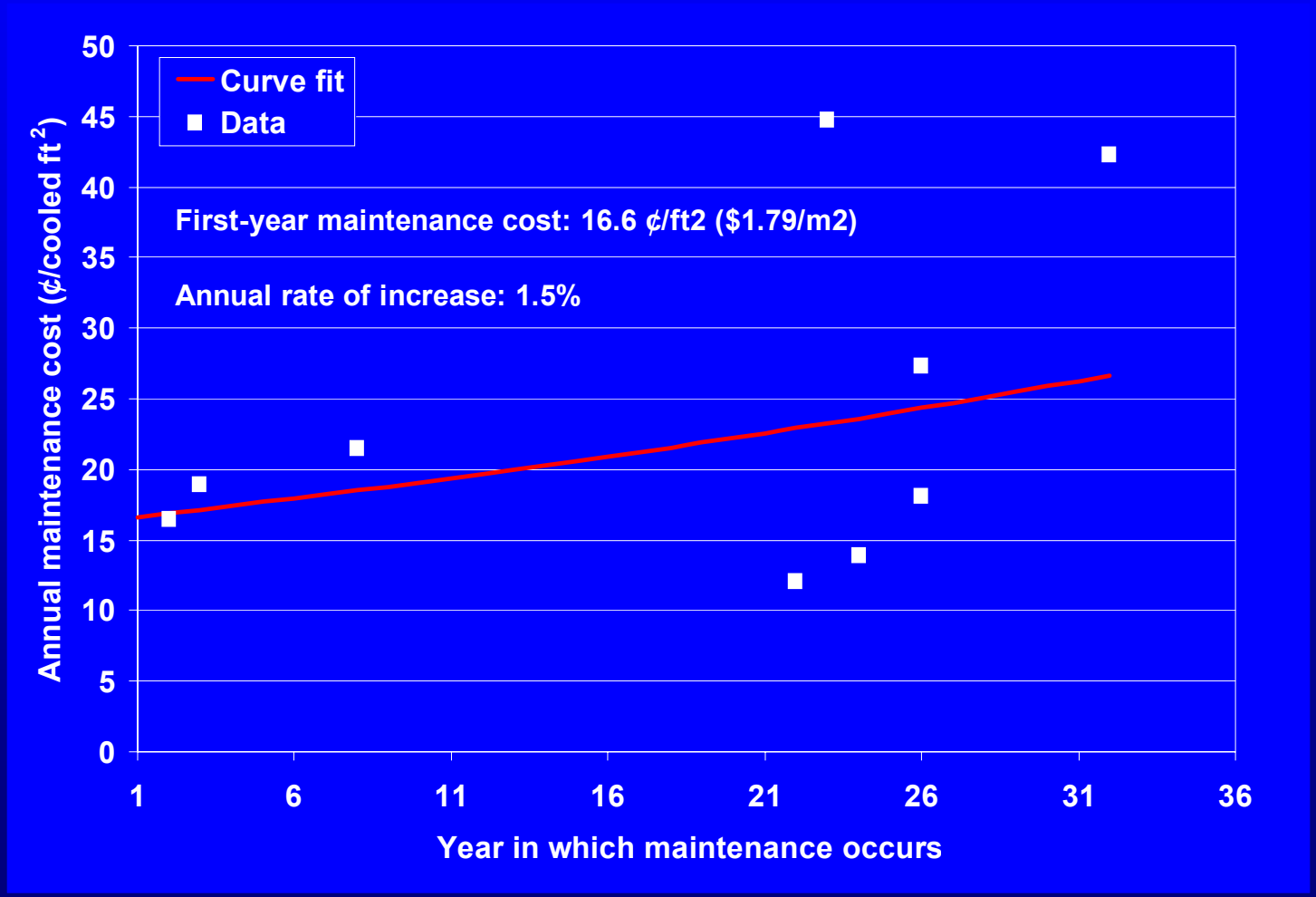
Estimating maintenance costs was somewhat problematic

- Wanted to determine first-year maintenance cost and rate of cost increase for each alternative
- Only 18 systems in database (4 GHP, 2 ACC/VAV, 3 WCC/VAV, 9 WCC/CV)
- Not enough data to perform a statistically significant analysis
- Alternative sources generally unreliable

Data for most numerous system type (WCC/CV)



Values appeared reasonable



How maintenance costs were estimated

- Assumed maintenance costs for all systems rose by 1.5% per year
- Calculated initial year maintenance cost on this basis
  - GHP: 9.0 ¢/ft^2
  - ACC/VAV: 9.5 ¢/ft^2
  - WCC/CV: 16.6 ¢/ft^2
  - WCC/VAV: 9.7 ¢/ft^2

Developed independent cost estimates for each system

- Capital costs were estimated for each system by staff estimators, without reference to actual installed cost
- Estimates then given a “reality check” by an experienced estimator familiar with school HVAC systems (including geothermal)
- Estimates also compared to published square foot cost estimating guides

Capital cost estimates for the four systems

System type	Installed cost	cost per ft^2
GHP	$ 1,021,257	$ 14.66
ACC/VAV	$ 1,129,286	$ 16.21
WCC/CV	$ 835,916	$ 12.00
WCC/VAV	$ 1,164,268	$ 16.71

Things to note about the capital cost estimates

- Based on published figures for schools, the estimates appear reasonable
- Excluding the constant volume system, geothermal has the lowest first cost
- A cost of $9.45 per square foot was published for the geothermal systems. We were unable to determine what was included in this estimate
- School district's accounting system does not separate out the cost of HVAC from the entire school cost.

Inputs for the life cycle cost analysis

- Energy use for each system based on calibrated simulation models
- Local Lincoln, Nebraska rates (gas, electric and water) used to calculate utility costs
- Maintenance costs based on Lincoln School District database → first year + annual escalation
- Capital costs of HVAC systems based on estimates performed by staff cost estimators
- Real discount rate of 3.1%, DOE energy cost projections, 20 year equipment life

Comparison of life cycle costs

	Baseline Geothermal	Option 1 ACC/VAV	Option 2 WCC/CV	Option 3 WCC/VAV
Initial Cost	**$1,021,257**	**$1,129,286**	**$835,916**	**$1,164,268**
First year maintenance cost	$7,383	$7,824	$13,651	$7,928
First year electric cost	$22,138	$23,037	$34,152	$19,448
First year gas cost	$3,533	$10,963	$23,944	$11,034
Water cost			$385	$385
Total annual O&M costs	**$33,054**	**$41,824**	**$73,826**	**$38,795**
Life Cycle Cost	**$1,498,835**	**$1,734,327**	**$1,912,297**	**$1,728,736**

Results of the analysis

- Lincoln school district made the correct decision in installing GHPs in these four schools
- Over 20 year life, GHPs have the lowest life cycle cost -- about $230,000 less than the next most economical technology
- First cost is the most important factor in the analysis, followed by energy costs and maintenance costs.
- Maintenance costs of GHPs in this district are marginally lower (about 6%) than the cost of maintaining VAV chiller/boiler systems.

Results of the analysis

- GHPs have the lowest annual operating costs
- Of the system types commonly installed in schools, GHPs also have the lowest first cost
- Reduced energy use reduces emission of greenhouse gases and other pollutants

Conclusions

- Obviously, these results apply only to the school examined
- They confirm that GHPs can cause significant reductions in energy use (17%) and energy costs (24%)
- They also counter some of the myths about GHPs:
  - No “cost premium” in this case. GHPs have lower first cost
  - Maintenance costs comparable with other common technologies