ANALYSIS OF AIR-CONDITIONING OPTIONS FOR FOURTEEN EXISTING SCHOOLS IN COLORADO

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ABSTRACT

This paper describes the process used to simulate the performance, energy, and economic impact of four different AC system types selected for investiagtion at fourteen schools in a Colorado School District using the DOE-2 building energy simulation. The AC systems investigated included direct expansion, chilled water, indirect evaporative, and geoexchange systems.

The project encountered many interesting challenges, including assessment of potential energy conservation measures that would affect the cooling load, accurately modeling the geoexchange systems, assessment of the impact that the increased energy use would have on electricity billing rates, and other miscellaneous modeling challenges. All of these challenges were overcome in one form or another, and the results presented interesting insight into the comparative performance of these four system types at different schools, regarding initial installation costs, annual energy costs, and life-cycle costs.

These simulation results will be used to make highly informed decisions about cost-effective energy conservation and AC system options in these schools, and help the Distrcit decide what to finance from their operations budget, how much money to ask for from a bond issue, and what to include as part of a performance contract.

INTRODUCTION

A Colorado School District investigated the feasibility and impact of integrating different air-conditioning (AC) systems into fourteen schools as part of a longer-term effort to provide cooling in approximately one-half of all schools in the District. The effort was in response to a growing summer instructional requirement within the District.

The purpose of the feasibility study was to determine and establish the comparative cost and viability of various heating and cooling technologies. This feasibility study served as an extension of a technical energy audit of these schools that was conducted as part of an energy savings performance contracting effort managed by an energy service company (ESCo). Consequently, this cooling study was performed with this fact in mind, and as a result, future energy conservation measures (ECMs) that would be implemented as part of this performance contract, and that would impact building heating and cooling requirements, were assessed and incorporated into the feasibility study. This allowed for accurate assesment of potential future cooling loads, and accurate sizing of the proposed AC systems.

Preliminary audits of the fourteen schools were performed to determine if these schools were viable candidates for the integration of AC. The preliminary audits determined that all fourteen schools were, indeed, viable candidates.

Once the list of schools was established, detailed energy audits of the schools were performed. These audits included interviews with facility personnel and school occupants, and review of building plans and controls diagrams. The information gathered in these detailed audits was subsequently used to generate DOE-2.1E version 133 building energy simulation (DOE-2) models, which were then calibrated to monthly historical utility billing data.

The calibrated DOE-2 models were used to assess the economic impact of proposed ECMs identified during the detailed walkthroughs. Using this information, ECMs were selected that were likely candidates for implementation under the performance contract, and subsequently used to generate the adjusted baseline DOE-2 models.

With a baseline of annual energy consumption and costs established through the DOE-2 analysis, selected AC system types were analyzed at each school. The AC system types considered at each school depended on the existing heating systems, but typically included the following system types:

a) Direct expansion (DX) system utilizing DX coils served by individual unit compressors and condensers.

b) Chilled water system using chilled water coils served by a central air-cooled chiller.

c) Indirect evaporative system, utilizing chilled water coils and a central cooling tower (in place of the chiller in option b).

d) Single-zone heat pumps, served by a geoexchange system .

Direct evaporative systems were not considered, due to ductwork characteristics, exhaust problems, health considerations, and other miscellaneous concerns expressed by the District. A water-to-water, multi-zone heat pump geoexchange option was also initially considered, but was dropped due to significant increase in cost over the single-zone heat pump option and corresponding alternative water-to-water options (chiller and indirect evaporative options).

The AC system options were analyzed at each school using the DOE-2 simulations. The results (economic impact of the proposed AC systems) were combined with estimates of system integration and installation costs, system maintenance costs, future equipment replacement costs, as well as gas and electric rate escalation, to develop life-cycle costs for each option.

SIMULATION PROCESS

The DOE-2 building energy simulation program was used exclusively to perform all analysis for this study. The simulations were used to:

- Investigate baseline performance
- Investigate ECMs and their impact on building heating and cooling loads prior to HVAC system retrofits
- Investigate the performance of the proposed AC system options
- Perform life-cycle cost analysis

Building Energy Baselines

Energy baselines for the fourteen buildings were established through the use of DOE-2.1E. The models of the buildings were based on building plans and specifications, information gathered during walkthrough audits, and interviews with the building operators, occupants, and maintenance personnel. The models were calibrated to five-year average monthly historical utility bills.

ECMs were identified during the preliminary audits that would potentially impact the buildings' heating and cooling loads. Comparisons between the ECMs identified during the these walk-through audits were performed by making changes to the models corresponding to characteristics of the individual ECMs. These parametric analyses resulted in predicted utility consumption savings, and were used along with estimated implementation costs by the District to ultimately decide which measures to potentially include as part of the performance contract. The calibrated DOE-2 baselines, modeled with the selected ECMs in place as packages, subsequently represented the improved baselines used for analysis of the proposed AC systems.

Air-conditioning System Selection

An initial list of fourteen AC system options was presented to the District as candidates for consideration. At the request of the the District staff, this list was pared down to a smaller set of system options. The systems were selected based on: heating and air-distribution systems currently being used at each school; the age and condition of these existing systems; other contributing factors such as limitations due to building structural characteristics, ductwork or piping sizes and layout; and other miscellaneous factors unique to each school.

Other points pertaining to system retrofits that were kept in mind during the selection process:

- In some cases, existing conditions within the school might need to be updated to meet current codes and ASHRAE 62 standards.
- A geothermal system would need to provide both heating and cooling.
- Existing hot water systems that would not be used in the upgraded system would be abandoned in place, if possible. However, demolition might be deemed necessary in some cases to provide necessary space for a proposed new system.
- Reuse of as much existing ductwork as possible.
- Condensate drain would be required for all cooling retrofits.
- Electrical capacity upgrades may be required for cooling retrofits.
- All fourteen schools have ample area for ground heat exchanger.
- All geothermal loop fields will have a pumping system, with either distributive pumping (one circulation pump per heat pump), or centralized pumping with variable-speed drives.

Ultimately, four main system options were selected for analysis, including direct expansion (DX), chilled water (CHW), indirect evaporative (EVAP), and single-zone ground source heat pump (SZ GSHP).

Direct Expansion Cooling Option and Modeling Considerations

The DX cooling system option involved the addition of DX cooling coils and refrigerant piping served by individual compressors and condensers. Many schools' existing systems utilized packaged multi-zone units (MZUs) to provide ventilation air and to heat the spaces. These units contained space for cooling coils, such that the DX coils could be easily introduced into the cold deck, requiring no other alterations to the MZU. In cases where the RTUs or AHUs were old and beyond their serviceable lifetime, the units would be replaced with new RTUs or AHUs with DX cooling coils. The new compressors, condensing coil units, and refrigerant piping for the DX coils would be located on the roof.

For the purposes of the DOE-2 analysis, the existing system configuration remained the same. The cooling system type was changed to a DX cooling delivery while the cooling schedule was defined according to District guidelines. The efficiency of the DX unit was defined for the compressor only. The energy efficiency ratio (EER) for the DX systems specified was 10.5 when accounting for fan power or 12 when the fans were omitted. The DOE-2 simulation program was used to automatically size the cooling capacity for the proposed system.

The DX option was not evaluated at Elementary E, due to insufficient room for DX coils in the existing units.

Chilled Water Option and Modeling Considerations

The chilled water cooling system option was similar to the DX option, but involved the addition of chilled water coils (as opposed to DX coils) and chilled water piping, with chilled water provided by a centrally located air-cooled chiller. As with the DX option, chilled water coils would be introduced into units that contained space for these coils, with no other alterations required. Furthermore, RTUs or AHUs beyond their serviceable lifetime would be replaced with new RTUs or AHUs with chilled water cooling coils.

For the purposes of the DOE-2 analysis, as with the DX system analysis, the existing system configuration remained the same. The cooling system type was changed to a chilled water coil cooling delivery while the cooling schedule was defined according to the District guidelines. A packaged air-cooled chilling unit was defined in the program to serve the chilled water coils. The peak efficiency of the packaged chiller was defined at 1.2 kW/ton. The chiller was set to provide 44°F chilled water to the cooling coils. A primary only chilled water pumping system was also defined in the program. The DOE-2 simulation was allowed to size the pump and flow of the system according to the peak loads. The pumps specified in the program were single-speed, nominal efficiency pumps with a pump head of 40 feet. These flows were adjusted if DOE-2 sizing appeared unrealistic. The DOE-2 simulation program was also used to automatically size the cooling capacity for the proposed system.

For Elementary E a two-pipe changeover system, utilizing new water coils in place of existing hot water coils was recommended, due to insufficient room for additional coils in the existing units.

Indirect Evaporative Option and Modeling Considerations

The indirect evaporative cooling system option was identical to the chilled water option, with the exception that the chilled water would be provided by a cooling tower as opposed to a chiller. The centrally located cooling tower (located next to the school) would provide chilled water, which would be pumped through a heat exchanger that would then cool the chilled water serving the new chilled water coils.

For the purposes of the DOE-2 analysis, as with the DX system analysis, the existing system configuration remained the same. The cooling system type was changed to a chilled water coil cooling delivery while the cooling schedule was defined according to District guidelines. A cooling tower was defined in the system to deliver chilled water to the chilled water cooling coils via a heat exchanger. The indirect evaporative cooling system was defined as an indirect system in the program and designed to serve the entire cooling load, with no other mechanical cooling provided. The cooling EIR of the system was left as the DOE-2 cooling system default of 0.36. As with the chilled water system, the DOE-2 simulation was allowed to size the pump and flow of the system according to the peak loads. The pumps specified in the program were single-speed, nominal efficiency pumps with a pump head of 40 feet. These flows were adjusted if DOE-2 sizing appeared unrealistic. The DOE-2 simulation program was also used to automatically size the cooling capacity for the proposed system.

As with the chilled water option, a two-pipe changeover system was recommended for Elementary E, utilizing new water coils in place of existing hot water coils.

One important consideration was noted regarding this system option regarding the fact that the DOE-2 model results suggested that in some cases the indirect evaporative system might not be able to adequately handle building cooling loads. This was due to the fact that water temperatures supplied to the chilled water coils are directly related to ambient wet-bulb temperatures. As wet-bulb temperatures increase, water temperatures supplied to the coils would also increase, limiting the system's cooling capacity during peak ambient conditions. However, it was noted that higher wet-bulb temperatures typically occur later in the afternoon, when summer classes should be out of session, so this would not present a control issue.

Ground Source Heat Pump Option and Modeling Considerations

Due to the expected challenges associated with modeling the ground source heat pump option using the DOE-2 simulation, a geothermal contractor was consulted for this portion of the study.

The geothermal contractor determined that a single-zone heat pump geoexchange cooling option should be used at each school. This system option would involve the use of small single-zone water-to-water heat pumps serving each zone. The single-zone heat pumps would serve zones that would not be so large that some portions required heating while others required cooling, so that the individual heat pumps would only operate in either heating or cooling mode at any given time. All heat pumps would be connected to a vertical ground loop outside the school.

For the purposes of the DOE-2 analysis, the existing system configuration was adjusted so that the new heat pumps each served only a single zone. The cooling system type was changed to a ground source heat pump system while the cooling schedule was defined according to School District guidelines.

The heating and cooling loads in the building, as well as soil characteristics and thermal properties of the school grounds, define the ground loop system sizes. Soil type, moisture content, composition, density, and uniformity all affect the success of the heat exchange between the water loop and the ground.

The assumptions for the ground loop were based on geological research of soil properties at each school site that were provided by the geothermal contractor. The assumptions for the ground source heat pump and the ground loop as they were used in the DOE-2 models were also provided by the geothermal contractor.

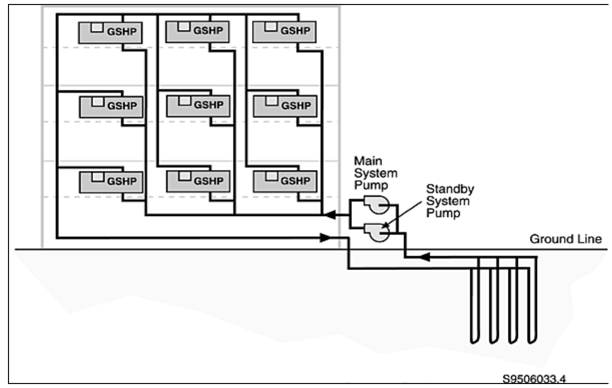

Figure 1 Typical basic single-zone heat pump geoexchange configuration

A major challenge encountered during the modeling of the SZ GSHP option dealt with sizing of the loop fields. The geothermal contractor could not specify the size of the loop fields until a specific type of heat pump was chosen, so general loop field sizes were estimated for each school. However, it was discovered that the DOE-2 models could not adequately maintain loop temperatures given the loop sizes specified by the geothermal contractor. In all cases, these loop fields were found to be too small to maintain water temperatures within the limits required by the water source heat pumps.

Part of this problem was due to modeling limitations of the DOE-2 software. Thermal conductivity in DOE-2 is limited to a maximum value of 1.0 Btu/hr-ft-F. During soil conductivity tests conducted at the schools, however, the geothermal contractor determined that the soil thermal conductivity was greater than 1.0 Btu/hr-ft-F in some cases, and as high as 1.32 Btu/hr-ft-F in one case.

To handle this situation, the model was run with the loop size specified by the geothermal contractor, and the pumping power for the loop distributuion was determined. The loop size was then adjusted in the model until loop temperatures could be adequately maintained, but the original pumping power determined in the "contractor-sized loop" run was used to estimate associated loop pumping power.

System Implementation Costs

Implementation costs for the DX, CHW, and EVAP system options were calculated using R. S. Means Mechanical Cost Data and manufacturer provided costs. Implementation costs for the SZ GSHP option were determined by the geothermal contractor. To calculate these costs, it was necessary to determine single zone equipment sizes. Zone peak equipment loads (peak heating and cooling loads) were used to determine zone equipment sizes. These zone equipment sizes were summed together, and an adjustment factor of 50% was applied to the sum to determine the size of the main system components (chiller, cooling tower, etc). This adjustment factor accounts for the fact that not all zones will require maximum heating or cooling at the same time. The calculated main system component sizes were compared to the DOE-2 model estimated sizing, and were within an acceptable range in all cases (approximately the same or slightly higher than the DOE-2 model estimated them to be).

Zone peak cooling and heating equipment sizes were determined using the following assumptions:

- Cooling airflow of 1.25 CFM/sf
- Cooling capacity of 400 sf/ton
- Heating airflow of 1.0 CFM/sf
- Heating capacity of 30 Btuh/sf

In many cases the cooling system could be incorporated into the existing air distribution equipment or as stand-alone cooling coils installed in existing ductwork. For equipment that was deemed beyond its useful life (as of the time of the study), new air distribution components equipped with cooling coils were assumed (this applied to Elementary L, Elementary M, H Middle, M Middle, and portions of Elementary E, Elementary WA and C High. Additionally, new ductwork was deemed necessary at Elementary L, Elementary M, and portions of C High). In all SZ GSHP applications, all existing equipment would be replaced with the new heat pumps and water loop.

A particular consideration involving existing system conditions and future replacements developed due to the fact that the SZ GSHP option would involve replacement of all of the existing equipment at each school with a completely new system. Since this would present a considerably higher first cost at most schools, especially those schools that could integrate the other three system types into the existing systems, considerations regarding life-cycle cost analysis became particularly important. To represent accurate life-cycle cost estimates, the District facility staff determined which existing system components would need replacement within the next twenty-five years. These costs were introduced into the analysis reduced based on how far out they would occur. Interestingly enough, this only changed the results of the analysis in three cases, resulting in the SZ GSHP option as the lowest life-cycle cost option for three additional schools (at Elementary L, Elementary G, and Elemantary WI).

Additional infrastructure within several buildings had to be considered during the analysis. These infrastructure upgrades included ducting for new RTU systems and piping for new chilled water or condenser water systems. Other costs included in the analysis involved electrical system installation, architectural system installations, balancing, controls, commissioning, contractor overhead and profit and an estimating contingency. In all cases, careful coordination between the consultant and the geothermal contractor ensured that the same costing assumptions were used for all four AC system options under consideration.

Utility Rates and Escalation

Three different utility rate schedules apply to these schools, one for the elementary schools (rate E2C), one for the middle schools (rate ETL), and one for the high schools (rate E8T). The rate category applicable to each school was based on the school's monthly demand and consumption during the previous twelve months.

It was recognized during the analysis process that the addition of the AC systems to the schools would increase overall electrical consumption and demand. Thus, the potential existed for a school to move into a new rate category. This was especially true for buildings using the SZ GSHP option, since all heating requirements would be met using electricity, as opposed to natural gas.

The DOE-2 model results were analyzed for each system type to assess electrical consumption and demand on a monthly basis to estimate whether these schools would potentially move into a new rate category for each AC system type. The results of this analysis indicated that the estimated consumption or demand for a number of system options would put some schools into higher rate categories. For these system options, the DOE-2 models were run with the appropriate higher rate category.

Future rate escalation was determined collaboratively by the consultant and the District. An annual escalation rate of 3% was assumed for electricity. For gas, a 5% escalation rate was assumed for the first two years, 4% for the following three years, and 3% thereafter. These assumptions were based on expected gas price increases and the need to maintain a realistic ratio between the costs of natural gas and elelctricty, since electricty is often generated by burning natural gas.

DISCUSSION AND RESULT ANALYSIS

Discussion

To accurately assess various considerations pertaining to the four AC system options, a variety of sources were used in this study. In some cases, these involved traditional resources such as R. S. Means Costworks Database and ASHRAE specifications and guidelines. In other cases, more novel sources for information were adopted, including consultation from a geothermal contractor, and the School District's assesment of equipment longevity. In the end, these various sources helped to provide informed inputs to the DOE-2 models, which included:

- potential impacts to building cooling loads due to proposed ECMs,
- life-cycle costs,
- future energy rate escalations and rate changes due to predicted increases in electricity consumption and demand,
- operation and maintenance costs, and
- implementation and system replacement costs for all AC options.

Overall, this approach provided a thorough and comprehensive approach to deciding which AC systems to select at each school, providing the District with important information needed to determine financing options, including use of current operations budgets, potential bond options, and the use of a performance contract.

Analysis Results

The DOE-2 simulation results for predicted annual energy costs, as well as estimated first costs and twenty-five year life-cycle costs for each school are presented in Table 3. Annual maintenance costs, used in the life-cycle cost analysis, are also presented in this table. For schools in which the lowest first cost option and lowest life-cycle cost option were not the same, the "crossover year" is indicated. This value represents the year that the lowest life-cycle cost option becomes lower than the life-cycle cost of the lowest first cost option (in other words, how many years out before the lowest life-cycle cost option starts costing less overall than the lowest first cost option). These system analysis results are summarized in Table 1 and Table 2.

Table 1 Lowest cost system option frequency

	Lowest First Cost	Lowest Life-Cycle Cost	Lowest Annual Energy Cost
DX Option	11	6	0
Chilled Water Option	0	0	0
Indirect Evaporative Option	2	2	1
Single-Zone GSHP Option	1	6	13

The results indicate that in most cases the DX option represents the lowest first cost option, and that the SZ GSHP option represents the lowest annual energy cost option. These two factors combined account for the even split demonstarted by the results between the DX option and the SZ GSHP option as the lowest twenty-five year life-cycle cost options.

Intersetingly enough, the CHW option was never either the lowest first cost or lowest life-cycle cost option. This was attributed to the fact that it was all but identical to the EVAP option, with the simple difference that the cooling tower and heat exchanger were used in place of the air-cooled chiller. However, as was mentioned in this paper, the models indicated that the EVAP option may not be able to adequately satisfy cooling needs during the peak summer hours. Since these systems do not serve "critical spaces" (they are not currently utilizing AC), then the fact that the system might not be able to meet these cooling needs at peak times may not be a concern. However, if this is a concern, then the CHW option would be prefered over the EVAP option.

Table 2 Lowest cost system option by school

School Name	Lowest First Cost	Lowest Life-Cycle Cost	Lowest Annual Energy Cost
Elementary B	DX	DX	SZ GSHP
Elementary C	EVAP	EVAP	SZ GSHP
Elementary E	EVAP	EVAP	SZ GSHP
Elementary G	DX	SZ GSHP	SZ GSHP
Elementary J	DX	DX	SZ GSHP
Elementary L	SZ GSHP	SZ GSHP	EVAP
Elementary M	DX	DX	SZ GSHP
Elementary R	DX	DX	SZ GSHP
Elementary WA	DX	SZ GSHP	SZ GSHP
Elementary WI	DX	SZ GSHP	SZ GSHP
H Middle	DX	SZ GSHP	SZ GSHP
M Middle	DX	DX	SZ GSHP
C High	DX	SZ GSHP	SZ GSHP
M High	DX	DX	SZ GSHP

CONCLUSION

Analyzing four cooling system options at fourteen schools using the DOE-2 simulation indicated that the SZ GSHP represented the lowest annual energy costs at the majority (thirteen out of fourteen) of the schools, while the DX option represented the lowest first cost option at the majority (eleven out of fourteen) of the schools. This resulted in a split between these two system types regarding lowest twenty-five year life-cycle costs, with the DX option lowest for six schools, and the SZ GSHP option lowest for six as well. The EVAP option represented the lowest first cost and life-cycle cost at two schools, and the lowest annual energy cost at one school. The CHW option was not the lowest cost option in any category at any school, but should be considered as a replacement for the EVAP option if system capacity during peak hours of the summer are a concern.

ACKNOWLEDGMENT

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NOMENCLATURE

AC = air conditioning
AHU = air-handling unit
CHW = chilled water system option
DX = direct expansion
EVAP = indirect evaporative system option
FCU = fan coil unit
MAU = make-up air unit
MZU = multi-zone unit
RTU = rooftop unit
SZ GSHP = single-zone ground source heat pump
UV = unit ventilator

REFERENCES

American Society of Heating Refrigeration and Air-Conditioning Engineers. 2000. Heating, Ventilation, and Air-Conditioning Systems and Equipment, Atlanta, GA.

Table 3 Economic analysis results for each system type at each school

School	System Option	First Cost[1]	25-year LCC	Annual Energy Costs	Annual Maintenance Costs	Crossover Year[2]
Elementary B	DX	$296,707	$1,047,935	$18,068	$1,619	n/a
	CHW	$325,829	$1,084,779	$18,102	$1,800	-
	EVAP	$308,110	$1,052,906	$17,247	$2,254	-
	SZ GSHP	$834,856	$1,128,074	$5,590	$2,452	-
Elementary C	DX[3]	$245,604	$1,014,545	$18,832	$1,662	-
	CHW	$251,613	$833,659	$13,522	$1,847	-
	EVAP	$229,895	$782,138	$12,249	$2,314	n/a
	SZ GSHP[3]	$850,368	$1,133,200	$5,240	$2,517	-
Elementary E	DX	n/a	n/a	n/a	n/a	n/a
	CHW	$436,013	$1,723,043	$31,381	$2,134	-
	EVAP	$416,698	$1,680,592	$30,272	$2,673	n/a
	SZ GSHP[3]	$1,020,637	$1,686,106	$15,344	$2,908	-
Elementary G	DX[3]	$480,052	$2,590,383	$53,166	$2,425	n/a
	CHW[3]	$534,951	$2,464,112	$47,873	$2,697	10
	EVAP[3]	$507,988	$2,230,786	$41,823	$3,378	3
	SZ GSHP[3]	$1,182,831	$2,104,169	$21,595	$3,675	17
Elementary J	DX	$225,840	$1,169,291	$23,066	$1,760	n/a
	CHW	$257,783	$1,204,107	$22,948	$1,957	-
	EVAP	$241,564	$1,209,733	$23,054	$2,450	-
	SZ GSHP[3]	$866,842	$1,516,345	$15,148	$2,666	-
Elementary L	DX	$1,533,681	$2,399,663	$20,335	$2,502	-
	CHW	$2,302,568	$3,477,456	$28,056	$2,782	-
	EVAP	$2,273,414	$3,158,296	$19,870	$3,485	-
	SZ GSHP[3]	$1,246,368	$2,216,882	$22,828	$3,791	n/a
Elementary M	DX	$615,468	$1,202,571	$13,576	$2,030	n/a
	CHW	$940,759	$1,515,805	$12,998	$2,257	-
	EVAP	$912,951	$1,412,028	$10,368	$2,824	-
	SZ GSHP	$1,000,943	$1,352,386	$6,564	$3,075	-

1. *New system components were deemed necessary for Elementary L, Elementary M, H Middle, M High, and portions of Elementary E, Elementary WA and C High. Additionally, new ductwork was deemed necessary at Elementary L, Elementary M, and portions of C High. This is reflected in the relatively higher first costs for the system options at these schools.*
2. *For schools in which the lowest first cost option and lowest 25-year life-cycle cost option are not the same, the crossover year represents the year that the lowest life-cycle cost option becomes lower than the life-cycle cost of the lowest first cost option.*
3. *Calculations were performed using the ETL electric rate.*
4. *Calculations were performed using the E8T electric rate*

Table 3 Economic analysis results for each system type at each school (continued)

School	System Option	First Cost[1]	25-year LCC	Annual Energy Costs	Annual Maintenance Costs	Crossover Year[2]
Elementary R	DX	$284,527	$1,142,609	$20,537	$2,069	n/a
	CHW	$398,812	$1,446,931	$25,199	$2,301	-
	EVAP	$325,855	$1,191,804	$19,941	$2,881	-
	SZ GSHP[3]	$1,067,707	$1,657,989	$13,055	$3,135	-
Elementary WA	DX	$600,263	$1,371,835	$18,790	$1,557	n/a
	CHW	$727,116	$1,433,892	$16,850	$1,731	-
	EVAP	$713,050	$1,402,621	$15,930	$2,168	-
	SZ GSHP	$839,793	$1,085,279	$4,374	$2,359	14
Elementary WI	DX[3]	$502,176	$2,009,360	$37,752	$2,397	n/a
	CHW[3]	$551,069	$1,855,033	$31,909	$2,664	8
	EVAP[3]	$526,651	$1,759,217	$29,283	$3,337	4
	SZ GSHP[3]	$1,158,570	$1,727,845	$11,983	$3,631	20
H Middle	DX	$1,541,260	$5,051,258	$83,204	$9,309	n/a
	CHW	$3,593,162	$6,912,973	$77,969	$9,309	-
	EVAP	$3,544,381	$6,814,302	$76,611	$9,320	-
	SZ GSHP	$2,017,412	$3,483,827	$33,877	$6,343	8
M Middle	DX[4]	$615,399	$3,937,342	$77,832	$10,700	n/a
	CHW	$1,996,628	$4,768,745	$62,751	$10,700	-
	EVAP	$1,955,888	$4,660,753	$60,907	$10,704	-
	SZ GSHP[4]	$2,303,785	$3,956,698	$38,044	$7,291	-
C High	DX	$2,396,022	$10,836,741	$212,217	$11,950	n/a
	CHW	$4,637,136	$12,442,645	$193,465	$13,285	-
	EVAP	$4,550,486	$11,271,137	$160,306	$16,634	-
	SZ GSHP	$5,335,939	$8,747,581	$75,468	$18,106	17
M High	DX	$2,378,704	$11,360,831	$206,759	$31,048	n/a
	CHW	$7,397,590	$18,208,998	$256,933	$31,048	-
	EVAP	$7,373,080	$17,762,412	$245,353	$31,052	-
	SZ GSHP	$6,149,259	$12,111,124	$142,364	$21,157	-

1. *New system components were deemed necessary for Elementary L, Elementary M, H Middle, M High, and portions of Elementary E, Elementary WA and C High. Additionally, new ductwork was deemed necessary at Elementary L, Elementary M, and portions of C High. This is reflected in the relatively higher first costs for the system options at these schools.*
2. *For schools in which the lowest first cost option and lowest 25-year life-cycle cost option are not the same, the crossover year represents the year that the lowest life-cycle cost option becomes lower than the life-cycle cost of the lowest first cost option.*
3. *Calculations were performed using the ETL electric rate.*
4. *Calculations were performed using the E8T electric rate*