Supporting analysis for proposed changes to the commercial provisions of the 2012 IECC: Water-side Economizer for Non-Fan Cooling Systems

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Proposal Description

This proposal modifies Section C403.4.1 of the 2012 IECC for the 2015 version. It expands the water-cooled economizer requirement to systems without fans.

Energy Impact

Based on average national energy prices[1] of $0.1032 per kWh, the energy savings is determined based on a post processing of results from a large hotel modeled in EnergyPlus™.[2] The guest rooms served by fan coil units are used as a proxy for cooling loads without an economizer.

The electric savings from precooling the chilled water return (CHWR) with a water-side economizer is shown in Figure 1. The gross chiller savings is shown with the added energy for closed circuit cooling tower pumps and fans subtracted resulting in a net energy savings. Selected climate zones analyzed are shown.

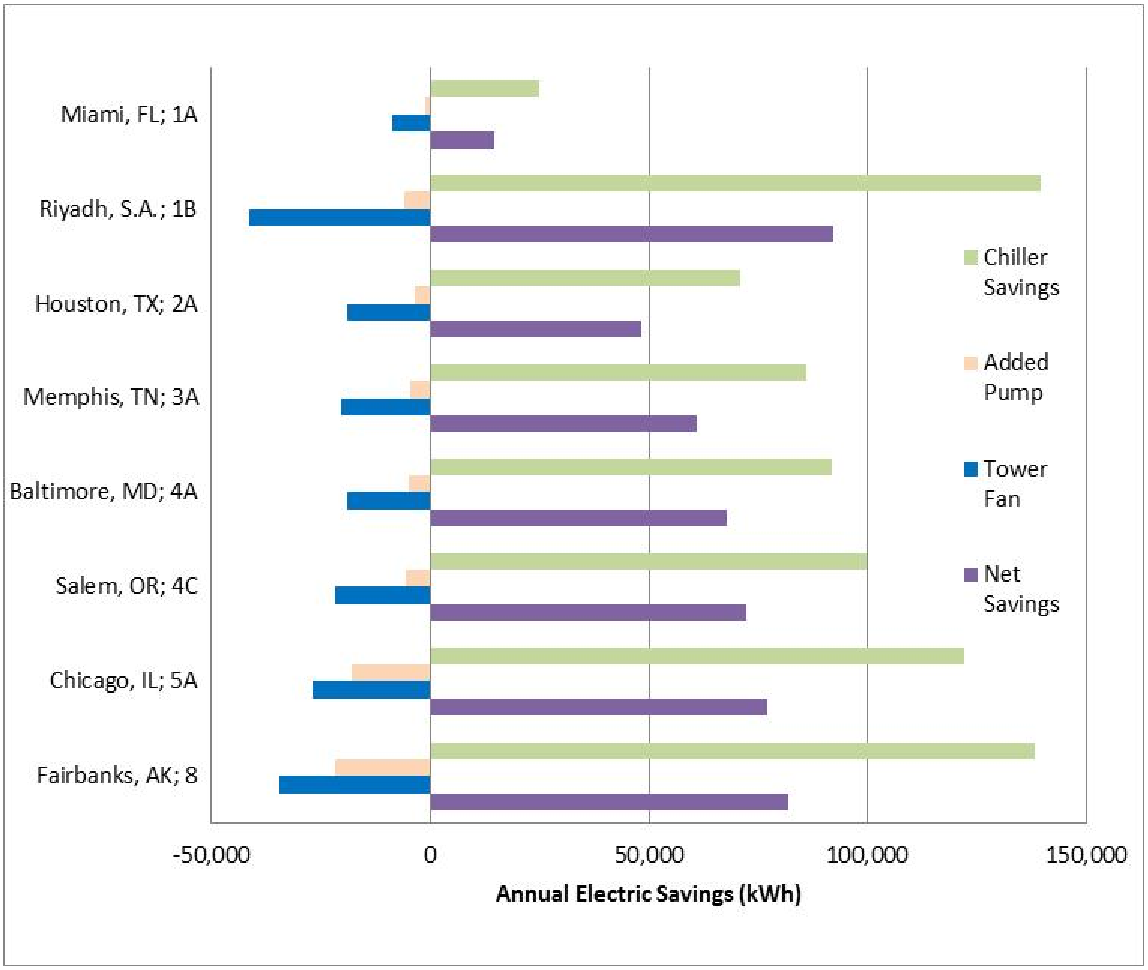

Figure 1: Water-side Economizer Annual Electric Savings

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[1] Weighted commercial national average energy prices developed by the ASHRAE 90.1 standards committee for analysis of 90.1-2013 proposals; based on national data from the 2011 *Annual Energy Outlook* by US Energy Information Administration. www.eia.gov.

[2] EnergyPlus is an advanced building simulation model. More information online at: http://apps1.eere.energy.gov/buildings/energyplus/

Based on this analysis, there is demonstrated savings from using a water-side economizer in all the analyzed climate zones.

Approach

There are several approaches to applying water-side economizers to systems without airside economizers. Such systems include radiant cooling, chilled beams, computer room air conditioners, and fan coil units. To test if the approach is cost effective, analysis of an evaporative closed circuit pre-cooler for return air is applied to loads for a cooling system without outside air economizers. While there are several approaches to this, a separate evaporative fluid cooler or closed circuit cooling tower was modeled, as shown in Figure 2.

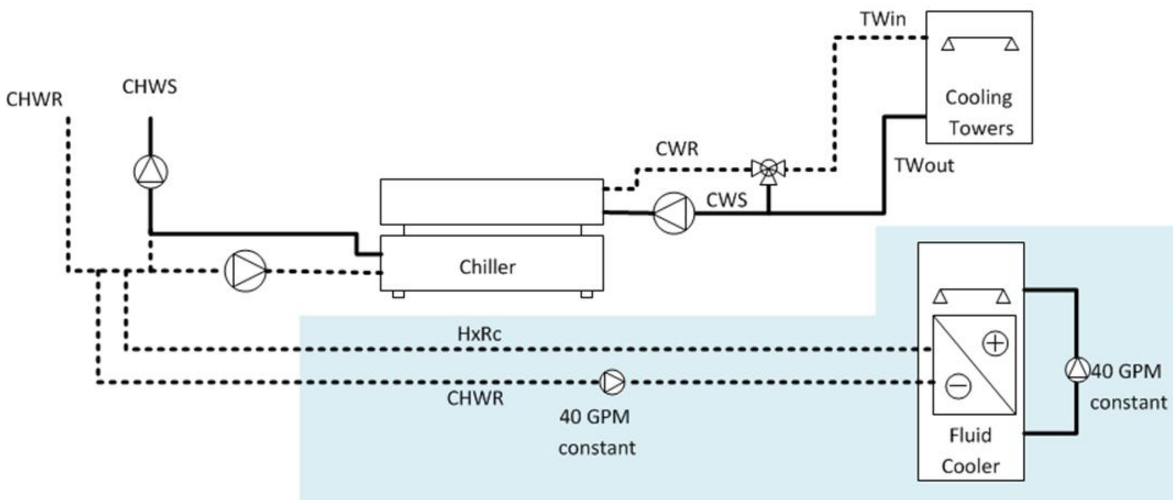

Figure 2: Schematic of Analyzed System

Using a separate fluid cooler for the water-side economizer allows maximum water economizer effect, as a separate closed circuit tower leaving water temperature is not impacted by the need to maintain a minimum condenser entering water temperature when the chiller is operating. This allows the best integrated operation. The arrangement also allows the chiller pump to be off when the chiller is not necessary. Further, the arrangement can be applied to either water-cooled chiller systems, air-cooled chiller systems, or to buildings served by a district cooling plant. An additional advantage of this system is that it can provide partial cooling while the chiller maintains the chilled water supply (CHWS) temperature necessary for dehumidification where required. With its decoupled hydronic attachment to the chilled water system, the closed circuit cooling tower CHWR pre-cooler would have the same impact on the chilled water plant as a reduction in general cooling load. On larger systems, there may be some benefit for the constant volume pump to the fluid cooler to be variable flow.

Analyzing this system provided the best indication of the cost effectiveness of a water-side economizer approach, as it clearly showed the savings from adding a discrete water-side economizer that was sized to match full cooling load without a chiller at 50°F DB and 45°F WB outside air conditions. As an independent pre-cooler add on, the control strategy was simple and there were few interdependencies with the main system that would complicate the analysis.

The cost of the arrangement in Figure 2 can be reduced by including valves and piping that will use the fluid cooler for peak load condenser cooling when water-side economizing is not possible, although this option was not included in the cost effectiveness analysis here as it involves some control complexity.

An alternative method can be applied, using the existing cooling towers for the water-side economization. In this approach, the sequence moves through three phases:

- A total economizer phase where the chiller is off total cooling load is met by evaporatively cooling the chilled water return.
- A mixed phase where both the condenser water and chilled water return are cooled by the same tower in conjunction with a flat plate heat exchanger.
- Operation with only the chiller when there is no benefit to chilled water return pre-cooling.

This approach can save cost, but the savings are more dependent on the mix of non-economizer and airside economizer loads served by the cooling plant, and the ability to pre-cool chilled water return is limited by the need to maintain a high condenser water supply (CWS) temperature for the chiller condenser to maintain adequate evaporator valve refrigerant flow. In some cases and locations the savings can be greater than in Figure 2, especially where a larger cooling tower can extend the time that cooling can be provide without chiller operation or a larger overall cooling load can benefit from precooling. A schematic for the mixed approach is shown in Figure 3.

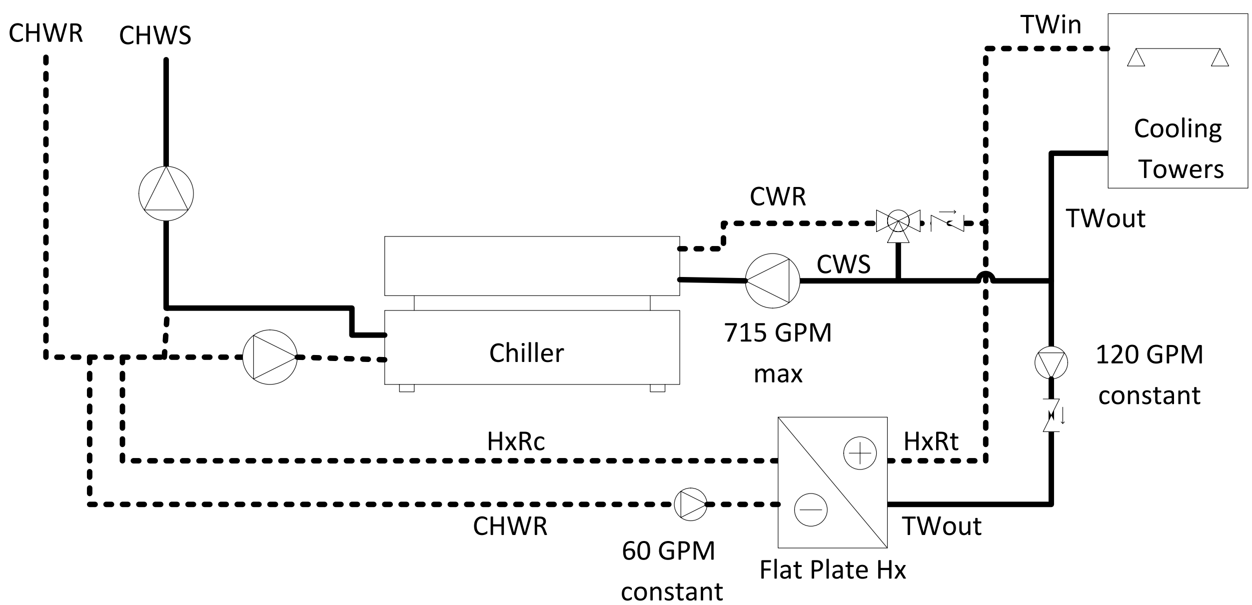

Figure 3: Schematic of Alternative Mixed System

Either of the systems shown in Figures 2 or 3 or multiple hybrid or alternate systems can be used to meet the proposed requirement as long as the cooling load for systems without airside economizers can be met solely with the water-side economizer and without a chiller at 50°F DB and 45°F WB outside air conditions, or other conditions specified in the code provisions.

In colder climate zones (climate zones 5 and colder) a flat plate heat exchanger and additional pump is added as shown in Figure 4. This allows operation in freezing conditions, although there is a reduction in savings due to the needed approach at the extra heat exchanger.

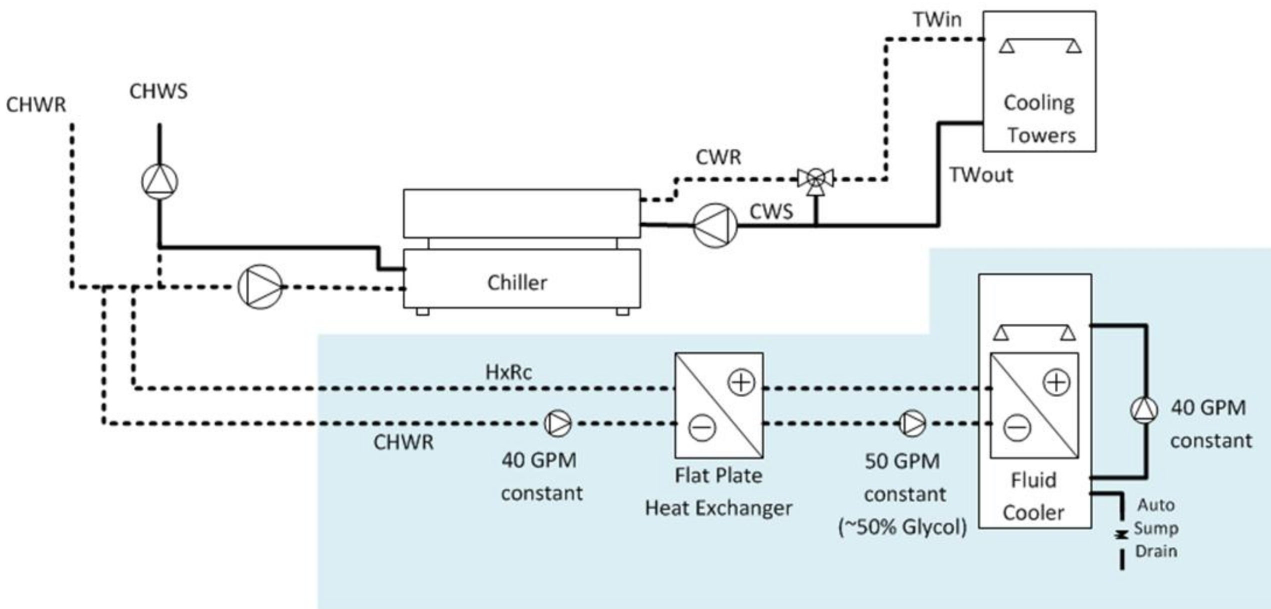

Figure 4: Schematic of Cold Climate Analyzed System

For the climate zones analyzed, the savings using a system shown in Figure 2 or 4 is developed, and then the life cycle operating cost is found, using the prototype loading and typical cooling tower and pump performance criteria, and life cycle cost parameters. For each location, the incremental energy savings is found, to arrive at a net present value of energy savings for the proposed water-side economizer addition.

Basis for Analysis

PNNL conducted the analysis for this requirement using the Large Hotel prototype building. This prototype includes both guest rooms served by fan coil units without airside economizers and larger lobby and meeting room systems with airside economizers. The savings was based on the hourly loads for cooling systems without airside economizers. In the analysis, the peak cooling loads served by the water-side economizer ranged from 50 tons to 80 tons, depending on climate zone. While in the model, these units were served by fan coil units, the load would be identical if served by radiant cooling systems or chilled beams. Building parameters are based on 2012 IECC. The prototypes have been developed by PNNL to represent a typical building with typical loading profiles where savings measures are applied. The prototypes and parameters are documented at www.energycodes.gov.[3]

The chillers in the EnergyPlus model meet minimum efficiency under 2012 IECC. While the code baseline model did not use chilled water reset, in the post processing, chilled water reset from 45°F to 55°F was assumed in conjunction with the baseline variable chilled water flow control to maximize the chilled water return temperature, improving energy recovery. While

[3] The prototype descriptions and models can be found at http://www.energycodes.gov/development/commercial/90.1_models

CHWS reset was used, no credit in this savings analysis was taken for the change from fixed 45°F chilled water supply in the code baseline to a reset schedule. To ensure that high humidity space conditions would not occur as a result of the reset schedule, a 45°F chilled water supply was maintained in the post processing model whenever the outside humidity ratio exceeded 0.009 lb. H_20/lb. air, equivalent to a dewpoint temperature of about 54.5°F. As a result, reasonable dehumidification would be maintained where necessary.

Coil load response models for variable flow vs. load were developed from a typical FCU coil to determine CHWR based on CHWS and load. A closed circuit tower model was developed from manufacturer's performance data to determine the tower leaving temperature based on outside wet bulb temperature and the CHWR entering the tower. The chiller COP for each hour was based on the hourly EnergyPlus large hotel prototype model.

For each climate zone analyzed, the cooling load without airside economizer was determined and a closed circuit cooling tower and associated fans and pumps sized to meet the 50°F DB and 45°F WB outside air condition full load requirement. The control strategy in the post processor operated the tower pumps whenever the outside wet bulb temperature was 3°F to 6°F (adjusted by climate zone) lower than the CHWR. The tower spray and chilled water pre-cool pumps operated in a constant flow mode and the tower fan airflow was adjusted based on the ratio of the potential full airflow rejected heat to the actual cooling load.

The incremental cost included a cooling tower, heat exchanger (could be separate or included in the tower – the higher cost separate approach was used for this analysis), pumps, electric starters and connection, controls, piping, fittings, and valves.[4] The system was sized for each climate zone to meet the 50°F DB and 45°F WB outside air condition full load requirement. Costs for the water-side economizer systems in hot and moderate climates with capacities from 20 to 30 tons ranged from $30,000 to $42,000. In cold climates (zones 5 through 8) due to the extra heat exchanger, a larger system is needed to achieve the economies of scale needed for an effective payback, and the added fluid cooler is in the 55 to 78 ton range with costs ranging from $78,000 to $102,000. Note that in all climate zones the water-side economizer system had about half the capacity of the cooling system without airside economizers based on meeting full load at 50°F DB and 45°F WB outside air conditions.

Cost Effectiveness

Two different cost effectiveness techniques are applied:

- The ASHRAE 90.1 committee scalar method uses the economic factors to arrive at a discounted threshold or target simple payback period (SPP) based on the measure life. If the calculated simple payback is less than this target, it is deemed to be cost effective. This method accounts for tax impacts and uses a nominal discount rate appropriate to commercial and private industry owners.

- The DOE/FEMP method uses an institutionally oriented discount rate to determine the net present value (NPV) for a particular measure. The discount rate considers the real time value of money, fuel escalation costs, and the measure life to arrive at an NPV. The NPV is the present value of savings minus the first cost. When that NPV is greater than zero, a measure is considered cost effective. This method does not include tax considerations or the opportunity value of invested capital.

[4] R S Means. *Mechanical Cost Data*. Kingston MA: Reed Construction Data.

Economic factors for the scalar method are those arrived at by the ASHRAE 90.1 committee for analysis of Standard 90.1-2013 measures. National average electric and gas rates are from EIA for 2011. The DOE/FEMP discount rate and electric and gas present value factors are from the NIST Life Cycle Cost 2011 supplement (NISTIR 85-3273-26).[5] The factors shown in Table 1 are used.

Table 1: Economic Factors

	ASHRAE SPP Method	DOE/ FEMP NPV
Economic Life - Years	22	22
Fuel Escalation Rate - %	3.76%	(varies depending on life)
Electric UPWF	N/A	15.31
Maintenance UPWF	N/A	15.94
Discount Rate - %	7.00%	3.00%
Loan Interest Rate - %	6.25%	N/A
Federal Tax Rate - %	34.00%	N/A
State Tax Rate - %	6.50%	N/A
Heating - Gas Price - $/therm	$0.9900	$0.9900
Cooling - Electric Price - $/kWh	$0.1032	$0.1032
Metric for cost effectiveness	SPP	NPV
Metric threshold	< 13.077	> 0

A maintenance cost allowance was included to cover the expected cost of water, chemical treatment, and added tower and pump maintenance. While a detailed maintenance analysis was not conducted for each climate zone, a brief literature review found case studies showing cooling tower annual maintenance at $12 to $25 per ton. To be conservative, the higher number of $25 per ton was used, adjusted for tower size in each analyzed climate zone.

The cost effectiveness results are shown in Figure 5 for net present value using FEMP economic criteria. The net present value is the present value of energy savings over the life of the measure minus the first cost and the present value of the maintenance cost allowance. In a net present value analysis, the proposal is cost effective when the net present value is greater than zero. Using this criterion, the added water-side economizer is cost effective in all analyzed climate zones except climate zone 1A (Miami).

[5] Amy Rushing, Joshua Kneifel, and Barbara Lippiatt, "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011" (NIST for USDOE FEMP, September 2011), http://www.nist.gov/customcf/get_pdf.cfm?pub_id=909539.

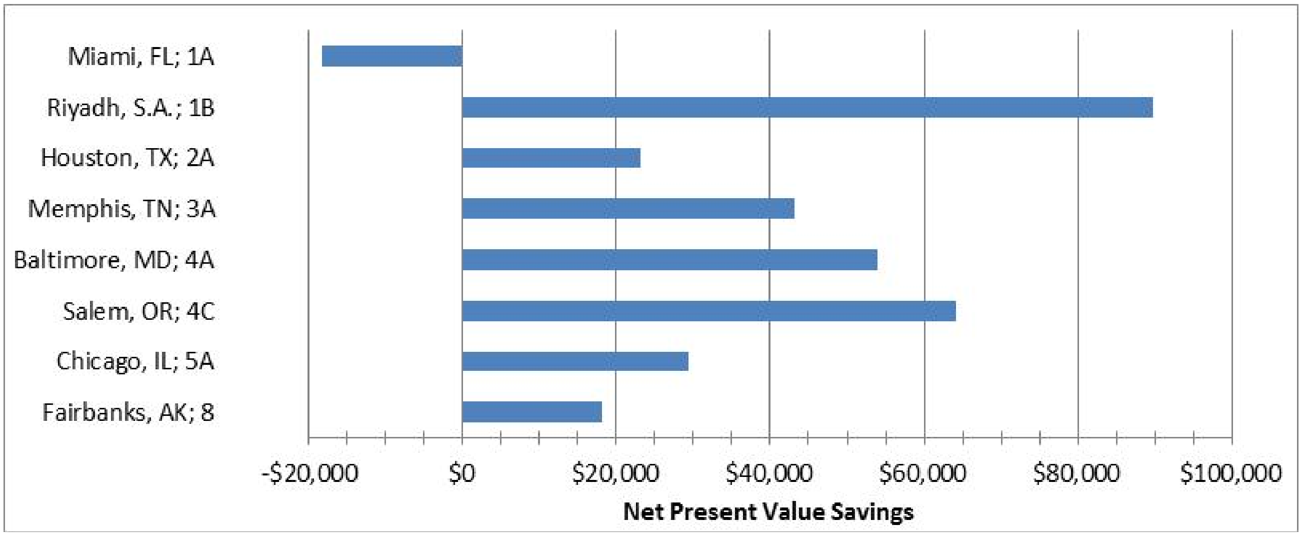

Figure 5: Net Present Value of Savings

The cost effectiveness results are shown in Figure 6 for simple payback compared to a discounted payback limit. The simple payback period (SPP) is the cost of the project, divided by the annual savings in dollars (annual energy savings minus maintenance cost). The discounted payback limit is calculated using a method and agreed to parameters developed by the ASHRAE 90.1 standard committee.[6] The discounted limit (also known as the scalar) accounts for discounting, tax impacts, and fuel escalation and a measure is cost effective when the simple payback is less than the discounted simple payback limit. For the added water-side economizer, the simple payback is below the discounted limit, and therefore cost effective, in all analyzed climate zones except 1A (Miami). In Fairbanks, the payback is just under the limit.

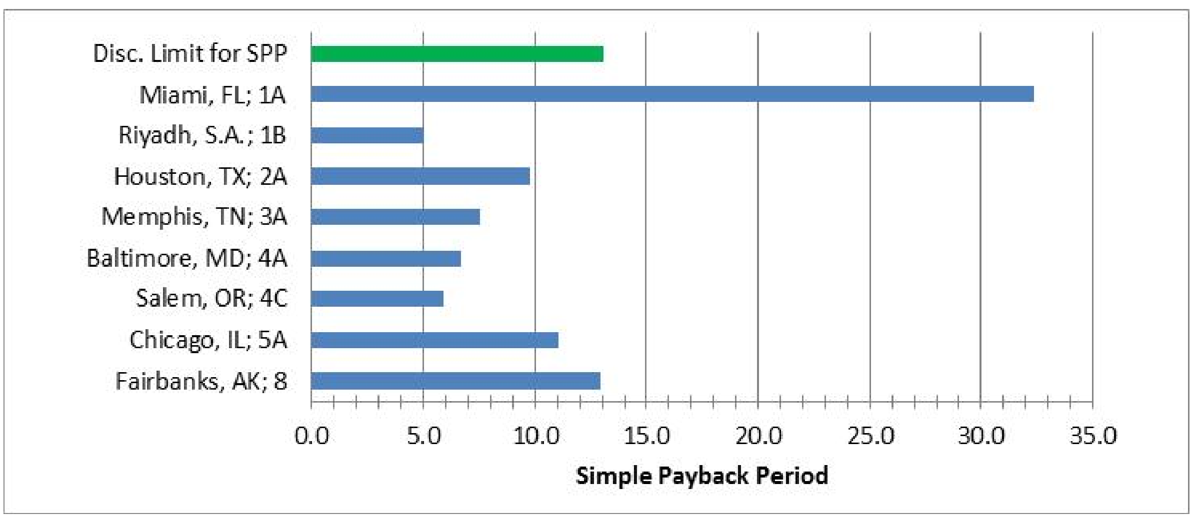

Figure 6: Simple Payback for Chilled Water Return Precooling

[6] M. F. McBride, "Development of Economic Scalar Ratios for ASHRAE Standard 90.1 R," in Proceedings of Thermal Performance of the Exterior Envelopes of Buildings VI, ASHRAE (presented at the Thermal Performance of the Exterior Envelopes of Buildings VI, ASHRAE, 1995), http://consensus.fsu.edu/FBC/2010-Florida-Energy-Code/901_Scalar_Ratio_Development.pdf.

Under both analysis methods, the added water-side economizer is cost effective in all analyzed climate zones except 1A (Miami). The analyzed climate zones were selected to cover the range of moisture level and temperature extremes. In dry climate zones, the measure is cost effective in both hot and cold extremes (1B & 8). In moist climate zones, it is cost effective in both 2A and 3A, but not climate zone 1A. It is also cost effective in intermediate climate zones 4C, 4A and 5A. By covering the extreme conditions, and both moist climate zones neighboring 1A where it was not cost effective, the analysis indicates a strong likelihood that the measure will be cost effective in all climate zones except 1A. This analysis is consistent with earlier exceptions that excluded climate zone 1A from an economizer requirement. Since the water-side approach is quite cost effective in climate zone 1B, it makes sense to require it for chilled water systems in climate zone 1B. As a result of the analysis, the additional water-side economizer is recommended in all climate zones except 1A for chilled water systems that do not have an airside economizer.