Work Paper SCE13HC039 Limitations Memo

January 27, 2014

# The purpose of this memo is to inform SCE of the limitations of the modeled calculations performed for Work Paper SCE13HC039 (VSD Retrofit to Central Plant Systems).

# Modeled Appraoch

For the VFD on CW pump measure the modelled approach varies the condenser water flow linearly with the load. This was confirmed using the hourly reporting feature of eQUEST for three sample runs: 1) constant CW flow, 2) variable CW flow with a 70% minimum flow rate, and 3) variable CW flow with a 50% minimum flow rate, as shown in the chart below.

Figure . CW Flow vs PLR

This is as expected – as the load decreases the CW flow rate is decreased down to an allowable minimum. A review of available literature was conducted to determine the viability of the modeled approach. According to an article by Taylor Engineering[[1]](#endnote-1), when optimum condenser water pump speed and flow were plotted against various parameters such as PLR, wet-bulb temperature, chiller percent power, and lift, the best correlation was flow vs. PLR. In the same article, the modeled approach for CW flow is also determined by a linear relationship (CWFR = C × PLR + D).

Further research was conducted to arrive at a reasonable selection for the minimum flow rate. According to the DOE2 dictionary[[2]](#endnote-2), this minimum flow should be above the point where the flow transitions from turbulent to laminar. One reason for this is because turbulent flow results in much better heat transfer. A cursory review of chiller manufacturer data indicates that the minimum CW flow rate can be as low as 30% of the maximum flow.[[3]](#endnote-3) Note that the baseline prototype models used in this workpaper default to 40% minimum CW flow when variable CW flow is selected. This value will depend on the number of tubes, number of passes, and tube design (e.g., smooth vs. enhanced), and will typically be on the order of 40% to 70% of design flow.[[4]](#endnote-4)

However, there are other important determinants to consider when establishing the minimum CW flow. With regard to chillers, variable condenser flow is not the norm, especially for such chillers that depend on head pressure reductions at part load. In centrifugal chillers, reduced condenser water flows may elevate head pressures, resulting in a loss of efficiency and possible chiller instability.[[5]](#endnote-5) In addition, reducing the CW flow too much when the chiller is heavily loaded and the wet bulb temperature is high will cause a centrifugal chiller to surge.[[6]](#endnote-6)

The cooling tower also imposes limits on how far the CW flow can be reduced. The CW flow must be sufficient to provide the required static lift, and to provide full coverage to the fill. If the nozzles don’t fully wet the fill, air will go through the dry spots providing no cooling benefit and cause the water at the edge of the dry spot to flash evaporate depositing dissolved solids on the fill (known as scaling).[[7]](#endnote-7) There are two kinds of cooling towers: 1) crossflow, in which the water flows vertically through the fill while the air flows horizontally across the flow of the falling water; and 2) counterflow, in which air flows vertically upward, counter to the flow of falling water in the fill. In general, crossflow cooling towers can handle much higher turndown rates (50-70% or more, which would correlate to a minimum CW flow of 50-30%). Counterflow cooling towers are not easily modified but variable flow can be achieved as long as the limitations of nozzle design and fill coverage are taken into account on the specific cooling tower model and design conditions. Counterflow towers have a limited turndown capability; enough head is needed to properly pressurize the piping plus cover the fill and the head varies with the square of the water flow (ex., 50% turndown reduces head 4x; if 3’-0” of head is needed at the inlet at half flow, 12’-0” head is required at design flow).[[8]](#endnote-8)

Summarizing the above limitations, the minimum condenser water flow for a specific application is the highest of: 1) the minimum condenser flow rate allowed by the chiller; 2) the minimum flow rate allowed by the tower. The table below summarizes general acceptable ranges for each.

Table . Minimum Flow Requirements for Chillers and Cooling Towers

|  |  |  |
| --- | --- | --- |
| **Technology** | **Minimum CW flow** | **Source** |
| Chiller | 30-70% | Taylor1 |
| Cooling Tower: Crossflow | 30-50% | SPX8 |
| Cooling Tower: Counterflow | 50-70% | T24 2008[[9]](#endnote-9) & 2013[[10]](#endnote-10) |

A source for acceptable CW flow turndown range for existing counterflow towers could not be located; the range of 50-70% given is from the latest Title 24 code cycles, which provide turndown capability requirements for new installations. As described above, the minimum CW flow values will depend greatly on the characteristics of the installed system. Furthermore, survey data could not be located regarding the minimum CW flow capabilities of chilled water systems throughout SCE territory. Therefore, rather than varying the minimum CW flow for each prototype model based on some dependent such as climate zone, vintage, etc., a conservative estimate of 70% was selected as the minimum CW flow for all of the measure simulations. Due to the limitations imposed on the CW flow rate by the chiller and tower, it is imperative that chiller manufacturer selection data and cooling tower manufacturer retrofit information be carefully reviewed before implementing this measure.

Taylor gives further caution to this measure, warning that “variable speed drives should only be used on condenser water pumps if the designer takes the time to ensure that control sequences are near-optimum”.[[11]](#endnote-11) According to Taylor, this measure can increase the energy use of the plant if not optimally controlled. As Taylor notes, “as condenser water flow falls, both pump energy and cooling tower energy (for the same condenser water supply temperature) will fall, but chiller energy will rise as leaving condenser water temperature rises.” The leaving condenser water temperature is an important determinant of chiller performance, and must be taken into account when simulating a chiller with a condenser flow other than the rated flow.2 This was observed in early modeled runs for the MBT (manufacturing/bio-technology) building type. It was found that if the leaving condenser temperature was not limited, the penalty of higher chiller consumption was greater than any pumping savings during periods of high loads. Therefore an adjustment was made to the control strategy for all of the modeled building types so that the leaving condenser temperature would not exceed the rated condenser temperature for the modeled chiller (85degF); this was achieved by setting the MAX-COND-T keyword to 85. A summary of the modeled changes for this measure is given in the table below.

Table . Modeled Changes

|  |  |  |
| --- | --- | --- |
| **Keyword** | **Baseline value** | **Measure value** |
| PUMP:CAP-CTRL | N/A | VAR-SPEED-PUMP |
| CHILLER:CW-FLOW-CTRL | CONSTANT-FLOW | VARIABLE-FLOW |
| CHILLER:CW-MIN-FLOW | N/A | 0.70 (ratio) |
| CHILLER:MAX-COND-T | N/A | 85.0 (degF) |

# DOE2 Dictionary

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# References

1. Taylor, Steven T. 2011. “Optimizing Design & Control of Chilled Water Plants Part 5: Optimized Control Sequences“ ASHRAE Journal 54(6):56-74 [↑](#endnote-ref-1)
2. http://doe2.com/download/doe-22/DOE22Vol2-Dictionary.pdf#page=193 [↑](#endnote-ref-2)
3. http://www.trane.com/Commercial/Uploads/Pdf/1049/CTV-PRC001-E4\_09012004.pdf#page=12, 2004 [↑](#endnote-ref-3)
4. Taylor, Steven T. 2011. “Optimizing Design & Control of Chilled Water Plants Part 5: Optimized Control Sequences“ ASHRAE Journal 54(6):56-66 [↑](#endnote-ref-4)
5. http://phila.ashraechapters.org/1009-CTTC.pdf [↑](#endnote-ref-5)
6. http://www.tranehk.com/eng\_news/vol41\_3.pdf#page=3 [↑](#endnote-ref-6)
7. http://www.energy.ca.gov/2008publications/CEC-400-2008-017/rev1\_chapters/NRCM\_Chapter\_4\_Mechanical\_Systems.pdf#page=83 [↑](#endnote-ref-7)
8. http://spxcooling.com/pdf/TR-014.pdf [↑](#endnote-ref-8)
9. http://www.energy.ca.gov/2008publications/CEC-400-2008-017/rev1\_chapters/NRCM\_Chapter\_4\_Mechanical\_Systems.pdf#page=83 [↑](#endnote-ref-9)
10. http://www.energy.ca.gov/2013publications/CEC-400-2013-002/chapters/04\_mechanical\_systems.pdf#page=107 [↑](#endnote-ref-10)
11. Taylor, Steven T. 2011. “Optimizing Design & Control of Chilled Water Plants Part 2: Condenser Water System Design“ *ASHRAE Journal* 53(9):26-36 [↑](#endnote-ref-11)