ANNEX VIII I 2008 I 8DHC-08-04

IEA DHC|CHP

International Energy Agency
IEA Implementing Agreement on District Heating and Cooling, including the integration of CHP

ASSESSING THE ACTUAL ENERGY EFFICIENCY OF BUILDING SCALE COOLING SYSTEMS

International Energy Agency

IEA District Heating and Cooling
Programme of Research, Development and Demonstration on
District Heating and Cooling including integration of CHP

Assessing the Actual Energy Efficiency of Building Scale Cooling Systems

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By Robert Thornton, Robert Miller, Asa Robinson and Ken Gillespie

This report is the final result from a project performed within the Implementing Agreement on District Heating and Cooling, including the integration of CHP. However, this report does not necessarily fully reflect the views of each of the individual participant countries of the Implementing Agreement.

Project report 2008: 8DHC-08-04

Preface

Introduction

The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries and reduce the dependency on oil and other fossil fuels. Thirty years later, the IEA again drew attention to serious concerns about energy security, investment, the environment and energy poverty. The global situation is resulting in soaring oil and gas prices, the increasing vulnerability of energy supply routes and ever-increasing emissions of climate-destabilising carbon dioxide.

At the 2005 Gleneagles G8 an important role was given to the IEA in advising on alternative energy scenarios and strategies aimed at a clean, clever and competitive energy future. Two years later, at the Heiligendamm G8, it was agreed that "instruments and measures will be adopted to significantly increase the share of combined heat and power (CHP) in the generation of electricity". District Heating and Cooling is an integral part of the successful growth of CHP: heat networks distribute what would otherwise be waste heat to serve local communities.

The IEA is active in promoting and developing knowledge of District Heating and Cooling (DHC). While the DHC programme (below) itself is the major global R&D programme, the IEA Secretariat has also initiated the International DHC/CHP Collaborative, the kick-off event of which took place in March 2, 2007 with a 2-year Work Plan aiming to raise the profile of DHC/CHP among policymakers and industry. More information on the Collaborative may be found on IEA's website www.IEA-org.

The major international R&D programme for DHC/CHP

DHC is an integrative technology that can make significant contributions to reducing emissions of carbon dioxide and air pollution and to increasing energy security.

The fundamental idea of DHC is simple but powerful: connect multiple thermal energy users through a piping network to environmentally optimum energy sources, such as combined heat and power (CHP), industrial waste heat and renewable energy sources such as biomass, geothermal and natural sources of heating and cooling.

The ability to assemble and connect thermal loads enables these environmentally optimum sources to be used in a cost-effective way, and also offers ongoing fuel flexibility. By integrating district cooling, carbon-intensive electrically-based air-conditioning, which is rapidly growing in many countries, can be displaced.

As one of the IEA's 'Implementing Agreements', the District Heating & Cooling programme is the major international research programme for this technology. Active now for more than 25 years, the full name of this Implementing Agreement is 'District Heating and Cooling including the integration of Combined Heat and Power'. Participant countries undertake co-operative actions in energy research, development and demonstration.

Annex VIII

In May 2005 Annex VIII started, with the participation from Canada, Denmark, Finland, the Netherlands, Norway, South Korea, Sweden, United Kingdom, and the United States of America.

Below you will find the Annex VIII research projects undertaken by the Implementing Agreement "District Heating & Cooling including the Integration of Combined Heat and Power".

Project title	Company	Report No.
New Materials and Constructions for Improving the Quality and Lifetime of District Heating Pipes including Joints – Thermal, Mechanical and Environmental Performance	Chalmers University of Technology Project Leader: Ulf Jarfelt	8DHC-08-01
Improved Cogeneration and Heat Utilization in DH Networks	Helsinki University of Technology Project Leader: Carl-Johan Fogelholm	8DHC-08-02
District Heating Distribution in Areas with Low Heat Demand Density	ZW Energiteknik Project leader: Heimo Zinko	8DHC-08-03
Assessing the Actual Energy Efficiency of Building Scale Cooling Systems	International District Energy Association Project leader: Robert P. Thornton	8DHC-08-04
Cost Benefits and Long Term Behaviour of a new all Plastic Piping System	NUON Project leader: Hans Korsman	8DHC-08-05

Benefits of membership

Membership of this implementing agreement fosters sharing of knowledge and current best practice from many countries including those where:

- DHC is already a mature industry
- DHC is well established but refurbishment is a key issue
- DHC is not well established

Membership proves invaluable in enhancing the quality of support given under national programmes. Participant countries benefit through the active participation in the programme of their own consultants and research organisations. Each of the projects is supported by a team of experts, one from each participant country. As well as the final research reports, other benefits include sharing knowledge and ideas and opportunities for further collaboration.

New member countries are very welcome – please simply contact us (see below) to discuss.

Information

General information about the IEA Programme District Heating and Cooling, including the integration of CHP can be obtained from our website www.iea-dhc.org or from:

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The IA DHC/CHP, Annex VIII, also known as the Implementing Agreement District Heating and Cooling, including the Integration of Combined Heat and Power, functions within a framework created by the International Energy Agency (IEA). Views, findings, and publications of the IA DHC/CHP do not necessarily represent the views or policies of all its individual member countries nor of the IEA Secretariat.

Acknowledgements

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Executive Summary

The costs, energy efficiency and environmental impacts of district cooling (DC) are often compared to those of building-scale chiller systems. In such comparisons, the assumptions regarding the efficiency of building-scale systems have a significant impact on the comparative economic conclusions as well as the analysis of efficiency and the related environmental impacts. Generally, the assumptions for building systems are based on theoretical values or equipment ratings based on static laboratory conditions rather than "real world" data reflecting part load operations, weather variations, operator inputs and system depreciation. This may result in underestimation of the economic, efficiency and environmental benefits of DC.

This project set out to develop more realistic data on building-scale system efficiencies, by investigating the actual annual efficiency of building cooling systems and determining how this differs from the theoretical annual efficiency using values based on test conditions. Many variables affect the efficiency of building chiller systems, including type of chiller equipment, size of chillers and cooling towers relative to seasonal loads, condenser temperatures, chilled water supply temperatures, use of variable frequency drives (VFDs) and the age and maintenance history of the equipment.

While a great deal of attention is given to the efficiency of the chiller itself, we have found very few studies or data relating to the total plant efficiency including the auxiliaries (cooling tower fans, condenser water pumps). Auxiliaries can have a significant negative impact on annual efficiency, particularly if fans and pumps are driven by fixed speed motors rather than variable frequency drives (VFDs).

Very few data are available that directly quantify the actual annual efficiency of building-scale chiller systems through sub-metering, and some of the data obtained had gaps or flaws that constrain their usefulness. Limited case study data on submetered building chiller systems reported in the literature are summarized below:

Plant type	Plant size (tons)	Annual total plant efficiency (kW/ton)
Air cooled	176	1.50
Variable speed screw	440	1.20
Ultra-efficient all variable speed with oil-less compressors	750	0.55
District cooling plant	3200	0.85

Although it is possible to obtain very high seasonal efficiencies (less than 0.65 kW/ton) with well-designed, well-operated all-VFD plants operating in favorable climate conditions, during the course of this study we were unable to obtain primary data documenting such performance.

There were also very few data available for the indirect analytical approach to quantifying building chiller efficiency – by comparing building electricity consumption before and after connection to district cooling, and using post-connection cooling consumption data to estimate the efficiency of the building chiller system operations thus eliminated.

Limited case study data on electricity consumption before and after connection to district cooling yielded calculated annual efficiencies as summarized below:

Building Name	Location	Chiller type	Calculation method	Average annual kW/ton
Gross Chemistry	Duke University, NC	Water-cooled	1	1.33
(Confidential)	Phoenix, AZ	Water-cooled	1	1.25
ITS Franklin	UNC Chapel Hill, NC	Air-cooled	2	1.21
Cheek Clark	UNC Chapel Hill, NC	Air-cooled	1	0.92

Calculation Methods

1. Based on electricity consumption before and after connection to district cooling, and cooling consumption following connection.
2. Submetering of chiller system.

Introduction

The costs, energy efficiency and environmental impacts of District Cooling (DC) are often compared to those of building-scale chiller systems. In such comparisons, the assumptions regarding the efficiency of building-scale systems have a significant impact on the comparative economic conclusions as well as the analysis of efficiency and the related environmental impacts. Generally, the assumptions for building systems are based on theoretical values or equipment ratings based on static laboratory conditions rather than "real world" data reflecting part load operations, weather variations, operator inputs and system depreciation. This may result in underestimation of the economic, efficiency and environmental benefits of DC.

This project set out to develop more realistic data on building-scale system efficiencies, by investigating the actual annual efficiency of building cooling systems and determining how this differs from the theoretical annual efficiency using values based on test conditions. Particularly when considering all auxiliaries (e.g. cooling tower fans, pumps) and the relative frequency of part load vs. full load operating conditions, the annual efficiency could differ dramatically from the stated efficiency at design conditions.

The project goal was to provide documentation for realistic comparisons of DC to building-scale systems in a number of contexts, including:

- marketing of DC service to prospective customers by DC utility companies;
- municipal planning for a development area;
- private sector planning for multi-building developments; and
- local, national or EU energy/environmental policy analysis.

Key Technical Variables and Measures

Introduction

The fundamental question this project attempted to answer is "What is the total real-world annual electrical efficiency of building-scale chiller systems?" The investigation was focused on larger buildings (peak cooling load >200 tons or 700 kW), although some data on smaller systems was obtained and is presented.

There are three basic approaches to assessing chiller system efficiency:

- Modelling, typically using detailed building and system simulation;
- Indirect measurement (monitor changes in total building electricity consumption after a building is connected to district cooling, and compare the reduction to the measured chilled water consumption following connection); and
- Direct measurement (submetering) of chiller system components and chilled water production).

Modelling has the advantage that it is known that the comparison is between exactly similar situations, except for those aspects that have been deliberately changed. It also allows comparable results to be produced for different climates and systems. The disadvantage is that the results are only as good as the models used, and the models do not capture the negative impacts of performance degradation due to suboptimal operation and maintenance practices.

Indirect measurement has the advantage of reflecting actual rather than theoretical conditions, but it is difficult to ensure that conditions are truly the same for the pre-connection and post-connection measurements (or to reliably compensate for any differences). Such differences may arise, for example, because of weather or changing occupancy. Direct measurement is best, but it is expensive and time-consuming to implement.

The chiller plant equipment of interest is that required to produce cooling, i.e. chillers, cooling towers, condenser pumps, and in some cases chilled water pumps* along with special equipment such as cooling tower sump heaters and water conditioning equipment. Chilled water pumps are asterisked because they are not part of the equipment that produces the cooling in these chiller plants. They move the chilled water from the plant to the terminal equipment in the building HVAC system. The primary pumps in primary/secondary pumping may be an exception, since they are there to pump constant flow through each chiller.

While a great deal of attention is given to the efficiency of the chiller itself, we have found very few studies or data relating to the total plant efficiency including the auxiliaries (cooling tower fans, condenser water pumps). Auxiliaries can have a significant negative impact on annual efficiency, particularly if fans and pumps are driven by fixed speed motors rather than variable frequency drives.

This section of the report reviews the key variables affecting system efficiency, in order to provide a context for the later discussion of data. These variables include but are not limited to:

- Type of chiller equipment
- Sizing of chiller(s) and cooling tower(s) relative to seasonal loads
- Condenser temperature
- Chilled water supply temperature
- Use of variable frequency drives (VFDs)
- Age of equipment and maintenance history

Before discussing the impact of these variables, basic efficiency measures are introduced and defined.

Basic Efficiency Measures

Coefficient of Performance (COP)

Coefficient of Performance (COP) is the ratio of the rate of heat removal to the rate of energy input at a specific set of load and condensing conditions. More efficient systems have a higher COP. Since this parameter is a ratio, consistent application of any unit of energy can be used, e.g., COP = kilowatts (kW) cooling output / kW power input.

kW/ton Efficiency

In the USA, cooling system efficiency is often quantified in kW/ton. One ton of cooling is equal to the removal of 3.516 kW (12,000 Btu per hour) of heat. Thus, the relationship between COP and kW/ton can be depicted as shown in Figure 1.

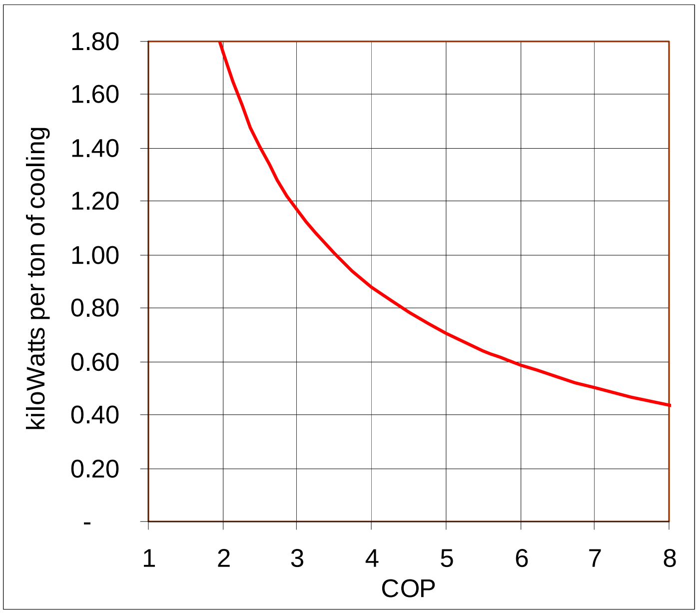

Figure 1. Conversion of COP to kW/ton

Key Variables

Chiller type

The three basic types of compressors used in compression water chillers are reciprocating, rotary and centrifugal. Table 1 below summarizes the size ranges of the various compression chiller types. Centrifugal chiller compressors are the most efficient, and are most likely to be the chiller type used by buildings targeted for district cooling service (i.e., larger buildings).

Chiller Type	**Size range**	
	tons	**kW**
Reciprocating	50 – 230	175-800
Rotary	70 – 400	240-1400
Centrifugal	200 – 2,500	700-8800

Table 1. Size ranges of chiller compressor types

A reciprocating compressor uses a piston driven from a crankshaft. Similar to a car engine, refrigerant is drawn into the cylinder during the down stroke and compressed in the up-stroke.

Although rotary compressors can use scrolls or rotating vanes, the more common type for packaged water chillers is the helical screw type.

Large commercially available compression chiller systems are based on centrifugal compressors. Usually the compressors are driven with electric motors, but it is also possible to drive chillers directly with reciprocating engines, combustion turbines, steam turbines, or a combination of technologies.

Like centrifugal pumps, an impeller provides the force to compress the refrigerant vapor. Centrifugal chillers can use single stage or multiple stage compressors. With multiple stage compressors the efficiency can be improved through the use of inter-stage economizers.

Sizing of chillers and cooling towers relative to load

The experience of the international district cooling industry over the past 30 years is clear: conventional load estimation methodologies and software tend to overstate peak loads. This is understandable, given the consequences of underestimating loads for the purposes for which these methods are used. The last thing a consulting engineer wants is to be blamed for inadequate capacity. Consequently, typical load estimation methodologies tend to result in unrealistically high load estimates. Design practices that contribute to high load estimates include:

- Using inappropriately high design temperatures for wet bulb and dry bulb;
- Assuming the peak dry bulb and wet bulb temperatures are coincident;
- Compounding multiple safety factors; and
- Inadequate recognition of load diversity within the building.

The result of overestimation of load is oversizing of chillers and cooling towers, which contributes to operation of systems at suboptimal levels during much of the year. Poor operations, particularly lack of attention to chiller staging, can exacerbate this problem.

During the last 15 years, great improvements have been made in part-load efficiency of commercially available chillers. “Part-load performance” of chillers is usually presented based on corresponding decreases in entering condenser water temperature (ECWT) as the load decreases. At a fixed ECWT, the efficiency of older chiller compressors dropped significantly at lower loads. With today’s state-of-the-art chillers, constant-speed chiller efficiency degrades very little until load drops below about 40% (Figure 2). This figure is based on data from Reference 16. With variable-speed chillers, efficiency is actually maximized at about 50% loading, with kW/ton increasing as load goes up or down from that level. Below 40% loading the efficiency of even variable-speed compressors degrades significantly.

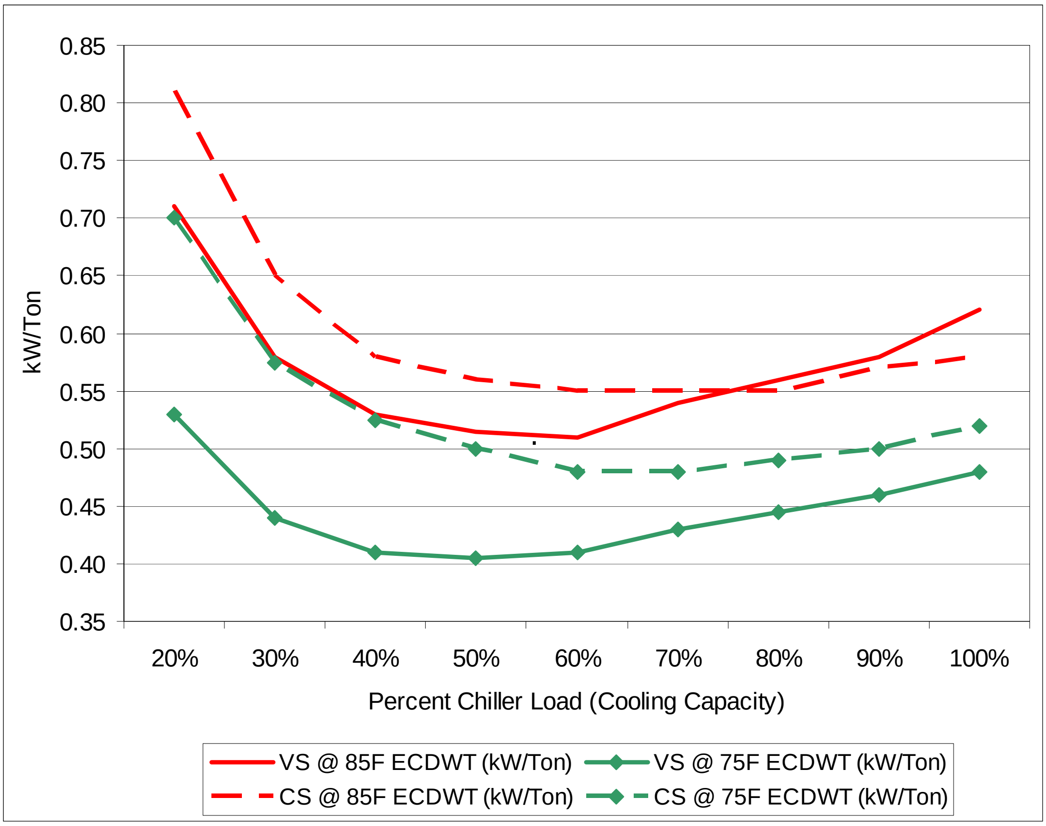

Figure 2. Part-load efficiency of constant-speed and variable-speed chiller compressors at fixed ECWT

Note that these data address only the chiller compressor. As discussed below, part-load performance of cooling tower fans and condenser pumps can significantly reduce total annual plant efficiency.

Condenser temperatures

Chillers are more efficient at lower heat sink temperatures (which generally occur at lower cooling loads). For example, as illustrated in Figure 3, COP increases from 5.31 to 6.23 as the ECWT decreases from 85°F to 75°F (29.4°C to 23.9°C), a drop of 17%. This figure is based on Reference 16, Table 6.8.1I (Minimum Efficiencies for Centrifugal Chillers of 150-300 tons capacity). The COPs illustrated are at 42°F (5.6°C) LCWT and 3 gallons per minute (gpm) or 0.183 liters per second (lps) per ton condenser flow rate.

Chilled water supply temperature

Chillers are more efficient at higher leaving chilled water temperatures. For example, as illustrated in Figure 4, COP increases from 5.06 to 5.55 as the leaving chilled water temperature (LCWT) increases from 40°F to 44°F (4.4°C to 6.7°C), an increase of 10%. This illustration is based on Reference 16, Table 6.8.1I (Minimum Efficiencies for Centrifugal Chillers of 150-300 tons capacity). The COPs illustrated are at 85°F (29.4°C) ECWT and 3 gpm/ton (0.183 lps) condenser flow rate.

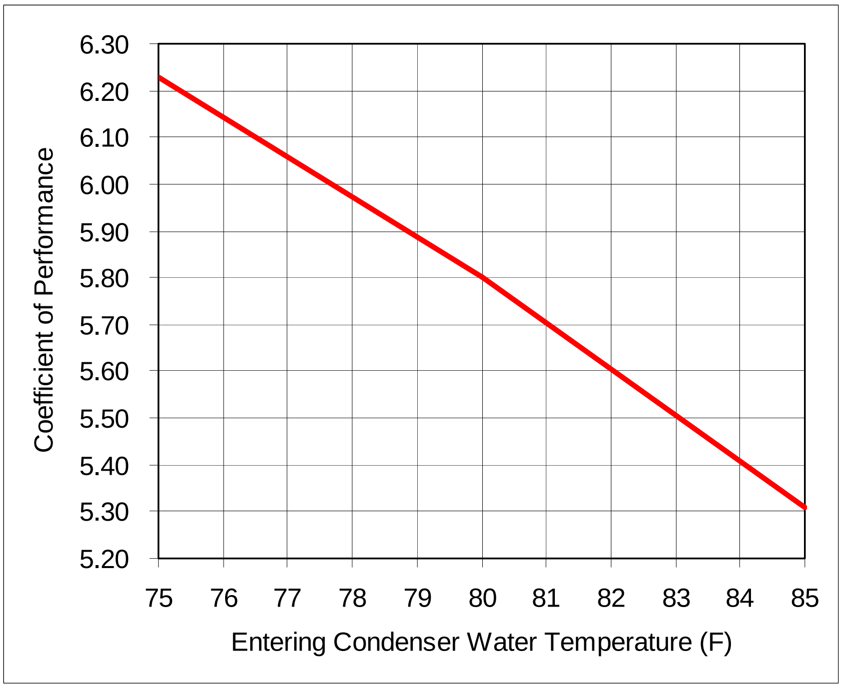

Figure 3. Impact of Entering Condenser Water Temperature on Coefficient of Performance

(From ASHRAE 90.1-2004, Table 6.8.1 I: Chillers between 150 and 300 tons)

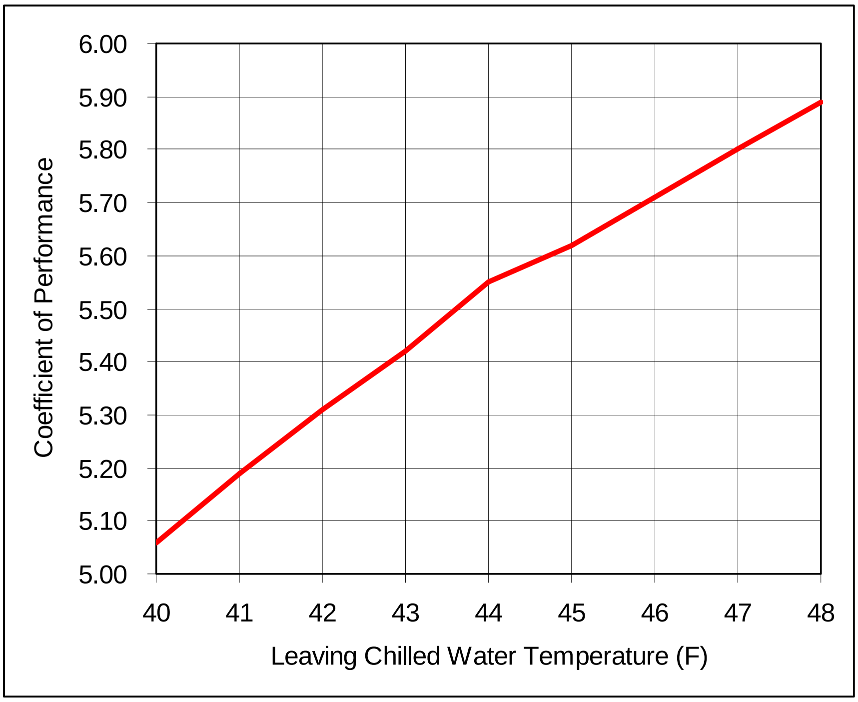

Figure 4. Impact of Leaving Chilled Water Temperature on Coefficient of Performance

(From ASHRAE 90.1-2004, Table 6.8.1 I: Chillers between 150 and 300 tons)

Variable frequency drives

Thus far, the discussions above have focused solely on the chiller. However, the cooling tower fans and condensers pumps can have a significant impact of total annual chiller plant efficiency. Fixed-speed fans and pumps degrade annual performance as they operate at low loads. Increasingly, variable-speed drives, or variable-frequency drives (VFDs), are being recommended for driving pumps and fans. Although these drives have a higher capital cost, they can prove cost-effective depending on many case-specific variables, including voltage level, annual loads on an hourly basis, electric tariffs and control system design. Table 2 summarizes one author's generalizations regarding centrifugal chiller plant efficiencies in Southern California (Reference 2) showing the significant impact that all-VFD design could have on efficiencies.

	kW/ton		
	Low	High	Average
New all-variable-speed chiller plants	0.45	0.65	0.55
High-efficiency optimized chiller plants	0.65	0.75	0.70
Conventional code-based chiller plants	0.75	0.90	0.83
Older chiller plants	0.90	1.00	0.95
Chiller plants with design or operational problems	1.00	1.30	1.15

Table 2. Generalized centrifugal chiller plant efficiencies in S. California

Age and maintenance

Older chillers were typically designed for lower efficiencies, and age and poor maintenance practices can have a significant negative effect on total efficiency.

Annual Efficiency Measures

ARI 550 (IPLV and NPLV)

The Air-conditioning and Refrigeration Institute (ARI) published ARI Standard 550/590-98 in 1998. This standard was updated in 2003, and establishes several measures of efficiency to facilitate comparison of chiller alternatives.

IPLV

Integrated Part Load Value (IPLV) is based on specific rating parameters, with a calculation of the weighted average efficiency at part load capacities based on an assumed "typical season". IPLV rating conditions are:

- 44°F (6.7°C) leaving chilled-water temperature;
- 85°F (29.4°C) entering condenser water temperature (ECWT) for water cooled systems or 95°F (35.0°C) outdoor dry bulb temperature for air cooled systems;
- 2.4 gallons per minute (gpm) per ton, equal to 0.043 liters per second (lps) per kW, evaporator flow;
- 3.0 gpm/ton (0.054 lps per kW) condenser flow; and
- 0.0001 square foot-°F-hr/Btu (0.000018 square meters-°C/W) fouling factor.

The IPLV formula uses a set of four operating conditions. Each condition consists of a "% design load" and a "head." The head is represented by either an outdoor dry bulb (db) temperature for air-cooled chillers, or an entering condenser water temperature (ECWT) for water-cooled chillers. For water-cooled chillers, the four conditions are summarized in Table 3. The weighting is based on weather data from around the United States, and is an attempt to estimate an average condition recognizing the major impact of weather on both chiller loading and efficiency.

% load	ECWT	Weighting
100%	85	1%
75%	75	42%
50%	65	45%
25%	65	12%

Table 3. Weighting assumptions for Integrated Part Load Value (IPLV)

The result of the formula is a chiller efficiency number expressed in kW/ton. If the chiller design conditions are the standard ARI conditions, then the efficiency number is known as IPLV.

NPLV

If chiller design conditions are anything other than the standard ARI conditions, then the efficiency number is known as the Non-standard Part Load Value (NPLV). With NPLV, case-specific ECWT are used for the 100% and 75% load calculations, with a 65°F (18.3°C) ECWT for the 50% and 25% load conditions. Weighting factors are the same as for IPLV.

ARI recognizes that an NPLV rating can't predict exactly what the absolute chiller efficiency would be in an actual installation. NPLV does, however, provide a meaningful way of comparing the relative efficiency of different chiller models. The actual efficiency may differ from the NPLV, but each chiller model should differ by a similar amount.

ESEER

A European index equivalent to the ARI's IPLV has now been defined. Manufacturers have to present data to Eurovent in order to achieve certification. Seven points of operation have to be presented: full load and, for each part-load percentage, two points around the exact value. It is then possible, using interpolation, to calculate the ESEER. From the certified part-load performance table, Eurovent compute a single figure allowing the comparison of chiller performance in the cooling mode. This system is equivalent to the American IPLV system.

The ESEER figure is designed to be representative of the seasonal annual performance, taking into account the different climatic conditions found within the different member states of the EU.

This single figure (for each system) is published in the Eurovent Directory of Certified Products together with cooling capacity and power input for standard conditions at full load.

ASHRAE Guideline GPC 22

ASHRAE has published a guideline for instrumentation for monitoring central chilled water efficiency (Reference 4). Guideline 22 was developed by ASHRAE to provide a source of information on the instrumentation and collection of data needed for monitoring the efficiency of an electric-motor-driven central chilled-water plant. A minimum level of instrumentation quality is established to ensure that the calculated results of chilled-water plant efficiency are reasonable. Several levels of instrumentation are developed so that the user of this guideline can select that level that suits the needs of each installation.

The basic purpose served by this guideline is to enable the user to continuously monitor chilled-water plant efficiency in order to aid in the operation and improvement of that particular chilled-water plant, not to establish a level of efficiency for all chilled-water plants. Therefore, the goal is to improve individual plant efficiencies and not to establish an absolute efficiency that would serve as a minimum standard for all chilled-water plants.

Standards

ASHRAE 90.1

The original ASHRAE 90 standard was published in 1975 by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, and has been periodically updated since then. The current version is 90.1-2004, and a new update is being prepared.

In Tables 6.8.1 H, I and J, ASHRAE 90.1 establishes standards for minimum efficiency performance at specified rating conditions and with specific test procedures. Chiller efficiencies are quantified as COP and NPLV, based on ranges of conditions for LCWT, ECWT and condenser flow rate, for three size ranges of chillers:

- Less than 150 tons;
- 150 to 300 tons; and
- Over 300 tons.

In Table 6.8.1 G, minimum cooling tower fan efficiency standards are set for design conditions, expressed as maximum flow rating of the tower in gallons per minute divided by the fan nameplate rated motor power (gpm/hp) as follows:

- Propeller or axial fan cooling tower 38.2 gpm/hp
- Centrifugal fan cooling towers 20.0 gpm/hp

As these standards are only for rated conditions, they do not address annual efficiency.

Condenser pumps are not addressed in the main body of the 90.1 standard, but are addressed in Informative Appendix G – Performance Rating Method. In paragraph G3.1.3.11, the baseline building design condenser water pump power is specified as 19 W/gpm. Again, this is for the design condition only.

Energy Performance of Buildings Directive (EPBD)

The European Union (EU) directive on the energy performance of buildings (2002/91/EC) requires Member states to develop a calculation method for the energy performance of buildings. Although this is in theory left to member states, the EU has developed a standard to be used at a Europe-wide level.

The UK has developed a calculation method and a timetable for implementation of energy performance certificates (EPCs) to promote the improvement of the energy performance of buildings. The EPC program is part of the implementation in England and Wales of the Energy Performance of Buildings Directive (EPBD).

The legislation for EPBD was laid in Parliament in March 2007, and will come into force in a phased manner as outlined in the Table 4 below. The first key milestone was when Energy Performance Certificates (EPC) were introduced for the marketed sale of domestic homes, as part of the Home Information Pack. The Government announced on 13 March 2008 transitional arrangements for buildings already on the market as of 6 April. Any building which is on the market before then and remains on the market afterwards will need an EPC by 1 October at the latest. If it is sold or rented out in the meantime, an EPC must be commissioned and then handed over as soon as reasonably practicable. This is intended to make it easier for owners and landlords of large buildings to comply with the legislation. Similar provisions will apply for the introduction of EPCs on buildings over 2,500 square meters. This responds to industry's expectations and is intended to ensure a smooth introduction on 6 April.

6 April 2008	EPCs required on construction for all dwellings. EPCs required for the construction, sale or rent of buildings, other than dwellings, with a floor area over 10,000 $m^{2.}$
1 July 2008	EPCs required for the construction, sale or rent of buildings, other than dwellings, with a floor area over 2,500 m^2.
1 Oct. 2008	EPCs required on the sale or rent of all remaining dwellings EPCs required on the construction, sale or rent of all remaining buildings, other than dwellings. Display certificates required for all public buildings >1,000 $m^{2.}$
4 Jan. 2009	First inspection of all existing air-conditioning systems over 250 kW must have occurred by this date*.
4 Jan. 2011	First inspection of all remaining air-conditioning systems over 12 kW must have occurred by this date. (A system first put into service on or after 1 January 2008 must have a first inspection within 5 years of it first being put into service.)

Table 4. Schedule for implementation of energy performance certificates in England and Wales

Prior Studies

North America

A small number of studies, papers and articles address the issue of seasonal chiller system efficiency. Kolderup, et al (Reference 5) described a research project to determine the impact of design decisions on the performance of large commercial HVAC systems in San Jose CA. However, the focus was on air-side design and performance of built-up variable air volume (VAV) systems with chilled water cooling. The conditions for this project are summarized in Table 5.

Occupancy type	Office with data center
Location	San Jose, CA, USA
Floor area	105,000 square feet
Occupancy date	October 1999
Monitoring period	Nov. 2001 -- February 2002
Chilled water plant	Two water-cooled chillers, 250 tons each
Load during monitored period	20-40 tons

Table 5. San Jose case study of low-load efficiencies

Monitored efficiencies during low load conditions were very poor, with chiller energy accounting for only one half or less of the total chilled water system power consumption. At 40 tons load (8% of total capacity or 16% of the capacity of one chiller), the auxiliaries consumed almost 1.0 kW/ton. Efficiencies for the chiller only are shown in Figure 5, and total plant efficiency (including chiller, condenser pump, cooling tower fan and chilled water pump) is illustrated in Figure 6.

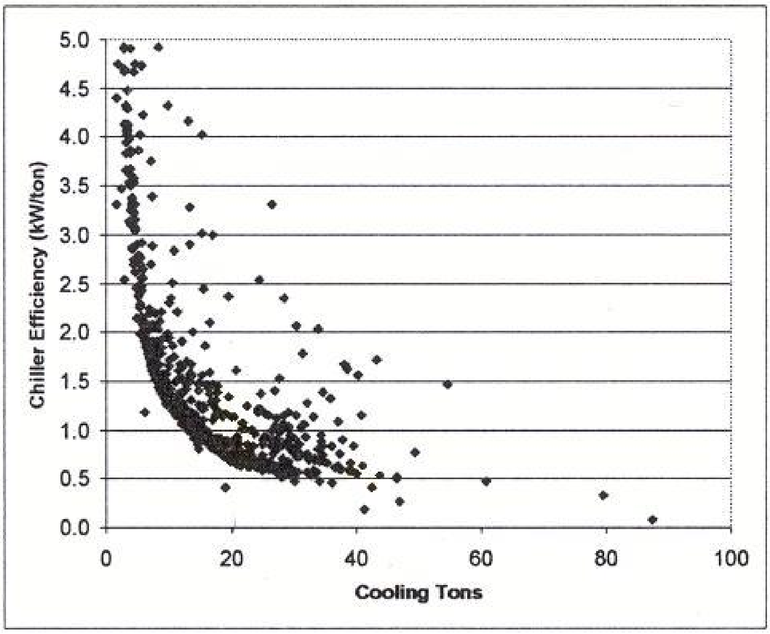

Figure 5. Measured chiller efficiency at part load, San Jose case study

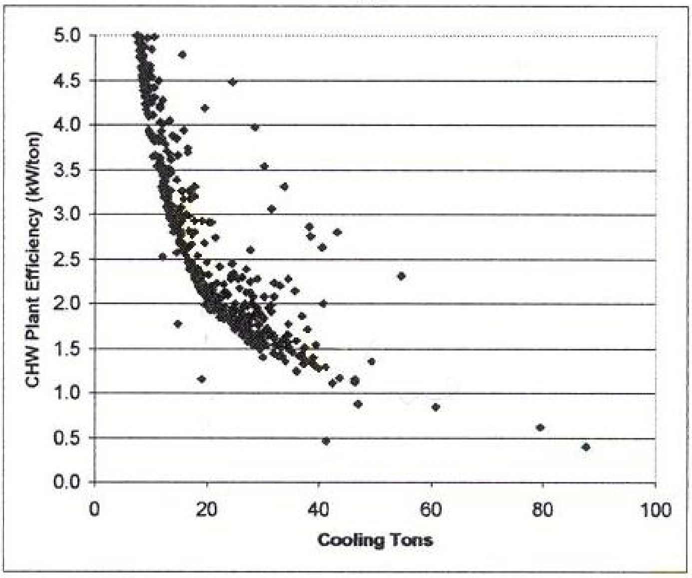

Figure 6. Measured chilled water system efficiency, San Jose case study

An article published in HPAC Engineering in May 2007 (Reference 15) reports on results of monitoring of total plant efficiencies in a range of chiller plant types, as summarized in Table 6. The data indicate a comparative advantage for the large central plant compared with typical building chiller plants. However, the potential efficiencies with state-of-the-art technology is also indicated.

Plant type	Plant size (tons)	Annual total plant efficiency (kW/ton)
Air cooled	176	1.50
Variable speed screw	440	1.20
Ultra-efficient all variable speed with oil-less compressors	750	0.55
District cooling plant	3200	0.85

Table 6. Four case studies of total plant efficiencies of various plant types

Results of chiller and chiller system modelling for a "prototypical" office building in Northern California is shown in Appendix 1 (Reference 19) Although these data do not reflect improvements in chiller efficiency during the last 10 years, they clearly illustrate the impact of loading on chiller system performance.

Europe

Measured Chiller Efficiency in use: Liquid Chillers and Direct Expansion Systems within UK Offices (2004)

This report (Reference 11) concerns work undertaken by the Welsh School of Architecture under contract to BRE on the measurement of the energy efficiency in-use of three liquid chillers and a split direct expansion (DX) system between May 2002 and July 2003. The report summarizes the monitoring work carried out and presents analysis of the data obtained. The work was supported by the Carbon Trust and technical assistance was provided by Toshiba Carrier Air Conditioning UK Ltd. The data was based on actual metered performance of the different system at a frequency of less than one hour.

Results are summarized in the following tables. Table 7 indicates the results in EER (COP) and Table 8 shows the results in kW/ton.

		Size		Efficiency (EER)							Typical system efficiency (EER)	
					Actual daily chiller		Actual daily system					
System	Type	kW	tons	Rated chiller	Low	High	Low	High	Actual daily peak	Average system load	Low	High
1	Packaged air cooled chiller and fancoil	50	14.2	2.48	2.00	4.50	0.50	2.00	1.60	21.0%	1.00	1.40
2	Water cooled screw chiller and fancoil	1,275	362.6	4.46	3.20	5.30	1.10	2.00	1.70	19.0%	0.80	1.60
3	Packaged air cooled chiller and fancoil	100	28.4	2.66	2.10	3.30	0.40	1.70	1.40	8.3%	0.30	1.40
4	DX split	8	2.3	2.42	NA	NA	1.20	5.50	3.40	44.0%	1.30	1.70

Table 7. Efficiency results from UK study (EER)

		Size		Efficiency (kW/ton)							Typical system efficiency (kW/ton)	
					Actual daily chiller		Actual daily system					
System	Type	kW	tons	Rated chiller	Low	High	Low	High	Actual daily peak	Average system load	Low	High
1	Packaged air cooled chiller and fancoil	50	14.2	1.42	1.76	0.78	7.03	1.76	2.20	21.0%	3.52	2.51
2	Water cooled screw chiller and fancoil	1,275	362.6	0.79	1.10	0.66	3.20	1.76	2.07	19.0%	4.39	2.20
3	Packaged air cooled chiller and fancoil	100	28.4	1.32	1.67	1.07	8.79	2.07	2.51	8.3%	11.72	2.51
4	DX split	8	2.3	1.45	NA	NA	2.93	0.64	1.03	44.0%	2.70	2.07

Table 8. Efficiency results from UK study (kW/ton)

A/C Energy Efficiency in UK Office Environments

This study (Reference 13) presents findings of a two-year programme of field research and monitoring of the energy consumption of generic Air-Conditioning (A/C) systems in UK Office environments. The work has been undertaken to provide information on the actual energy consumption of the systems as operated in these environments.

The findings presented are derived from monitoring the energy consumption of 34 Office A/C systems at 15-minute intervals around the UK for between 12 and 18 months. Monitoring commenced in April 2000 and concluded in the summer of 2002.

This study monitored the hourly electricity demand of the chiller units but did not monitor the hourly cooling output of the systems. The study therefore provides more information regarding the demand patterns of the load rather than detailed performance information under different operating conditions. The study was of limited use to this project.

Energy Efficiency Certification of Centralised Air Conditioning (EECCAC) Study

BRE were the UK participant in a recent European R&D project EECCAC (Energy Efficiency Certification of Centralised Air-Conditioning) that included the development of energy performance rating indices for chillers (the proposed ESEER – European Seasonal Energy Efficiency Rating) chiller performance measurements. This project included chiller measurements by industrial and academic partners. (Reference 12)

BRE also worked on air-conditioning energy calculation methods for building energy certification in support of the European Energy Performance of Buildings Directive. This requires the inclusion of HVAC seasonal efficiency as well as building construction practices. Specifically, BRE represents the UK on European standards working groups in this area, and are producing the National Calculation Tool for the UK.

Air-conditioning constitutes a rapidly growing electrical end-use in the European Union (EU), yet the possibilities for improving its energy efficiency have not been fully investigated. Within the EECCAC study twelve participants from eight countries including the EU manufacturers' association, Eurovent, engaged in identifying the most suitable measures to improve the energy efficiency of commercial chillers and air conditioning systems. Definitions of all centralised air conditioning (CAC) systems found on the EU market have been given. All CAC equipment test standards have been reviewed and studied to assess their suitability to represent energy efficiency under real operating conditions. European CAC market and stock data have been assembled for the first time. BRE was a participant in this project.

This study involved the hourly simulation using the DOE2 building simulation model rather than monitoring at a building level. The project made use of tests conducted on chillers in laboratories under different part load conditions.

Data Obtained in this Study

Introduction

Several sources of additional data were sought in this study:

- Data on submetering of building chiller systems;
- Data on buildings that have converted to district cooling from building chillers

Submetering data

Building chiller systems

Data from submetering of six sites was provided by Pacific Gas & Electric and is summarized in Appendix 2. These data address a wide variety of circumstances, including different chiller types, pumping arrangements, chiller loading and seasonal monitoring periods. Some of the data are only for selected dates. Information regarding auxiliary equipment (cooling towers, primary chilled water pumps, and condenser water pumps) is incomplete.

Performance across these sites varies significantly, from 0.47 kW/ton for the all-VFD plant at Site 4 to 1.41 kW/ton for a poorly loaded screw chiller plant at Site 6. The Site 4 data are only for two one-week periods. The Site 4 plant, in addition to being all-VFD, appears to have been operating at loads which would facilitate high efficiency (average load was 83% of the capacity of a chiller). The data could not be verified, and we note that the maximum cooling load indicated in the data substantially exceeds the total capacity of the plant.

The Site 6 plant suffered from poor loading (average load was 15% of the total plant capacity or 30% of the capacity of each chiller). The single compressor screw chillers operate very inefficiently at low loads. VFDs on condenser pumps are controlled based on chiller lift. Lift never changes on the screw chillers (condenser water is held at 80°F (26.7°C) and the chilled water temperature is held constant too). VFDs on the primary pumps were used for balancing. Therefore the VFDs never modulate. VFD on tower fans maintains 80°F (26.7°C) pan water. Also, note that secondary pumps were included in performance calculations.

The Site 5 data only shows the performance of the lead chiller, so these data may show an efficiency that would exceed that of the entire plant. On the other hand, however, note that the average load for the monitored period is quite low (16% of the chiller capacity).

Sites 1-3 each cover six months of operation (July-Dec. or June-Nov.), with a wide range of results (0.64 kW/ton at Site 1 to 1.17 kW/ton at Site 3). The Site 1 data specifically state that off and start-up conditions are not included in the performance calculations.

At the University of North Carolina – Chapel Hill, at the ITS Franklin building, a 255 ton chiller plant (three air-cooled screw chillers, each 85 tons capacity) was submetered during the period February 2007 to February 2008. The average power consumption was 1.21 kW/ton.

District cooling plant

Table 9 and Figures 7-12 summarise monthly data on the efficiencies of five electric centrifugal chillers obtained from the Franklin Heating Station, a district energy system in Rochester, Minnesota. These data are for chillers only, without cooling towers or condenser pumps, and they represent a district cooling plant rather than a building scale system. However, the data do provide examples of how chiller efficiency varies depending on chiller loading.

Elecric chiller kW/ton

	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1			0.79		0.78	0.75	0.74	0.74	0.75	0.75		0.92	0.75
Chiller #4	0.61	0.60	0.62	0.69	0.63	0.62	0.64	0.63	0.65	0.65	0.69	0.63	0.63
Chiller #7			0.65	0.67	0.61	0.59	0.60	0.60	0.60	0.60	0.66		0.61
Chiller #8			0.53	0.64	0.57	0.56	0.58	0.58	0.57	0.57	0.58		0.58
Chiller #9			0.63	0.67	0.60	0.58	0.58	0.58	0.59	0.60	0.63		0.59

Electric chiller average load as % of total chiller capacity

	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1			74%		82%	92%	98%	96%	95%	93%		60%	93%
Chiller #4	71%	68%	86%	52%	77%	76%	76%	77%	74%	69%	53%	76%	70%
Chiller #7			70%	60%	75%	87%	89%	89%	103%	78%	52%		83%
Chiller #8			94%	58%	89%	92%	94%	92%	89%	89%	81%		89%
Chiller #9			73%	54%	75%	87%	91%	90%	113%	72%	60%		82%

Table 9. Monthly electric chiller efficiencies & average chiller load, 2007, Rochester MN

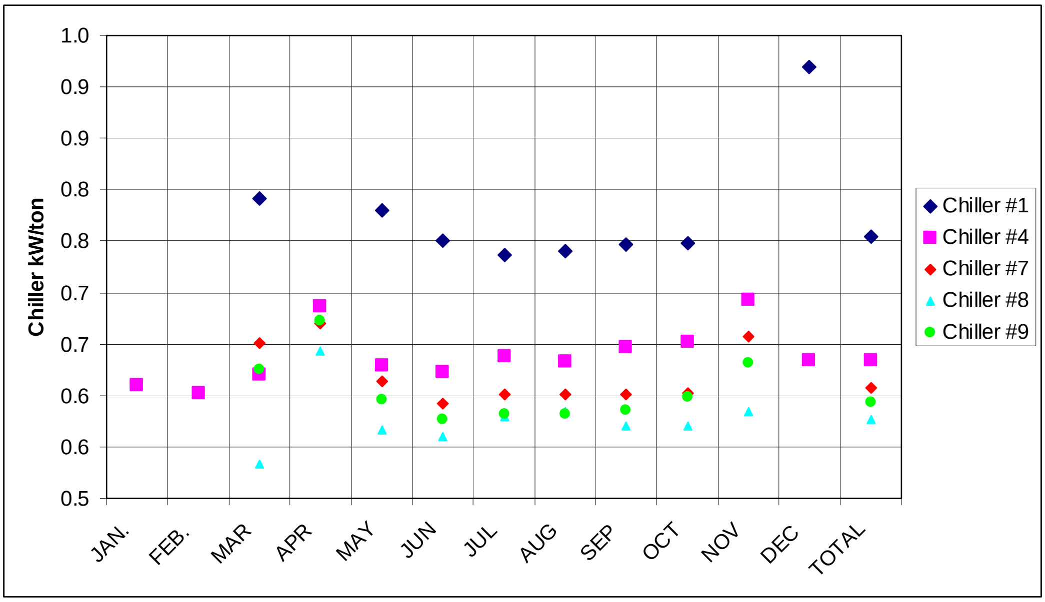

Figure 7. Chiller efficiency data by month, 2007, Rochester MN

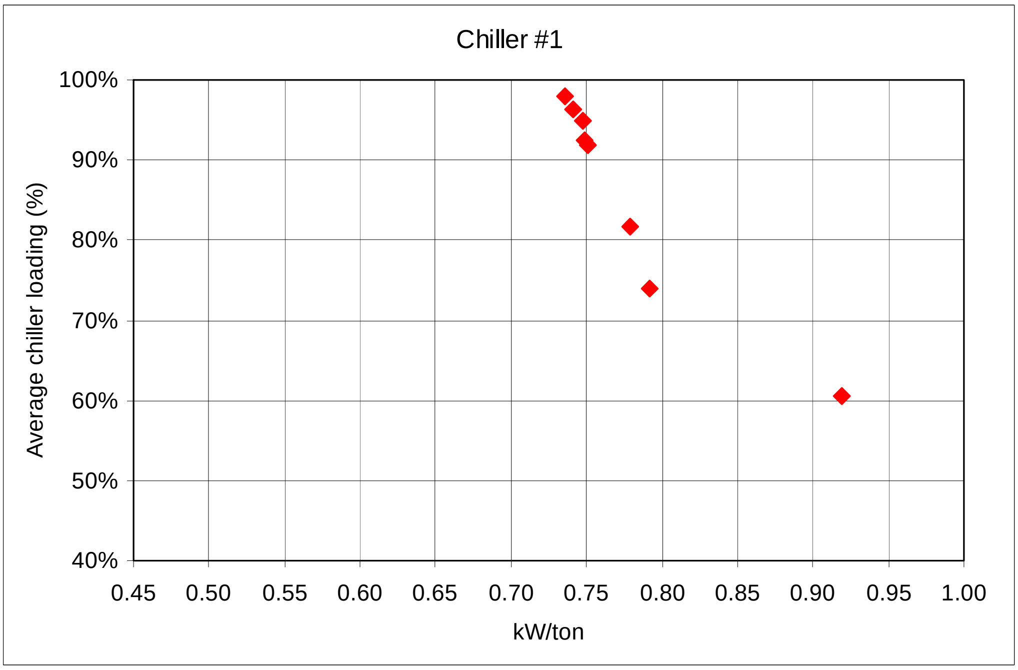

Figure 8. Relationship of chiller efficiency and chiller loading, Chiller #1

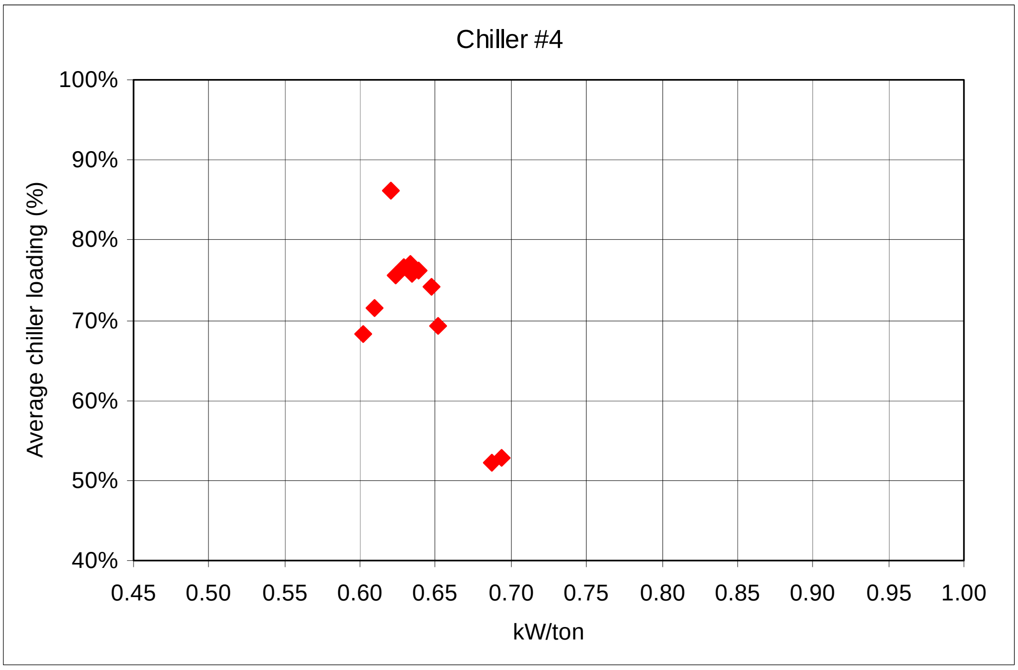

Figure 9. Relationship of chiller efficiency and chiller loading, Chiller #4

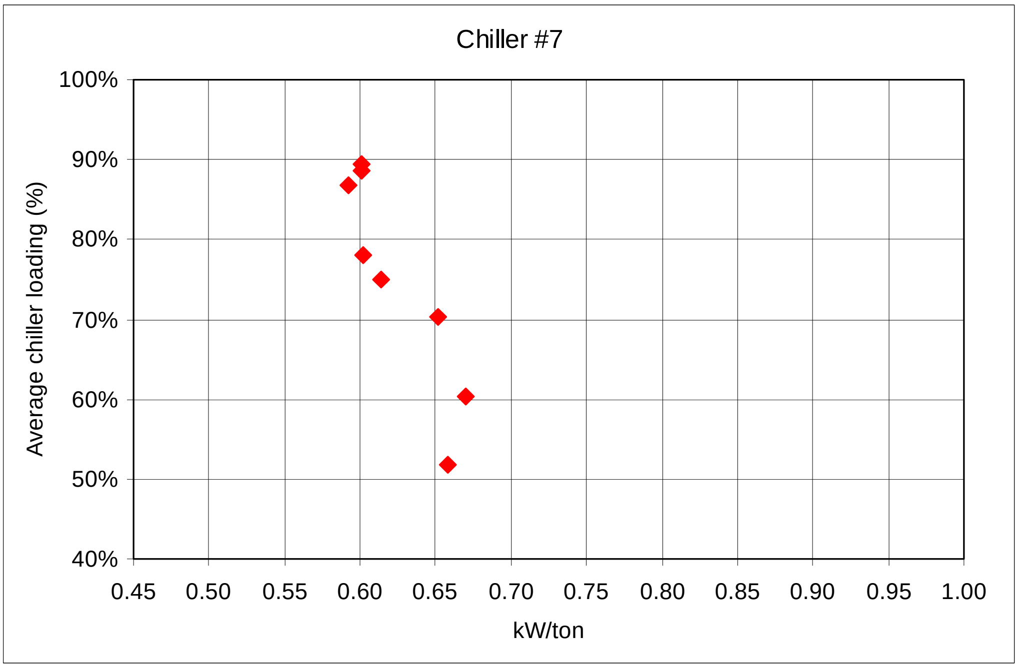

Figure 10. Relationship of chiller efficiency and chiller loading, Chiller #7

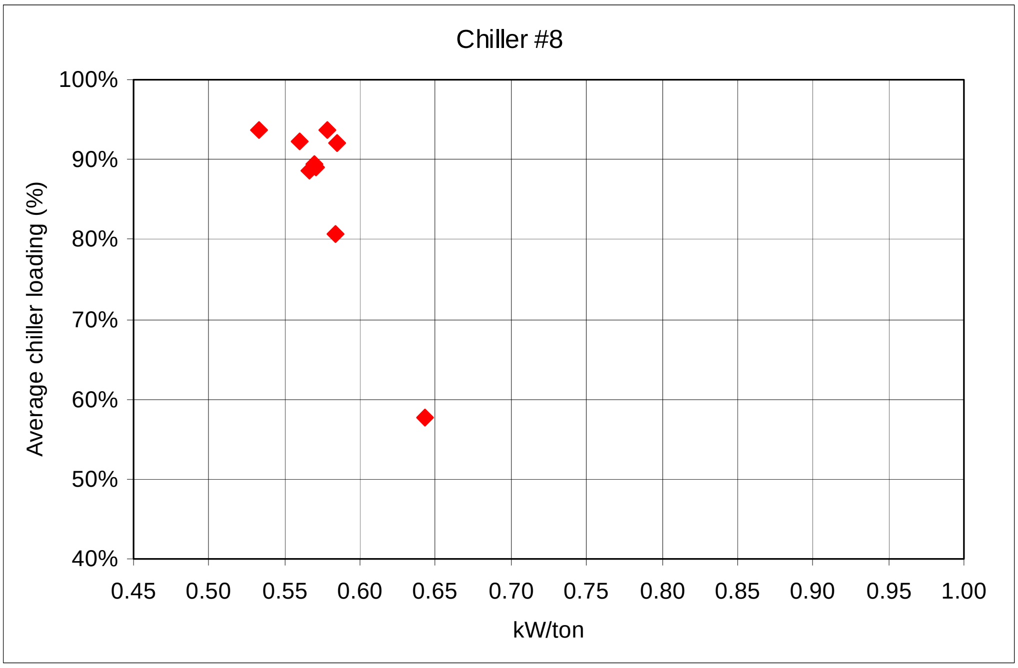

Figure 11. Relationship of chiller efficiency and chiller loading, Chiller #8

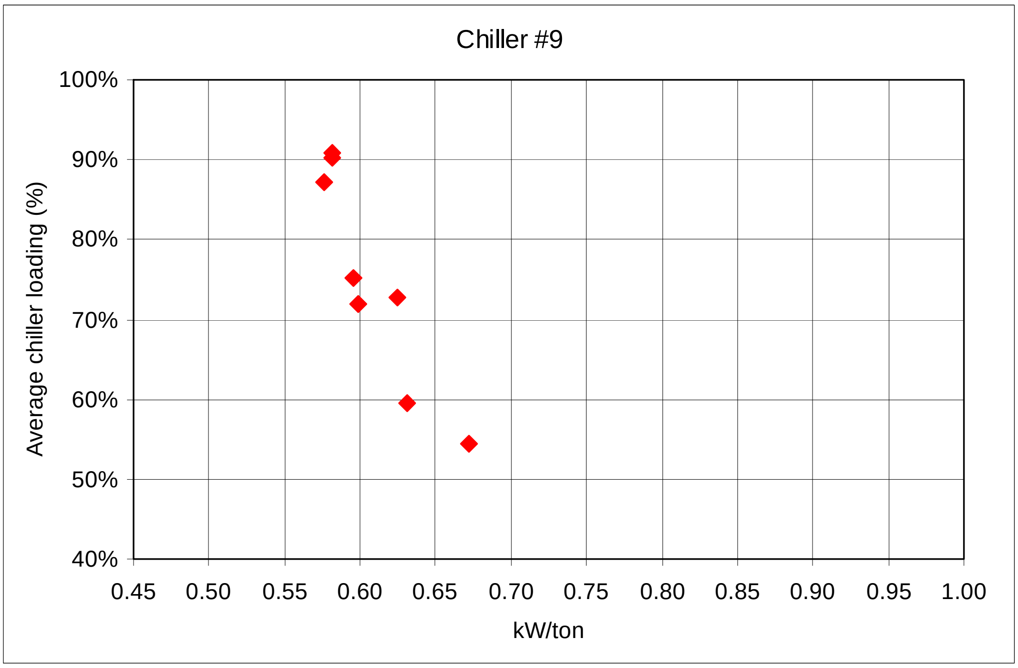

Figure 12. Relationship of chiller efficiency and chiller loading, Chiller #9

Buildings converted to district cooling

IDEA surveyed 11 commercial district cooling utilities and over 70 campus district cooling systems. Systems contacted are listed in Appendix 3.

Data was sought from these systems regarding "before and after" power consumption data for buildings converted to district cooling. Specifically, IDEA requested data on:

- Total electricity consumption of the building before and after connection to the district cooling system.

- Chilled water consumption (ton-hours) following connection to district cooling.

- Cooling degree day data for the periods before and after connection.

- To the extent available, data on: type and age of chillers; supply and return temperatures at which the equipment was operated; changes in building occupancy; changes in building envelope or HVAC systems; and ambient temperatures during the data period.

Phoenix

Data were collected for a 20-story high rise office building in downtown Phoenix of about 375,000 square feet, and the conversion over to district cooling was in March of 2003. No major changes in occupancy or building use occurred after conversion to district cooling. Prior to conversion, there were three building chillers, each 660 ton centrifugal units that were about 15 years old. As calculated in Table 10, the average calculated chiller system efficiency is 1.25 kW/ton. Cooling degree day adjustment was made with the assumption that the weather-related portion of the cooling-related power consumption is 85% of the total cooling-related power consumption.

Year	2002	2003	2004	2005	Average 2003-2005
Building kWhs	12,308,700	9,015,800	8,421,200	8,356,700	
Cooling degree days	4,916	4,960	4,755	4,709	
Cooling degree days (% above 2002)		0.9%	-3.3%	-4.2%	
Cooling load adjustment factor		0.999	1.005	1.006	
Removed Cooling kWh		3,297,327	3,868,496	3,927,195	
Ton-Hrs		2,746,253	2,945,678	3,213,174	
kW/ton		1.20	1.31	1.22	1.25

Table 10. Calculated chiller system efficiency in Phoenix building

University of North Carolina

At the University of North Carolina – Chapel Hill, the Cheek Clark building was connected to the district cooling system beginning in June 2006. Electricity consumption for the air-cooled chillers was collected and is illustrated by the dashed line in Figure 13. The electricity use is contrasted with cooling degree days (base temperature is 65°F or 18°C) data in the solid blue line. As illustrated, the cooling degree days (CDD) were multiplied by a factor of 50 to bring the data into a range that is visible compared with the electricity data. The data show a clear but imperfect correlation of chiller electricity use and CDD.

Following connection to district cooling, the total actual monthly chilled water consumption was metered as illustrated by the dashed line in Figure 14. The estimated base cooling consumption (unrelated to weather) is 6,200 ton-hours per month, as indicated by the dashed line. These data are contrasted with the CDD multiplied by a factor of 50 to bring the data into a range that is visible compared with the cooling consumption data. As calculated in Table 11, the average calculated chiller system efficiency is 0.92 kWh/ton-hour. This calculation is the sum of the base cooling load and weather-related cooling load estimated based on the ratio of cooling ton-hours to CDD from the post-connection data.

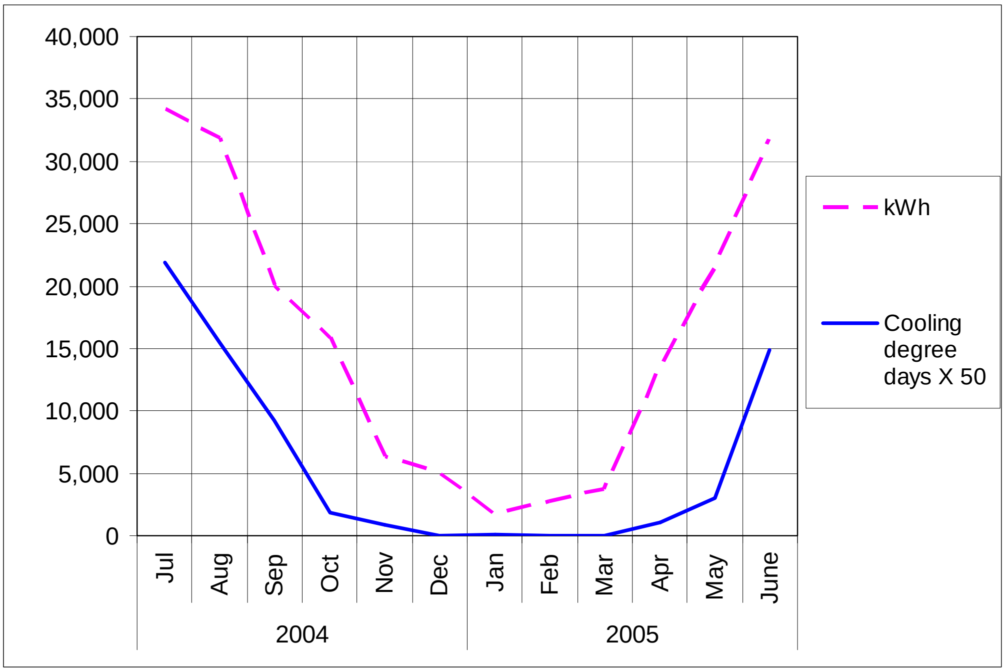

Figure 13. Cheek Clark Building Chiller Electricity Consumption and Cooling Degree Days Prior to District Cooling Connection

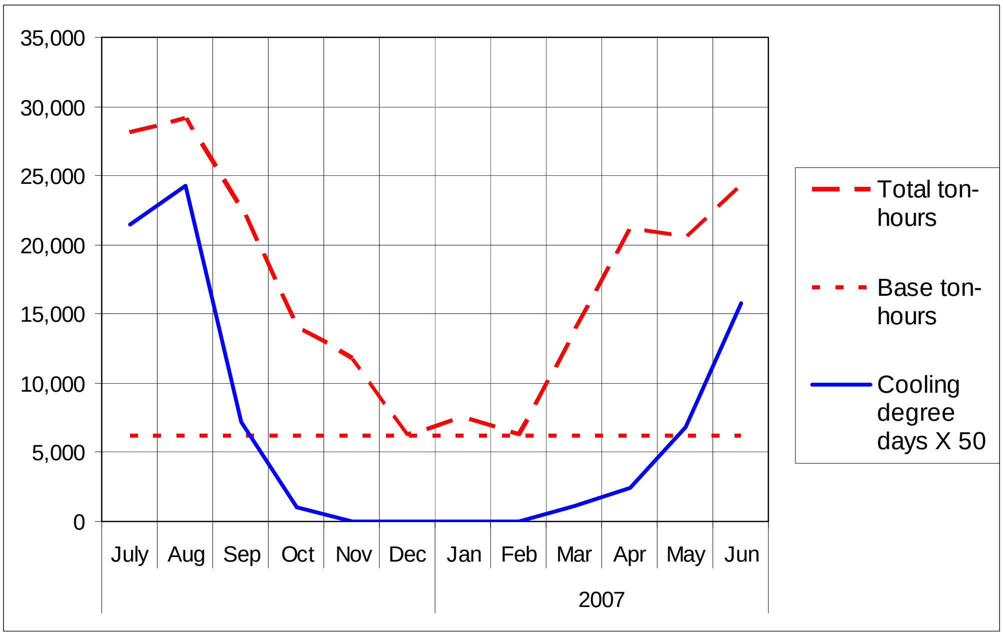

Figure 14. Cheek Clark Building Chilled Water Consumption and Cooling Degree Days Following District Cooling Connection

Post-connection

Data collection period	July 06 -- June 07
Number of months in period	12
Cooling degree days	1,366
Cooling energy	
Actual total ton-hours	205,436
Estimated base cooling load	74,400
Estimated weather-related load	131,036
Base monthly ton-hours	6,200
Ton-hours per cooling degree day	95.9

Pre-connection

Data collection period	July 04 -- June 05
Number of months in period	12
Pre-conversion air-cooled chiller electricity consumption (kWh)	188,146
Cooling degree days	1,366
Estimated ton-hours cooling energy	
Base cooling load (1)	74,400
Weather-related load (2)	131,036
Total	205,436
Calculated kW/ton	0.92

Notes
(1) Base monthly ton-hours X months
(2) CDD X ton-hours/CDD

Table 11. Calculated chiller system efficiency in UNC Chapel Hill building

Duke University

The Gross Chemical Building at Duke University was connected to district cooling service in Sept. 2001. Prior to connection the building was cooling with a water-cooled chiller system located in the building. Total building electricity consumption was metered starting in 1999 and continuing through 2005. Electricity consumption dropped significantly after connection, as illustrated in Figure 15.

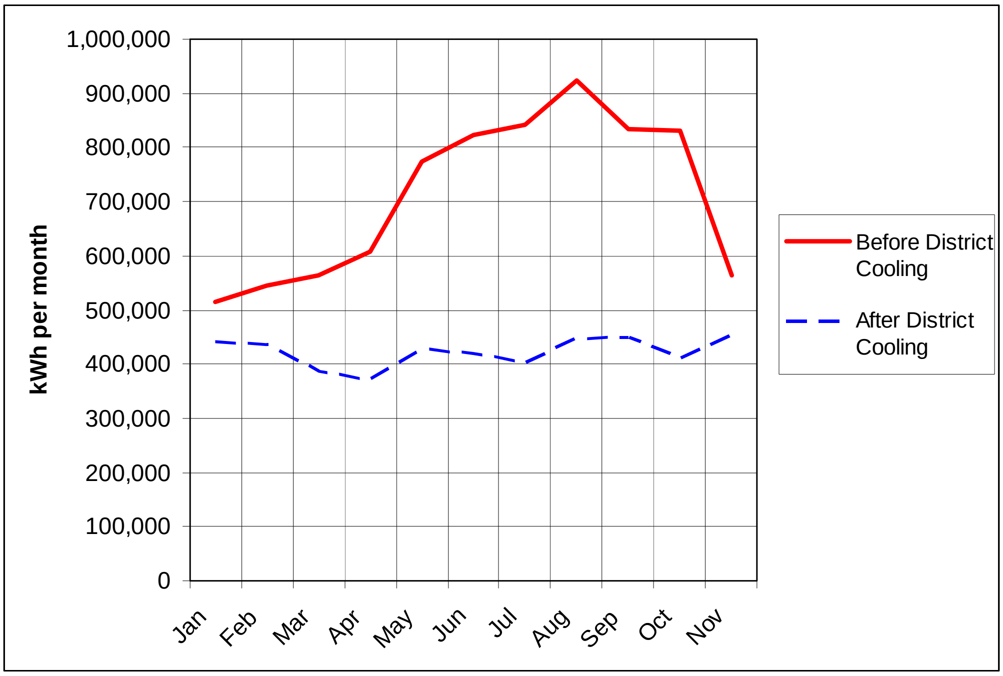

Figure 15. Total building electricity consumption before and after connection to district cooling -- Gross Chemistry Building, Duke University

Following connection to district cooling, the building cooling consumption was metered. Subsequent to district cooling, the sum of the building electricity consumption for the monitored months dropped 40%, from 7.82 million kWh to 4.65 million kWh. Based on metered chilled water consumption following connection to district cooling, the calculated average building chiller system efficiency is 1.33 kW/ton. The data for this case are summarized in Table 12.

	Electricy (kWh)					
			Reduction attributable to building cooling (3)		Chilled water (ton-hrs)	
	Before District Cooling (1)	**After District Cooling (2)**	**Unadjusted**	**Adjusted for Cooling Degree Days (4)**	**Building Cooling**	**Average building cooling efficiency (kW/ton)**
Period	**1999-2001**	**2001-2005**			**2004-2005**	
Jul	841,600	404,000	437,600	419,097	442,904	
Aug	924,800	446,133	478,667	481,987	389,161	
Sep	833,600	448,800	384,800	365,685	357,368	
Oct	832,000	412,267	419,733	419,733	204,008	
Nov	563,600	453,333	110,267	119,933	149,573	
Jan	514,000	442,400	71,600	71,600	95,127	
Feb	544,000	435,467	108,533	108,533	63,884	
Mar	564,400	387,733	176,667	202,933	71,695	
Apr	608,000	369,333	238,667	225,583	143,618	
May	774,000	428,533	345,467	380,673	169,334	
Jun	822,400	420,800	401,600	397,916	323,223	
Total	7,822,400	4,648,800	**3,173,600**	**3,193,674**	**2,409,895**	
Average						**1.33**

Notes:

(1) includes electricity for building, chillers and cooling towers.

(2) includes electricity for building only.

(3) With no modifications to building electric system during 1999-2005 and no changes to building occupancy the reduction in electricity is attributed to building cooling.

(4) Assumes base (non-weather-related0 load is 71,600 kWh.

Table 12. Calculation of average chiller plant efficiency at Gross Chemistry Building -- Duke University

Conclusions

Many variables affect the efficiency of building chiller systems, including type of chiller equipment, size of chillers and cooling towers relative to seasonal loads, condenser temperature, chilled water supply temperature, use of variable frequency drives (VFDs) and the age and maintenance history of the equipment.

Very few data are available that directly quantify the actual annual efficiency of building-scale chiller systems through sub-metering, and some of the data obtained had gaps or flaws that constrain their usefulness. Limited case study data on submetered building chiller systems, summarized above in Table 6, showed the following annual average kW/ton: air cooled 1.50, variable speed screw 1.20, ultra-efficient all variable speed with oil-less compressors 0.55, and district cooling plant 0.85 kW/ton. Although it is possible to obtain very high seasonal efficiencies (less than 0.65 kW/ton) with well-designed, well-operated all-VFD plants in favorable climate conditions, during the course of this study we were unable to obtain primary data documenting such performance.

There were also very few data available for the indirect analytical approach to quantifying building chiller efficiency: comparing building electricity consumption before and after connection to district cooling, and using post-connection cooling consumption data to estimate the efficiency of the building chiller system operations thus eliminated.

Limited case study data on electricity consumption before and after connection to district cooling yielded calculated annual efficiencies as summarized in Table 13.

Building Name	Location	Chiller type	Calculation method	Average annual kW/ton
Gross Chemistry	Duke University, NC	Water-cooled	1	1.33
(Confidential)	Phoenix, AZ	Water-cooled	1	1.25
ITS Franklin	UNC Chapel Hill, NC	Air-cooled	2	1.21
Cheek Clark	UNC Chapel Hill, NC	Air-cooled	1	0.92

Calculation Methods

1. Based on electricity consumption before and after connection to district cooling, and cooling consumption following connection.
2. Submetering of chiller system.

Table 13. Summary of annual average efficiency case studies

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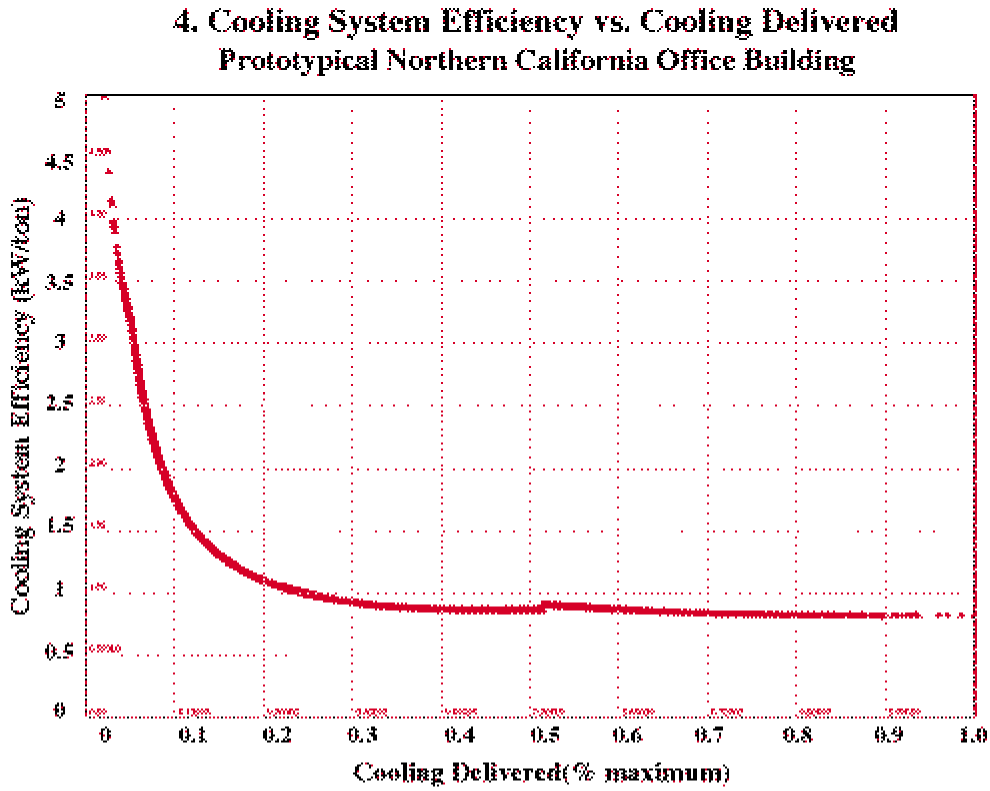
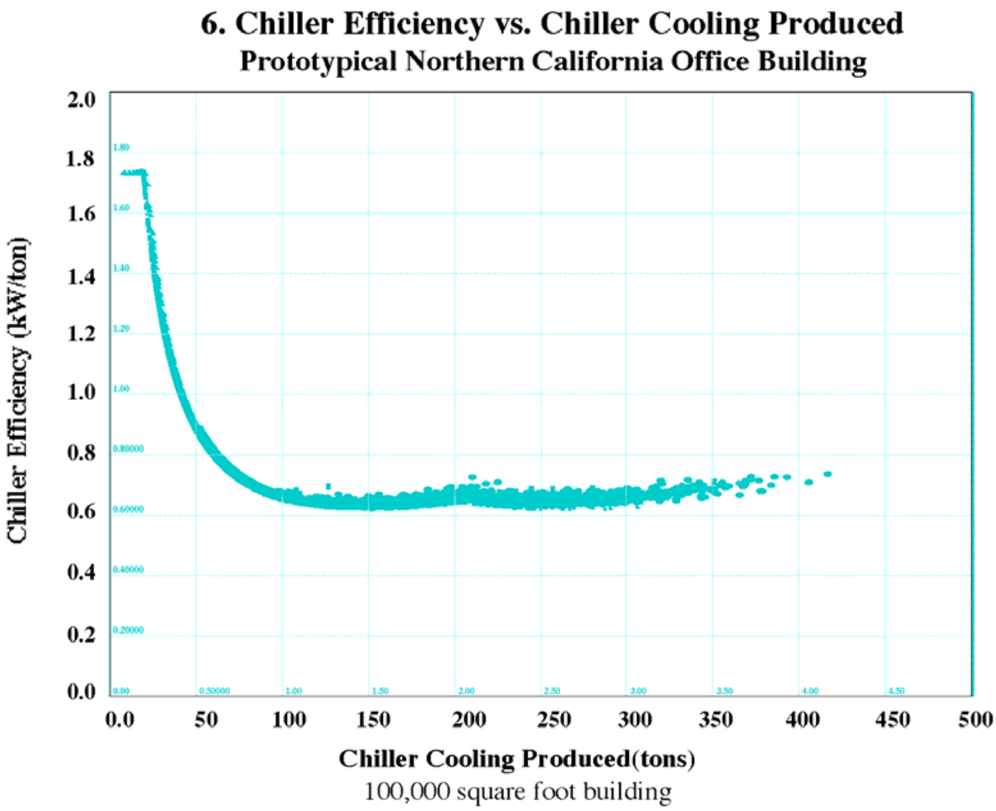
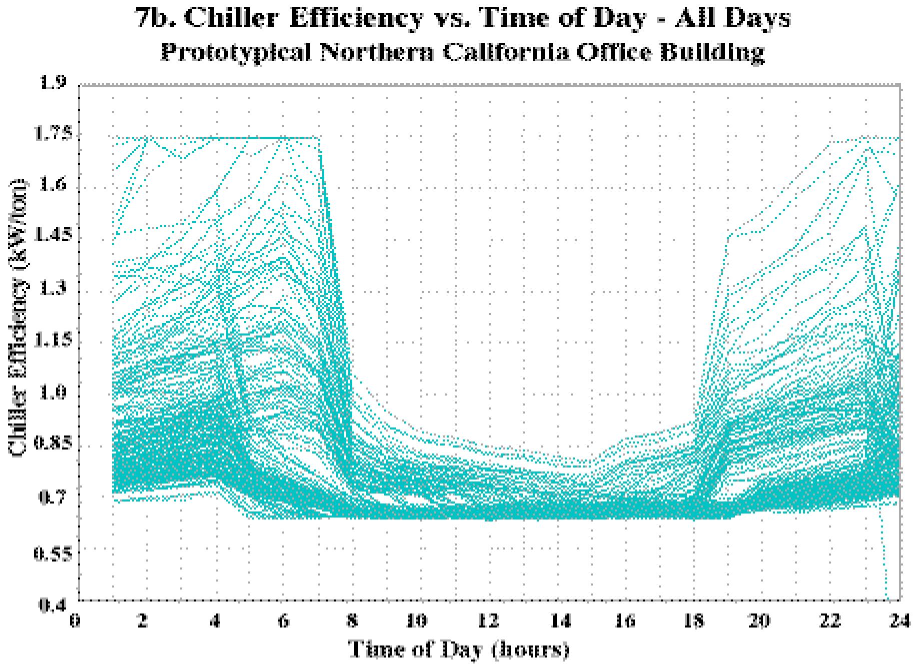
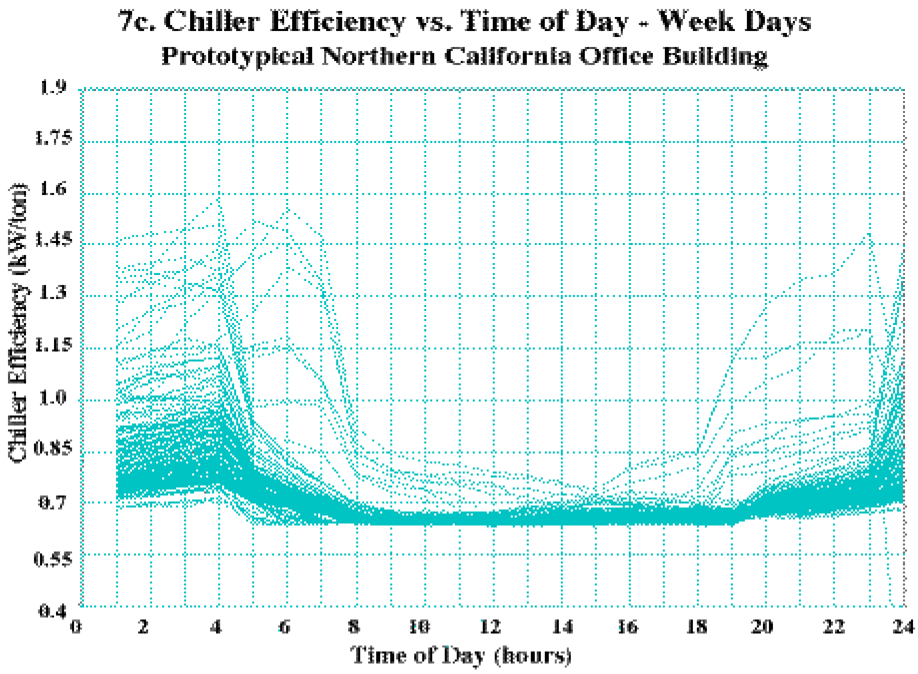
Appendix 1: Results of Modelling for Northern California






7b. Chiller Efficiency vs. Time of Day - All Days
Prototypical Northern California Office Building
Chiller Efficiency (kW/ton)
1.9
1.75
1.6
1.45
1.3
1.15
1.0
0.85
0.7
0.55
0.4
0
2
4
6
8
10
12
14
16
18
20
22
24
Time of Day (hours)


7c. Chiller Efficiency vs. Time of Day - Week Days
Prototypical Northern California Office Building
Chiller Efficiency (kW/ton)
1.9
1.75
1.6
1.45
1.3
1.15
1.0
0.85
0.7
0.55
0.4
0
2
4
6
8
10
12
14
16
18
20
22
24
Time of Day (hours)

Appendix 2: Monitoring Data from Six USA Sites

Site 1

Site Description: Mail Distribution Facility, near Dallas, Texas

System Type: Chillers in parallel with dedicated primary pumps / secondary pumping

Chiller: (2) 1000 ton York Millennium chillers w/ VFDs

Cooling Tower: (2) BAC open tower w/ 75 hp 2 speed fans

Primary Chilled Water Pump: (2) constant speed 25 hp (2080 gpm)

Secondary Chilled Water Pump: (2) with VFDs

Condenser Water Pump: (2) dedicated constant speed 125 hp (3000 gpm)

Monitored Points: Chiller kW, ChW Flow, ChWS Temp, ChWR Temp, CondW Flow, CondInW Temp, CondOutW Temp, PChW Pump kW, SChW Pump kW, Cond Pump1+Cooling Tower 1, Cond Pump2+Cooling Tower2, OA Temp, OA %RH, Sample Zone Temp

Monitoring Period: July 2005 through December 2005

Monitoring Comments: 1 minute data converted to 15 minute data; off & start-up conditions not included in performance calculations; secondary pump not included in calculations; single chiller operated during monitoring period

Average Cooling Load: 783 tons

Maximum Cooling Load: 1211 tons

Minimum Cooling Load: 245 tons

Average Plant Performance: 0.64 kW/ton

Average Outdoor Dry Bulb Temperature: 83.9 °F

Average Outdoor Wet Bulb Temperature: 70.3 °F

Site 2

Site Description: High School #M, near Phoenix Arizona

System Type: constant speed primary / variable speed secondary. VFDs on tower fans. Constant speed condenser pumps

Chillers: 2x500-ton Carrier centrifugal w/VFDs

Cooling Tower: ??

Primary Chilled Water Pumps: ??

Condenser Water Pumps: ??

Secondary Chilled Water Pumps: ??

Monitored Points: Monthly Total ChWPlant kWh, which includes all central plant equipment (chillers, cooling tower fans, condenser pumps and primary / secondary pumps; Monthly Total ChWPlant Cooling tons

Monitoring Period: June 2002 through November 2005

Monitoring Comments: The plant operated on various days and schedules throughout the winter and with schedules varying from 4:30 AM to 8:00 PM in mid November 2005 to 7:00 AM to 8:30PM in January 2006.

Average Cooling Load: 289 tons, assumes 5 days per week year around less standard holidays and 12 hour day

Maximum Monthly Average Cooling Load: 693 tons in peak month, assumes 5 days per week year around less standard holidays and 12 hour day

Minimum Monthly Average Cooling Load: 82 tons in lowest month, assumes 5 days per week year around less standard holidays and 12 hour day

Average Plant Performance: 0.89 kW/ton

Site 3

Site Description: High School #A, near Phoenix Arizona

System Type: constant speed primary / variable speed secondary. VFD on tower fans. Constant speed condenser pumps.

Chillers: 2x400-ton Carrier centrifugal w/VFD

Cooling Tower: ??

Primary Chilled Water Pumps: ??

Condenser Water Pumps: ??

Secondary Chilled Water Pumps: ??

Monitored Points: Monthly Monthly Total ChWPlant kWh, which includes all central plant equipment (chillers, cooling tower fans, condenser pumps and primary / secondary pumps; Monthly Total ChWPlant Cooling tons

Monitoring Period: June 2002 through November 2005

Monitoring Comments:
The plant operated on various days and schedules throughout the winter and with schedules varying from 4:30 AM to 8:00 PM in mid November 2005 to 7:00 AM to 8:30PM in January 2006.

Average Cooling Load: 200 tons, assumes 5 days per week less standard holidays and 12 hour day

Maximum Monthly Average Cooling Load: 594 tons in peak month, assumes 5 days per week less standard holidays and 12 hour day

Minimum Monthly Average Cooling Load: 12 tons in lowest month, assumes 5 days per week less standard holidays and 12 hour day

Average Plant Performance: 1.17 kW/ton

Site 4

Site Description: North County Regional Center (courthouse, offices and jail) in Vista, CA

System Type: All VFD plant with primary/booster direct coupled chilled water distribution with all 3-way valves and decouplers eliminated

Chillers: (3) 575 ton centrifugal chillers with VFDs

Cooling Tower: (2) 850 ton towers, fans with VFDs

Primary Chilled Water Pumps: (4) 20 hp (1150 gpm) pumps with VFDs

Condenser Water Pumps: (4) 60 hp (1740 gpm) pumps with VFDs

Booster Chilled Water Pumps: (6) 60 hp pumps with VFDs

Monitored Points: Total Chiller kW (point 1), Total Primary ChWPump kW (point 4), Total Cooling Tower kW (point 3), Total Booster1 ChWPump kW (point 5), Total Booster2 ChWPumps kW (point 6), Total Plant kW (point 2), Total Plant Cooling tons (point 8), Total Plant kW/ton (point 7), OA Temp and OA %RH

Monitoring Period: 11/2-8/2005 and 7/27-8/4/2006

Monitoring Comments: 5 minute data; outdoor ambient temperature and humidity data are spot measurements only. Point 5 (Total Booster1 ChWPump kW) is included in point 2 (Total Plant kW). Total condenser water kW is included in point 2 (Total Plant kW).

Average Cooling Load: 479 tons

Maximum Cooling Load: 2822 tons

Average Plant Performance: 0.47 kW/ton

Site 5

Site Description: Juvenile Hall in San Diego, CA

System Type: Primary/booster chilled water distribution

Chillers: (1) 300 ton centrifugal chiller with 3 Turbocor TT300 90 ton compressors and integrated VFD (lag) and (1) 450 ton centrifugal chiller with 3 Turbocor TT440 150 ton compressors and integrated VFD (lead)

Cooling Tower: 30 hp and 20 hp fan, 10 ºF approach

Primary Chilled Water Pump: 15 hp (600 gpm) and 7.5 hp (390 gpm)

Condenser Water Pumps: 40 hp (1350 gpm) and 15 hp (900 gpm)

Secondary and Tertiary Chilled Water Pumps: 3 hp, 7.5 hp and 15 hp

Monitored Points: 450 ton Chiller kW, 450 ton chiller tons

Monitoring Period: 1/6/2006 through 7/6/2006

Monitoring Comments: ~20 minute data, chiller only. Measured cooling load is not the total building cooling load; the data only shows cooling that the 450-ton chiller is doing.

Average Cooling Load: 73 tons

Maximum Cooling Load: 306 tons

Average Plant Performance: 0.55 kW/ton

Site 6

Site Description: Police Administration Building in Chula Vista, CA

Chillers: (2) 217 ton Trane screw chillers, Model RTHC B2-C2-D2

Cooling Towers: (2) BAC Model 333A-2 w/ 15 hp fan (VFD)

Primary Chilled Water Pumps: (2) 10 hp (440 gpm) with VFDs

Condenser Water Pumps: (2) 25 hp (660 gpm) with VFDs

Secondary Chilled Water Pumps: (2) 25 hp (440 gpm) with VFD

Monitored Points: Chiller1 kW, Chiller2 kW, ChW Flow, ChWS Temp, ChWR Temp, PChW Pump kW, SChW Pump kW, Cond Pump kW, Cooling Tower kW

Monitoring Period: 3/21/2006 through 7/31/2006

Monitoring Comments: The building was fully occupied for one year prior to data collection. The secondary pumps were included in performance calculations.

Average Cooling Load: 66 tons

Maximum Cooling Load: 350 tons

Average Plant Performance: 1.407 kW/ton

Appendix 3 – District Cooling Systems Surveyed

Utility District Cooling Systems Surveyed

Organization	Name
Hartford Steam	Jeff Lindberg
Energy Systems Company	Dave Woods
Xcel Denver	Steve Kutska
Northwind Phoenix	Jim Lodge
District Energy St. Paul	Alex Sleiman
Comfortlink	Dennis Manning
Enwave	Chris Asimakis
Austin Energy	Cliff Braddock
Metro Nashville	Harvey Gershman
Exelon	Jack Kattner
Entergy	Steve Martins

Campus District Cooling Systems Surveyed

Organization	First Name	Last Name
AMGEN, Inc.	Jimmy	Walker
Auburn University	Michael	Harris
Brown University	James	Coen
Chevron Energy Solutions - Maryland	Robert	McNally
Cleveland State University	Shehadeh	Abdelkarim
Colorado State University	Roger	Elbrader
Columbia University	Dominick	Chirico
Cornell University	Jim	Adams
Dallas Fort Worth International Airport	John	Smith
Dartmouth College	Bo	Petersson
Duke University FMD	Steve	Palumbo
Franklin Heating Station	Tom	DeBoer
Gainesville Regional Utilities	Gary	Swanson
Georgia Institute of Technology - Facilities Dept.	Hank	Wood
Harvard University	Douglas	Garron
Hennepin County	Craig	Lundmark
Indiana University	Mark	Menefee
Iowa State University	Clark	Thompson
Kent State University	Thomas	Dunn
Massachusetts Institute of Technology	Roger	Moore
McMaster University	Joe	Emberson

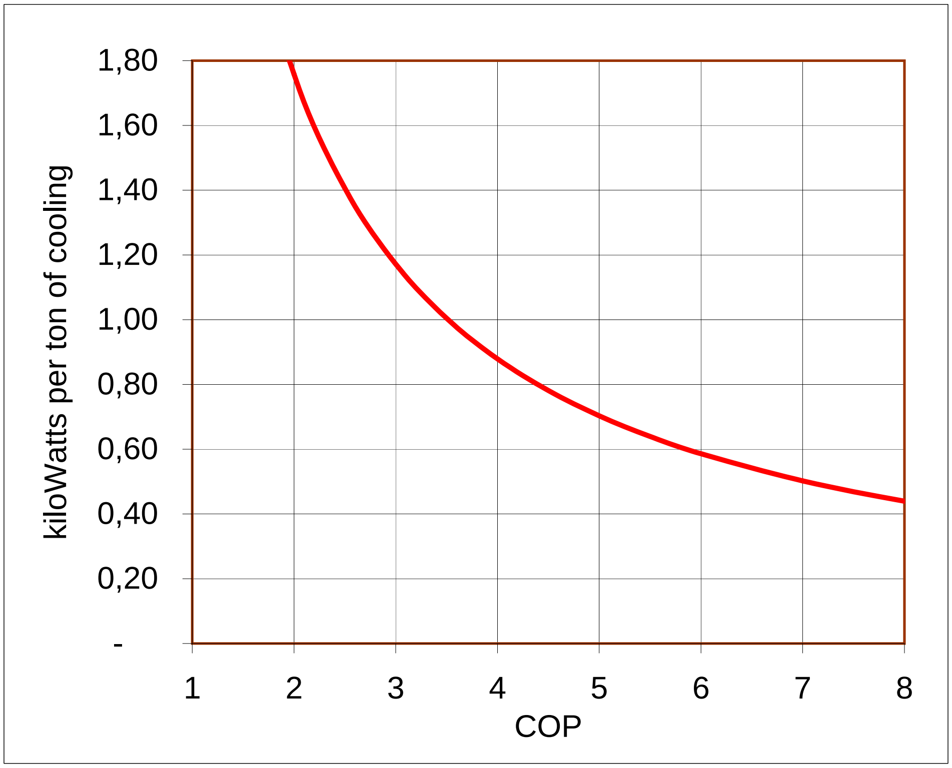
Organization	First Name	Last Name
Medical Center Steam & Chilled Water	Edward	Dusch
New York University	Jim	Sugaste
North Carolina State University	Alan	Daeke
Oklahoma State University	Bill	Burton
Pennsylvania State University	William	Serencsits
Princeton University	Edward	Borer
Purdue University	Mark	Nethercutt
Rice University	Douglas	Wells
Rutgers University	Joe	Witkowski
San Diego State University	Glenn	Vorraro
San Francisco State University	Richard	Stevens
Simon Fraser University	Sam	Dahabieh
Stanford University	Mike	Goff
Syracuse University	Tom	Reddinger
Tarleton State University	Steven	Bowman
The College of New Jersey	Lori	Winyard
The Medical Center Company	Michael	Heise
Thermal Energy Corporation (TECO)	Stephen	Swinson
Trinity College	Ezra	Brown
University of Akron	Rob	Kraus
University of Alberta	Angelo	da Silva
University of Arizona	Bob	Herman
University of California - Davis Medical Center	Joseph	Stagner
University of California - Irvine	Gerald	Nearhoof
University of California - Los Angeles	David	Johnson
University of Cincinnati	Joe	Harrell
University of Colorado - Boulder	Paul	Caldara
University of Connecticut	Eugene	Roberts
University of Georgia	Kenneth	Crowe
University of Idaho	Thomas	Sawyer
University of Illinois Abbott Power Plant	Robert	Hannah
University of Iowa	Janet	Razbadouski
University of Manitoba	Joe	Lucas
University of Maryland	J. Frank	Brewer
University of Massachusetts Medical School	John	Baker
University of Miami	Eric	Schott
University of Miami - Ohio	Mark	Lawrence
University of Michigan	William	Verge
University of Minnesota	Michael	Nagel

Organization	First Name	Last Name
University of Missouri at Columbia	Paul	Hoemann
University of Nevada, Reno	Stephen	Mischissin
University of New Mexico	Lawrence	Schuster
University of North Carolina - Chapel Hill	Raymond	DuBose
University of Northern Iowa	Tom	Richtsmeier
University of Regina	Neil	Paskewitz
University of Rochester	Morris	Pierce
University of Texas - Austin	Juan	Ontiveros
University of Vermont	Salvatore	Chiarelli
University of Virginia	Cheryl	Gomez
University of Washington	Guarrin	Sakagawa
University of Wisconsin - Madison	Dan	Dudley
Virginia Tech	Ben	Myers
Yale University	David	Spalding

Appendix 4: Additional Information Resources

1. ACEEE: “Energy data acquisition and verification for a large office building”. Mazzucchi, Gillespie and Lippman. 8-9/1996
2. AEE: “How is your thermal energy storage system performing?” Gillespie & Turnbull. 14th World Environmental Engineering Conference. 1991
3. ASHRAE: “Commercial building energy use monitoring for utility load research”. Mazzucchi. ASHRAE Transactions 93(1).
4. ASHRAE: “Performance of a Hotel Chilled Water Plant With Cool Storage”. Gillespie, Blanc and Parker. ASHRAE Transactions 99(2).
5. ASHRAE: Standard 150-2000. Method of Testing the Performance of Cool Storage Systems.
    a. Look specifically at Section 6: Instruments and Appendices C & E
6. ASHRAE: Guideline 14-2002. Measurement of Energy and Demand Savings
    a. Clause 7: Instrumentation and Data Management
        i. 7.1-7.8 Text
        ii. See other citations in 7.9 References and 7.10 Bibliography
    b. Annex A: Physical Measurements
        i. A.1 Sensors
        ii. A.3 Equipment Testing Standards
        iii. A.5 Cost and Error Considerations
7. ASHRAE: Research Manual, Appendix 1: Field Monitoring Project Guidelines, 2002.
8. EPRI: Monitoring Guide for Commercial Cool Storage Systems. SAIC. 1988
9. LBNL/PG&E: Benefits of Monitoring. Presentation slides, Cool $ense National Forum on Integrated Chiller Retrofits. Gillespie. 1997
10. NCBC9: Commissioning Tools & Techniques Used in a Large Chilled Water Plant Optimization Project. Gillespie, editor. 1999
11. NCBC9: Commissioning Tools & Techniques Used in a Large Chilled Water Plant Optimization Project. Presentation slides. Gillespie. 5/1999
12. PG&E: Building baseline monitoring project points list spreadsheet. Gillespie. 1995
13. PG&E: Measurement and Monitoring Chiller Plant Performance. Pacific Energy Center (San Francisco) class presentation slides. Hydeman & Gillespie. 9/1996
14. PG&E: “Determining the Performance of a Chilled Water Plant”. Cool $ense National Forum on Integrated Chiller Retrofits, CoolTools. Gillespie. 1997, updated 1998
15. PG&E: CoolTools Plant Monitoring Guide. 1999
16. PG&E: Field Assessments of Chilled Water Plants. PEC class presentation slides. Gillespie & Miller. 12/1999
17. PG&E: CoolTools Chilled Water Plant Design and Specification Guide. 2000
    a. Section 5: Controls and Instrumentation
18. PG&E CoolTools Building Cooling Load Profile Database Documentation, 9/2000 final report.

F1



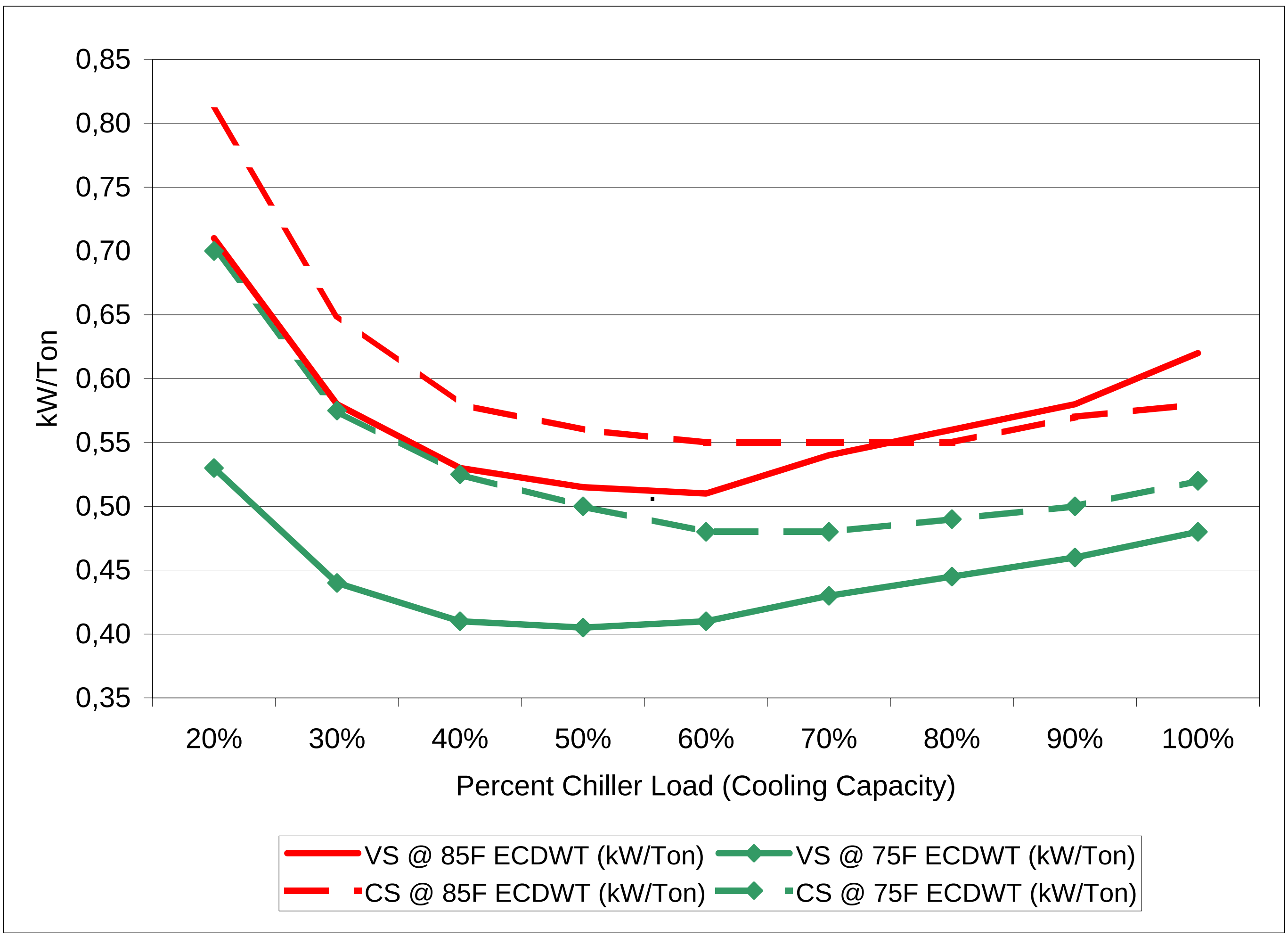
kiloWatts per ton of cooling
1,80
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
-
1
2
3
4
5
6
7
8
COP

F2

Comparison Chiller Efficiencies (kW/ton) for Variable & Constant Speed Chilllers of the Same First Cost

From “Real Efficiencies of Central Plants”, Ben Erpelding, HPAC Engineering, May 2007.

Percent Chiller load Efficiency	VS @ 85F ECDWT (kW/Ton)	VS @ 75F ECDWT (kW/Ton)	CS @ 85F ECDWT (kW/Ton)	CS @ 75F ECDWT (kW/Ton)
20%	0,71	0,53	0,81	0,7
30%	0,58	0,44	0,65	0,575
40%	0,53	0,41	0,58	0,525
50%	0,515	0,405	0,56	0,5
60%	0,51	0,41	0,55	0,48
70%	0,54	0,43	0,55	0,48
80%	0,56	0,445	0,55	0,49
90%	0,58	0,46	0,57	0,5
100%	0,62	0,48	0,58	0,52

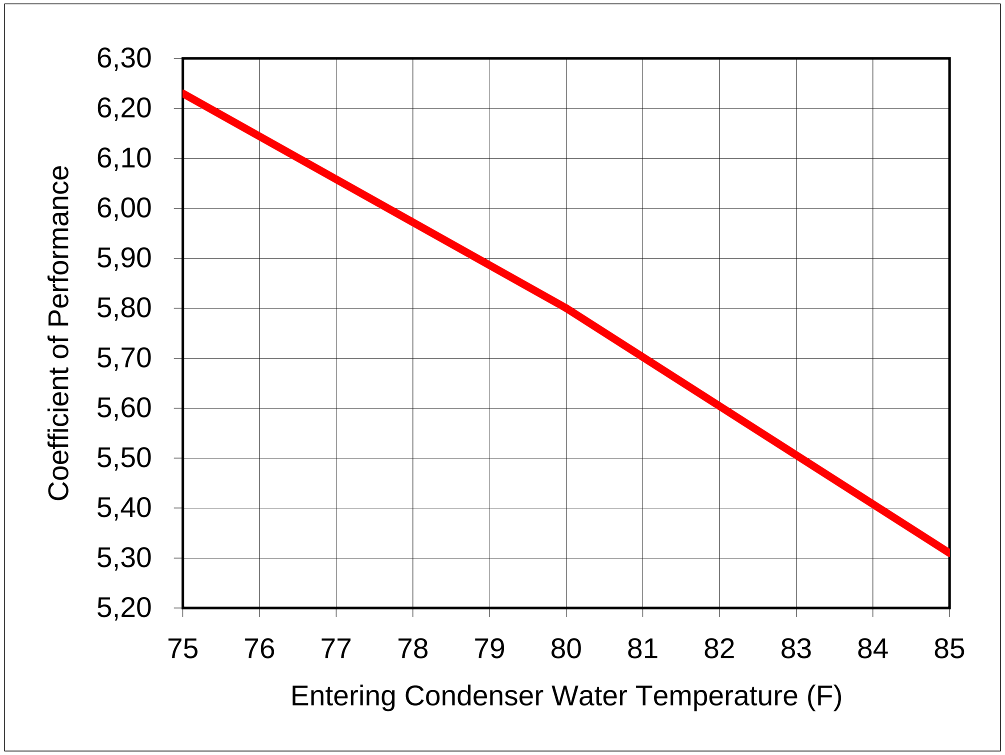


F3

From ASHRAE 90.1-2004, Table 6.8.1 I (Chillers between 150 and 300 tons)

COPs at 42 F LCWT and 3 gpm/ton condenser flow rate

ECWT	COP	
75	6,23	1,173258
80	5,80	
85	5,31	



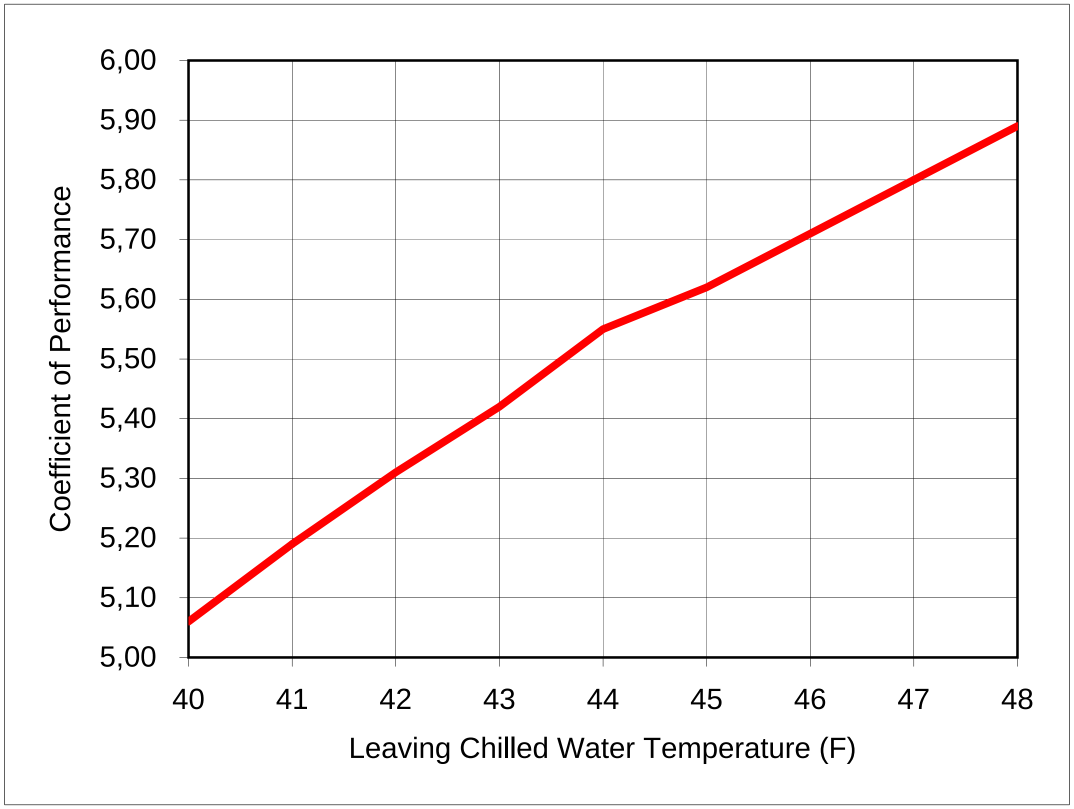
F4

From ASHRAE 90.1-2004, Table 6.8.1 I (Chillers between 150 and 300 tons)

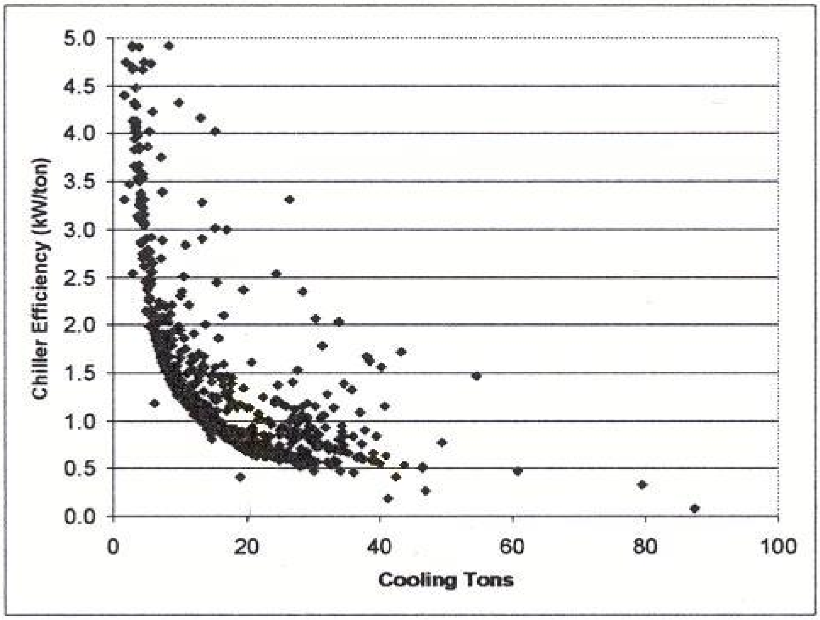
COPs at 85 ECWT and 3 gpm/ton condenser flow rate

LCWT	COP	
40	5,06	
41	5,19	
42	5,31	
43	5,42	
44	5,55	1,096838
45	5,62	
46	5,71	
47	5,80	
48	5,89	

ECWT
85
85
85
85
85
85
85
85
85

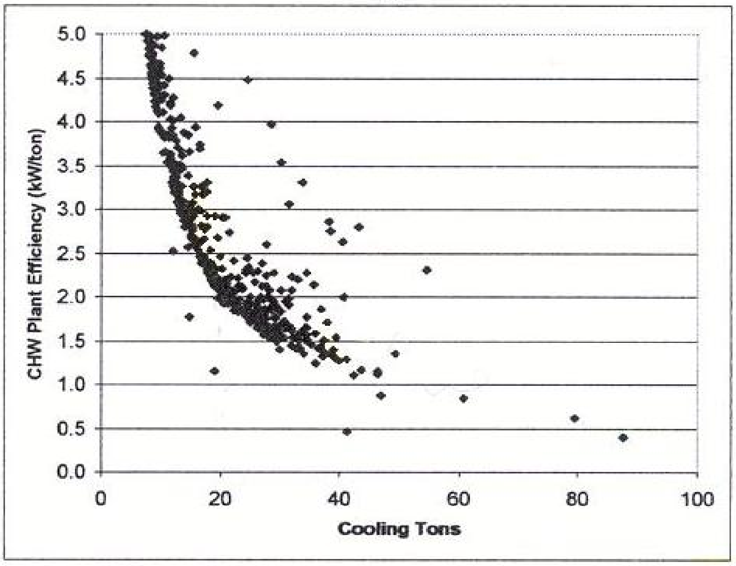


F5



5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Chiller Efficiency (kW/ton)
0
20
40
60
80
100
Cooling Tons

F6



5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
CHW Plant Efficiency (kW/ton)
0
20
40
60
80
100
Cooling Tons

F7

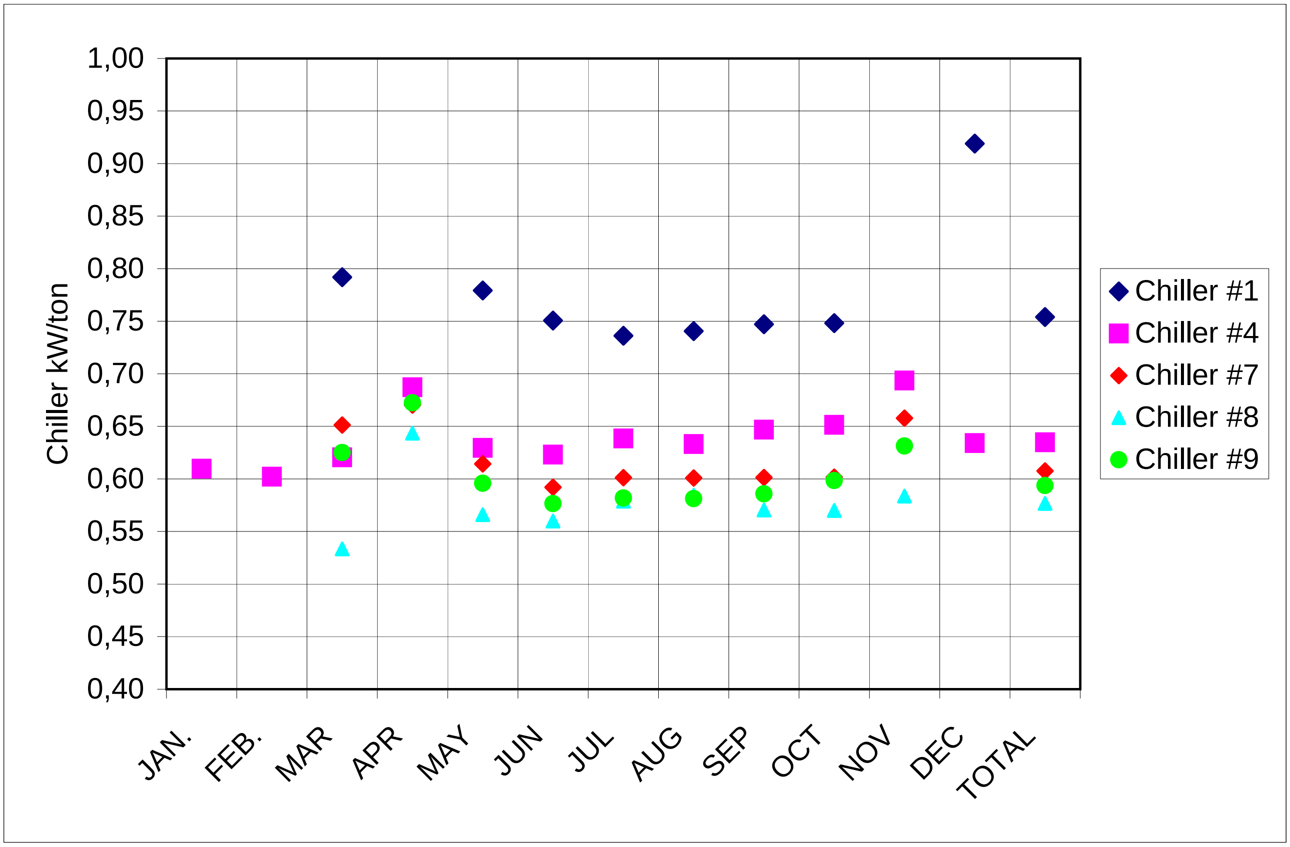
2007

Electric chiller kW/ton

	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1			0,79		0,78	0,75	0,74	0,74	0,75	0,75		0,92	0,75
Chiller #4	0,61	0,60	0,62	0,69	0,63	0,62	0,64	0,63	0,65	0,65	0,69	0,63	0,63
Chiller #7			0,65	0,67	0,61	0,59	0,60	0,60	0,60	0,60	0,66		0,61
Chiller #8			0,53	0,64	0,57	0,56	0,58	0,58	0,57	0,57	0,58		0,58
Chiller #9			0,63	0,67	0,60	0,58	0,58	0,58	0,59	0,60	0,63		0,59

Electric chiller average load as % of total chiller capacity

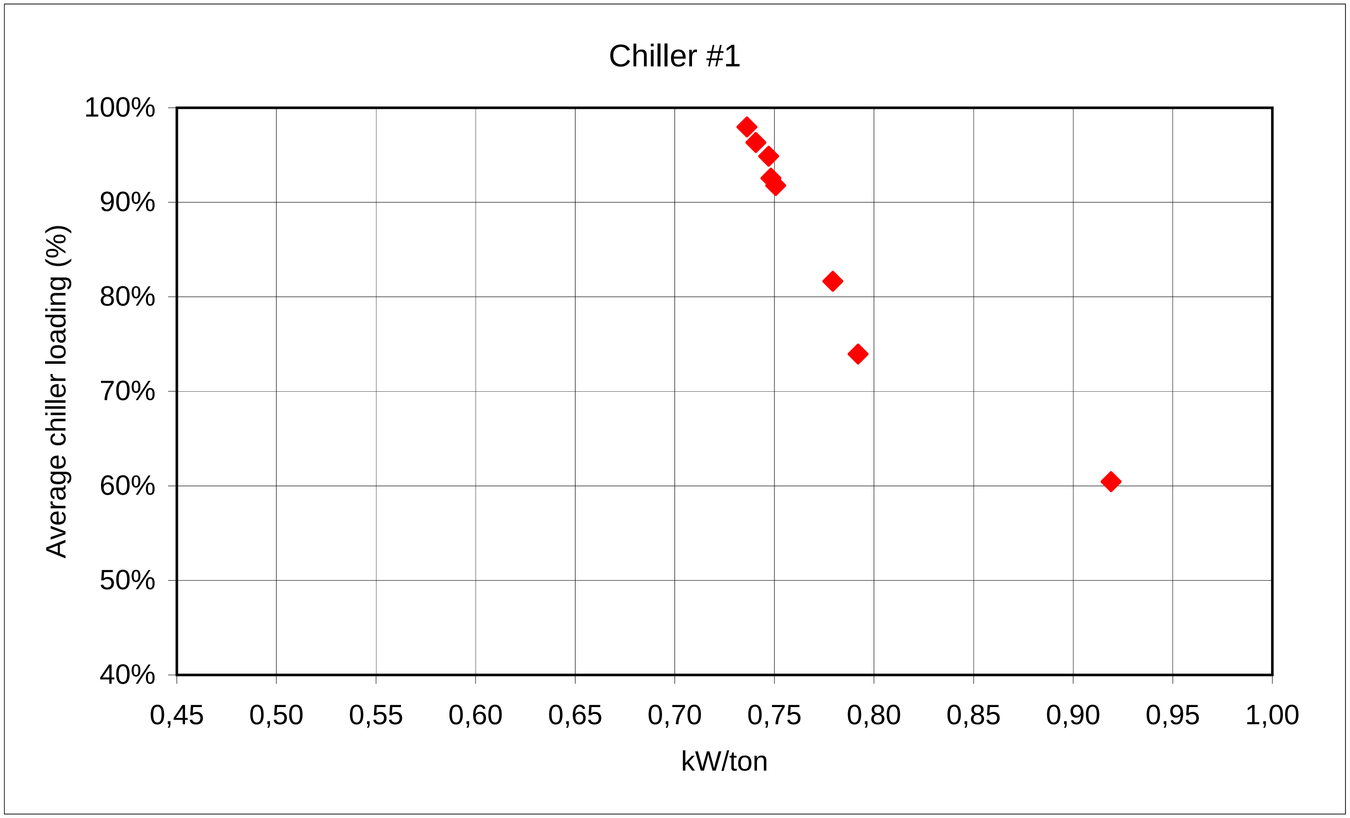
	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1			74%		82%	92%	98%	96%	95%	93%		60%	93%
Chiller #4	71%	68%	86%	52%	77%	76%	76%	77%	74%	69%	53%	76%	70%
Chiller #7			70%	60%	75%	87%	89%	89%	103%	78%	52%		83%
Chiller #8			94%	58%	89%	92%	94%	92%	89%	89%	81%		89%
Chiller #9			73%	54%	75%	87%	91%	90%	113%	72%	60%		82%



F8

2007, Chiller #1

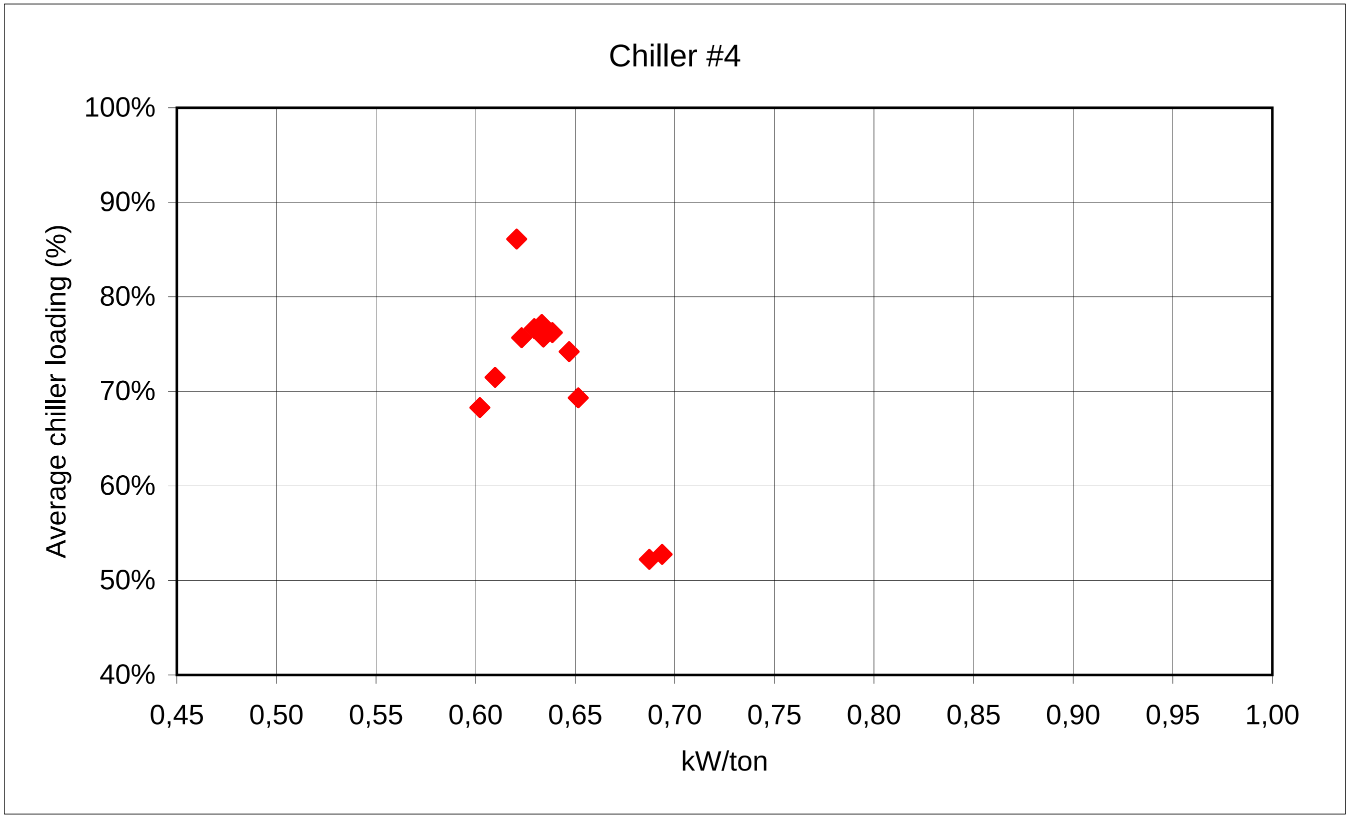
kW/ton	-	-	0,79	-	0,78	0,75	0,74	0,74	0,75	0,75	-	0,92
% chiller lo	0%	0%	74%	0%	82%	92%	98%	96%	95%	93%	0%	60%



F9

2007, Chiller #4

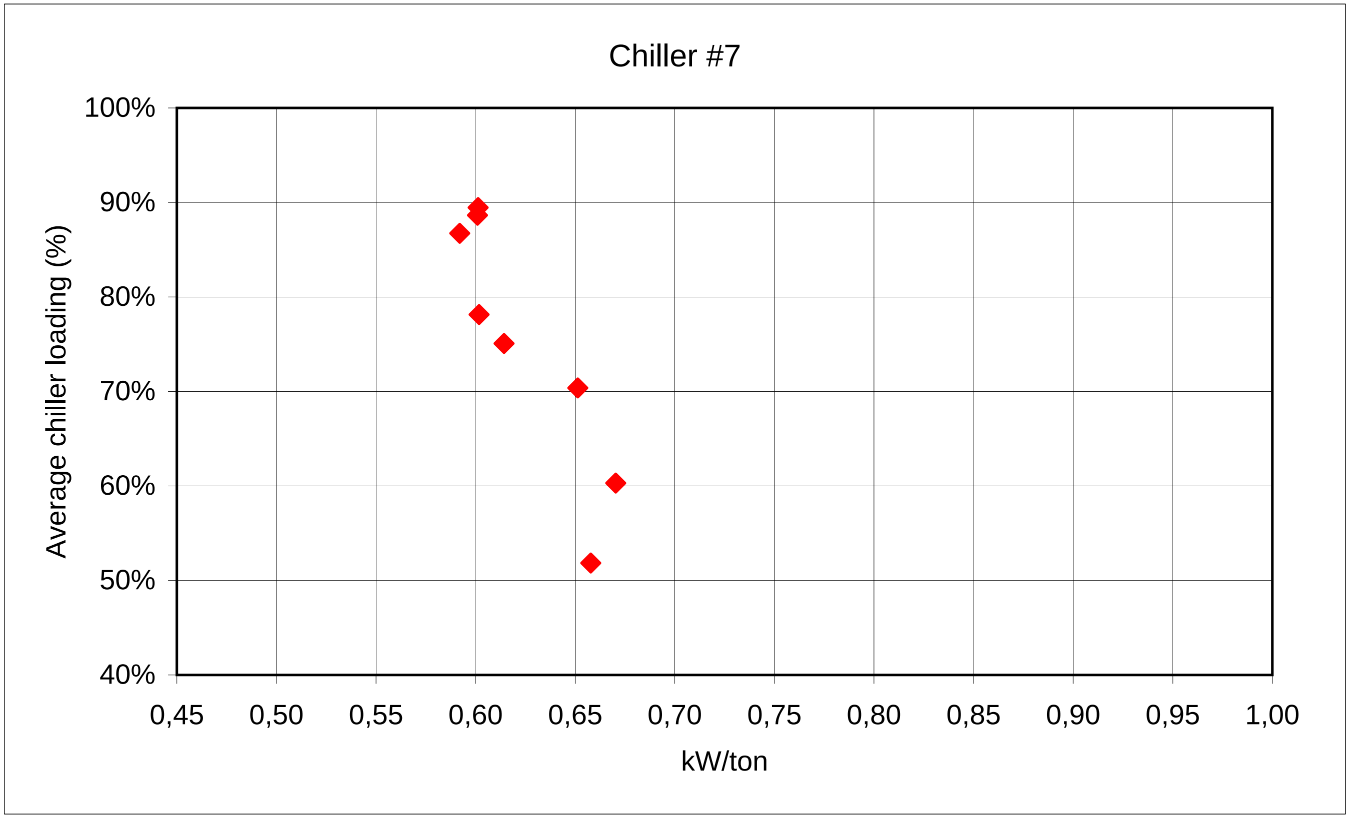
kW/ton	0,61	0,60	0,62	0,69	0,63	0,62	0,64	0,63	0,65	0,65	0,69	0,63
% chiller lo	71%	68%	86%	52%	77%	76%	76%	77%	74%	69%	53%	76%



F10

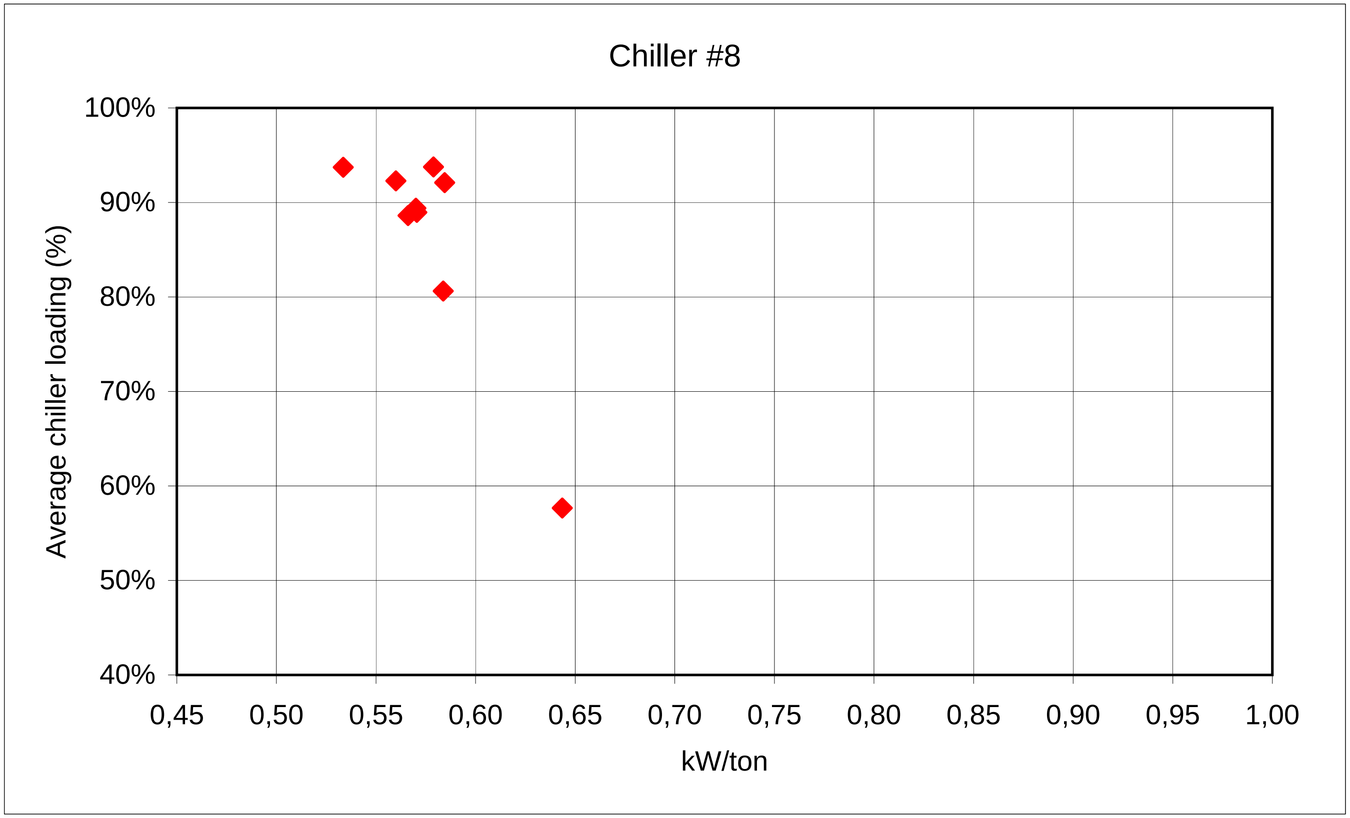
2007, Chiller #7

kW/ton	-	-	0,65	0,67	0,61	0,59	0,60	0,60	0,60	0,60	0,66	-
% chiller lo	0%	0%	70%	60%	75%	87%	89%	89%	103%	78%	52%	0%



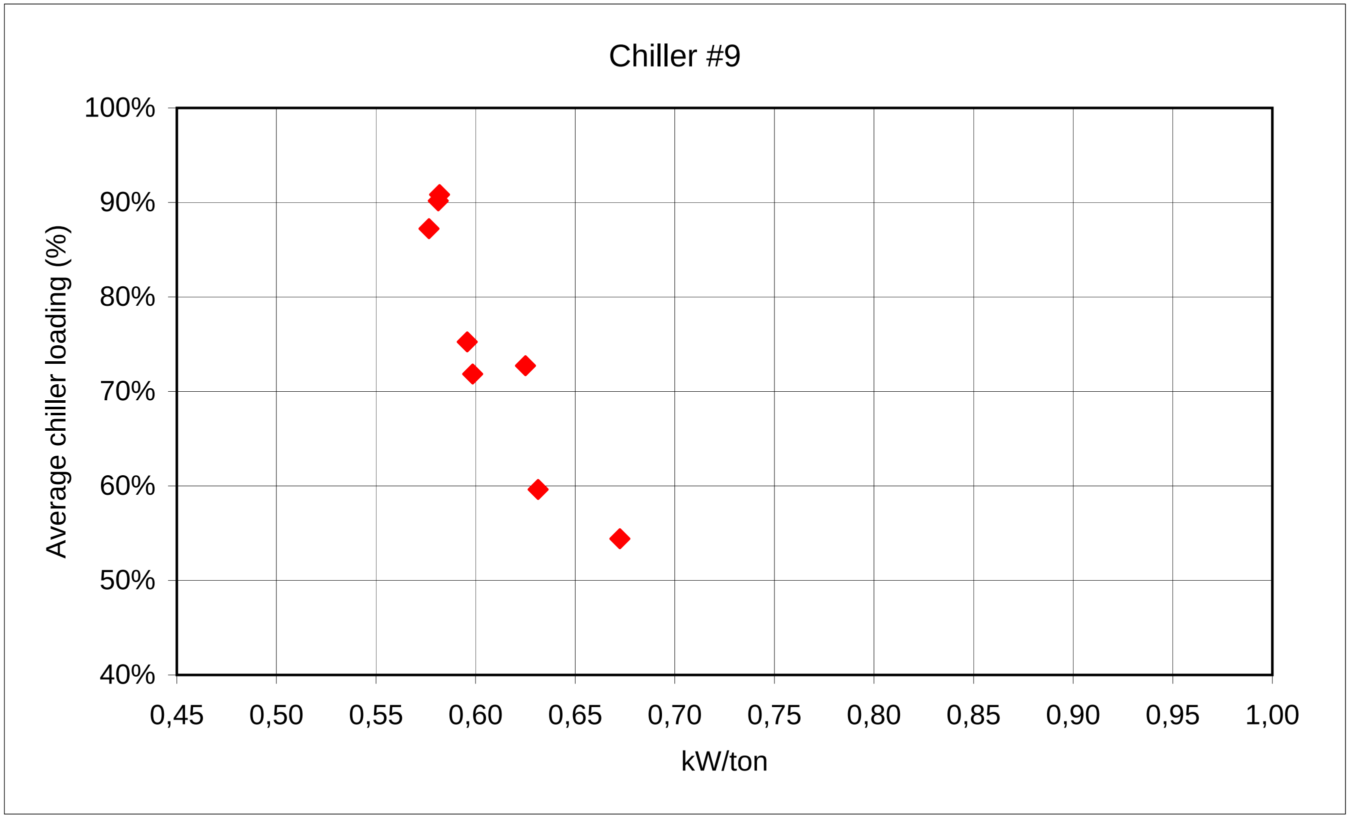
F11
2007, Chiller #8

kW/ton	-	-	0,53	0,64	0,57	0,56	0,58	0,58	0,57	0,57	0,58	-
% chiller lo	0%	0%	94%	58%	89%	92%	94%	92%	89%	89%	81%	0%

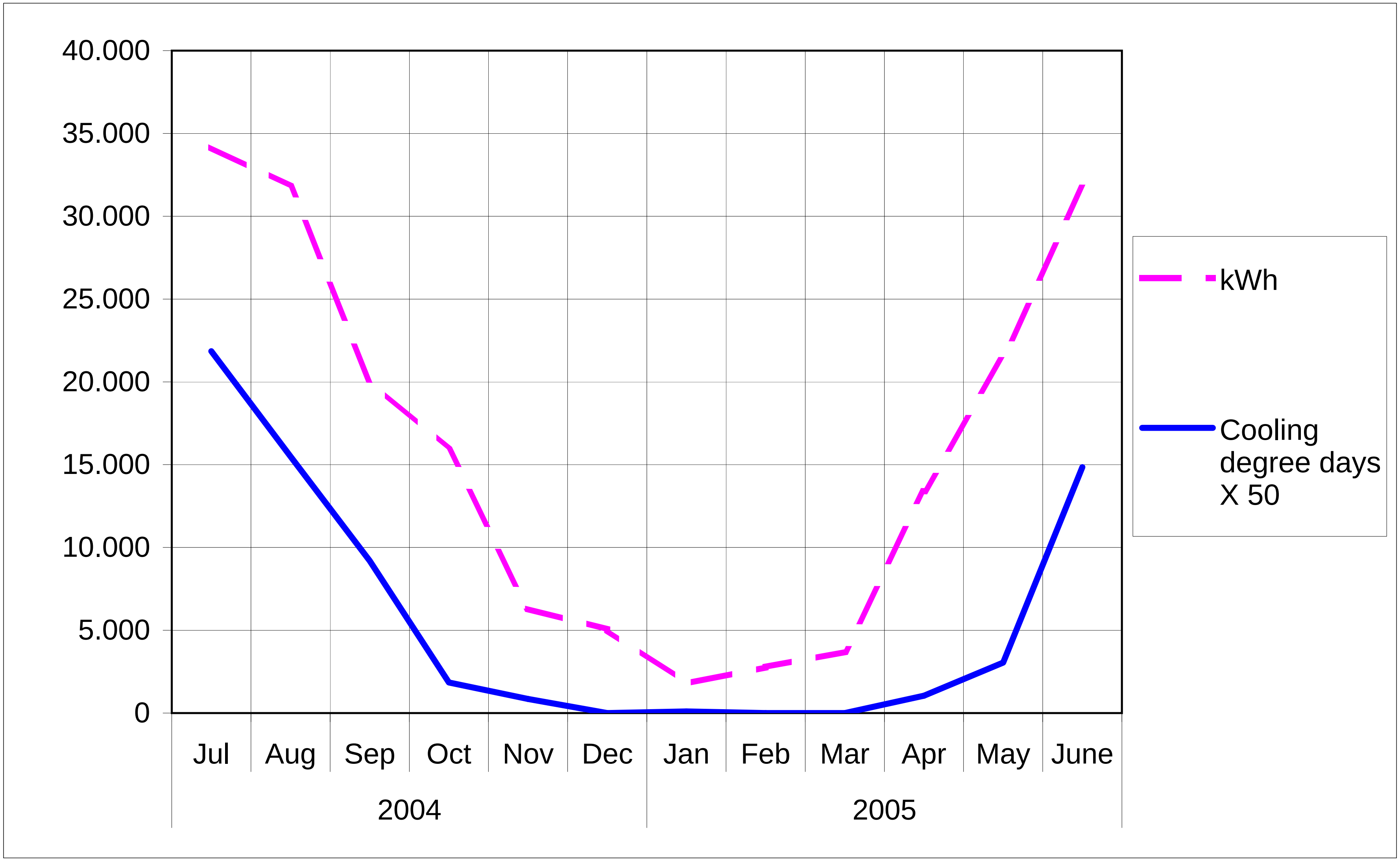


F12
2007, Chiller #9

kW/ton	-	-	0,63	0,67	0,60	0,58	0,58	0,58	0,59	0,60	0,63	-
% chiller lo	0%	0%	73%	54%	75%	87%	91%	90%	113%	72%	60%	0%

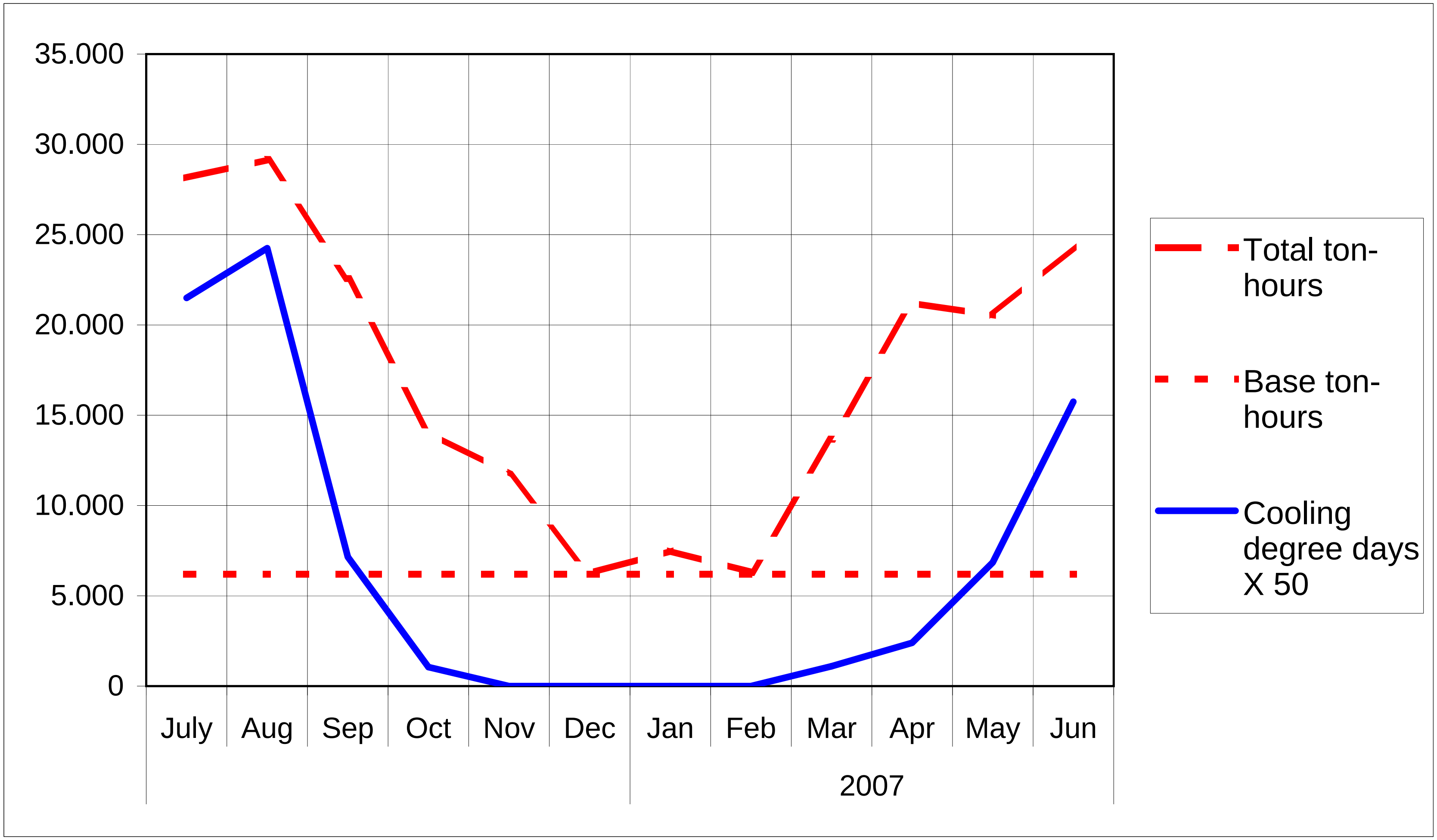


F13



40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
June
2004
2005
kWh
Cooling degree days X 50

F14


35.000
30.000
25.000
20.000
15.000
10.000
5.000
0
July
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2007
Total ton-hours
Base ton-hours
Cooling degree days X 50

F15

	Electricy (kWh)				Chilled water (ton-hrs)	
			Reduction attributable to building cooling (3)			
	Before District Cooling (1)	After District Cooling (2)	Unadjusted	Adjusted for Cooling Degree Days (4)	Building Cooling	Average building cooling efficiency (kW/ton)
Period	**1999-2001**	**2001-2005**			**2004-2005**	
Jul	841.600	404.000	437.600	419.097	442.904	
Aug	924.800	446.133	478.667	481.987	389.161	
Sep	833.600	448.800	384.800	365.685	357.368	
Oct	832.000	412.267	419.733	419.733	204.008	
Nov	563.600	453.333	110.267	119.933	149.573	
Jan	514.000	442.400	71.600	71.600	95.127	
Feb	544.000	435.467	108.533	108.533	63.884	
Mar	564.400	387.733	176.667	202.933	71.695	
Apr	608.000	369.333	238.667	225.583	143.618	
May	774.000	428.533	345.467	380.673	169.334	
Jun	822.400	420.800	401.600	397.916	323.223	
Total	7.822.400	4.648.800	3.173.600	3.193.674	2.409.895	
Average						**1,33**

Notes:

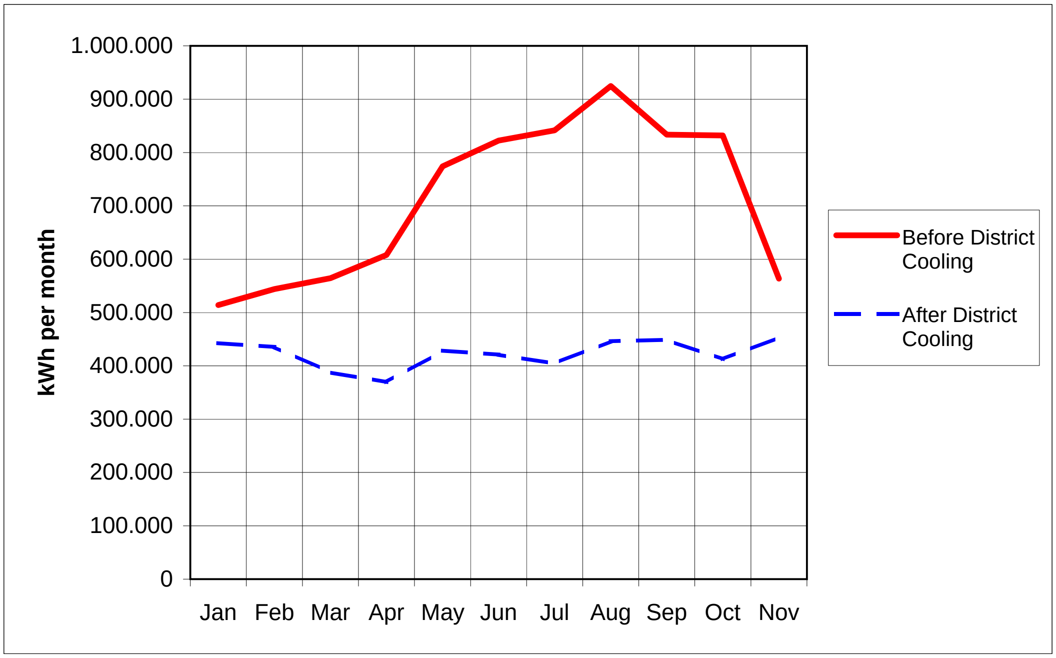
(1) includes electricity for building, chillers and cooling towers.

(2) includes electricity for building only.

(3) With no modifications to building electric system during 1999-2005 and no changes to building occupancy the reduction in electricity is attributed to building cooling.

(4) Assumes base (non-weather-related0 load is 71.600 kWh.

	Before District Cooling	After District Cooling
Jan	514.000	442.400
Feb	544.000	435.467
Mar	564.400	387.733
Apr	608.000	369.333
May	774.000	428.533
Jun	822.400	420.800
Jul	841.600	404.000
Aug	924.800	446.133
Sep	833.600	448.800
Oct	832.000	412.267
Nov	563.600	453.333



F3-4 for under 150 TR

From ASHRAE 90.1-2004, Table 6.8.1 H (Chillers under 150 tons)

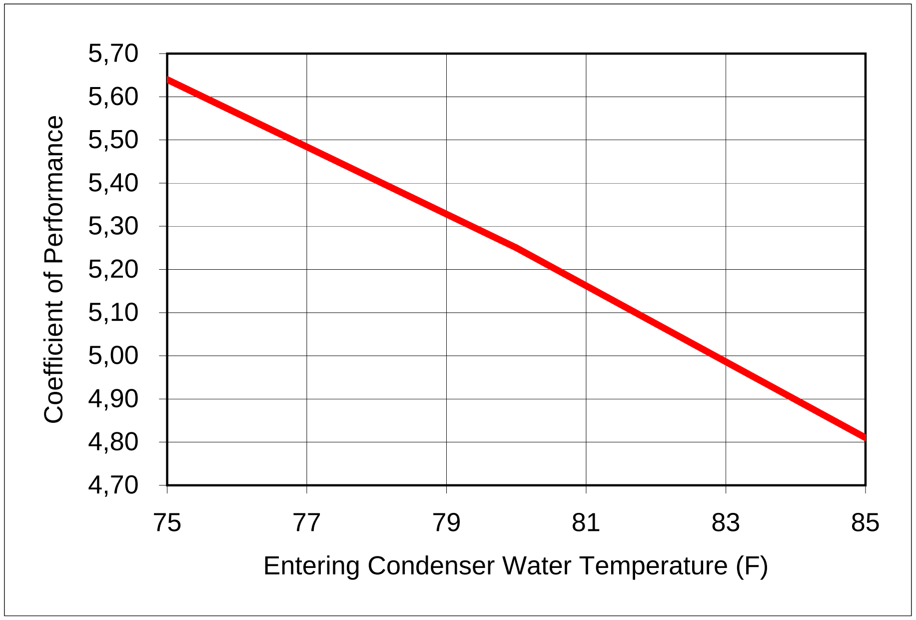
COPs at 85 ECWT and 3 gpm/ton condenser flow rate

LCWT	COP
40	4,58
41	4,70
42	4,81
43	4,91
44	5,00
45	5,09
46	5,17
47	5,25
48	5,32

ECWT
85
85
85
85
85
85
85
85
85

COPs at 42 F LCWT and 3 gpm/ton condenser flow rate

ECWT	COP	
75	5,64	1,172557
80	5,25	
85	4,81	



T1

New table 1

Chiller Type	Size range	
	tons	kW
Reciprocating	50 – 230	175-800
Rotary	70 – 400	240-1400
Centrifugal	200 – 2,500	700-8800

50	230	175,7984	808,6727
70	400	246,1178	1406,387
200	2500	703,1937	8789,921

T2

Ultraefficient All Variable-Speed Chilled Water Plants
Ben Erpelding, PE, CEM
HPAC Engineering, March 2006

Figure 1 data. Average annual chiller plant efficiency

	kW/ton		
	Low	High	Average
New all-variable-speed chiller plants	0,45	0,65	0,55
High-efficiency optimized chiller plants	0,65	0,75	0,70
Conventional code-based chiller plants	0,75	0,90	0,83
Older chiller plants	0,90	1,00	0,95
Chiller plants with design or operational problems	1,00	1,30	1,15

T3

% load	ECWT	Weighting
100%	85	1%
75%	75	42%
50%	65	45%
25%	65	12%

T4

6 April 2008	EPCs required on construction for all dwellings. EPCs required for the construction, sale or rent of buildings, other than dwellings, with a floor area over 10,000 $m^{2.}$
1 July 2008	EPCs required for the construction, sale or rent of buildings, other than dwellings, with a floor area over 2,500 m^2.
1 Oct. 2008	EPCs required on the sale or rent of all remaining dwellings EPCs required on the construction, sale or rent of all remaining buildings, other than dwellings. Display certificates required for all public buildings >1,000 $m^{2.}$
4 Jan. 2009	First inspection of all existing air-conditioning systems over 250 kW must have occurred by this date*.
4 Jan. 2011	First inspection of all remaining air-conditioning systems over 12 kW must have occurred by this date. (A system first put into service on or after 1 January 2008 must have a first inspection within 5 years of it first being put into service.)

T5

Case study from "Measured Performance and Design Guidelines for Large Commercial HVAC Systems", Kolderup et al, 2004.

Occupancy type	Office with data center
Location	San Jose, CA, USA
Floor area	105,000 square feet
Occupancy date	October 1999
Monitoring period	Nov. 2001 -- February 2002
Chilled water plant	Two water-cooled chillers, 250 tons each
Load during monitored period	20-40 tons

T6

From “Real Efficiencies of Central Plants”, Ben Erpelding, HPAC Engineering, May 2007.

Plant type	**Plant size (tons)**	**Annual total plant efficiency (kW/ton)**
Air cooled	176	1,50
Variable speed screw	440	1,20
Ultra-efficient all variable speed with oil-less compressors	750	0,55
District cooling plant	3200	0,85

T7&8

Data from "Measured Chiller Efficiency In-Use: Liquid Chillers & Direct Expansion Systems within UK offices"
Dunn and Knight, Welsh School of Architecture, and Hitchin, Building Research Establishment
Building Performance Congress (no date)

				Efficiency (EER)								
		Size			Actual daily chiller		Actual daily system				Typical system efficiency (EER)	
System	Type	kW	tons	Rated chiller	Low	High	Low	High	Actual daily peak	Average system load	Low	High
1	Packaged air cooled chiller and fancoil	50	14,2	2,48	2,00	4,50	0,50	2,00	1,60	21,0%	1,00	1,40
2	Water cooled screw chiller and fancoil	1.275	362,6	4,46	3,20	5,30	1,10	2,00	1,70	19,0%	0,80	1,60
3	Packaged air cooled chiller and fancoil	100	28,4	2,66	2,10	3,30	0,40	1,70	1,40	8,3%	0,30	1,40
4	DX split	8	2,3	2,42	NA	NA	1,20	5,50	3,40	44,0%	1,30	1,70

				Efficiency (kW/ton)								
		Size			Actual daily chiller		Actual daily system				Typical system efficiency (kW/ton)	
System	Type	kW	tons	Rated chiller	Low	High	Low	High	Actual daily peak	Average system load	Low	High
1	Packaged air cooled chiller and fancoil	50	14,2	1,42	1,76	0,78	7,03	1,76	2,20	21,0%	3,52	2,51
2	Water cooled screw chiller and fancoil	1.275	362,6	0,79	1,10	0,66	3,20	1,76	2,07	19,0%	4,39	2,20
3	Packaged air cooled chiller and fancoil	100	28,4	1,32	1,67	1,07	8,79	2,07	2,51	8,3%	11,72	2,51
4	DX split	8	2,3	1,45	NA	NA	2,93	0,64	1,03	44,0%	2,70	2,07

T9

2007

Elecric chiller kW/ton

	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1			0,79		0,78	0,75	0,74	0,74	0,75	0,75		0,92	0,75
Chiller #4	0,61	0,60	0,62	0,69	0,63	0,62	0,64	0,63	0,65	0,65	0,69	0,63	0,63
Chiller #7			0,65	0,67	0,61	0,59	0,60	0,60	0,60	0,60	0,66		0,61
Chiller #8			0,53	0,64	0,57	0,56	0,58	0,58	0,57	0,57	0,58		0,58
Chiller #9			0,63	0,67	0,60	0,58	0,58	0,58	0,59	0,60	0,63		0,59

Electric chiller average load as % of total chiller capacity

	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1			74%		82%	92%	98%	96%	95%	93%		60%	93%
Chiller #4	71%	68%	86%	52%	77%	76%	76%	77%	74%	69%	53%	76%	70%
Chiller #7			70%	60%	75%	87%	89%	89%	103%	78%	52%		83%
Chiller #8			94%	58%	89%	92%	94%	92%	89%	89%	81%		89%
Chiller #9			73%	54%	75%	87%	91%	90%	113%	72%	60%		82%

T10

Phoenix

Year	2002	2003	2004	2005	Average 2003-2005	2006
Building kWhs	12.308.700	9.015.800	8.421.200	8.356.700		
Cooling degree days	4.916	4.960	4.755	4.709		4.776
Cooling degree days (% above 2002)		0,9%	-3,3%	-4,2%		-2,8%
Cooling load adjustment factor		0,999	1,005	1,006		97,6%
Removed Cooling kWh		3.297.327	3.868.496	3.927.195		
Ton-Hrs		2.746.253	2.945.678	3.213.174		3.185.188
kW/ton		1,20	1,31	1,22	1,25	

Base cooling load assumption 15%

T11

Cheek Clark summary

Post-connection

Data collection period	July 06 -- June 07	
Number of months in period	12	
Cooling degree days	1.366	
Cooling energy		
Actual total ton-hours	205.436	100%
Estimated base cooling load	74.400	36%
Estimated weather-related load	131.036	64%
Base monthly ton-hours	6.200	
Ton-hours per cooling degree day	95,9	

Pre-connection

Data collection period	July 04 -- June 05	
Number of months in period	12	
Pre-conversion air-cooled chiller electricity consumption (kWh)	188.146	
Cooling degree days	1.366	
Estimated ton-hours cooling energy		
Base cooling load (1)	74.400	36%
Weather-related load (2)	131.036	64%
Total	205.436	100%
Calculated kW/ton	0,92	

Notes

(1) Base monthly ton-hours X months

(2) CDD X ton-hours/CDD

T12

Gross Chemistry Building cooling efficiency before district cooling

	Electricy (kWh)					
			Reduction attributable to building cooling (3)		Chilled water (ton-hrs)	
	Before District Cooling (1)	After District Cooling (2)	Unadjusted	Adjusted for Cooling Degree Days (4)	Building Cooling	Average building cooling efficiency (kW/ton)
Period	**1999-2001**	**2001-2005**			**2004-2005**	
Jul	841.600	404.000	437.600	419.097	442.904	
Aug	924.800	446.133	478.667	481.987	389.161	
Sep	833.600	448.800	384.800	365.685	357.368	
Oct	832.000	412.267	419.733	419.733	204.008	
Nov	563.600	453.333	110.267	119.933	149.573	
Jan	514.000	442.400	71.600	71.600	95.127	
Feb	544.000	435.467	108.533	108.533	63.884	
Mar	564.400	387.733	176.667	202.933	71.695	
Apr	608.000	369.333	238.667	225.583	143.618	
May	774.000	428.533	345.467	380.673	169.334	
Jun	822.400	420.800	401.600	397.916	323.223	
Total	7.822.400	4.648.800	**3.173.600**	**3.193.674**	**2.409.895**	
Average						**1,33**

Notes:

(1) includes electricity for building, chillers and cooling towers.

(2) includes electricity for building only.

(3) With no modifications to building electric system during 1999-2005 and no changes to building occupancy the reduction in electricity is attributed to building cooling.

(4) Assumes base (non-weather-related0 load is 71.600 kWh.

T13

Summary of annual efficiency case studies

Building Name	Location	Chiller type	Calculation method	Average annual kW/ton
Gross Chemistry	Duke University, NC	Water-cooled	1	1,33
(Confidential)	Phoenix, AZ	Water-cooled	1	1,25
ITS Franklin	UNC Chapel Hill, NC	Air-cooled	2	1,21
Cheek Clark	UNC Chapel Hill, NC	Air-cooled	1	0,92

Calculation Methods

1. Based on electricity consumption before and after connection to district cooling, and cooling consumption following connection.
2. Submetering of chiller system.

UNC CDD data

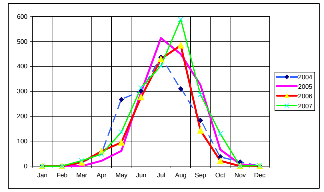
July-June

	2004-2005 kWh	2004-2005 CDD	2006-2007 ton-hours	2006-2007 CDD	CDD ratio
July	34.161	437	28.135	430	0,98
Aug	31.792	310	29.162	485	1,56
Sep	20.085	184	22.566	143	0,78
Oct	15.893	37	14.079	21	0,57
Nov	6.302	17	11.720	-	-
Dec	5.042	0	6.230	-	-
Jan	1.782	2	7.499	-	-
Feb	2.773	0	6.290	-	-
Mar	3.702	0	13.669	22	-
Apr	13.400	21	21.223	48	2,29
May	21.491	61	20.526	137	2,25
June	31.723	297	24.337	315	1,06
Total	188.146	1.366	205.436	1.601	1,17

Summary of Cooling Degree Days

	Chapel Hill				Durham									Average CDD UNC		
	2004	2005	2006	2007	1999	2000	2001	2002		2003	2004	2005		Before	After	Ratio After/Before
Jan	.	2	0	0	3	0	0	4		0	0	6	Jan	1	-	-
Feb	0	0	0	0	0	0	0	0		0	0	0	Feb	-	-	#DIV/0!
Mar	13	0	15	22	0	9	3	15		7	10	0	Mar	8	22	2,93
Apr	53	21	60	48	64	19	83	104		19	58	23	Apr	41	48	1,19
May	267	61	95	137	100	185	137	160		101	294	80	May	78	137	1,76
Jun	301	297	277	315	292	374	364	391		274	342	351	Jun	297	296	1,00
Jul	437	514	430	403	513	380	356	489		419	445	544	Jul	476	417	0,88
Aug	310	450	485	589	474	351	461	422		436	329	481	Aug	380	537	1,41
Sep	184	326	143	287	161	176	176	253		171	200	339	Sep	255	215	0,84
Oct	37	66	21	130	24	38	46	86		16	52	85	Oct	52	76	1,47
Nov	17	8	0	0	0	8	17	6		24	17	12	Nov	13	-	-
Dec	0	0	0	2	0	0	2	0		0	0	0	Dec	-	1	#DIV/0!
Total	1619	1745	1526	1933	1631	1540	1645	1930		1467	1747	1921	Total	1.599	1.748	1,09

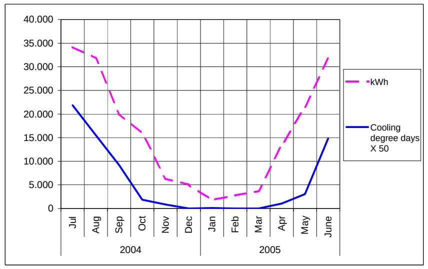
0,914474



July-Dec 04	985
Jan-June 05	381
July 04-June 05	1366
July-Dec 05	1364
Jan-June 06	447
July 05-June 06	1811
July-Dec 06	1079
Jan - June 07	522
July 06 - June 07	1601

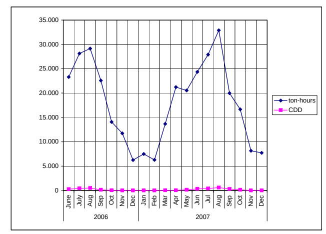
		kWh	Cooling degree days X 50	Projected 100 ton-hours
	Jul	34.161	21.850	1.495.999
	Aug	31.792	15.500	1.063.037
	Sep	20.085	9.200	633.484
2004	Oct	15.893	1.850	132.339
	Nov	6.302	850	64.156
	Dec	5.042	0	6.200
	Jan	1.782	100	13.018
	Feb	2.773	0	6.200
	Mar	3.702	0	6.200
	Apr	13.400	1.050	77.792
	May	21.491	3.050	214.158
	June	31.723	14.850	1.018.718
2005	July	27.035	25.700	1.758.504
	Aug	48.231	22.500	1.540.318
	Sep	11.107	16.300	1.117.583
	Oct	7.161	3.300	231.204
	Nov	286	400	33.473
	Dec	321	0	6.200
	Jan	271	0	6.200
	Feb	274	0	6.200
2006	Mar	265	750	57.337
	Apr	272	3.000	210.749
	May	315	4.750	330.069
	Total	283.684	145.000	10.029.140

Base ton-hours 6200
CDD multiplier 68,18

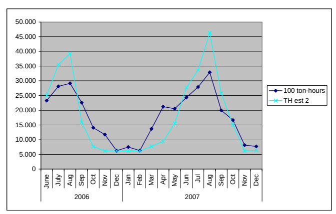


Projected 100 ton-hours / **Projected 100 ton-hours minus actual**

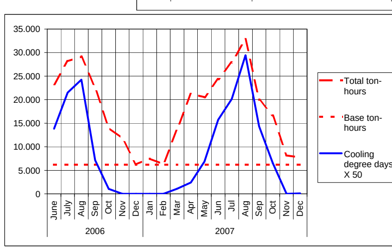
		ton-hours	CDD	TH est 1	TH est 2	TH est 3	TH est 4	TH est 5	TH est 6		Actual	TH est 1	TH est 2	TH est 3	TH est 4	TH est 5	TH est 6	CDD inverse X 100
	June	23.295	277	24.617	25.087	25.087	25.087	25.087	25.087	-	23.295	1.322	1.792	1.792	1.792	1.792	1.792	0,36
	July	28.135	430	34.348	35.519	35.519	35.519	35.519	35.519	-	28.135	6.213	7.384	7.384	7.384	7.384	7.384	0,23
	Aug	29.162	485	37.846	39.269	39.269	39.269	39.269	39.269	-	29.162	8.684	10.107	10.107	10.107	10.107	10.107	0,21
2006	Sep	22.566	143	16.095	15.950	15.950	15.950	15.950	15.950	-	22.566	(6.471)	(6.616)	(6.616)	(6.616)	(6.616)	(6.616)	0,70
	Oct	14.079	21	8.336	7.632	7.632	7.632	7.632	7.632	-	14.079	(5.743)	(6.447)	(6.447)	(6.447)	(6.447)	(6.447)	4,76
	Nov	11.720	0	7.000	6.200	6.200	6.200	6.200	6.200	-	11.720	(4.720)	(5.520)	(5.520)	(5.520)	(5.520)	(5.520)	#DIV/0!
	Dec	6.230	0	7.000	6.200	6.200	6.200	6.200	6.200	-	6.230	770	(30)	(30)	(30)	(30)	(30)	#DIV/0!
	Jan	7.499	0	7.000	6.200	6.200	6.200	6.200	6.200	-	7.499	(499)	(1.299)	(1.299)	(1.299)	(1.299)	(1.299)	#DIV/0!
	Feb	6.290	0	7.000	6.200	6.200	6.200	6.200	6.200	-	6.290	710	(90)	(90)	(90)	(90)	(90)	#DIV/0!
	Mar	13.669	22	8.399	7.700	7.700	7.700	7.700	7.700	-	13.669	(5.270)	(5.969)	(5.969)	(5.969)	(5.969)	(5.969)	4,55
	Apr	21.223	48	10.053	9.473	9.473	9.473	9.473	9.473	-	21.223	(11.170)	(11.750)	(11.750)	(11.750)	(11.750)	(11.750)	2,08
	May	20.526	137	15.713	15.541	15.541	15.541	15.541	15.541	-	20.526	(4.813)	(4.985)	(4.985)	(4.985)	(4.985)	(4.985)	0,73
	Jun	24.337	315	27.034	27.678	27.678	27.678	27.678	27.678	-	24.337	2.697	3.341	3.341	3.341	3.341	3.341	0,32
2007	Jul	27.905	403	32.631	33.678	33.678	33.678	33.678	33.678	-	27.905	4.726	5.773	5.773	5.773	5.773	5.773	0,25
	Aug	32.907	589	44.460	46.360	46.360	46.360	46.360	46.360	-	32.907	11.553	13.453	13.453	13.453	13.453	13.453	0,17
	Sep	19.974	287	25.253	25.769	25.769	25.769	25.769	25.769	-	19.974	5.279	5.795	5.795	5.795	5.795	5.795	0,35
	Oct	16.656	130	15.268	15.064	15.064	15.064	15.064	15.064	-	16.656	(1.388)	(1.592)	(1.592)	(1.592)	(1.592)	(1.592)	0,77
	Nov	8.161	0	7.000	6.200	6.200	6.200	6.200	6.200	-	8.161	(1.161)	(1.961)	(1.961)	(1.961)	(1.961)	(1.961)	#DIV/0!
	Dec	7.720	2	7.127	6.336	6.336	6.336	6.336	6.336	-	7.720	(593)	(1.384)	(1.384)	(1.384)	(1.384)	(1.384)	50,00
Total		342.054	3.289	342.180	342.054	342.054	342.054	342.054	342.054									
Difference vs actual				126	0	0	0	0	0									
Base ton-hours				7000	6200	6200	6200	6200	6200									
CDD multiplier				63,60	68,18	68,18	68,18	68,18	68,18									



		100 ton-hours	TH est 1	TH est 2	TH est 3	TH est 4	TH est 5	TH est 6
	June	23.295	24.617	25.087	25.087	25.087	25.087	25.087
	July	28.135	34.348	35.519	35.519	35.519	35.519	35.519
	Aug	29.162	37.846	39.269	39.269	39.269	39.269	39.269
2006	Sep	22.566	16.095	15.950	15.950	15.950	15.950	15.950
	Oct	14.079	8.336	7.632	7.632	7.632	7.632	7.632
	Nov	11.720	7.000	6.200	6.200	6.200	6.200	6.200
	Dec	6.230	7.000	6.200	6.200	6.200	6.200	6.200
	Jan	7.499	7.000	6.200	6.200	6.200	6.200	6.200
	Feb	6.290	7.000	6.200	6.200	6.200	6.200	6.200
	Mar	13.669	8.399	7.700	7.700	7.700	7.700	7.700
	Apr	21.223	10.053	9.473	9.473	9.473	9.473	9.473
	May	20.526	15.713	15.541	15.541	15.541	15.541	15.541
	Jun	24.337	27.034	27.678	27.678	27.678	27.678	27.678
2007	Jul	27.905	32.631	33.678	33.678	33.678	33.678	33.678
	Aug	32.907	44.460	46.360	46.360	46.360	46.360	46.360
	Sep	19.974	25.253	25.769	25.769	25.769	25.769	25.769
	Oct	16.656	15.268	15.064	15.064	15.064	15.064	15.064
	Nov	8.161	7.000	6.200	6.200	6.200	6.200	6.200
	Dec	7.720	7.127	6.336	6.336	6.336	6.336	6.336



		Total ton-hours	Base ton-hours	Cooling degree days X 50
	June	23.295	6.200	13.850
	July	28.135	6.200	21.500
	Aug	29.162	6.200	24.250
2006	Sep	22.566	6.200	7.150
	Oct	14.079	6.200	1.050
	Nov	11.720	6.200	-
	Dec	6.230	6.200	-
	Jan	7.499	6.200	-
	Feb	6.290	6.200	-
	Mar	13.669	6.200	1.100
	Apr	21.223	6.200	2.400
	May	20.526	6.200	6.850
	Jun	24.337	6.200	15.750
2007	Jul	27.905	6.200	20.150
	Aug	32.907	6.200	29.450
	Sep	19.974	6.200	14.350
	Oct	16.656	6.200	6.500
	Nov	8.161	6.200	-
	Dec	7.720	6.200	100



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Duke CDD data

	Durham									Average CDD		
	1998	1999	2000	2001	2002	2003	2004	2005		Average July 1999 -- June 2001	Average July 2002 -- June 2005	Average July 2005 -- June 2005
Jan	3	3	0	0	4	0	0	6		-	3	3
Feb	0	0	0	0	0	0	0	0		-	-	-
Mar	23	0	9	3	15	7	10	0		6	8	5
Apr	29	64	19	83	104	19	58	23		51	51	41
May	158	100	185	137	160	101	294	80		161	159	187
Jun	382	292	374	364	391	274	342	351		369	340	347
Jul	457	513	380	356	489	419	445	544		447	474	495
Aug	401	474	351	461	422	436	329	481		413	417	405
Sep	302	161	176	176	253	171	200	339		169	241	270
Oct	32	24	38	46	86	16	52	85		31	60	69
Nov	0	0	8	17	6	24	17	12		4	15	15
Dec	12	0	0	2	0	0	0	0		-	-	-
		1631	1540	1645	1930	1467	1747	1921		1.650	1.766	1.834

Fiscal years

	1999	2000	2001	2002	2003	2004	2005	Average FY 1999-2001	Average FY 2001-2005	Raw Ratio	Adjusted Ratio
July	457	513	380	356	489	419	445	450	427	0,95	0,95
Aug	401	474	351	461	422	436	329	409	412	1,01	1,01
Sep	302	161	176	176	253	171	200	213	200	0,94	0,94
Oct	32	24	38	46	86	16	52	31	50	1,60	1,00
Nov	0	0	8	17	6	24	17	3	16	6,00	1,25
Dec	12	0	0	2	0	0	0	4	1	0,13	1,00
Jan	3	0	0	4	0	0	6	1	3	2,50	1,00
Feb	0	0	0	0	0	0	0	-	-	#DIV/0!	1,00
Mar	0	9	3	15	7	10	0	4	8	2,00	1,25
Apr	64	19	83	104	19	58	23	55	51	0,92	0,92
May	100	185	137	160	101	294	80	141	159	1,13	1,13
Jun	292	374	364	391	274	342	351	343	340	0,99	0,99
Total	1663	1759	1540	1732	1657	1770	1503	1.654	1.666	1,01	1,01

Franklin 06

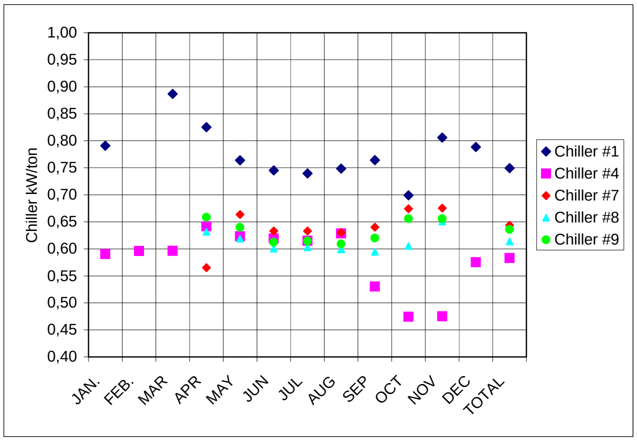
2006

Elecric chiller kW/ton

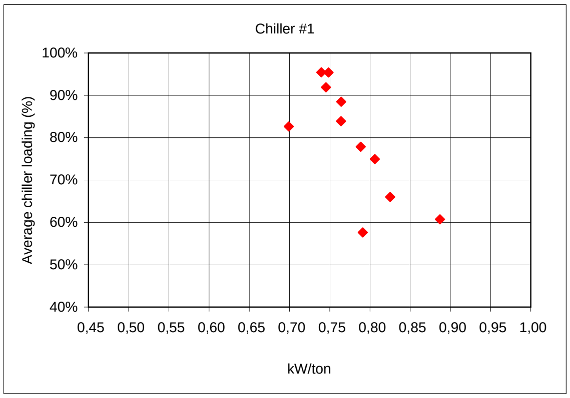
	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1	0,79		0,89	0,83	0,76	0,75	0,74	0,75	0,76	0,70	0,81	0,79	0,75
Chiller #4	0,59	0,60	0,60	0,64	0,62	0,62	0,61	0,63	0,53	0,47	0,48	0,58	0,58
Chiller #7				0,57	0,66	0,63	0,63	0,63	0,64	0,67	0,68		0,64
Chiller #8				0,63	0,62	0,60	0,60	0,60	0,59	0,61	0,65		0,61
Chiller #9				0,66	0,64	0,61	0,61	0,61	0,62	0,66	0,66		0,64

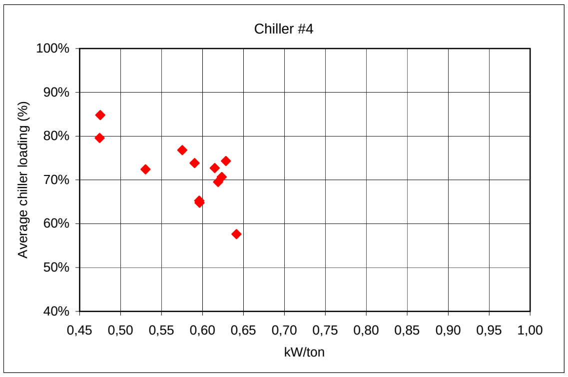
Electric chiller average load as % of total chiller capacity

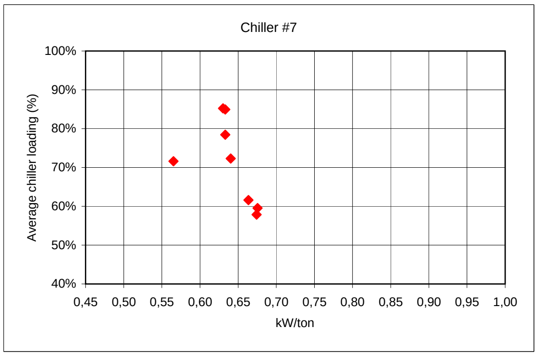
	JAN.	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Chiller #1	58%		61%	66%	84%	92%	95%	95%	88%	83%	75%	78%	90%
Chiller #4	74%	65%	65%	58%	71%	70%	73%	74%	72%	80%	85%	77%	71%
Chiller #7				72%	62%	78%	85%	85%	72%	58%	60%		73%
Chiller #8				68%	70%	86%	88%	90%	84%	73%	70%		83%
Chiller #9				58%	63%	81%	87%	87%	74%	60%	59%		72%



Chiller #1												
kW/ton	0,79	-	0,89	0,83	0,76	0,75	0,74	0,75	0,76	0,70	0,81	0,79
% chiller lo	58%	0%	61%	66%	84%	92%	95%	95%	88%	83%	75%	78%
Chiller #4												
kW/ton	0,59	0,60	0,60	0,64	0,62	0,62	0,61	0,63	0,53	0,47	0,48	0,58
% chiller lo	74%	65%	65%	58%	71%	70%	73%	74%	72%	80%	85%	77%
Chiller #7												
kW/ton	0	0	0	0,56521	0,66347	0,63321	0,63311	0,63017	0,64017	0,67425	0,67541	0
% chiller lo	0%	0%	0%	72%	62%	78%	85%	85%	72%	58%	60%	0%







Phoenix Data per NOAA

	2002	2003	2004	2005
January	0	0	0	0
February	0	8	6	4
March	19	6	1	0
April	89	79	281	35
May	358	179	249	227
June	525	576	580	557
July	858	810	791	770
August	971	1023	920	1005
September	940	924	867	850
October	749	779	699	745
November	325	556	341	418
December	82	20	20	98
Total	4916	4960	4755	4709

Phoenix CDD 2002	Year/Month/Day	Low	High	Average	Cooling Degrees	Heating Degrees
	1-1-2002 0:00	45	53	49	0	16
	2-1-2002 0:00	52	59	55,5	0	9,5
	3-1-2002 0:00	50	59	54,5	0	10,5
	4-1-2002 0:00	45	52	48,5	0	16,5
	5-1-2002 0:00	43	53	48	0	17
	6-1-2002 0:00	42	48	45	0	20
	7-1-2002 0:00	44	53	48,5	0	16,5
	8-1-2002 0:00	48	59	53,5	0	11,5
	9-1-2002 0:00	53	61	57	0	8
	10-1-2002 0:00	56	61	58,5	0	6,5
	11-1-2002 0:00	52	63	57,5	0	7,5
	12-1-2002 0:00	49	59	54	0	11
	13-1-2002 0:00	46	57	51,5	0	13,5
	14-1-2002 0:00	45	57	51	0	14
	15-1-2002 0:00	49	56	52,5	0	12,5
	16-1-2002 0:00	54	57	55,5	0	9,5
	17-1-2002 0:00	46	53	49,5	0	15,5
	18-1-2002 0:00	39	45	42	0	23
	19-1-2002 0:00	39	49	44	0	21
	20-1-2002 0:00	37	47	42	0	23
	21-1-2002 0:00	39	46	42,5	0	22,5
	22-1-2002 0:00	41	50	45,5	0	19,5
	23-1-2002 0:00	50	52	51	0	14
	24-1-2002 0:00	39	50	44,5	0	20,5
	25-1-2002 0:00	42	58	50	0	15
	26-1-2002 0:00	46	59	52,5	0	12,5
	27-1-2002 0:00	48	57	52,5	0	12,5
	28-1-2002 0:00	52	57	54,5	0	10,5
	29-1-2002 0:00	50	52	51	0	14
	30-1-2002 0:00	42	52	47	0	18
	31-1-2002 0:00	37	44	40,5	0	24,5
	1-2-2002 0:00	40	52	46	0	19
	2-2-2002 0:00	49	53	51	0	14
	3-2-2002 0:00	40	49	44,5	0	20,5
	4-2-2002 0:00	45	57	51	0	14
	5-2-2002 0:00	45	60	52,5	0	12,5
	6-2-2002 0:00	44	58	51	0	14
	7-2-2002 0:00	42	58	50	0	15
	8-2-2002 0:00	44	56	50	0	15
	9-2-2002 0:00	49	59	54	0	11
	10-2-2002 0:00	54	60	57	0	8
	11-2-2002 0:00	43	59	51	0	14
	12-2-2002 0:00	45	60	52,5	0	12,5
	13-2-2002 0:00	46	62	54	0	11
	14-2-2002 0:00	51	64	57,5	0	7,5
	15-2-2002 0:00	52	63	57,5	0	7,5
	16-2-2002 0:00	52	70	61	0	4
	17-2-2002 0:00	53	61	57	0	8
	18-2-2002 0:00	54	59	56,5	0	8,5
	19-2-2002 0:00	45	55	50	0	15
	20-2-2002 0:00	48	58	53	0	12
	21-2-2002 0:00	50	65	57,5	0	7,5
	22-2-2002 0:00	58	70	64	0	1
	23-2-2002 0:00	55	70	62,5	0	2,5
	24-2-2002 0:00	52	63	57,5	0	7,5
	25-2-2002 0:00	50	65	57,5	0	7,5
	26-2-2002 0:00	50	65	57,5	0	7,5
	27-2-2002 0:00	56	66	61	0	4
	28-2-2002 0:00	56	63	59,5	0	5,5
	1-3-2002 0:00	52	62	57	0	8
	2-3-2002 0:00	46	53	49,5	0	15,5
	3-3-2002 0:00	39	52	45,5	0	19,5
	4-3-2002 0:00	44	60	52	0	13
	5-3-2002 0:00	47	61	54	0	11
	6-3-2002 0:00	49	63	56	0	9
	7-3-2002 0:00	53	61	57	0	8
	8-3-2002 0:00	53	61	57	0	8
	9-3-2002 0:00	54	64	59	0	6
	10-3-2002 0:00	54	68	61	0	4
	11-3-2002 0:00	53	67	60	0	5
	12-3-2002 0:00	56	69	62,5	0	2,5
	13-3-2002 0:00	57	71	64	0	1
	14-3-2002 0:00	52	63	57,5	0	7,5
	15-3-2002 0:00	45	55	50	0	15
	16-3-2002 0:00	45	55	50	0	15
	17-3-2002 0:00	47	57	52	0	13
	18-3-2002 0:00	56	61	58,5	0	6,5
	19-3-2002 0:00	48	58	53	0	12
	20-3-2002 0:00	52	67	59,5	0	5,5
	21-3-2002 0:00	56	80	68	3	0
	22-3-2002 0:00	62	76	69	4	0
	23-3-2002 0:00	57	71	64	0	1
	24-3-2002 0:00	56	65	60,5	0	4,5
	25-3-2002 0:00	54	63	58,5	0	6,5
	26-3-2002 0:00	55	68	61,5	0	3,5
	27-3-2002 0:00	57	70	63,5	0	1,5
	28-3-2002 0:00	58	72	65	0	0
	29-3-2002 0:00	59	64	61,5	0	3,5
	30-3-2002 0:00	57	68	62,5	0	2,5
	31-3-2002 0:00	62	76	69	4	0
	1-4-2002 0:00	64	78	71	6	0
	2-4-2002 0:00	63	80	71,5	6,5	0
	3-4-2002 0:00	66	80	73	8	0
	4-4-2002 0:00	64	79	71,5	6,5	0
	5-4-2002 0:00	65	79	72	7	0
	6-4-2002 0:00	68	73	70,5	5,5	0
	7-4-2002 0:00	57	65	61	0	4
	8-4-2002 0:00	61	72	66,5	1,5	0
	9-4-2002 0:00	63	77	70	5	0
	10-4-2002 0:00	65	79	72	7	0
	11-4-2002 0:00	65	81	73	8	0
	12-4-2002 0:00	68	83	75,5	10,5	0
	13-4-2002 0:00	73	85	79	14	0
	14-4-2002 0:00	71	84	77,5	12,5	0
	15-4-2002 0:00	72	81	76,5	11,5	0
	16-4-2002 0:00	65	72	68,5	3,5	0
	17-4-2002 0:00	64	72	68	3	0
	18-4-2002 0:00	61	73	67	2	0
	19-4-2002 0:00	62	71	66,5	1,5	0
	20-4-2002 0:00	58	67	62,5	0	2,5
	21-4-2002 0:00	57	73	65	0	0
	22-4-2002 0:00	61	79	70	5	0
	23-4-2002 0:00	64	81	72,5	7,5	0
	24-4-2002 0:00	67	81	74	9	0
	25-4-2002 0:00	78	85	81,5	16,5	0
	26-4-2002 0:00	71	77	74	9	0
	27-4-2002 0:00	61	66	63,5	0	1,5
	28-4-2002 0:00	61	77	69	4	0
	29-4-2002 0:00	71	79	75	10	0
	30-4-2002 0:00	64	77	70,5	5,5	0
	1-5-2002 0:00	69	73	71	6	0
	2-5-2002 0:00	58	71	64,5	0	0,5
	3-5-2002 0:00	62	75	68,5	3,5	0
	4-5-2002 0:00	63	79	71	6	0
	5-5-2002 0:00	64	81	72,5	7,5	0
	6-5-2002 0:00	66	80	73	8	0
	7-5-2002 0:00	67	81	74	9	0
	8-5-2002 0:00	68	82	75	10	0
	9-5-2002 0:00	67	83	75	10	0
	10-5-2002 0:00	68	83	75,5	10,5	0
	11-5-2002 0:00	67	80	73,5	8,5	0
	12-5-2002 0:00	67	80	73,5	8,5	0
	13-5-2002 0:00	71	92	81,5	16,5	0
	14-5-2002 0:00	76	90	83	18	0
	15-5-2002 0:00	73	89	81	16	0
	16-5-2002 0:00	71	86	78,5	13,5	0
	17-5-2002 0:00	71	87	79	14	0
	18-5-2002 0:00	72	88	80	15	0
	19-5-2002 0:00	75	86	80,5	15,5	0
	20-5-2002 0:00	72	83	77,5	12,5	0
	21-5-2002 0:00	62	72	67	2	0
	22-5-2002 0:00	63	75	69	4	0
	23-5-2002 0:00	63	80	71,5	6,5	0
	24-5-2002 0:00	66	82	74	9	0
	25-5-2002 0:00	69	85	77	12	0
	26-5-2002 0:00	71	86	78,5	13,5	0
	27-5-2002 0:00	69	85	77	12	0
	28-5-2002 0:00	71	87	79	14	0
	29-5-2002 0:00	73	90	81,5	16,5	0
	30-5-2002 0:00	76	94	85	20	0
	31-5-2002 0:00	80	95	87,5	22,5	0
	1-6-2002 0:00	83	94	88,5	23,5	0
	2-6-2002 0:00	77	92	84,5	19,5	0
	3-6-2002 0:00	79	89	84	19	0
	4-6-2002 0:00	72	85	78,5	13,5	0
	5-6-2002 0:00	77	92	84,5	19,5	0
	6-6-2002 0:00	78	97	87,5	22,5	0
	7-6-2002 0:00	81	95	88	23	0
	8-6-2002 0:00	80	96	88	23	0
	9-6-2002 0:00	81	91	86	21	0
	10-6-2002 0:00	76	88	82	17	0
	11-6-2002 0:00	75	90	82,5	17,5	0
	12-6-2002 0:00	78	91	84,5	19,5	0
	13-6-2002 0:00	78	93	85,5	20,5	0
	14-6-2002 0:00	81	98	89,5	24,5	0
	15-6-2002 0:00	81	97	89	24	0
	17-6-2002 0:00	81	98	89,5	24,5	0
	18-6-2002 0:00	79	96	87,5	22,5	0
	19-6-2002 0:00	79	96	87,5	22,5	0
	20-6-2002 0:00	81	96	88,5	23,5	0
	21-6-2002 0:00	82	97	89,5	24,5	0
	22-6-2002 0:00	79	95	87	22	0
	23-6-2002 0:00	79	95	87	22	0
	24-6-2002 0:00	80	98	89	24	0
	25-6-2002 0:00	84	99	91,5	26,5	0
	26-6-2002 0:00	86	98	92	27	0
	27-6-2002 0:00	98	98	98	33	0
	28-6-2002 0:00	79	95	87	22	0
	29-6-2002 0:00	81	95	88	23	0
649	30-6-2002 0:00	83	96	89,5	24,5	0
	1-7-2002 0:00	85	97	91	26	0
	2-7-2002 0:00	89	98	93,5	28,5	0
	3-7-2002 0:00	88	93	90,5	25,5	0
	4-7-2002 0:00	82	94	88	23	0
	5-7-2002 0:00	82	95	88,5	23,5	0
	6-7-2002 0:00	82	97	89,5	24,5	0
	7-7-2002 0:00	85	97	91	26	0
	8-7-2002 0:00	85	99	92	27	0
	9-7-2002 0:00	93	101	97	32	0
	10-7-2002 0:00	86	98	92	27	0
	11-7-2002 0:00	88	99	93,5	28,5	0
	12-7-2002 0:00	89	100	94,5	29,5	0
	13-7-2002 0:00	93	102	97,5	32,5	0
	14-7-2002 0:00	89	107	98	33	0
	15-7-2002 0:00	81	88	84,5	19,5	0
	16-7-2002 0:00	85	93	89	24	0
	17-7-2002 0:00	87	93	90	25	0
	18-7-2002 0:00	88	95	91,5	26,5	0
	19-7-2002 0:00	90	97	93,5	28,5	0
	20-7-2002 0:00	87	94	90,5	25,5	0
	21-7-2002 0:00	85	93	89	24	0
	22-7-2002 0:00	87	95	91	26	0
	23-7-2002 0:00	85	96	90,5	25,5	0
	24-7-2002 0:00	79	91	85	20	0
	25-7-2002 0:00	89	93	91	26	0
	26-7-2002 0:00	88	96	92	27	0
	27-7-2002 0:00	86	91	88,5	23,5	0
	28-7-2002 0:00	82	94	88	23	0
	29-7-2002 0:00	84	95	89,5	24,5	0
	30-7-2002 0:00	88	94	91	26	0
	31-7-2002 0:00	87	93	90	25	0
	1-8-2002 0:00	88	95	91,5	26,5	0
	2-8-2002 0:00	87	94	90,5	25,5	0
	3-8-2002 0:00	88	95	91,5	26,5	0
	4-8-2002 0:00	86	90	88	23	0
	5-8-2002 0:00	82	90	86	21	0
	6-8-2002 0:00	79	87	83	18	0
	7-8-2002 0:00	84	92	88	23	0
	8-8-2002 0:00	84	98	91	26	0
	9-8-2002 0:00	86	99	92,5	27,5	0
	10-8-2002 0:00	87	98	92,5	27,5	0
	11-8-2002 0:00	88	96	92	27	0
	12-8-2002 0:00	88	95	91,5	26,5	0
	13-8-2002 0:00	88	96	92	27	0
	14-8-2002 0:00	90	97	93,5	28,5	0
	15-8-2002 0:00	89	98	93,5	28,5	0
	16-8-2002 0:00	87	95	91	26	0
	17-8-2002 0:00	88	96	92	27	0
	18-8-2002 0:00	88	96	92	27	0
	19-8-2002 0:00	85	90	87,5	22,5	0
	20-8-2002 0:00	84	93	88,5	23,5	0
	21-8-2002 0:00	82	93	87,5	22,5	0
	22-8-2002 0:00	82	93	87,5	22,5	0
	23-8-2002 0:00	80	94	87	22	0
	24-8-2002 0:00	77	92	84,5	19,5	0
	25-8-2002 0:00	77	93	85	20	0
	26-8-2002 0:00	79	94	86,5	21,5	0
	27-8-2002 0:00	79	95	87	22	0
	28-8-2002 0:00	84	96	90	25	0
	29-8-2002 0:00	83	91	87	22	0
	30-8-2002 0:00	85	96	90,5	25,5	0
	31-8-2002 0:00	83	98	90,5	25,5	0
	1-9-2002 0:00	89	98	93,5	28,5	0
	2-9-2002 0:00	86	96	91	26	0
	3-9-2002 0:00	86	95	90,5	25,5	0
	4-9-2002 0:00	86	99	92,5	27,5	0
	5-9-2002 0:00	87	98	92,5	27,5	0
	6-9-2002 0:00	89	96	92,5	27,5	0
	7-9-2002 0:00	75	87	81	16	0
	8-9-2002 0:00	76	82	79	14	0
	9-9-2002 0:00	74	79	76,5	11,5	0
	10-9-2002 0:00	75	86	80,5	15,5	0
	11-9-2002 0:00	75	86	80,5	15,5	0
	12-9-2002 0:00	78	89	83,5	18,5	0
	13-9-2002 0:00	78	89	83,5	18,5	0
	14-9-2002 0:00	80	93	86,5	21,5	0
	15-9-2002 0:00	84	95	89,5	24,5	0
	16-9-2002 0:00	83	94	88,5	23,5	0
	17-9-2002 0:00	80	92	86	21	0
	18-9-2002 0:00	82	86	84	19	0
	19-9-2002 0:00	77	87	82	17	0
	20-9-2002 0:00	75	87	81	16	0
	21-9-2002 0:00	75	87	81	16	0
	22-9-2002 0:00	75	90	82,5	17,5	0
	23-9-2002 0:00	79	96	87,5	22,5	0
	24-9-2002 0:00	81	96	88,5	23,5	0
	25-9-2002 0:00	80	93	86,5	21,5	0
	26-9-2002 0:00	77	90	83,5	18,5	0
	27-9-2002 0:00	76	87	81,5	16,5	0
	28-9-2002 0:00	77	87	82	17	0
	29-9-2002 0:00	75	87	81	16	0
	30-9-2002 0:00	68	81	74,5	9,5	0
	1-11-2002 0:00	59	69	64	0	1
	2-11-2002 0:00	59	69	64	0	1
	3-11-2002 0:00	63	68	65,5	0,5	0
	4-11-2002 0:00	55	66	60,5	0	4,5
	5-11-2002 0:00	52	64	58	0	7
	6-11-2002 0:00	51	67	59	0	6
	7-11-2002 0:00	58	67	62,5	0	2,5
	8-11-2002 0:00	63	69	66	1	0
	9-11-2002 0:00	66	74	70	5	0
	10-11-2002 0:00	67	71	69	4	0
	11-11-2002 0:00	55	66	60,5	0	4,5
	12-11-2002 0:00	56	70	63	0	2
	13-11-2002 0:00	58	73	65,5	0,5	0
	14-11-2002 0:00	54	64	59	0	6
	15-11-2002 0:00	54	68	61	0	4
	16-11-2002 0:00	58	67	62,5	0	2,5
	17-11-2002 0:00	51	66	58,5	0	6,5
	18-11-2002 0:00	50	62	56	0	9
	19-11-2002 0:00	49	62	55,5	0	9,5
	20-11-2002 0:00	55	74	64,5	0	0,5
	21-11-2002 0:00	58	76	67	2	0
	22-11-2002 0:00	57	68	62,5	0	2,5
	23-11-2002 0:00	53	66	59,5	0	5,5
	24-11-2002 0:00	52	64	58	0	7
	25-11-2002 0:00	50	57	53,5	0	11,5
	26-11-2002 0:00	49	62	55,5	0	9,5
	27-11-2002 0:00	59	65	62	0	3
	28-11-2002 0:00	56	66	61	0	4
	29-11-2002 0:00	59	62	60,5	0	4,5
	30-11-2002 0:00	58	65	61,5	0	3,5
	1-12-2002 0:00	51	58	54,5	0	10,5
	2-12-2002 0:00	51	56	53,5	0	11,5
	3-12-2002 0:00	49	56	52,5	0	12,5
	4-12-2002 0:00	48	56	52	0	13
	5-12-2002 0:00	48	61	54,5	0	10,5
	6-12-2002 0:00	52	64	58	0	7
	7-12-2002 0:00	54	59	56,5	0	8,5
	8-12-2002 0:00	48	56	52	0	13
	9-12-2002 0:00	49	61	55	0	10
	10-12-2002 0:00	47	58	52,5	0	12,5
	11-12-2002 0:00	48	53	50,5	0	14,5
	12-12-2002 0:00	45	54	49,5	0	15,5
	13-12-2002 0:00	46	55	50,5	0	14,5
	14-12-2002 0:00	45	50	47,5	0	17,5
	15-12-2002 0:00	52	58	55	0	10
	16-12-2002 0:00	48	57	52,5	0	12,5
	17-12-2002 0:00	54	61	57,5	0	7,5
	18-12-2002 0:00	49	55	52	0	13
	19-12-2002 0:00	41	49	45	0	20
	20-12-2002 0:00	43	51	47	0	18
	21-12-2002 0:00	39	45	42	0	23
	22-12-2002 0:00	38	44	41	0	24
	23-12-2002 0:00	44	47	45,5	0	19,5
	24-12-2002 0:00	40	45	42,5	0	22,5
	25-12-2002 0:00	41	48	44,5	0	20,5
	26-12-2002 0:00	39	49	44	0	21
	27-12-2002 0:00	39	50	44,5	0	20,5
	28-12-2002 0:00	45	59	52	0	13
	29-12-2002 0:00	46	61	53,5	0	11,5
	30-12-2002 0:00	42	50	46	0	19
	31-12-2002 0:00	42	50	46	0	19

This can't be right. Looks like Tucson data.

Total 3,355

Cheek Clark

Connected to district system. Same building CW pumps remain in service. No significant changes in building or load.

		Bld	Sqft	Meter #	Start Date	June (Ton-hrs)	June Building kWh	July (Ton-hrs)	July Building kWh	August (Ton-hrs)	August Building kWh	September (Ton-hrs)	September Building kWh	October (Ton-hrs)	October Building kWh	November (Ton-hrs)	November Building kWh	December (Ton-hrs)	December Building kWh	January (Ton-hrs)	January Building kWh	February (Ton-hrs)	February Building kWh	March (Ton-hrs)	March Building kWh	April (Ton-hrs)	April Building kWh	May (Ton-hrs)	May Building kWh
FY06-07	Cheek Clark	182	34.461	**04-3822**	05-26-06	23.295		28.135		29.162		22.566		14.079		11.720		6.230		7.499		6.290		13.669		21.223		20.526	
FY07-08	Cheek Clark	182	34.461	**04-3822**	05-26-06	24.337		27.905		32.907		19.974		16.656		8.161		7.720		6.668									

Total ton-hours July 06 -- May 07	181.099
Total ton-hours June 07	24.337
Total ton-hours July 06 -- June 07	205.436
Cooling degree days July 06-June 07	1.601
Tons-hours per CDD	128

		ton-hours
	June	23.295
	July	28.135
	August	29.162
2006	September	22.566
	October	14.079
	November	11.720
	December	6.230
	January	7.499
	February	6.290
	March	13.669
	April	21.223
	May	20.526
2007	June	24.337
	July	27.905
	August	32.907
	September	19.974
	October	16.656
	November	8.161
	December	7.720
2008	January	6.668

Estimated base cooling (ton-hr	7000
Percent of peak monthly	21,3%

Standalone aircooled chiller operation. Electricity metered for chiller only.

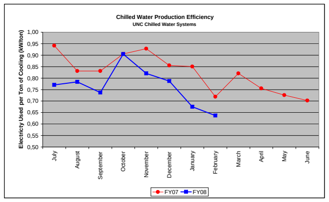
	Building Number	Sevice	Model #	Efficiency	juli-04 (KWH)	juli-04 Elec Cost	juli-04 (TON -HRS)	augustus-04 (KWH)	augustus-04 Elec Cost	augustus-04 (TON -HRS	september-04 (KWH)	september-04 Elec Cost	september-04 (TON -HRS	oktober-04 (KWH)	oktober-04 Elec Cost	oktober-04 (TON -HRS	november-04 (KWH)	november-04 Elec Cost	november-04 (TON -HRS	december-04 (KWH)	december-04 Elec Cost	december-04 (TON -HRS
Chiller Electric	182 Cheek Clark	Electric	Trane RTA	1.25	34.161	$1.676,54	27.329	31.792	$1.590,82	25.434	20.085	$1.061,65	16.068	15.893	$726,56	12.714	6.302	$636,60	5.042	5.042	$604,72	4.034
Building Electric	183 Cheek Clark	Electric																				

	januari-05 (KWH)	januari-05 Elec Cost	januari-05 (TON -HRS	februari-05 (KWH)	februari-05 Elec Cost	februari-05 (TON -HRS	maart-05 (KWH)	maart-05 Elec Cost	maart-05 (TON -HRS	april-05 (KWH)	april-05 Elec Cost	april-05 (TON -HRS	mei-05 (KWH)	mei-05 Elec Cost	mei-05 (TON -HRS	juni-05 (KWH)	juni-05 Elec Cost	juni-05 (TON -HRS
Chiller Electric	1.782	$452,16	1.426	2.773	$413,75	2.218	3.702	$408,58	2.962	13.400	$778,00	10.720	21.491	$1.343,09	17.193	31.723	$1.825,00	25.378
Building Electric																		

	juli-05 (KWH)	juli-05 Elec Cost	juli-05 (TON -HRS	augustus-05 (KWH)	augustus-05 Elec Cost	augustus-05 (TON -HRS	september-05 (KWH)	september-05 Elec Cost	september-05 (TON -HRS	oktober-05 (KWH)	oktober-05 Elec Cost	oktober-05 (TON -HRS	november-05 (KWH)	november-05 Elec Cost	november-05 (TON -HRS	december-05 (KWH)	december-05 Elec Cost	december-05 (TON -HRS
Chiller Electric	27.035	$1.773,13	21.628	48.231	$2.319,48	38.585	11.107	$958,98	8.886	7.161	$773,51	5.729	286	$18,41	229	321	$19,43	257
Building Electric																		

	januari-06 (KWH)	januari-06 Elec Cost	januari-06 (TON -HRS	februari-06 (KWH)	februari-06 Elec Cost	februari-06 (TON -HRS	maart-06 (KWH)	maart-06 Elec Cost	maart-06 (TON -HRS	april-06 (KWH)	april-06 Elec Cost	april-06 (TON -HRS	mei-06 (KWH)	mei-06 Elec Cost	mei-06 (TON -HRS)
Chiller Electric	271	$21,96	217	274	$22,11	219	265	$21,77	212	272	$22,04	218	315	$18,90	252
Building Electric															

Chiller elecric (kWh)	July 04-June 05	188.146	12 months
Chiller elecric (kWh)	July 04-May 05	156.423	11 months
Chiller elecric (kWh)	July 05-May 06	95.538	11 months
Chiller elecric (kWh)	July 05-June 06	118.833	12 months



	kWh	CDD
juli-04	34.161	437
augustus-04	31.792	310
september-04	20.085	184
oktober-04	15.893	37
november-04	6.302	17
december-04	5.042	0
januari-05	1.782	2
februari-05	2.773	0
maart-05	3.702	0
april-05	13.400	21
mei-05	21.491	61
juni-05	31.723	297
juli-05	27.035	514
augustus-05	48.231	450
september-05	11.107	326
oktober-05	7.161	66
november-05	286	8
december-05	321	0
januari-06	271	0
februari-06	274	0
maart-06	265	15
april-06	272	60
mei-06	315	95

UNC ITS Franklin

				TOTAL			februari-07			maart-07		
Building Number	Sevice	Description	Model #	(KWH)	Elec Cost ($)	(TON -HRS)	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS
454 Franklin Street / 440W	CW	85 Ton aircooled screw chiller				**496.607**			23.653			30.758
454 Franklin Street / 440W	CW	86 Ton aircooled screw chiller				**437.781**			16.503			40.468
454 Franklin Street / 440W	CW	87 Ton aircooled screw chiller				**440.327**			27.337			24.659
455 Franklin Street / 440W	Electric			**1.660.160**			96480			100160		
TOTAl Ton-hrs						**1.374.715**			**67.493**			**95.885**
kW/ton						**1,208**			**1,429**			**1,045**

	april-07			mei-07			juni-07			juli-07			augustus-07		
Building Number	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS
454 Franklin Street / 440W			44.837			41.495			42.454			47.160			48.342
454 Franklin Street / 440W			21.777			27.450			39.860			38.595			46.700
454 Franklin Street / 440W			28.270			38.769			41.492			45.025			41.074
455 Franklin Street / 440W	131000			117080			176480			149480			181000		
TOTAl Ton-hrs			**94.884**			**107.714**			**123.806**			**130.780**			**136.116**
kW/ton			**1,381**			**1,087**			**1,425**			**1,143**			**1,330**

	september-07			oktober-07			november-07			december-07			januari-08			februari-08		
Building Number	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS	(KWH)	Elec Cost ($)	(TON -HRS)
454 Franklin Street / 440W			41.737			30.960			37.538			38.763			32.801			36.109
454 Franklin Street / 440W			36.584			39.277			30.279			39.742			31.054			29.492
454 Franklin Street / 440W			42.468			41.148			28.363			22.102			33.330			26.290
455 Franklin Street / 440W	143440			150840			90680			155200			70360			97960		
TOTAl Ton-hrs			**120.789**			**111.385**			**96.180**			**100.607**			**97.185**			**91.891**
kW/ton			**1,188**			**1,354**			**0,943**			**1,543**			**0,724**			**1,066**

Feb.	1,429
Mar	1,045
Apr	1,381
May	1,087
Jun	1,425
Jul	1,143
Aug	1,330
Sep	1,188
Oct	1,354
Nov	0,943
Dec	1,543
Jan	0,724
Feb	1,066

App 4 part 1

Organization	Name
Hartford Steam	Jeff Lindberg
Energy Systems Company	Dave Woods
Xcel Denver	Steve Kutska
Northwind Phoenix	Jim Lodge
District Energy St. Paul	Alex Sleiman
Comfortlink	Dennis Manning
Enwave	Chris Asimakis
Austin Energy	Cliff Braddock
Metro Nashville	Harvey Gershman
Exelon	Jack Kattner
Entergy	Steve Martins

Organization	First Name	Last Name
AMGEN, Inc.	Jimmy	Walker
Auburn University	Michael	Harris
Brown University	James	Coen
Chevron Energy Solutions - Maryland	Robert	McNally
Cleveland State University	Shehadeh	Abdelkarim
Colorado State University	Roger	Elbrader
Columbia University	Dominick	Chirico
Cornell University	Jim	Adams
Dallas Fort Worth International Airport	John	Smith
Dartmouth College	Bo	Petersson
Duke University FMD	Steve	Palumbo
Franklin Heating Station	Tom	DeBoer
Gainesville Regional Utilities	Gary	Swanson
Georgia Institute of Technology - Facilities Dept.	Hank	Wood
Harvard University	Douglas	Garron
Hennepin County	Craig	Lundmark
Indiana University	Mark	Menefee
Iowa State University	Clark	Thompson
Kent State University	Thomas	Dunn
Massachusetts Institute of Technology	Roger	Moore
McMaster University	Joe	Emberson

App 4 part 2

Organization	First Name	Last Name
Medical Center Steam & Chilled Water	Edward	Dusch
New York University	Jim	Sugaste
North Carolina State University	Alan	Daeke
Oklahoma State University	Bill	Burton
Pennsylvania State University	William	Serencsits
Princeton University	Edward	Borer
Purdue University	Mark	Nethercutt
Rice University	Douglas	Wells
Rutgers University	Joe	Witkowski
San Diego State University	Glenn	Vorraro
San Francisco State University	Richard	Stevens
Simon Fraser University	Sam	Dahabieh
Stanford University	Mike	Goff
Syracuse University	Tom	Reddinger
Tarleton State University	Steven	Bowman
The College of New Jersey	Lori	Winyard
The Medical Center Company	Michael	Heise
Thermal Energy Corporation (TECO)	Stephen	Swinson
Trinity College	Ezra	Brown
University of Akron	Rob	Kraus
University of Alberta	Angelo	da Silva
University of Arizona	Bob	Herman
University of California - Davis Medical Center	Joseph	Stagner
University of California - Irvine	Gerald	Nearhoof
University of California - Los Angeles	David	Johnson
University of Cincinnati	Joe	Harrell
University of Colorado - Boulder	Paul	Caldara
University of Connecticut	Eugene	Roberts
University of Georgia	Kenneth	Crowe
University of Idaho	Thomas	Sawyer
University of Illinois Abbott Power Plant	Robert	Hannah
University of Iowa	Janet	Razbadouski
University of Manitoba	Joe	Lucas
University of Maryland	J. Frank	Brewer
University of Massachusetts Medical School	John	Baker
University of Miami	Eric	Schott
University of Miami - Ohio	Mark	Lawrence
University of Michigan	William	Verge
University of Minnesota	Michael	Nagel

App 4 part 3

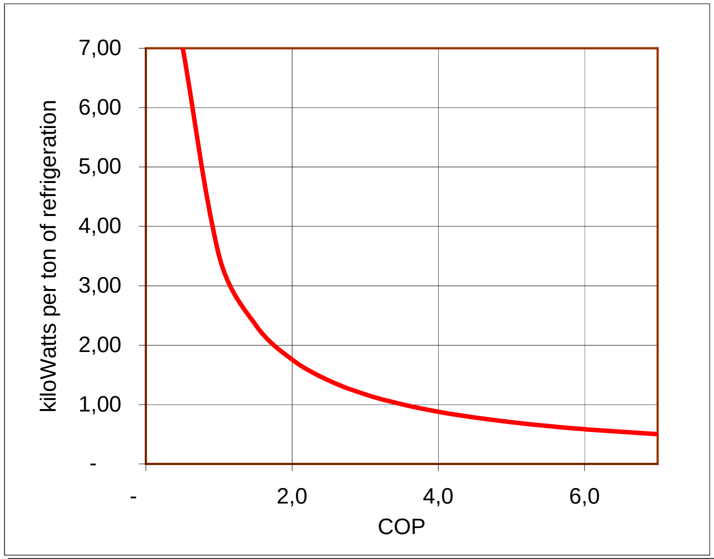
Organization	First Name	Last Name
University of Missouri at Columbia	Paul	Hoemann
University of Nevada, Reno	Stephen	Mischissin
University of New Mexico	Lawrence	Schuster
University of North Carolina - Chapel Hill	Raymond	DuBose
University of Northern Iowa	Tom	Richtsmeier
University of Regina	Neil	Paskewitz
University of Rochester	Morris	Pierce
University of Texas - Austin	Juan	Ontiveros
University of Vermont	Salvatore	Chiarelli
University of Virginia	Cheryl	Gomez
University of Washington	Guarrin	Sakagawa
University of Wisconsin - Madison	Dan	Dudley
Virginia Tech	Ben	Myers
Yale University	David	Spalding

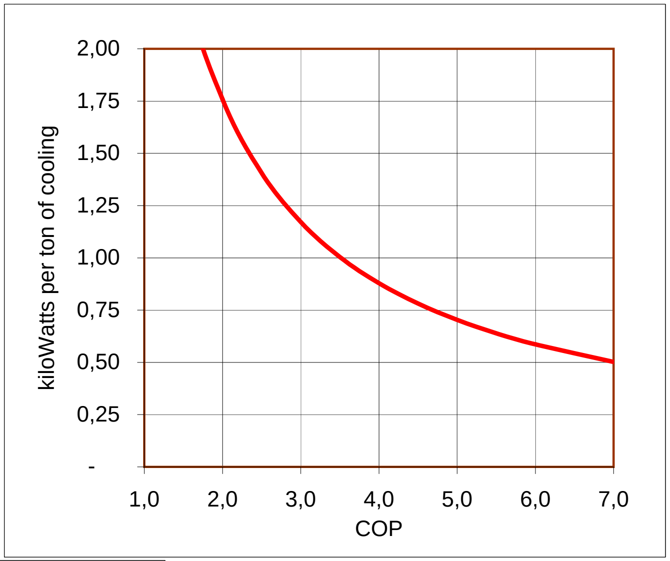
Franklin Heating Station Electric Centrifugal Chillers

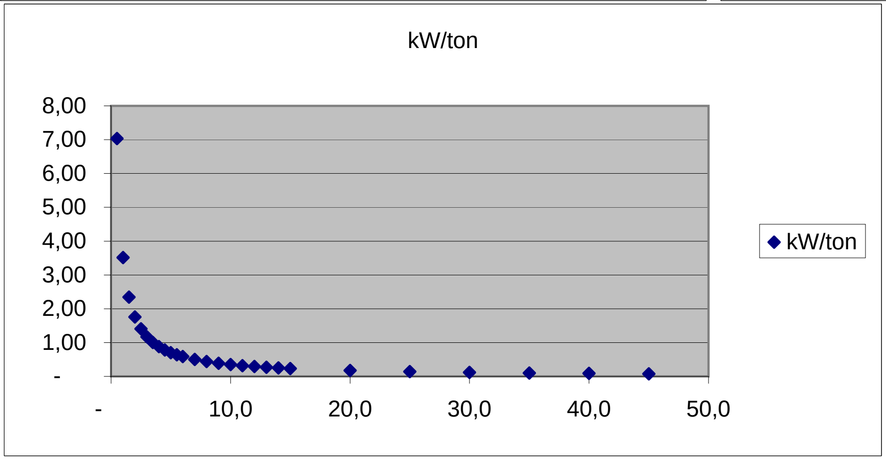
Unit #	Manufacturer (age)	Capacity (tons)
1	CARRIER (1985)	2700
4	YORK (1997)	2000
7	CARRIER (2000)	2000
8	CARRIER (2000)	2000
9	CARRIER (2000)	2000

Conversion of COPs to kW/ton

COP	kW/ton
45,0	0,08
40,0	0,09
35,0	0,10
30,0	0,12
25,0	0,14
20,0	0,18
15,0	0,23
14,0	0,25
13,0	0,27
12,0	0,29
11,0	0,32
10,0	0,35
9,0	0,39
8,0	0,44
7,0	0,50
6,0	0,59
5,5	0,64
5,0	0,70
4,5	0,78
4,0	0,88
3,5	1,00
3,0	1,17
2,5	1,41
2,0	1,76
1,5	2,34
1,0	3,52
0,5	7,03
0,01	351,60

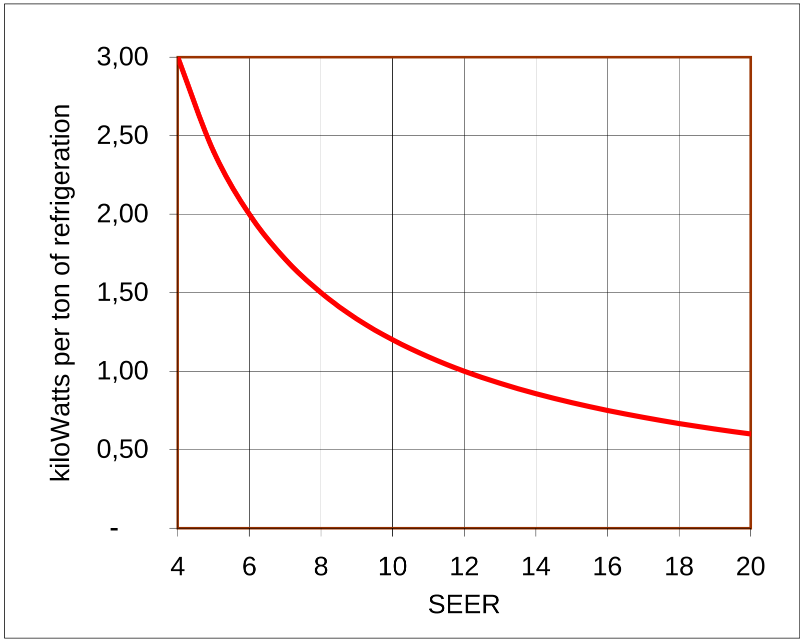






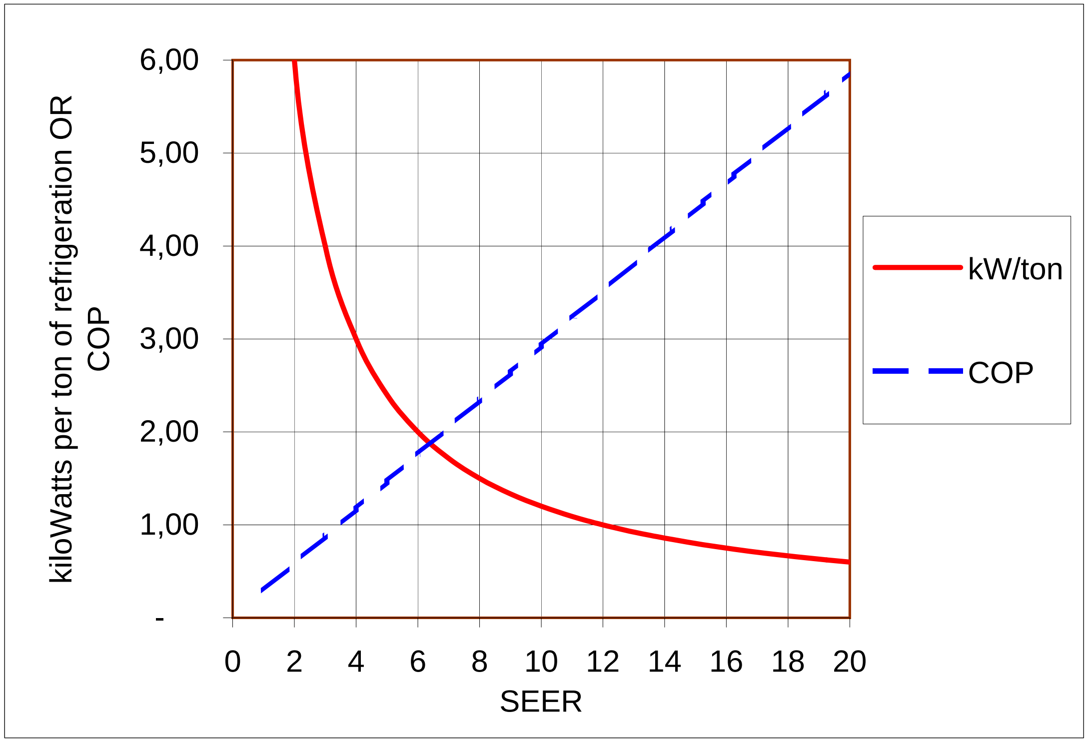
Conversion of SEER to kW/ton

SEER	kW/ton	COP
4,0	3,00	1,17
5,0	2,40	1,46
6,0	2,00	1,76
7,0	1,71	2,05
8,0	1,50	2,34
9,0	1,33	2,64
10,0	1,20	2,93
11,0	1,09	3,22
12,0	1,00	3,52
13,0	0,92	3,81
14,0	0,86	4,10
15,0	0,80	4,39
16,0	0,75	4,69
17,0	0,71	4,98
18,0	0,67	5,27
19,0	0,63	5,57
20,0	0,60	5,86



Conversion of SEER to kW/ton

SEER	kW/ton	COP
1,0	12,00	0,29
2,0	6,00	0,59
3,0	4,00	0,88
4,0	3,00	1,17
5,0	2,40	1,46
6,0	2,00	1,76
7,0	1,71	2,05
8,0	1,50	2,34
9,0	1,33	2,64
10,0	1,20	2,93
11,0	1,09	3,22
12,0	1,00	3,52
13,3	0,91	3,88
14,3	0,84	4,18
15,3	0,79	4,47
16,3	0,74	4,76
17,3	0,70	5,05
18,3	0,66	5,35
19,3	0,62	5,64
20,3	0,59	5,93



Definitions

EER - The Energy Efficiency Ratio is the efficiency of the air conditioner. It is capacity in Btu per hour divided by the electrical input in watts. EER changes with the inside and outside conditions, falling as the temperature difference between inside and outside gets larger. EER should not be confused with SEER.
SEER - The Seasonal Energy Efficiency Ratio is a standard method of rating air conditioners based on three tests. All three tests are run at 80°F inside and 82°F outside. The first test is run with humid indoor conditions, the second with dry indoor conditions, and the third with dry conditions cycling the air conditioner on for 6 minutes and off for 24 minutes. The published SEER may not represent the actual seasonal energy efficiency of an air conditioner in your climate.




IEA DHC|CHP

International Energy Agency
IEA Implementing Agreement on District Heating and Cooling, including the integration of CHP

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