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Review of standards for energy performance of chiller systems serving commercial buildings

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Abstract

A prescriptive approach is primarily used to establish energy benchmarks for energy systems in buildings. This paper reviews national standards and guidelines for the energy performance of chiller systems which provide cooling energy in commercial buildings but their operation causes the major proportion of electricity consumption in the building sector. The standards reviewed are currently adopted in nine places (in alphabetical order): Australia, California, Canada, China, Chinese Taipei, the EU, Hong Kong, New Zealand and the USA. Under standard rating conditions at full load operation, the minimum required coefficient of performance (COP) ranges from 2.40 to 3.06 for air-cooled chillers and from 3.80 to 6.39 for water-cooled chillers. Some standards state also the COP requirements at part load operation with integrated part load values or seasonal energy efficiency ratios. A classification scheme is provided in the EU and Chinese standards which helps labeling and certifying high efficient chiller products. Criteria for enhancing energy ratings of chiller systems are suggested.

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Keywords: Chiller system ; Coefficient of performance; Energy performance standards

1. Introduction

To accomplish carbon emissions control, many engineering systems are required to comply with prescriptive energy performance. The minimum energy efficiency levels required by standards and guidelines provide benchmarking criteria for assessing the energy performance of engineering systems. Furthermore, regular updates on performance requirements would help phase out low efficient products and drive continuous performance improvement of engineering systems. Energy reduction targets are generally set in the building sector to reduce carbon emissions. For medium to large scale buildings with cooling demand, chiller systems are commonly installed to provide cooling energy and their operation

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accounts for the major proportion in the overall electricity consumption of buildings. Setting the minimum energy performance and energy efficient practices for chiller systems is a direct way to improve building energy efficiency. There are national standards and guidelines for the energy efficiency of chiller systems in buildings. It is worth examining their similarity and difference and hence to advise on more effective tools to rate and assess the energy performance of chiller systems under actual operating conditions.

This paper aims at reviewing national standards and guidelines for rating the energy performance of chiller systems. The rating criteria and minimum requirements for the energy performance of chiller systems will be compiled and compared. Discussion will be made on how to enhance the performance rating. The significance of this study is to provide insights into how to rate effectively the energy performance of chiller systems under actual operating conditions and how to encourage more advanced control for chiller systems to enhance their energy performance.

2. Description of standards and guidelines for energy performance of chiller systems

Table 1 lists the standards and guidelines reviewed. The list may not be exhaustive but should be sufficient to represent assessment criteria for many chiller systems nationwide. Standards with labels B, F, G, H and I are energy standards for buildings in which the minimum performance requirements on chiller systems form a part. Standards A, C, D and E are specifically commissioned for chiller systems.

Table 1. List of standards and guidelines reviewed for chiller systems

Description	Standard/guideline	Place used	Label
Minimum energy performance standards and compliance requirements for liquid chilling packages using the vapour compression cycle [1]	Australia/New Zealand standard AS/NZS 4776.2-2008	Australia and New Zealand	A
Large Non-Residential Standard Performance Contract (LNSPC) program [2]	California Public Utilities Commission	California	B
Performance standard for rating packaged water chillers [3]	Canadian Standards Association (CSA) CSA-C743-09	Canada	C
Minimum allowable values of the energy efficiency and energy efficiency grades for water chillers [4]	GB 19577-2004	China	D
Minimum requirement of full load COP for water chillers [5]	Chinese National Standard (CNS) CNS 12575-2007	Chinese Taipei	E
Eurovent Certification Programme [6]	Eurovent	EU	F
Code of practice for energy efficiency of building services installation [7]	EMSD, HKSAR	Hong Kong	G
Energy Standard for buildings except low-rise residential buildings [8]	ASHRAE Standard 90.1-2013	USA	H
Meeting energy efficiency requirements for products [9]	Federal Energy Management Program, DOE	USA	I

2.1. Rating conditions for chiller operation

The energy performance of chillers is often described as the coefficient of performance (COP) which is the cooling capacity output in kW over the electric power input in kW. Given that the COP varies with the load and ambient operating conditions, most manufacturers test their chillers and specify their COP based on rating requirements in the AHRI standard 550/590 launched by the Air-conditioning, Heating and Refrigeration Institute (AHRI) [10]. Considering that chiller systems operate frequently under part load conditions, the AHRI standard specifies part load rating conditions with an integrated part load value (IPLV) formula given in Eq. (1) to calculate an aggregate COP at part load operation, where A, B, C and D are COPs at 100% load, 75% load, 50% load and 25% load, respectively. The weightings of 0.01, 0.42, 0.45 and 0.12 used in Eq. (1) are based on common building operation and climate conditions for 29 US cities. For chiller systems serving buildings in European cities, a European seasonal energy efficiency ratio (ESEER), similar to the IPLV, is used to calculate an average part load COP.

$$IPLV = 0.01\ A + 0.42\ B + 0.45\ C + 0.12\ D \qquad (1)$$

The IPLV and ESEER cannot truly reflect the part load operation of chiller systems. The assumed linear relationship between the chiller loads and heat rejection temperatures is only applied to a system with one chiller, which is inapplicable for most chiller design and climatic conditions. Many studies [11-15] addressed that multiple chillers tend to operate near full load with diverse temperatures of condenser water or air based on ambient dry bulb or wet bulb temperatures.

3. Results of minimum COP requirements

3.1 Comparisons on the minimum COP requirements for full load operation

The minimum COPs required for different types and capacities of chillers are summarized in Tables 2 and 3. The minimum full load COP varies from 2.40 to 3.06 for air-cooled chillers, and from 3.80 to 6.39 for water-cooled chillers, depending on the cooling capacity and compressor type. The variation suggests different degrees of tightness in controlling the energy performance of chillers. The lower COP requirements appear to be used in the standards launched earlier without updated editions. For the standards G and H with regular updates, the COP requirements tend to have more stringent control. A survey was conducted by authors in 2008 about the performance of chillers from leading manufacturers. Regarding a sample of 327 air-cooled chiller models, the minimum, average and maximum full load COP were 2.4, 3.1 and 4.2, respectively, with a standard deviation of 0.4. It is possible to specify the minimum full load COP in a range of 2.8 - 3.0 for air-cooled chillers to reflect actual available performance while providing certain flexibility for selecting different capacities and compressor types. In a sample of 56 water-cooled chiller models, the minimum, average and maximum full load COP were 3.72, 4.45 and 5.82, respectively, with a standard deviation of 0.40. Some of the standards reviewed put a challenging COP of 5.7 or above for water-cooled chillers. Complying with this requirement would call for using high efficiency centrifugal chillers.

Table 2. Minimum full load COP for air-cooled water chillers by different standards and guidelines

Compressor type	Reciprocating		Scroll	Screw	Centrifugal
Capacity Range (kW)	< 400	≥400	All ratings	All ratings	All ratings
Standard A	2.7	2.7	2.7	2.7	2.7
Standard B	2.7	2.5/2.7	2.5/2.7	2.5/2.7	2.5/2.7
Standard C	2.8	2.8	2.8	2.8	2.8
Standard D	2.4/2.6	2.6	2.4/2.6	2.4/2.6	2.4/2.6
Standard E	2.79	2.79	2.79	2.79	2.79
Standard F	2.7*	2.7*	2.7*	2.7*	2.7*
Standard G	2.6	2.8	2.7	2.9	2.8
Standard H	2.8	2.8	2.8	2.8	2.8
Standard I	3.06	3.06	3.06	3.06	3.06

Note: * The COPs refer to grade C in a range of grades A to G requirements

Table 3. Minimum full load COP for water-cooled water chillers by different standards and guidelines

Compressor type	Reciprocating			Scroll			Screw			Centrifugal		
Capacity Range (kW)	<500	500-1000	>1000	<500	500-1000	>1000	<500	500-1000	>1000	<500	500-1000	>1000
Standard A	5.0	5.1/5.5	5.8/6.0	5.0	5.1/5.5	5.8/6.0	5.0	5.1/5.5	5.8/6.0	5.0	5.1/5.5	5.8/6.0
Standard B	3.8	4.2	4.7	3.8	4.2	4.7	3.8	4.2	4.7	3.8	4.2	4.7
Standard C	4.51/4.54	5.17	5.67	4.51/4.54	5.17	5.67	4.51/4.54	5.17	5.67	5.55	6.10	6.17
Standard D	3.8	4.0	4.2	3.8	4.0	4.2	3.8	4.0	4.2	3.8	4.0	4.2
Standard E	4.45	4.90	5.50	5.00	5.55	6.10	5.00	5.55	6.10	5.00	5.55	6.10
Standard F	4.25*	4.25*	4.25*	4.25*	4.25*	4.25*	4.25*	4.25*	4.25*	4.25*	4.25*	4.25*
Standard G	4.1	4.6	5.2	4.1	4.6	5.2	4.6	4.7	5.5	5.1	5.6	5.7
Standard H	4.51/4.54	5.17	5.67	4.51/4.54	5.17	5.67	4.51/4.54	5.17	5.67	5.55	6.10	6.17
Standard I	4.69/4.95	5.17	6.06	4.69/4.95	5.17	6.06	4.69/4.95	5.17	6.06	5.67	5.96	6.28/6.39

Note: * The COPs refer to grade C in a range of grades A to G requirements

3.2 Comparisons on the minimum COP requirements for part load operation

The minimum IPLVs required in the standards A, C, H and I are summarized in Tables 4 and 5. The IPLVs are higher than the corresponding full load COPs by 3.82 – 51.85%. This suggests an improvement of COP at part load operation based on an assumption that a chiller works effectively at part loads with lower condenser air/water temperatures. In fact, such an improvement is hardly achieved in actual operation with head pressure control—non-optimal condensing temperature control. The seasonal COP, indeed, is lower than the full load COP in many existing cases [16].

Table 4. Minimum IPLVs for air-cooled water chillers by different standards and guidelines

Compressor type	Reciprocating		Scroll	Screw	Centrifugal
Capacity Range (kW)	< 400	≥400	All ratings	All ratings	All ratings
Standard A	3.7	3.7/4.1	3.7/4.1	3.7/4.1	3.7/4.1
Standard C	3.67/3.74	3.74	3.74	3.74	3.74
Standard H	3.67/3.74	3.74	3.74	3.74	3.74
Standard I	3.67/3.74	3.74	3.74	3.74	3.74

Table 5. Minimum IPLVs for water-cooled water chillers by different standards and guidelines

Compressor type	Reciprocating			Scroll			Screw			Centrifugal		
Capacity Range (kW)	<500	500-1000	>1000	<500	500-1000	>1000	<500	500-1000	>1000	<500	500-1000	>1000
Standard A	5.5	6.0/6.2	6.5	5.5	6.0/6.2	6.5	5.5	6.0/6.2	6.5	5.5	6.0/6.2	6.5
Standard C	5.58/5.72	6.06	6.51	5.58/5.72	6.06	6.51	5.58/5.72	6.06	6.51	5.90	6.40	6.52
Standard H	5.58/5.72	6.06	6.51	5.58/5.72	6.06	6.51	5.58/5.72	6.06	6.51	5.90	6.40	6.52
Standard I	5.58/5.72	6.06	6.51	5.58/5.72	6.06	6.51	5.58/5.72	6.06	6.51	5.90	6.40	6.52

3.3 Certification and labelling of energy performance of chillers in different classes

To distinguish high efficient chillers from the low efficient ones, the standards D and F state full load COP requirements for labelling chiller products in different classes, as shown in Tables 6 and 7. The COP requirements of standard D appear to be more stringent than that of standard F and align better with the range of full load COPs of existing products surveyed by authors in 2008. Under technology advancement, the COP of chiller products would have a gentle improvement from time to time. To boost the use of chiller products with higher classes and COPs, it is preferable to update regularly the COP data in different classes based on the latest performance data by manufacturers.

Table 6. Classification of the COP of chillers in Eurovent Certification Program (standard F) for all capacity ranges

Class	A	B	C	D	E	F	G
Air-cooled	≥ 3.1	2.9 - 3.1	2.7 - 2.9	2.5 - 2.7	2.3 - 2.5	2.1 - 2.3	< 2.1
Water-cooled	≥ 5.05	4.65 - 5.05	4.25 - 4.65	3.85 - 4.25	3.45 - 3.85	3.05 - 3.45	< 3.05

Table 7. Classes with the minimum required COP of chillers in GB 19577-2004 (standard D)

Class	Cooling capacity CC (kW)	1	2	3	4	5
Air-cooled	CC >50	3.4	3.2	3.0	2.8	2.6
Water-cooled	CC ≤ 528, 528 < CC ≤ 1163, CC > 1163	5.0, 5.5, 6.1	4.7, 5.1, 5.6	4.4, 4.7, 5.1	4.1, 4.3, 4.6	3.8, 4.0, 4.2

4. Discussion and conclusions

A review of nine standards and guidelines shows that the minimum full load COPs and part load COPs in terms of IPLVs are commonly specified for baseline chiller performance. The minimum required COP ranges from 2.40 to 3.06 for air-cooled chillers and from 3.80 to 6.39 for water-cooled chillers. Based on a set of chiller products surveyed in 2008, most air-cooled chillers met the minimum full load COP levels easily while tighter control was in place for water-cooled chillers with a minimum full load COP of above 5.7. Some standards propose a labelling or certification scheme to classify high efficiency chillers. Yet the minimum COP levels in different classes should be reviewed regularly based on the nominal COP of the latest chiller products. Both the full load COP and IPLV, in fact, cannot truly reflect the energy performance of chiller systems under actual operating conditions.

Regarding the whole system, some standards state power limits on system components like chilled water and condenser water pumps. The use of variable speed drives is recommended to enhance system energy performance. Such requirements would be met through robust system design and dedicated selection of highly efficient system components. System performance can be further enhanced by optimal controls, e.g. using variable flow control for chilled water and condenser water, applying variable speed control to cooling tower fans and condensing temperature control, etc. To measure and verify the benefits of such control in actual operation, it is important to specify the COP at different condensing temperatures and flow rates of chilled water and condenser water, along with different chiller loads and ambient conditions. The algorithms used to implement the optimal controls should be stated explicitly to examine controllability. It is envisaged that the standards and guidelines can be further developed to form a driving tool to allow system designers and operators to realize more transparent and comprehensive performance data under actual operating conditions.

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References

[1] Australia/New Zealand standard™. *Minimum energy performance standards and compliance requirements for liquid chilling packages using the vapour compression cycle (AS/NZS 4776.2-2008),* Author Press; 2008.

[2] California Public Utilities Commission. *Large Non-Residential Standard Performance Contract (LNSPC) program*, 2000. Available at http://www.cpuc.ca.gov/puc/

[3] Canadian Standards Association. *Performance standard for rating packaged water chillers (CSA-C743-09)*, 2010. Available at http://www.nrcan.gc.ca/energy/regulations-codes-standards/bulletins/7209

[4] Code of China. *Minimum allowable values of the energy efficiency and energy efficiency grades for water chillers (GB 19577-2004)*, Author Press; 2004.

[5] Chinese National Standard of Chinese Taipei. *CNS 12575 (water chilling unit)*. Author Press; 2007.

[6] Eurovent. *Eurovent certification program*, 2014. Available at http://www.eurovent-certification.com/

[7] Electrical & Mechanical Services Department (EMSD). *Code of practice for energy efficiency of building services installation*, EMSD, HKSAR Press; 2012.

[8] ASHRAE. *ASHRAE Standard 90.1-2013: Energy Standard for buildings except low-rise residential buildings*. Author Press; 2013.

[9] Depart of Energy (DOE). F*ederal Energy Management Program: Meeting energy efficiency requirements for products*, 2013. Available at http://energy.gov/eere/femp/federal-energy-management-program

[10] Air-conditoning, Heating and Refrigeration Institute (AHRI). *AHRI Standard 550/590: Performance rating of water-chilling and heat pump water-heating packages using the vapor compression cycle*, Author Press; 2011.

[11] Austin SB. Optimum chiller loading. *ASHRAE Journal* July 1991;**33**,40–3.

[12] Browne MW, Bansal PK. Transient simulation of vapour-compression packaged liquid chillers. *International Journal of Refrigeration* 2002;**25**:597–610.

[13] Landman WJ. Off-design chiller performance. *Trane Engineers Newsletter* December 1996;**25(5)**.

[14] Treado SJ, Snouffer T. Measurement considerations for the determination of central plant efficiency. *ASHRAE Transactions* 2001;**107(1)**:401–6.

[15] Chan KT, Yu FW. Applying condensing-temperature control in air-cooled reciprocating water chillers for energy efficiency. *Applied Energy* 2002;**72**:565–81.

[16] Yu FW, Chan KT. Electricity end-use characteristics of air-cooled chillers in hotels in Hong Kong. *Building and Environment* 2005;**40(1)**:143–51.

Biography

F.W. Yu started his PhD study on chiller system simulation at the Department of Building Services Engineering, The Hong Kong Polytechnic University (PolyU), since 2001. After graduation in 2004, he worked for various research projects on developing optimal controls for chiller systems. His current research interests are building energy study and HVAC&R systems analysis.