制冷与热泵产品的能效标准研究和循环热力学完善度的分析

Analysis on Energy Efficiency Standards and Thermodynamic Perfectibility for Products of Refrigeration and Heat Pump

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内 容 简 介

本书作者长期从事制冷、空调与热泵产品的节能与能效标准研究以及能效标准的制定工作，本书提出了一种新的关于制冷、空调与热泵产品能效及能效标准的评价体系——热力学完善度，并对产品能效标准的一致性进行了探讨。

全书共分 8 章：第 1 章是绪论，介绍国内外制冷、空调与热泵产品的能效及其他相关标准；第 2～4 章是热力学完善度的基本原理和分析计算方法；第 5～7 章是热力学完善度在相关产品的应用与分析；第 8 章用热力学完善度的分析方法对我国制冷、空调与热泵产品能效标准的走向提出预测。

本书可供从事制冷、空调与热泵产品设计、生产及相关各级标准制定的技术人员阅读，也可作为高等工科院校制冷、空调、低温等专业本科生、研究生的教学参考书，还可供有关专业的教师和从事能源与节能工作的科技人员参考。

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前　言

近年来，随着我国国民经济的快速发展，在工业、商业、民用等范围的制冷、空调与热泵产品的应用越来越多，所消耗的电能也越来越多。中国已经是制冷、空调工业的制造大国和使用大国，无论是设备装机容量，还是制造或使用的品种，中国都已位居世界前列。制冷、空调技术提高了人们的生活质量，尤其是各种热泵装置，通过消耗少量的高质能量，将地热、太阳能、生活污水、工业余热等可再生能源开采利用，减少了化石能源的消耗。我国通过学习国际上发达国家的先进经验，制定了制冷、空调与热泵产品的能效标准，对于提高制冷、空调与热泵产品的能效水平，节约能源和减少环境污染起到了重要作用。因此，通过制定合理的制冷、空调和热泵产品的能效标准，实行能效标识制度，对于推动合理用能，推动社会可持续发展，建设低碳社会有重要的意义。

近 20 年来，我国逐步开展了能效标准和能效标识的研究工作，现在已经制定的关于制冷、空调与热泵产品的能效标准有，电冰箱、房间空调器、单元式空调机、冷水机组、转速可控型房间空调器、多联式空调(热泵)机组等；而对水源热泵、热泵热水机、制冷陈列柜等产品的能效等级标准也在制定中。但是目前我国已制定的能效标准的数据大多来源于国外的经验和现有产品的数据分析，缺少理论支撑。此外，各种制冷与热泵产品相应建立了不同的性能评价指标，缺乏多种评价指标进行比较的基础平台。因此，本书提出将热力学完善度作为制定相关产品能效标准的限定值、节能值和能效等级的依据。

作者长期从事我国制冷、空调与热泵产品的能效标准的制定工作，总结出了热力学完善度的基本原理和计算方法，并将其应用到实际的标准制定中。热力学完善度可以作为指导我国制定与修订制冷、空调与热泵产品能效标准的依据。

热力学完善度可以将不同制冷、空调设备统一在一个基准上进行比较分析，而且热力学完善度是热力学第二定律效率，它反映的是设备偏离理想状态的程度，此参数可以帮助分析设备提高性能的空间和努力方向，进而提高我国制冷、空调设备水平，提高我国制冷、空调设备的竞争力。

本书首先详细介绍了热力学完善度的一般原理，包括理论基础、计算方法、特点和意义，以及影响因素等；其次对我国家用电冰箱、房间空调器、单元式空调机及冷水机组等制冷、空调与热泵产品现有的能效标准进行了热力学完善度分析。研究结果表明，家用电冰箱压缩机的热力学完善度为 0.2～0.34，房间空调器的热力学完善度为 0.2～0.3，而单元式空调机的热力学完善度为 0.15～0.23，现有冷水

机组以及正在制定的水源热泵的能效标准的热力学完善度为0.3～0.5。通过理论分析和数据统计，得出空气源热泵热水机的能效标准介于空气-空气系统和水-水系统之间，约为0.25～0.33。书中还对空气-空气系统与水-水系统的一致性，以及SEER和IPLV在热力学完善度方面的一致性问题进行探讨和研究。

在本书的撰写过程中，田华负责第2、3章的撰写，刘春涛负责第1、5章的撰写，刘忠彦负责第4章的撰写，袁秋霞、李晓凤负责第6、7章的撰写，赵丽负责第8章的撰写，张泽英、凌泓、郭光莹等负责资料收集与整理工作，马一太负责统稿工作。西安交通大学刘志刚教授对书稿进行了审阅，并提出了宝贵的修改意见，在此谨致谢意。

本书的出版得到国家科技支撑计划资助课题(2006BAK04A22)的资助。在本书的撰写过程中，得到了中国制冷学会、中国制冷空调工业协会、中国标准化研究院、合肥通用机械研究院以及国内外各制冷、空调生产企业的大力支持，在此一并表示感谢。

由于作者能力所限，或收集的资料不够广泛，书中难免存在不妥之处，还望广大读者能给予批评指正。

作　者

2011年7月

Preface

In recent years, with the rapid development of China's national economy, the application of refrigeration, air conditioning and heat pump products is becoming more and more extensive in the industrial, commercial, civil and other fields. Therefore, the consumption of electrical energy is increasing rapidly. China has been a leading power of manufacture and usage in the refrigeration and air conditioning industry. And China has come up the top in the world either for the installed capacity or the variety of manufacture and usage. The refrigeration and air condition technique improve people's quality of life, especially various heat pump instruments which reduce the consumption of fossil energy by consuming a small number of high quality energy to utilize the renewable energy, such as geothermal energy, solar energy, domestic sewage and industrial waste heat. Our country has established the energy efficiency standards for refrigeration, air condition and heat pump products with the advanced experience of developed countries, which play an important role in improving the energy efficiency standards of refrigeration, air conditioning and heat pump products, also in energy saving and reducing the pollution of environment. Therefore, it is of great significance in promoting the proper usage of energy and the sustainable development of society, and constructing low carbon society by formulating rational energy efficiency standard and energy efficiency label for refrigeration, air conditioning and heat pump products.

In the recently twenty years, China has been gradually developing the research work for energy efficiency standards and labels. And the energy efficiency standards about the refrigeration and air condition products includes: refrigerator, room air conditioner, unitary air conditioner, water chiller, variable speed air conditioner, multi-connected air conditioning (heat pump) unit have been established; and the energy efficiency standards about water source heat pump, heat pump water heater and refrigerated display cabinets are being formulated. However, the most part of the data of the established energy efficiency standards are based on the abroad experience and the data analysis of existing products, which is lack of theory support. In addition, different performance evaluation

indexes have been established for various refrigeration and heat pump products, which is lack of foundation platform to compare different evaluation indexes. Therefore, the thermodynamic perfectibility is presented as the basic standard for formulating the limitations, energy saving values and energy efficiency grades of the relevant products.

The author generalizes the fundamental principle and calculating method of the thermodynamic perfectibility and put it into the actual standards formulation in the process of engaging in establishing China's energy efficiency standards of refrigeration, air conditioning and heat pump for a long period. The thermodynamic perfectibility can be set as the basis to guide our country to establish and revise the energy efficiency standards of refrigeration, air conditioning and heat pump products.

Thermodynamic perfectibility provides a comparative basis for different types of refrigeration and air conditioning equipment. It is the Second Law of Thermodynamics efficiency, which reflects the degrees of the practical state deviating from the ideal state. This parameter represents the room for improving equipment efficiency, which can enhance the efficiency and competitiveness of refrigeration and air conditioning equipment of our country.

This manuscript covers the details of the general principle of thermodynamic perfectibility, which concludes theoretical fundamental, calculating method, characteristic and significance and influencing factors and so on. Then it carries out an analysis of thermodynamic perfectibility for the existing energy efficiency standards, such as household refrigerator, room air conditioner, unitary air conditioner and water chiller and so on. The results show that the thermodynamic perfectibility value of the household refrigerator compressor is 0.2～0.34, and that of the room air conditioner is 0.2～0.3, moreover, that of the unitary air conditioner is 0.15～0.23, and that of the existing water chiller and the being established energy efficiency standards of water source heat pump is 0.3～0.5. By theoretical analysis and data statistics, it comes out that the energy efficiency standard of the air source heat pump water heater is between that of the air-air system and water-water system, which is about 0.25～0.33. Finally, it presents the discussion and studies for the coherence of air-air system and water-water system, and that of the SEER and IPLV in term of thermodynamic perfectibility.

During the writing of this manuscript, Hua Tian is in responsible for drafting Chapters 2 and 3; Chuntao Liu for Chapters 1 and 5; Zhongyan Liu for

Chapter 4; Qiuxia Yuan and Xiaofeng Li for Chapters 6 and 7; Li Zhao for Chapter 8; Zeying Zhang, Hong Ling and Guangying Guo et al. are responsible for data collecting and reduction; and Yitai Ma is in charge of unifying the whole manuscript. I will like to express thanks to Prof. Zhigang Liu, from Xi'an Jiaotong University for the review and some valuable comments to this manuscript.

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Because of the limitation of my knowledge and capability and the data collecting being not extensive enough, it is hard to avoid the mistakes for the details and the data in this manuscript. The author is cordial that the general readers can give comments and correction.

Authors
July, 2011

符号表及缩写

APF	全年性能系数(annual performance factor)
COP	热泵的制热性能系数(coefficient of performance)
COP_C	卡诺循环的制热性能系数
COP_R	实际产品的制热性能系数
CSTE	制冷季节耗电量(cooling seasonal total energy)
CSTL	制冷季节总负荷(cooling seasonal total load)
EEI	能源效率指数(energy efficiency index)
EER	制冷机的制冷能效比(energy efficiency ratio)
EER_C	卡诺循环的制冷能效比
EER_R	实际产品的制冷能效比
HSTE	制热季节耗电量(heating seasonal total energy)
HSTL	制热季节总负荷(heating seasonal total load)
IEER	综合能效比(integrated energy efficiency ratio)
IPLV	综合部分负荷系数(integrated part load value)
MEPS	最低能效标准(minimum energy performance standard)
Q_0	制冷机或热泵产品所输出的冷量
Q_k	制冷机或热泵产品所输出的热量
SEER	季节能效比(seasonal energy efficiency ratio)
SHPF	制热季节能效比(seasonal heating performance factor)
W	制冷机或热泵产品输入的电功
η	热力学完善度(thermodynamic perfectibility)

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