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PEAK HEATING/COOLING LOAD DESIGN METHODS: HOW WE GOT TO WHERE WE ARE TODAY IN THE U.S.

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ABSTRACT

This paper presents an historical discussion of HVAC design calculation methods from the 1800s until the present, including methods that were used to size heating systems and cooling system. The discussion focuses primarily on U.S. analysis methods, although, as far as could be determined, most of the early peak heating/cooling engineering-based methods in the U.S. can be traced, either directly or indirectly to those published by Professor Hermann Rietschel (1893 – present), Professor of the Technical University of Berlin, Charlottenburg, the works of Thomas Tredgold (1836), or Eugéne Péclet (1850).

INTRODUCTION[1]

Currently, there is an increasing effort to analyse, design and construct new high performance buildings that will consume less energy, look appealing, and provide acceptable indoor air conditions. However, in many cities in the U.S. developers are asked to try to reuse some portion of an existing structure, or add-on to an existing structure without really knowing how that previous building was designed, especially the HVAC systems. Often, older buildings have existing HVAC systems that are significantly over/under sized, which makes them inappropriate for meeting the heating/cooling loads they must supply. In some cases, the thermal mass of these older buildings has never been adequately taken into account during the design process, which may have led to large errors in the thermal load sizing calculations.

Although there have been a number of previous papers that have presented historical discussions of the origins of computer simulation programs, few if any studies have provided an historical analysis that covered periods before computerized simulations came into use (Feldman and Merrian 1979; Kusuda 1985; Stamper 1995; Sowell and Hittle 1995; Shavit 1995).

[1]This paper discusses a history of peak load design methods. It does not cover building annual energy use, fenestration solar gain, moisture and peak weather data calculations. A discussion of the history of annual energy use is presented in the ESL report # ESL-TR-12-12-02, which also includes a complete listing of all the references in this paper, available at: http://esl.tamu.edu/terp/reports/2012

HISTORY OF RELATED SCIENCE

The development of peak load and annual energy use calculation methods could not be performed without a solid foundation based on the related sciences. This section provides a brief review of the previous sciences and engineering practices from the 1700s to the 1900s including [2]: gas laws, heat transfer, and thermodynamics.

Gas laws

The development of the science of the behavior of gasses, such as moist air, was important for sizing heating and cooling system. The studies of gas laws began in the 17th century first with experiments that defined temperature, pressure and volume relationships, followed shortly thereafter with a better understanding of partial pressures, molecules and eventually atoms. One of the earliest studies was performed by the British scientist and philosopher, Robert Boyle (1627-1691), who performed experiments with an air vacuum pump to observe the effects of reducing air pressure, which was reported in his book "*New Experiments Physico-Mechanicall, Touching the Spring of the Air, and its Effects*" in 1660; Two years later, he published his results, which demonstrated that the product of gas pressure and volume was constant at a given temperature; now referred to as "Boyle's Law". Robert Boyle is usually credited with being the first to research gas properties through observations based on experiments.

One hundred years later, in 1787, Jacques Charles (1746-1823), the French chemist and physicist, formulated Charles' Law stated that the gas volume was proportional to the gas temperature at a given gas pressure. However, Charles' Law was not published until 1802 when it was cited by Joseph Louis Gay-Lussac, a French chemist and physicist. Gay-Lussac's Law showed the relationship between gas pressure and temperature at a constant gas volume. A combined gas law that considered gas pressure, temperature and volume was later derived by combining Boyle's Law and Charles' Law.

[2]References for this introduction materials can be found in West (2005), Donaldson *et al.* (1994), Acott (1999), Elena and Manuela (2006), Gas Law History (n.d.), Sandfort (1962), Woo and Yeo (n.d.), Hirang (2008-2009), Bergles (1988), Cheng and Fujii (1988), Narasimhan (1999), Backman and Harman (2001), Mätzler (2012), Carter (2004), Winhoven and Gibbs (n.d.), Powers (2012), Javadi (n.d.).

In 1801, the English chemist, meteorologist and physicist, John Dalton (1766-1844), introduced the concept of “partial pressure”, which proposed that the summation of the partial pressures of each gas component was equal to the total pressure of mixture. This later became known as "Dalton's Law". Eight years later, in 1809, Joseph Louis Gay-Lussac developed another law about the conservation of gas volumes in chemical reactions at the same temperature and pressure. In 1811, based on Gay-Lussac's data, Amedeo Avogadro (1776-1856) proposed Avogadro's Law, which was the first to suggest that "molecules" should be differentiated from “atoms”, which helped to further understand gaseous mixture. Avogadro's Law also stated that gases with equal volumes at the same temperature and pressure had equal numbers of molecules. Eventually, all these discoveries lead to the Ideal Gas Law that formed the basis of today’s thermodynamic principles for moist air.

Heat transfer

Heat transfer, the discipline that studies the process transferring heat from one object to another, is composed of three important fields: conduction, convection and radiation. The earliest theories of heat transfer began with Isaac Newton (1642-1727) who published “Newton's Law of Cooling” in 1701 that first introduced the term “heat transfer coefficient”. Newton proposed a proportional relationship between the cooling rate and temperature difference of two surfaces based on his early experiments. His Law of Cooling was considered the beginning of convective heat transfer studies. The three modes of heat transfer: conduction, convection and radiation, were not separately distinguished until 1757 by Joseph Black (1728-1799), who also introduced the term "Latent Heat".

In 1807, the theory of heat conduction was first formulated by Joseph Fourier (1768-1830) through the use of partial differential equations that described the transient process. Fifteen years later, in 1822, Fourier's Law of Heat Conduction was formally proposed in his published paper *“The Analytic Theory of Heat”*. In the beginning of the 19th century, the earliest work on radiation heat transfer started with the recognition of “invisible light” by William Herschel in 1800. It was not until sixty years later, in 1860, that Kirchhoff’s law of radiation was formulated by Gustav Kirchhoff (l824-1887), which gave us an equation to calculate the radiative heat transfer process at the surface of a material. Shortly after this, Stefan's Law was proposed in 1879, based on experiments performed by Joseph Stefan (1835-1893), which stated that there was a proportional relation between radiation and the fourth power of surface temperature. Then, five years later, in 1884, Ludwig Boltzmann (1844-1906) provided a derivation of a fourth power radiative heat transfer law. Stefan and Boltzmann’s work were later combined and are now referred to as the "Stefan-Boltzmann Law", which includes the Stefan-Boltzmann constant for performing the radiative heat transfer calculation. In summary, these heat transfer discoveries provided the basic theories and equations to calculate dynamic building peak load calculations as well as annual energy use calculations.

Thermodynamics

Thermodynamics is a discipline that combines the concepts of heat, work and energy, including: the First, Second and Third Law of Thermodynamics. The science of thermodynamics developed gradually alongside the development of gas laws and heat transfer in the 19th century. Beginning in 1824, Sadi Carnot (1796-1832), also known as the "Father of Thermodynamics", proposed the Carnot cycle, which was published in his *“Reflections on the Motive Power of Fire and on Machines Filled to Develop That Power”*; this paper marked the birth of the science of thermodynamics and established the foundation for the First and Second Law of Thermodynamics. The First Law of Thermodynamics - Conservation of Energy was first introduced in 1842 by Robert Mayer (1814-1878) who proposed that heat was a form of energy. One year later, the equivalence of heat and mechanical work was demonstrated by James Prescott Joule (1818-1889)[3].

In 1847, an energy conservation formula was first proposed by Hermann von Helmholtz (1821-1894). This led to the development of the Second Law of Thermodynamics, which was presented by Rudolf J. Clausius (1822-1888) in 1850 when be introduced the term "entropy", which was based on Helmholtz and Carnot's work. The Third Law of Thermodynamics was not proposed until 1906 by the physical chemist, Walther Hermann Nernst (1864-1941), which stated that the entropy of a system was zero if the temperature was absolute zero. These three Laws of Thermodynamics helped consolidate the concepts of heat, work and energy into calculations of a single subject or system of equations, which together with the science of gas laws and heat transfer became the foundations of building peak heating and cooling load calculations and annual energy use calculations.

PEAK LOAD CALCULATION METHODS

Building peak load calculation methods, which include peak heating and cooling load calculations, are used for sizing HVAC equipment in order to provide adequate heating or cooling when extreme weather conditions occur. This section reviews the history of the major peak heating and cooling load methods in four different periods: Pre 1945, 1946-1969, 1970-1989, and 1990-Present.

[3]The S.I. energy unit was named after James Prescott Joule.

Pre 1945

The birth of most engineering methods is often inspired by the need to solve problems which are relevant and practical for a given period. Prior the development of standardized peak load calculation methods, most engineers tried to design building HVAC systems by relying on manufacturer's literature for a specific system, a few available textbooks or even fewer handbooks or guidebooks.

The earliest heating and ventilating design developments started in the 19th century. Unfortunately, engineers had to design systems with rules-of-thumb or approximate design methods because useful textbooks or guidebooks that were based on first principles were in scarce supply. As early as in 1834, Dr. Boswell Reid redesigned the heating and ventilating system for British House of Commons using a chimney to induce air flow through the building[4], with a water spray cooling and steam heating system (Donaldson *et al.*, 1994). This was probably one of the first successful applications of purposeful "fresh air" into a public space, with evaporative cooling and/or heating applied to the air under manual controls.

About the same time, Eugéne Péclet, a French physicist and a heat engineer, was probably the first to introduce heat transfer calculations by publishing his textbook "*Traité De La Chaleur*" (Treatise on Heating) in 1844 (Donaldson *et al.*, 1994; Nicholls, 1922). Unfortunately, few engineers and architects were aware of Péclet's work since it was written only in French. In 1904, some of Péclet's work was finally translated into English by Charles Paulding (Paulding, 1904).

In 1855, Robert Briggs designed and installed a heating and ventilation system for the U.S. House of Representatives (Donaldson *et al.*, 1994). His system used indirect steam heaters (i.e., underfloor radiators), a chimney[5], and subterranean airways for each wing. Engineers at that time could only count on their own practical design experience, which was often limited. Useful textbooks that contained design tables and equations did not start to appear until twenty to thirty years later.

In 1884, Frank E. Kidder introduced the first version of his book "*Architect's and Builder's Handbook*" (Kidder, 1906). This book was oriented towards architects and mostly contained information from manufacturer's literature regarding the sizing the steam radiators by the determination of the room size and boiler size. Although a heat loss calculation method was included, it was described in terms of words instead of equations. In addition, thermal mass was not considered in the system design, since all tabulated heat transfer coefficients were for steady-state calculations.

Shortly after, in 1894, a professor of the Technical University of Berlin, Hermann Rietschel published a German textbook called "*Lüftungs-und Heizungs-Anlagen*"[6] (Ventilation and Heating Systems) that was later translated into English version by C.W. Brabbee in 1927 (Rietschel and Brabbee, 1927). This book is widely recognized as Europe's first scientifically-based text on heating and ventilating. It contained relatively complete information about how to calculate heat transfer, including equations that are still in use today. It also described how to size steam systems, piping, etc., and it even provided a detailed solution to the dynamic heat transfer calculation in a single slab of wall material as well as steady-state heat loss calculations for walls, roofs, windows and ventilation. The book also included tables of useful heat transfer coefficients as well as charts and graphs with plotted properties of moist air (Usemann, 1995). Unfortunately, no formulas for moist air were included.

Shortly after, in 1896, Rolla Carpenter, a professor at Cornell University, published the first version of his textbook named *Heating and Ventilating Buildings* (Carpenter, 1896). This book included theory and applications of heating and ventilating apparatus by Thomas Tredgold (1836), Charles Hood (1855), and Eugéne Péclet (1850). It also included tables of materials, properties of air and math algorithms. It can be considered as an equivalent engineering handbook.

Around the same period, in the 1890s, Alfred R. Wolff, a well-known heating and ventilating design engineer in the U.S., published his "heat transfer coefficient" chart that was derived from the previous work by Eugéne Péclet and Thomas Box. It included a graph that showed the heat loss per unit area for windows, doors and walls and ceilings of varying thickness (Wolff, 1894; cited in Donaldson *et al.*, 1994). Wolff was regarded as one of the first U.S. engineers to use "heat transfer coefficients", and his chart that showed "varying thickness" was probably the first published dynamic effect of thermal mass[7]. Wolff was the designer of the first air conditioning system[8] for the Board Room of New York Stock Exchange in 1903[9], which was regarded as one of the earliest commercial air-conditioning systems to be designed and operated for comfort (Donaldson *et al.*, 1994).

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[4] This is because reliable air-handling units were not available.
[5] Originally, which was replaced with a large fan added afterwards.
[6] Private communication with Mr. Bernard Nagengast.
[7] Wolff was also aware of Rietschel's textbook.
[8] Wolff consulted Henry Torrance of the Carbondale Machine Company for this design.
[9] Two years later, in 1905, Stuart Cramer first used the term "air conditioning" for treating air in textile mills in N.C., which became widely adapted as the terminology that described artificial cooling system (Donaldson *et al.*, 1994).

Stepping into the 20th century, new peak cooling load methods began to be developed during the 1900 to 1945 period, including: the psychrometric chart and the governing equations for moist air, the sol-air temperature method and the thermal network method. In 1902, a young engineer at the Buffalo Forge company, named Willis Carrier designed his first ventilation system with cooling coils for the Sackett and Wilhelms Company, in Brooklyn, N.Y. (Donaldson *et al.*, 1994). Unfortunately, the system was not successful, because, although it could cool the air stream, it could not control the humidity. After studying the failure, Carrier determined that a spray-type air washer using chilled water could be used to control temperature and humidity[10].

In 1906, Carrier developed a working system and applied for a patent for an "apparatus for treating air", which allowed him to control the absolute humidity of the air stream exiting the chilled water spray (Donaldson *et al.*, 1994). Two years later, in 1908, Carrier published his first psychrometric chart based on his psychrometric formulas[11] (Donaldson *et al.*, 1994). In 1928, Carrier designed the mechanical system for the Milam Building in San Antonio, Texas, which was the first high-rise air-conditioned office building in U.S. (ASME, 1991). In the Milam building, two centrifugal refrigeration units developed by the Carrier Company, were used as the cooling system. Unfortunately, the radiant heat that was supposed to be absorbed by the heavy exterior construction was not well understood. This resulted in the system not working as planned due to an unexpected asymmetric cooling load. To remedy this, venetian blinds, cloth window shades and duct dampers were installed to solve morning or afternoon overheating problems (ASME, 1991).

In 1914, the Buffalo Forge Engineer's Handbook was published, which was recognized as the first comprehensive U.S. manufacturer's handbook for heating and ventilating (Carrier, 1914). It contained detailed equations for heat loss calculations for walls, roofs, windows and ventilation, including tables of useful coefficients as well as Carrier's psychrometric chart, which was the first time that a psychrometric chart was introduced in a handbook. Eight years later, in 1922, ASHVE published its first guide book, "*The American Society of Heating and Ventilating Engineers Guide*", which also had basic heat loss formula, unfortunately which were presented as "word formulas" (ASHVE, 1922).

During this period, several other useful textbooks appeared. In 1918, John R. Allen *et al.* published the first edition of their book "*Heating and Ventilation*" that provided detailed heat loss calculation methods that included tables of useful coefficients and equations (Allen *et al.*, 1931).

Shortly after Allen, in 1935, Charles Merrick Gay and Charles De Van Fawcett published their textbook, which contained detailed equation-based calculations for heat loss and a very terse advice about how to calculate summertime heat gain[12] (Gay and Fawcett, 1937). One year later, the TRANE Company published its first design manual, which provided a load estimate sheet for engineers to use (TRANE, 1938). This manual used tabulated "solar temperature differences" and also included instructions for using the TRANE air - conditioning ruler[13].

Several important papers were also published during this period in Europe and in the U.S. In 1925, the Response Factor Method was first introduced for transient flow calculation by André Nessi and Léon Nisolle in French (Nessi and Nisolle, 1925). In 1939, Alford *et al.* published a paper on heat storage/heat transfer through walls driven by temperature and solar intensity in the *ASHVE Transactions*. This paper provided a detailed solution to the differential equation in the form of a decrement factor and a time delay (Alford *et al.*, 1939). Three years later, in 1942, the thermal R/C network method was first developed by Victor Paschkis to simulate building walls (Paschkis, 1942). Later in 1944, C.O. Mackey and L.T. Wright Jr. used a modified version of Alford *et al.*'s equations and proposed the "sol-air temperature method" (Mackey and Wright, 1944). In the same year, in 1944, John G. Linvill and John J. Hess Jr. published their article "Studying Thermal Behavior of Houses", which was an undergraduate student project at M.I.T. Their article showed how the thermal network method could be used to simulate an entire house (Linvill and Hess, 1944).

In summary, during the period prior to 1945, there were at best inconsistent methods for calculating peak heating and cooling loads. These methods appeared in textbooks, handbooks, guidebooks and manufacturer's literature. However, during this same period, the foundation was laid for today's modern methods, which began with sol-air temperatures, decrement factors and the use of a thermal R/C network to calculate dynamic building heat gain/loss.

1946-1969

Most of the dynamic peak cooling calculation methods used today in the U.S. were proposed during the 1946-1969 period. In 1948, as a design engineer

[10]Information was retrieved from: http://en.wikipedia.org/wiki/Willis_Carrier

[11]Carrier's psychrometric chart was later formally published in 1911 in ASME (Carrier, 1911).

[12]In the book, they recommended the use of a rule-of-thumb method: "add 25°F to the dry bulb temperature difference for heat transmission calculation".

[13]This ruler was for use with the TRANE psychrometric chart. The heat transfer tables were listed according to the color of the wall, versus thermal mass characteristics.

at Carrier Cooperation, James P. Stewart was the first to outline Equivalent Temperature Differentials (ETD), based on Mackey and Wright's earlier work, which was intended to be used as an easy-to-use tabulated design method that would estimate the time delay and amplitude of the dynamic heat gain due to thermal mass. Stewart's method was shown to be suitable for calculating an extended hourly profile only if radiant components were averaged over the representative period for all the thermal mass of the building (Stewart, 1948). The ETD tables were adopted for use in the *1951 ASHVE Guide* (ASHVE, 1951). Unfortunately, judging the amount of thermal mass in a building was a difficult job for an average engineer, which ultimately made the method only useful in the hands of an experienced engineer. To help resolve this, additional tables of Total Equivalent Temperature Difference/ Time Averaging method (TETD/TA) values were later tabulated in the *1961 ASHRAE Guide and Data Book* (ASHRAE, 1961).

In 1955, a new edition of Gay and Fawcett's textbook was published that included a new author, William McGuinness who was a professor of Architecture at the Pratt Institute of Technology (Gay *et al.*, 1955). This new edition included a revised procedure for air conditioning design, as well as improved data for calculating heat gains (Gay *et al.*, 1955), which referenced the *1951 ASHVE Guide*[14]. So, by the mid-1950s either the direct use of Mackey and Wright's sol-air temperature equations or Stewart's tabulated TETD/TA values provided designers with an improved method to calculate the impact of thermal mass.

In the mid-1950, W.R. Brisken, S.G. Reque and P.R. Hill laid the foundations of today's thermal Response Factor Method (RFM), based on Nessi and Nisolle's 1925 work. In 1956, Brisken and Reque published their heat load calculations using the thermal response method (Brisken and Reque, 1956). In this method, they proposed using "square waves" to represent a time-varying "curve" of temperature response. One year later, Hill developed a more accurate "unit triangle" method for calculating the time-varying 1-D surface temperature (Hill, 1957). Based on these previous works, in 1967, G.P. Mitalas and D.G. Stephenson developed the thermal Response Factor Method (RFM), which allowed for the solution to the dynamic heat transfer problem without having the knowledge of how to solve a separate differential equation for each new wall type (Mitalas and Stephenson, 1967; Stephenson and Mitalas, 1967). Later, this method became part of the Weighting Factor Method, which was used for calculating building annual energy use in the *1981 ASHRAE Handbook* (ASHRAE, 1981).

[14] Gay *et al.*'s book cited the 1951 ASHVE Guide as the source of Mackey and Wright's 1944 sol-air equation.

Several authors investigated the use of thermal R/C network models for analysing dynamic heat transfer (Paschkis, 1942; Buchberg, 1955; Nottage and Parmelee, 1954). As previously mentioned, although the first thermal R/C network method appeared in 1942, Harry Buchberg developed a complete R/C thermal network for a house model using heat balance calculations in an analog computer in 1958. This project was an ASHRAE sponsored project and is regarded as the first time that the heat balance method and thermal network method were used together in an analog building simulation (Buchberg, 1958). The heat balance method was later adopted in the *1981 ASHRAE Handbook* along with the weighting factor method as building annual energy use calculation methods (ASHRAE, 1981).

The guide books during 1946-1969 included: the 1955 *TRANE Air Conditioning Manual* (TRANE, 1955), the 1960 *Carrier Handbook of Air Conditioning System Design* (Carrier, 1960), the 1951 *ASHVE Guide* (ASHVE, 1951), several *ASHRAE Guide and Data Book* (ASHRAE, 1961, 1963, 1965), and the first version of ASHRAE Handbook (ASHRAE, 1967). In these handbooks, thermal mass was considered as either sol-air temperature calculations or TETD/TA tables.

Besides the methods discussed above, there were two other widely used methods that were developed to solve the time-varying heat transfer problems: the Finite Difference/Finite Element Method (FDM/FEM) and the admittance method. The FDM/FEM was introduced in 1960 (Clough, 1960; Forsythe and Wasow, 1960) in the form of formal equations that could be directly used in computer algorithms. The admittance method was originally developed by A.G. Loudon in 1968 (Loudon, 1968). The concept of "*Thermal Admittance*" was first introduced in the U.K. by the *Institution of Heating and Ventilating Engineers Guide* (IHVE) in 1970 (Goulart, 2004) to measure the ability of building components to smooth out the temperature swings within a 24-hour cycle. This method was later adopted by the Charted Institution of Building Services Engineers (CIBSE) and is now widely used in the U.K.

In summary, during 1946-1969, the first edition of ASHRAE Handbook appeared, which adopted the available peak heating and cooling load methods from important papers. Several of the popular textbooks and manufacturer's literature were updated to reflect the new methods as well. Finally, steady-state peak heating calculation methods matured and time-varying cooling load calculation methods that considered ambient temperature and solar radiation became available for designers to use.

1970-1989

Peak cooling load methods continued to develop during the period 1970-1989. In 1972, the ASHRAE

Task Group on Energy Requirements (TGER) first introduced the Transfer Function Method (TFM) for peak cooling load calculation, which was based on Mitalas and Stephenson's earlier work and is considered the first, wide-spread computer-oriented method for solving dynamic heat transfer problems in buildings (Mitalas, 1972).

However, even as new computer-based methods were being developed, manual, tabulated methods were being updated and used. One such method, based on the principles of TFM, is the Cooling Load Temperature Difference/Cooling Load Factor method (CLTD/CLF), which was developed by William Rudoy and Fernando Duran in 1974 (Rudoy and Duran, 1974). It included tabulated results of controlled variable tests summarized in ASHRAE research project RP-138 for cooling load calculations. The CLTD/CLF method attempted to simplify the two-step TFM and TETD/TA method into a single-step technique, which was later published in the *1977 ASHRAE Handbook* of *Fundamentals* (ASHRAE, 1977). Fourteen years later, in 1988, the CLTD/CLF method was modified by Prof. Edward Sowell who ran 200,640 simulations to provide new tabulated answers (Sowell, 1988). That same year, Steven Merrill Harries and Faye C. McQuiston proposed an additional Conduction Transfer Function (CTF) coefficients to cover more groups of roof and wall construction conditions (Harries and McQuiston, 1988).

In summary, during the 1970 to 1979 period, peak heat load methods remain unchanged while major advances were made in peak cooling load calculation methods developed, which are still taught in textbooks today, but no longer exist in the current 2009 ASHRAE Handbook (ASHRAE, 2009)[15].

1990-Present

In 1993, Jeffery Spitler *et al.* updated the CLTD/CLF method to become the CLTD/SCL/CLF method by introducing the term "Solar Cooling Load (SCL)" for an improved solar heat gain calculation through fenestration (Spitler *et al.*, 1993). This new CLTD/SCL/CLF method was later incorporated into the *1993 ASHRAE Handbook* of *Fundamentals* (ASHRAE, 1993).

The most current cooling load calculation method is the Radiant Time Series (RTS) method that Spitler *et al.* developed in 1997, which is an improvement over all previous methods (Spitler *el al.*, 1997). In response to research proposed by ASHRAE Technical Committee TC 4.1, the RTS method was derived directly from, but is simpler than, the heat balance method. In the RTS method, the 1-D time-varying conduction is calculated using a 24-term response factor. The RTS method converts the radiant portion of hourly heat gain to hourly cooling loads using radiant time factors, which are the coefficients of the Radiant Time Series method. The accuracy of the Radiant Time Series method is similar to that of the TFM if custom weighting factors and custom conduction transfer function coefficients were used for all components in a building. Finally, in 2003, the ASHRAE building load calculation toolkit (LOADS toolkits) was developed by Curtis Pedersen (Pedersen, *et al.*, 2003), which provided a FORTRAN source code for the heat balance calculations for ASHRAE members to use.

For residential load calculations, the Residential Heat Balance (RHB) and the Residential Load Factor (RLF) methods were developed by Charles Barnaby in 2004 (Barnaby *et al.*, 2004). In a similar fashion as the RTS method and LOADS toolkit, the RHB method was developed to be a computer algorithm, which was coded using FORTRAN, while the RLF method was developed to be a simple method that could be used by manually or with a spreadsheet. In 2000, an extensive analysis was developed that compared peak cooling load calculation methods in the U.S. and the U.K. by Simon Rees (Rees *et al.*, 2000). The analysis concluded the cooling load calculation methods recommended in the U.S. and U.K. have the possibility to converge in the future.

SUMMARY

Prior to the 1944 sol-air temperature method by Mackey and Wright and the ETD tables by Stewart in 1948, there were no widely-used design methods for calculating time-varying peak cooling loads in the U.S. To design building HVAC systems during this period, engineers and architects had to refer to manufacturer's literature, textbooks, guidebooks or their own experiences, which varied widely. The earliest textbooks include: Eugéne Péclet, Frank Kidder, Hermann Rietschel, Rolla Carpenter, Charles Paulding, John Allen, Charles Merrick Gay and Charles De Van Fawcett. Manufacturers like TRANE and Carrier developed and used their own methods, which were eventually published. Interestingly, prior to 1944, building peak heating load calculation methods primarily used "word formulas" to describe the calculation procedure. In the U.S., building peak cooling load calculations began with the decrement factor by Alford *et al.* in 1939, which provided the foundation of the sol-air temperature method developed by Mackey and Wright in 1944.

In 1948, Stewart developed the Equivalent Temperature Differentials table from the sol-air temperature equations of Mackey and Wright, which resulted in the ETD tables adopted by 1951 ASHVE

[15] For non-residential buildings, the heat balance method and radiant time series methods are included in Chapter 18 in the 2009 ASHRAE Handbook of Fundamentals for peak cooling load calculations methods.

Guide and TETD/TA method later tabulated in *1961 ASHRAE Guide and Data Book*.

The thermal response factor method was introduced by Mitalas and Stephenson in 1967, based on the previous work done by Nessi and Nisolle, Hill, Brisken and Reque. In 1958, the heat balance and thermal network methods were demonstrated by Buchberg for simulating a house on an analog computer as part of ASHRAE sponsored research project. In 1972, ASHRAE Task Group published the transfer function method for calculating dynamic heat transfer, which laid the basis for the CLTD/CLF method that was later modified by Sowell, Harries, McQuiston, and Spitler to become the CLTD/SCL/CLF method. In 1993, Jeff Spitler published the Radiant Time Series method that remains as the most accurate method for dynamic peak cooling load calculation method. The RTS method served as a foundation for the residential RHB and RLF methods developed in 2004 by Barnaby. Finally, in 2003 ASHRAE released its LOADS Toolkit, developed by Professor Curtis Pedersen, which included FORTRAN code for the heat balance method.

Today, all three methods (i.e., TETD/TA, CLTD/SCL/CLF, RTS) remain in use in the industry. However, only the RTS method is referenced in the ASHRAE Handbook.

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[16] More information are provided in ESL report #ESL-TR-12-12-02 available at http://esl.tamu.edu/terp/reports/2012

[17] To comply with the maximum page requirement by IBPSA conference, this reference section only lists primary references. The completed reference list can be found in ESL report #ESL-TR-12-12-02 by Energy Systems Laboratory.

Table 1 Summary of Events

Year	People/Author	Accomplishment	Significance	Notes
1824	Thomas Tredgold	● Published a book, "Principles of Warming and Ventilating Public Buildings, Dwelling Houses, Manufactories, Hospitals, hot Houses, Conservations".	● Laid the foundation for designing large public projects.	● Rolla Carpenter referenced Tredgold's book published in 1836.
1834	David Boswell Reid	● Redesigned heating and ventilating system for the British House of Commons. ● Used a chimney to induce air flow. ● Used water spray cooling and steam heating.	● One of the first successful applications of "fresh air" into a public space, with evaporative cooling and/or heating applied. ● Thermal mass not considered in the system design.	● Dr. Reid was a professor of chemistry.
1844	Eugéne Péclet	● Published the textbook "Traité De La Chaleur ".	● First introduce heat transfer calculations.	● Eugéne Péclet was a French physicist and heat engineer.
1855	Robert Briggs	● Designed and installed a heating and ventilation system for the U.S. House of Representatives. ● Used indirect steam heaters (i.e., underfloor radiators). ● Originally used a chimney, with a large fan added afterwards, and subterranean airways in each wing of the building.	● First large-scale building in the U.S. with specially desgined heating and ventilating system. ● Thermal mass not considered in the system design.	● Robert Briggs was a consulting engineer.
1884	Buffalo Forge Company	● Began manufacturing heating and ventilating equipment.	● Development of mechanical ventilation/air handling units.	● Buffalo Forge Company was formed in 1878.
	Frank E. Kidder	● Kidder's book was oriented towards architects. ● It contained information from manufacturers regarding the sizing of steam radiators.	● No quantitative methods were included to calculate heat gain/loss. ● Used generalized word equations and tabulated data. ● Thermal mass not considered in the system design.	● First edition was published in 1884.
1894	Hermann Rietschel	● Rietschel's book contained detailed information about dynamic heat calculations, heat loss calculations for walls, roofs, windows and ventilation, including tables of useful coefficients. ● Contained relatively complete information about heat transfer, sizing of steam systems, piping, etc.	● Recognized as Europe's first scientifically- based text on heating and ventilating. ● The book referenced heat transfer equations from 1860 "Heat and Its Application" by Peclet- Hartmann.	● Dr. Hermann Rietschel was professor of the Technical University of Berlin, Charlottenburg. ● 7th edition translated into English by C.W. Brabbee in 1927.
1894	Alfred Wolff	● Delivered a lecture before the Franklin Institute about his design accomplishments. ● Used "heat transfer coefficient" derived by Eugéne Péclet and Thomas Box. ● Coefficients included windows, doors, and walls/ceilings of varying thickness.	● Introduced heat transfer calculations from Rietschel into U.S. practice. ● Alfred Wolff was one of the first U.S. engineers to use "heat transfer Coefficients". ● Wolff's use of the parameter "varying thickness" was probably one of the first published indirect effects heat transfer.	● Alfred Wolff was a heating and ventilating engineer. ● He designed a number of buildings, such as the Cornelius Vanderbilt House, N.Y.C. (1879-1892), John Jacobs Astor House (1891-1895), Carnegie Music Hall (1893), etc.
1896	Rolla Carpenter	● Published his book, "*Heating and Ventilating Buildings*".	● Carpenter's book included theory and apparatus by Thomas Tredgold, Charles Hood and Eugéne Péclet.	● Rolla Carpenter was a professor at Cornell University.
1902	Willis Carrier	● Designed his first cooling coil air conditioning system for Sackett & Wihelms Co., in Brooklyn, N.Y. ● The system was not successful. ● Carrier researched why system failed during 1902-1903. Research on this system led eventually to his psychrometric formulas.	● Carrier determined that a spray-type air washer could be used to control temperature and humidity.	● Carrier started working for Buffalo Forge as an engineer in 1901.
1903	Alfred Wolff	● Designed mechanical system for New York Stock Exchange in 1901-1902. It was put in trail operation in summer of 1902. It was in full operation in 1903. ● System used 3-100 ton steam-driven absorption chillers. ● Used steam from on-site cogeneration system. ● System had 42 distribution boxes in the ornate ceiling provided cooling to the exchange floor. ● Similar to systems Wolff designed for Cornell Medical College (1899), Hanover Nat'l Bank (1903).	● Earliest large-scale commercial air conditioning system to be designed and operated for comfort. ● First co-generation air conditioning system. ● Thermal mass considered in the system design through tables of varying wall thickness.	●The system relied on information from Prof.Hermann Rietschel's 1893 "Guide to Calculating and Design of Ventilating and Heating Installations", Berlin Royal Institute of technology.
1904	United Iron Works Company	● Designed mechanical system for Missouri State building at the Louisiana Purchase Exposition. ● Building had 1,000 seat auditorium. ● System used 35,000 CFM cooled by direct expansion air conditioning.	● First demonstration of air conditioning to be experienced by large numbers of people. ● Thermal mass not considered in the system design.	● The actual designer of the comfor air-conditioning system of the Mussouri State Building has not been discovered.
	Charles Paulding	● Published his book, "Practical Law and Data on the Condensation of Steam Covered and Bare Pipes".	● Translated some of Eugéne Péclet's work into English.	● Translation of Péclet' "Theory and Experiments on the Transmission of Heat Through Insulation".
1905	Stuart Cramer	● First used the term of "air conditioning" for treating air in textile mills in North Carolina.	● First use of the term "air-conditioning".	● Stuart Cramer was an mill engineer.
1906	Willis Carrier	● Developed first working system to control temperature and humidity. ● Applied for a patent for an "apparatus for treating air".	● System allowed him to control humidity of the existing air stream.	● This system was one of the first to cool air and control humidity.
	Buffalo Forge Company	● Began selling spray air washers.	● First applied to industrial settings.	● Buffalo Forge Company was formed in 1878.
1908	Willis Carrier	● Published his psychrometric chart based on his psychrometric formulas.	● Thermal mass not integrated in the psychrometric formulas.	●Psychrometric chart was formally published in 1911 in ASME.
1914	Buffalo Forge Company	● Buffalo Forge engineer's handbook contained detailed heat loss calculations for walls, roofs, windows and ventilation, including tables of useful coefficients.	● Recognized as the first U.S. handbook for heating and ventilating. ● First use of Carrier's Psychrometric Charts in a handbook. ● Word equation were used to explain how to calculate heat gain/loss.	● Buffalo Forge Company was formed in 1878.
1918	John Allen, James Herbert Walker and F.E. Giesecke	● Published the textbook, "Heating and Ventilation". ● Covered heat loss calculation for buildings.	● Included equations, design methods and tables that could be used by engineer and architects.	● Fredrick Giesecke established Texas first formal program in architectural education at Texas A&M in 1905.
1922	ASHVE	● 1922 ASHVE Guide published. ● It contained articles from ASHVE Transactions and advertisements for HVAC products. ● Had General Data Section on "Heating". ● Basic heat loss formula shown as "word formulas".	● This was the first guide ASHVE published.	● ASHVE was established in 1894.
1925	André Nessi and Léon Nisolle	● Published the book, "Regimes Variables de Fonctionnement dans les Installations de Chauffage Central".	● Response factor method was first introduced for transient heat flow calculation.	● This book was published in French Only.
1928	Carrier Company	● Carrier Co. designed mechanical system for " Milam Building" built in San Antonio. ● Building was the tallest reinforced-concrete high-rise office building. ● 11 AHUs provided cooling, thermal storage tank (chilled water). ● Two chillers with a maximum 375-ton capacity provided chilled water, 562 ft^2/ton. ● Venetian blinds, cloth window shades, duct dampers were added to solve morning/afternoon overheating due to misunderstanding of thermal mass.	● The first high-rise office building in U.S. to be completely air-conditioning. ● Radiant heat was supposed to be absorbed by the heavy construction. However, the system did not work well due to the control problems caused by radiant heat. ● Design methods never published.	● The Milam Building was the 4th national Mechanical Engineering Heritage Site.
1932	ASRE	● Published their refrigerating data book. ● It contained fundamental data for refrigeration systems.	● This was the first guide ASRE published.	● ASRE was established in 1904.
	Houghten, F.C., Blackshaw, J.L., Pugh, E.M. & McDermott, P.	● The study was to determine the "sun's effect" of different types of roofs. ● Their research showed that large errors occurs when"periodic" effects of the "sun's effect" were not properly taken into account. ● Test roofs were instrumented with thermocouples to record temperatures using strip chart recorders. ● Data recorded on strip chart recorders and manual readings for later transcription.	● ASHRAE began to study the effects of solar radiation and heat gain through roofs and windows. Included thermal mass effects. ● Published paper included complete solution to the differential equation for heat transfer through the homogeneous roof elements.	● Houghton was the director of ASHVE's lab. ● Blackshaw was a research engineer at ASHVE. ● Pugh was Associate Professor at the Carnegie Institute of Technology, Pittsburgh. ● McDermott was a research engineer at ASHVE. ● The ASHVE Bureau of Research was established in January 1919 at the U.S. Bureau of Mines Laboratory in Pittsburgh.
1935	Faust, F.H., Levine, L.& Urban, F.O.	● Published tables of heat gain coefficients for selected surfaces at specific orientations at different latitudes. ● The tables published allowed for an improved cooling load calculations for surfaces at different orientations/latitudes.	● The published tables quantified the "sun effect" for use in cooling calculating.	● Faust and Urban were at General Electric, Co.
1937	Charles Merrick Gay & Charles De Van Fawcett	● Wrote textbook for building designers. ● Textbook contained fundamental theories for mechanical and electrical equipment for buildings.	● Contained detailed calculations for heat loss. ● Only had rough calculations for heat gain.	● C.M. Gay was associate director of the Franklin Institute, formerly professor of Architectural Construction in University of Pennsylvania. ● C.D.V. Fawcett was professor of Electrical Engineering in University of Pennsylvania.
1938	TRANE Company	● Published its first design manual, "TRANE Air-Conditioning Design Manual". ● Provided a load estimate sheet for engineers to use. ● Used tabulated solar temperature differences. ● Book included "Instructions for using the TRANE Air Conditioning Ruler-for use with the TRANE Psychrometric Chart".	● "Solar Temperature Difference" method first appeared. ● This method was developed by TRANE company. It used a series of tables for different colors of walls and roofs based on different latitudes. ● "Solar Temperature Differences" were used for excess solar heat gains calculation method indirectly accounted for thermal mass.	● "Solar Temperature Difference" method is not the same as "Sol- Air temperature" Method. ● TRANE Manuals published later in1955, 1977, 1996 continued to use same tables.
1939	Alford, J.S., Ryan, J.E. & Urban, F.O.	● Published a paper on heat storage/heat transfer through walls driven by temperature & solar intensity in the ASHVE transactions.	● Provided detailed solution to the differential equation in the form of a decrement factor and time delay. Method provided a way to calculate time varying heat transfer without solving differential equation.	●Alford, J.S. (Turbine Engineering), Ryan, J.E.(Engineering General Dept.) and Urban, F.O. (Air Conditioning Dept.) were at the General Electric Company.
1942	Victor Paschkis	● Published a paper, studying periodic heat flow in building walls	● Thermal network method later used to simulate building walls first appeared in this paper.	● Paschkis referenced the research report No.923 by Houghten *et al*.'s work published in 1932.

Table1. Summary of Events (Cont.)

Year	People/Author	Accomplishment	Significance	Notes
1944	Mackey, C.O. & Wright Jr, L.T.	● Published the paper "Periodic heat flow-homogeneous wall or roofs". ● Used a modified version of Alford *et al.* 's equations.	● Developed Sol-Air Temperature Method. ● Thermal mass effect could be calculated without solving a new differential equation for each wall type.	● Mackey. was a professor of Heat-Power Engineering at Cornell University. ● Wright originally was an instructor. At Cornell. He became an Assistant Professor shortly after.
	Linvill, J.G. & Hess Jr, J.J.	● Published article, "Studying Thermal Behavior of Houses".	● Thermal network method used for modeling a house first appeared.	● This was an undergraduate student project at MIT, published in 1944 Electronic magazine.
1948	Stewart, J.P.	● First to outline Total Equivalent Temperature Difference Method. ● Intended as a manual design method. ● Suitable for calculating extended hourly profile only if radiant components are averaged over the representative time for general mass of the building. ● Judging the amount of thermal mass in a building had to be done by the engineer, which made method hard to use.	● First introduction of Total Equivalent Temperature Method. ● Thermal mass included in the TETD table by varying wall types.	●Stewart was a design engineer at Carrier Corp.
1955	Gay, C.M., Fawcett, C.D.V., & McGuinness, W.J.	● This textbook thoroughly revised the procedure for designing air conditioning. ● Included the new Sol-Air Temperature Method by Mackey and Wright.	● The published tables included the decrement factor for selected materials. ● The published tables also included the equivalent temperature differentials for roofs, walls and dark/light surfaces.	● McGuinness was a professor of Architecture at Pratt Institute of Technology.
1956	Brisken, W.R. & Reque, S.G.	● Published heat load calculations using thermal response method. ● Based on 1925 Nessi and Nisolle.	● Proposed using "square waves" to represent time varying "curve" of temperature response. ● Foundation of Thermal Response Factor Method.	● Brisken (Manager-Advanced Engineering) and Reque (System Analysis Engineer) were at the commercial and industrial air conditioning dept. of General Electric Co.
1957	Hill, P.R.	● Published an improved method of computing the transient temperature of thick walls.	● Introduced the "unit triangle variation of surface temperature". ● Used the Thermal Response Factor Method.	●Hill was with National Advisory Committee for Aeronautics, NACA precursor to NASA.
1958	Buchberg, H.	●Developed a complete R/C thermal network for a house as part of ASHRAE research project. ●Model used Heat Balance Calculations.	● Introduced Thermal Network Method for a whole-house. ● Introduced the use of the Heat Balance Method. ●Thermal mass was represented by an electrical R/C network, solved by analog computer.	● Tamami Kusuda studied Buchberg's work to develop his heat balance calculation. ● Based on this method, Kusuda developed NBSLD.
1961	ASHRAE	● Published ASHRAE Guide and Data Book-Fundamentals and Equipment. ● Sol-Air Temperature Method was tabulated in it. ● As Total Equivalent Temperature Difference Method.	● ASHRAE published a fore-runner of ASHRAE handbook.	● ASRE and ASHAE merged to ASHRAE in 1958.
Mid-1960s	Ayres, J.M. & Stamper, E. (1995)	● Reviewed historical development of building energy calculations.	● Heating Degree-Day method, Equivalent Full Load Hours Method and Bin Method used in mid-1960s. ● Bin calculation can give errors if the building balance point temperature is not accurate, if there is significant thermal mass and if there are significant solar loads.	● Ayers and Stamper wrote paper reviewing those manual methods in 1995.
1962	James L. Threlkeld	● Published the book "Thermal Environmental Engineering".	● Contained Sol-Air Temperature Method to the calculations of heat transmission in buildings.	● Book became widely used by HVAC engineers.
1967	Mitalas, G.P., & Stephenson, D.G. Stephenson, D.G. & Mitalas, G.P.,	● Introduced a method that allowed for the solution to the dynamic heat transfer problem without knowledge of how to solve differential equations. ● Based on 1950s work done by Nessi and Nisolle, Brisken & Reque, Hill. ● Appeared later as part of the Weighting Factor method in ASHRAE Handbook. ● Used later for CLTD/CLF tables in the ASHRAE Handbook.	● Thermal Response Factor Method from previous work by Nessi and Nisolle, Brisken, Reque and Hill.	● Stephenson and Mitalas were research officers at the Building Sciences Section, Division of Building Research, NRC Canada.
1972	Mitalas, G.P.	● Published revised method for cooling load calculation. ● Later adopted in 1972 ASHRAE Handbook.	● Introduced revised Transfer Function Method.	● ASHRAE Task Group on Energy requirements (TGER) developed first computer-oriented method for solving dynamic heat transfer based on TFM.
1974	Rudoy, W. & Duran, F.	● Developed CLTD/CLF Method and published in ASHRAE Transactions. ● CLTD/CLF Method attempted to simplify the two step TFM and TETD/TA Method into a single-step technique. ●CLTD/CLF permitted hourly estimations of dynamic heat gain.	● Introduced CLTD/CLF Method which later replaced TETD/TA method.	● Original CLTD/CLF (GRP 158) method contained 36 roofs, 96 walls based on Transfer Function method,for 40 N latitude, July, 21st.
1977	ASHRAE	● 1977 ASHRAE Handbook adopted CLTD/CLF Method ● TFM, TETD/TA and CLTD/CLF are no longer published in the ASHRAE Handbook	● Updated CLTD/CLF Method for cooling load calculation in the ASHRAE Handbook. ● Thermal mass in CLTD tables as varying materials.	● First ASHRAE Handbook of Fundamentals was published in 1967.
1979	Cane, R.L.D.	● Corrected solar and thermal gains for residential heat pumps.	● Proposed Modified Bin Method.	● Annual energy calculations using Bin method appeared in 1981 ASHRAE Handbook of Fundamentals.
1983	Knebel, D.E.	● Published the book "Simplified Building Load Analysis Using the Modified Bin Method", as part of ASHRAE Research Project.	● Incorporated into Simplified Building Load Analysis.	● Knebel was principle investigator .
1993	Spitler, J.D., McQuiston, F.C., & Lindsey, K.L.	● Introduced the term "Solar Cooling Load-SCL". ● Updated the CLTD/CLF method to become CLTD/SCL/CLF Method.	● Introduced SCL term. ● Thermal mass is in CLTD tables. ● SCL improved solar load calculation.	● Modified by McQuiston & Harris again in 1988 to obtained compact CTFs. ● Finally modification by Spitler, McQuiston, Lindsey in 1993 to add SCL.
1994	McQuiston, F.C. & Parker, J.D.	● Published the textbook,"Heating, Ventilating, and Air Conditioning Analysis and Design".	● Has a chapter on "Cooling Load". ● Covers Transfer Function Method. ● Uses CLTD/SCL/CLF Method from 1993 ASHRAE Fundamentals.	● McQuiston was a professor of Mechanical and Aerospace Engineering at Oklahoma State University. ● Parker was a professor of Mechanical Engineering at Oklahoma Christian University.
1997	Spitler, J.D., Fisher, D.E., & Pedersen, C.O.	● Radiant Time Series Method was derived directly from Heat Balance Method. ● Developed in response to TC 4.1 research. ● Uses 24 response factors to give time series solution to transient, 1-D heat transfer. ● Converts radiant portion of hourly heat gain to hourly cooling loads using radiant time factors, which are the coefficients of the Radiant Time Series. ● Accuracy of RTS is similar to that of the TFM if custom weighting factors and custom conduction transfer function coefficients were used.	● First paper to propose Radiant Time Series Method. ● Uses predetermined zone response to account for thermal mass heat storage/release.	● Spitler was a professor of Mechanical and Aerospace Engineering at Oklahoma State University. ● Fisher was a professor of Mechanical and Aerospace Engineering at Oklahoma State University. ● Pedersen was a professor emeritus of Mechanical Engineering at the University of Illinois.
1998	Kuehn, T.H., Ramsey, J.W., & Threlkeld, J.L	● Published the textbook, "Thermal Environmental Engineering".	● Has section on "Instantaneous Cooling Load". ● Uses CLTDs from 1989 ASHRAE Fundamentals.	● Updated version of the 1962 original.
2000	Simon Rees, Jeffrey Spitler, Morris Davies and Philip Haves	● Provided a qualitative comparison of cooling load calculation methods in U.S. and U.K	● Focused on the methods after 1900s ● No textbook methods discussed.	● Rees was a research associate at Oklahoma State University. ● Spitler was a professor of Mechanical and Aerospace Engineering at Oklahoma State University. ● Davies was a reader with university of Livepool, England. ● Haves was the leader of the Commercial Building and Systems Group, Lawrence Berkeley National Laboratories.
2003	Curtis Pedersen, Richard Liesen, Daniel Fisher and Richard Strand	● Develop ASHRAE LOADS Toolkit for building load calculation.	● Provided FORTRAN procedures for heat balance calculations.	● Pedersen was a professor emeritus of Mechanical Engineering at the University of Illinois. ● Liesen was an associate director at Building System Lab at the University of Illinois. ● Strand was an assistant professor at the University of Illinois. ● Fisher was a professor of Mechanical and Aerospace Engineering at Oklahoma State University.
2004	Barnaby, C.S., Spitler, J.D. & Xiao, D.	● Proposed two methods for residential calculations of dynamic cooling load calculations. ● Adopted by 2005 ASHRAE Handbook.	●Introduced the Residential Heat Balance method (RHB). ●Introduced the Residential Load Factor method (RLF). ●RHB and RLF based on RTS method.	● Barnaby was with Wrightsoft Corporation,Lexington, Massachusetts. ● Spitler was a professor of Mechanical and Aerospace Engineering at Oklahoma State University. ● Xiao was a graduate student in the School of Mechanical and Aerospace Engineering, Oklahoma State University.
2005	McQuiston, F.C., Parker, J.D., & Spitler, J.D.	● Published the textbook:Heating, Ventilating, and Air Conditioning Analysis and Design (6th edition).	● Contains detailed discussion of Heat Balance method and Radiant Time Series method.	● McQuiston was a professor emeritus of Mechanical and Aerospace Engineering at Oklahoma State University. ● Parker was a professor emeritus of Mechanical Engineering at Oklahoma Christian University. ● Spitler was a professor of Mechanical and Aerospace Engineering at Oklahoma State University.
2009	ASHRAE	● Published 2009 ASHRAE Handbook.	● 2009 ASHRAE Handbook covers RTS Method. ● Contains only a brief description of TFM, TETD/TA, CLTD/CLF Methods.	● ASHRAE Handbook of Fundamentals published in 1967, 1972, 1981, 1985, 1989, 1993, 1997, 2001, 2005, 2009. ● Chapters covering peak heating and cooling methods have changed significantly over the years.
2010	Grondzik, W.T., Kwok, A.G., Stein, B., & Reynold, J.S.	● Published the textbook: Mechanical and Electrical Equipment for Buildings (11 edition).	● Latest edition of textbook first published by Gay and Fawcett ● Contains approximate method for calculating heat gain (cooling load). ● Uses DETD, DCLF tables from 1981 and 1997 ASHRAE Handbook of Fundamentals.	● Grondzik was a professor of Architectural engineering at Ball State University. ● Kwok was a professor of Architecture at University of Oregon. ● Stein was a Consulting Architecture Engineer. ● Reynolds was a professor of Architecture at University of Oregon.