Chiller seasonal energy consumption in historical buildings

ARTŪRS BRAHMANIS
Lafivents LTD
Riga, Latvia
Arturs.Brahmanis@rtu.lv

EGĪLS DZELZĪTIS
Institute of Heat
Gas and Water technology
Faculty of Civil Engineering
Riga Technical University

ARTURS LEŠINSKIS
Institute of Heat
Gas and Water technology
Faculty of Civil Engineering
Riga Technical University

A plenty of studies are devoted to estimation methods of seasonal energy consumption of cooling equipment. Several computing instrument give the ability to calculate or simulate chiller's electricity consumption at variable conditions. Using European Seasonal energy efficiency ratio (ESEER), provided by equipment suppliers, engineers and project developers can make fast and rather rough calculations on annual cost in order to determine the economic feasibility for choosing the particular type of cooling equipment. And the question is, how precise those calculations could be for temperate and northern climates?

As a part of the research on evaporative cooling appliance in temperate climate of Baltic States, conducted in Latvia in 2011–2014 [1], an analytical research made in recently restored 19th century historical building, The Art Museum Riga Bourse.

Restoration of old buildings is a complex construction process, in which engineers and architects need to solve many atypical tasks concerning not only the structural stability of the building, but also the recovery of cultural—historical appearance of the building. Necessity of harmonious integration of modern HVAC devices in the historical interior also enforces limits to the equipment selection. The successful solving these and construction tasks results in a balanced and sustainable restoration of the building.

Figure 1. The Riga Bourse building in 19th century and nowadays after reconstruction.

The analytical research overtakes the results of water cooling system operation for one year cooling period. The data of electricity and water consumption, chiller operation modes and cooling system temperature data were logged with one-minute interval. The duration of analysis period was chosen, based on the building cooling demand. The data obtained were converted to average hour values after the analysis of errors. The calculated cooling output depending on the outdoor air (OA) temperature is displayed on **Figure 2**.

The information on equipment efficiency that is necessary for seasonal energy consumption calculations is limited. Usually, energy efficiency ratio and the seasonal efficiency of the device are available. The industry has implemented ESEER (European Seasonal Efficiency Ratio), recently published regulations or those in the process of being published talk about seasonal coefficient of performance (SCOP) in heating mode, and its equivalents SEER and SEPR in cooling mode. Seasonal energy efficiency, in accordance with EN14511:3 – 2013 and [2] is calculated according to the Equation (1) explained below:

$$ESEER = A \times EER_A + B \times EER_B + C \times EER_C + D \times EER_D, \quad (1)$$

Where:

EER = ratio of the total cooling capacity to the effective power input of the unit, Watt/Watt.

In authors' opinion ESEER introduction to the market was a great achievement within the equipment assessment principles, which is likely to reflect accurately the effectiveness of Central Europe or the Mediterranean part of Europe. On the other hand, when in Latvian climate conditions the building cooling load is traditionally calculated using an outdoor air temperature of +27°C (Riga), ESEER test parameters are quite distant from the real situation. Practice shows that the cooling demand in many objects occurs at much lower outdoor temperatures such as +15°C or even +10°C. Such objects may include: office premises with large amount of office equipment, facilities with high human density, retail spaces with great light intensity, and rooms with large windows surfaces and no shadows. The location of ventilation diffusers does not always provide cooling in the most comfortable way such as displacements ventilation, for people in the premises. In those cases the air cooling is carried out with chillers and the room terminal units like chilled beams or fan-coils. Sonderegger (1998), based on a number of energy efficiency project analysis pointed to a large inaccuracies in heating / cooling system energy savings estimates, if they are performed only based on the weather data [3].

The values of cooling energy produced at a certain temperature ranges with a step of 2.0°C are presented

Table 1. ESEER components description.

Conditions	Load ratio, %	Weighing coefficient	Air temperature at condenser inlet (air cooled chillers), °C	Water temperature at condenser inlet (water cooled chillers), °C
A	100	0.03	35	30
B	75	0.33	30	26
C	50	0.41	25	22
D	25	0.23	20	18

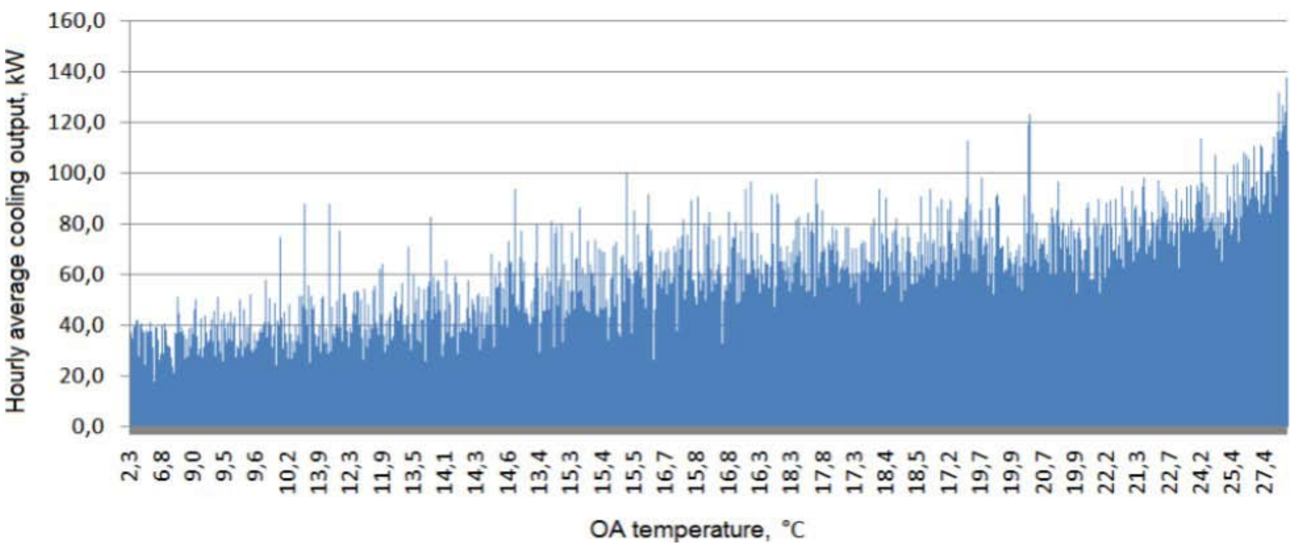

Figure 2. The calculated cooling output depending on the outdoor air (OA) temperature.

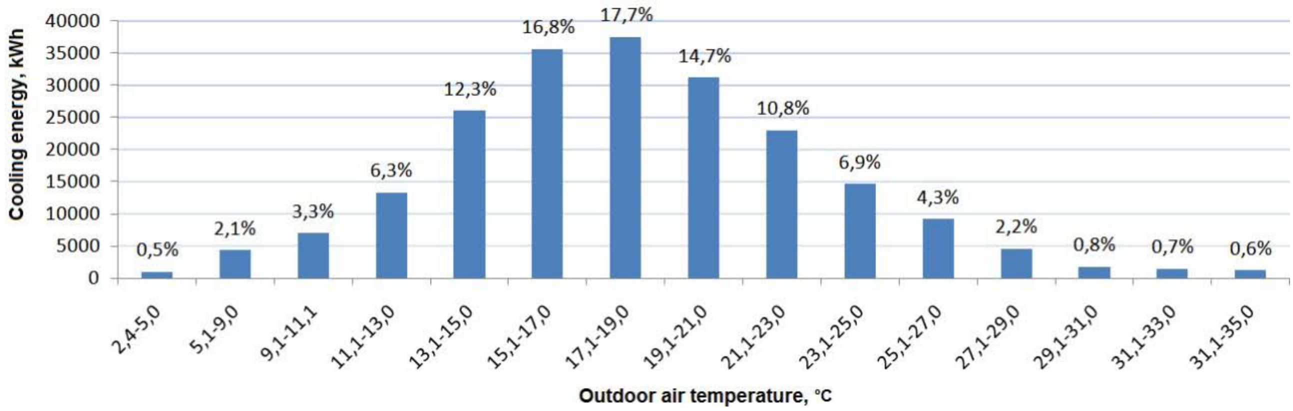

Figure 3. Cooling energy produced at outdoor air temperature diapasons.

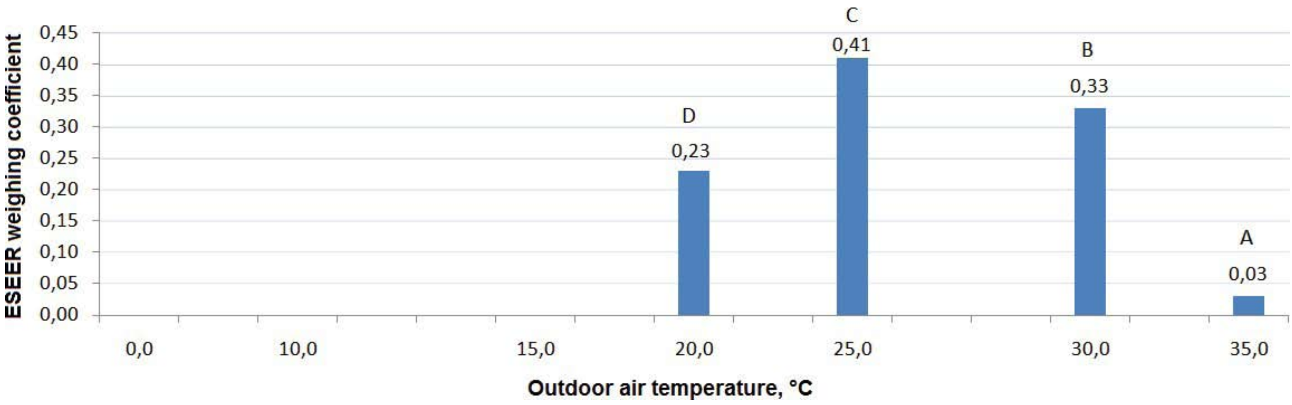

Figure 4. ESEER impact factors at the same outdoor (condenser inlet) temperature distribution for comparison.

in **Figure 3**. The vast majority or about 67% of cooling energy during the cooling period was produced when the outside temperature was in the range from 10 to 20°C. According to the generally accepted practice, the cooling is required when ϑ_{OA} is higher than 18–19°C, (which is also generally accepted base temperature for cooling degree-hour calculation). Within the particular building non-weather dependent cooling accounts for more than half of the total annual cooling energy. This characterizes the objects with high heat gains, and / or high microclimate requirements.

ESEER impact factors at the same outdoor (condenser inlet) temperature distribution for comparison are shown in **Figure 4**.

The acquired data in art museum showed cooling system showed significant difference on cooling energy produced on site and ESEER weighing methodology. Due to that, the more precise coefficient distribution method is offered. The calculation principle can be expressed as follows:

$$Q_{el.seas.} = \sum \Delta\vartheta_n \left(\frac{Q_{c.nom.}}{EER_{\Delta T_n}} \cdot DS_{\Delta\vartheta_n} GS_{\Delta T_n} \right) + Q_{el.st.} \qquad (2)$$

Where:

$Q_{el.seas.}$ = electricity consumption during cooling season, kWh

$\Delta\vartheta_n$ = outdoor air temperature interval

$Q_{c.nom.}$ = nominal cooling load of the device in standard conditions, kW

EER = energy efficiency ratio at a given interval

CL = cooling load at a given temperature interval, % or part of 1, from nominal device capacity

GS = the number of cooling degree hours at a given temperature interval, h

$Q_{el.st.}$ = standby electricity consumption, kWh

Using the proportional distribution method, seasonal energy consumption calculations are performed for combined compression cycle – evaporative chiller (KKCD). For comparison, one calculation is done for close to the ESEER temperature / load intervals. Cooling degree hours (CDH) was taken, using Latvian Typical Meteorological year data in temperature diapason ±2°C. We can see that it overtakes outdoor air temperatures from 18 to 37°C and the total electric energy consumed is 24 128 kWh for the chiller with maximum cooling capacity 320 kW (**Table 2**):

However, the actual yearly electricity consumption of the chiller, logged by electricity meters is 62 000 kWh. Using the above mentioned formula (2), proportional method calculation has been performed for 7 outdoor temperature / load intervals. EER data which was out of ESEER conditions was executed from laboratory experiments on the similar chiller. The portion of cooling energy at ϑ_{OA} less than 10°C, which was produced at the investigated site during the cooling season accounted for 5.9% of the total energy produced. This part of the calculation is added to the calculation due to the equipment operating efficiency drawbacks within this range (**Table 3**).

The results showed much higher precision when using 7 interval proportional methods for the investigated building. It could be proposed to extend the ESEER part load test methods to wider TOA and cooling load ranges. Surely, further investigations on real cooling load should be made in different types of buildings to increase the amount of trustable data. These factors could help to increase the accuracy of economic and energy consumption calculations, taking into consideration peculiarities of various object types and conditions of northern climate. ■

Table 2. Seasonal energy calculation using ESEER values and summarized CDH.

Condition	ϑ_{OA} interval, °C	CDH	Load ratio, %	KKCD EER	Yearly electrical energy consumption, kWh
A	33 – 37	2	100%	3,6	178
B	28 – 32	24	75%	4,2	1 371
C	23 – 27	288	50%	5,1	9 035
D	18 – 22	965	25%	5,7	13 544
				Total	**24 128**

Table 3. Seasonal energy calculation using 7 intervals with summarized CDH.

ϑ_{OA} interval, °C	CDH	Load ratio, %	KKCD EER	Yearly electrical energy consumption, kWh
27 – 33	49	90%	4,2	3 360
24 – 26	150	75%	5,1	7 059
20 – 23	580	50%	5,7	16 281
17 – 19	804	30%	6,0	12 864
14 – 16	964	15%	6,3	7 345
10 – 13	1 276	10%	7,0	5 833
0 – 10	5,9% of the overall kWh consumed			3 112
			Total	**55 853**

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