RIGA TECHNICAL UNIVERSITY

Artūrs BRAHMANIS

INDIRECT EVAPORATIVE COOLING IN AIR CONDITIONING SYSTEMS

Summary of the Doctoral Thesis

Riga 2014

RIGA TECHNICAL UNIVERSITY
Faculty of Civil Engineering
Institute of Heat, Gas and Water Technology

Artūrs BRAHMANIS
Doctoral candidate in „Heat, Gas and Water Technology" study program

INDIRECT EVAPORATIVE COOLING IN AIR CONDITIONING SYSTEMS

Summary of the Doctoral Thesis

Scientific advisor
Dr.sc. ing., professor
Arturs LEŠINSKIS

Riga 2014

Brahmanis A. Indirect evaporative cooling in air conditioning systems. Summary of the Doctoral Thesis – R.: RTU Press, 2014. – 20 p.

Printed according to resolution of the HGWT institute, 16th October, 2014. Protocol No. 9/1

Šis darbs izstrādāts ar Eiropas Sociālā fonda atbalstu projektā «Atbalsts RTU doktora studiju īstenošanai».

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University».

Эта работа выполнена при содействии Европейского социального фонда в рамках проекта «Поддержка развития докторантуры РТУ».

ISBN …….

DOCTORAL THESIS
PROMOTED FOR AWARD OF DOCTORAL DEGREE IN ENGINEERING SCIENCE AT RIGA TECHNICAL UNIVERSITY

Dissertation for the doctoral degree in engineering sciences will be publicly defended on 24th November 2014, at 15:00, at the Faculty of Civil Engineering at Riga Technical University, Āzenes str. 16/20, lecture room No. 250.

OFFICIAL OPPONENTS:

Dr.sc.ing., prof. Anatolijs Borodiņecs
Riga Technical university

Dr.sc.ing., Gaļina Kaškarova
Institute of Physical Energetics

Dr.habil.sc.ing., prof. Uldis Iljins
Latvia University of Agriculture

CONFIRMATION

I hereby confirm that I have developed this thesis, submitted to Riga Technical University for obtaining for the doctoral degree. This thesis has not been submitted to any other university to obtain the scientific degree.

Artūrs Brahmanis …………………………….(Signature)

Date: ....

The doctoral thesis is written in Latvian, contains an introduction, four chapters, conclusions, bibliography, 62 figures and illustrations, 119 pages together. The bibliography contains 112 references.

CONTENTS

INTRODUCTION

The energy consumption of cooling systems comprises a significant part of the total energy consumption in residential and public buildings.

According to the study published in 2009 that was carried out by the European Commission in 27 European Union member states, cooling in ventilation and air conditioning systems consumes 21TWh of electricity which comprises approximately 11% of total electricity consumption in these countries. The electricity consumption in buildings constitutes 30-40% of total electricity consumption in European countries where ventilation and air conditioning (HVAC) segment constitutes 19% of the total energy consumption.

One of the methods of reducing the energy consumption in air-conditioning process is application of evaporative water cooling where during constant enthalpy process evaporating water cools the heat exchange surface.

Historically, this cooling method has been widely applied in hot and dry areas where in conditions of low air humidity water evaporation brings the highest cooling efficiency. However, alongside with the development of air conditioning sector and the growing popularity of “high temperature” cooling, this cooling method is becoming more appealing to be used in more humid temperate climate conditions. Because of the insignificant difference in dry and humid thermometer temperature, the evaporative cooling separately, in a “pure” way, cannot provide comfortable environment during the whole cooling season. Therefore in HVAC systems, used all around the world, the application of combined compression cycle and evaporative coolers becomes more common. For example, spraying water on the surface of freon condenser significantly (by 10-15%) increases the efficiency of the cooler.

In HVAC systems of Latvian construction sector cooling is not being frequently used. This may be explained by the sceptical attitude of the designers and other sphere specialists as well as greater capital investments which are necessary for purchasing such devices.

The goal of the thesis is to establish the technical and economic aspects of indirect evaporative cooling system application in temperate Latvian climate evaluating the possibilities of reducing the energy consumption.

The following research objectives have been brought forward:

1. To evaluate the existing calculation methods, develop methodology for seasonal energy consumption and economic calculation; to perform calculations for application of indirect evaporative water cooling system (KKCD) combined with compression cycle, in comparison with other cooling principles.

2. To verify the indirect evaporative cooling (IEC) method in action in experimental object during the cooling season.

3. To identify the correlation between IEC efficiency and outdoor humidity by using the data obtained in the research object.

4. To evaluate the availability of the useful temperature of water that has been cooled with the IEC method (coolant supply temperature, which can be applied in the cooling system) in laboratory conditions.

The scientific novelty of the paper: the development of methodology for calculating the seasonal energy consumption in coolers based on the proportional power and energy efficiency ratio (EER) distribution according to a typical meteorological year. The methodology is approbated in calculations of energy consumption in cooling systems for the existing historical building in Latvian climate.

The practical significance of the thesis: in order to increase the accuracy of economic and energy consumption calculations, it has been proposed to make changes in the European standard 14511:3-2007 which defines the procedure of seasonal efficiency for ESEER, taking into consideration the peculiarities of different objects and conditions of cooler climate. Technical and economic indicators have been established for application of evaporative cooling. The proposed evaluation of seasonal energy consumption methodology may be implemented in calculations of other historical reconstructed buildings.

The results of the research are intended for energy efficiency improvement in air conditioning systems applying the principles of indirect evaporative cooling. They can be used by HVAC designers, architects and developers for evaluation of sustainable solutions in engineering systems.

The results of the research have been announced in 6 full-text publications in international issues and 5 international conferences.

1. THEORETICAL BASIS OF EVAPORATIVE COOLING

1.1. Previous studies

In scientific data bases, several articles on researches regarding direct and indirect evaporative cooling processes can be found.

In their research in 2000, J. Facao and A. Oliveira tested in laboratory conditions at that moment new compact cooling tower which was creating specifically for HVAC systems with cooled ceiling. The authors compared the results of experiment with calculations after three different heat exchange models.

The results of an analytical research, carried out by B. Costelloe and D. Finn in 2002, demonstrated a great potential for using evaporative water cooling in temperate European climate conditions in latitude from Dublin to Milan. Evaporative cooling research has been also carried out by scholars: K.T. Chan, E. Dzelzītis, T. Gaiani, A. Hasan, W.A. Kals, O. Kokorin, D. Kona, A. Krēsliņš, E. Manus, R. Mizushina, J. R. Watt, F.W. Yu, etc.

1.2. Description of physical processes in indirect evaporative cooling system

Indirect evaporative cooling process which takes place in the device can be divided in three stages:

1.heat exchange between primary and secondary circuit with liquid-liquid type heat exchanger;

2.heat exchange between secondary circuit and outdoors air through air-water type heat exchanger;

3.direct outdoors air evaporative cooling with water evaporation-recirculation circuit.

Elementary heat and mass exchange node in evaporative heat exchanger is shown in figure Figure 1.1.

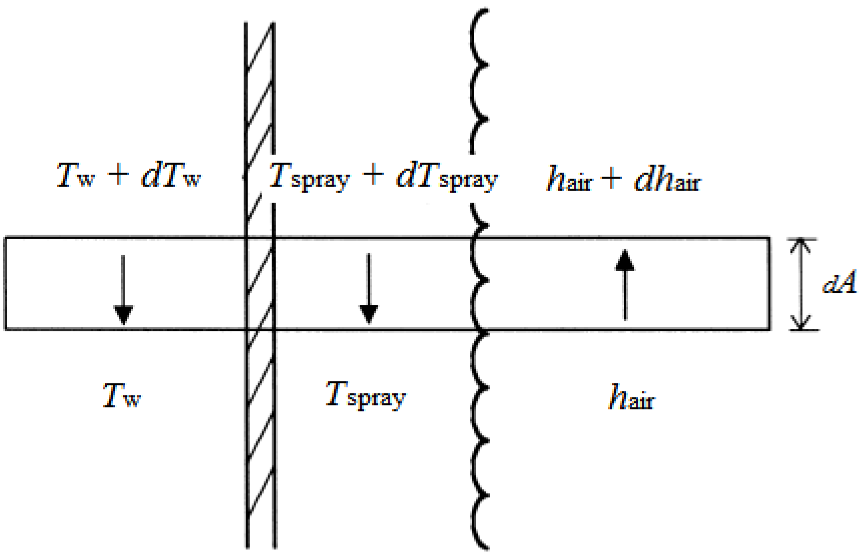

Figure 1.1. Simplified evaporative heat and mass transfer surface

Simultaneous heat and mass transfer in the case of heat flow can be calculated using the enthalpy potential:

$$q = \alpha_m (h_i - h_g), \quad (1.1)$$

where:
α_m – is the mass transfer coefficient for water vapour,
h_g – air enthalpy
h_i – enthalpy at water film/air interface

An enthalpy balance, for an elementary transfer surface dA, can be expressed as:

$$m_g dh_g = \alpha_m \left(h_i - h_g\right) dA. \quad (1.2)$$

Chiller cooling capacity can be calculated using equation:

$$Q = g \rho c_{cw} (T_{in} - T_{out}), \quad (1.3)$$

where:
Q – cooling output, kW
g – cooling fluid flow, m^3/s
ρ – cooling fluid density, kg/m3
c_{cw} – cooling fluid specific heat, kJ/(kg·°C)
T_{in}, T_{out} – return and supply flow temperatures, °C

The cooling efficiency of equipment according to the energy balance equations are:

$$EER = \frac{Cooling\ \ power}{Electrical\ \ input\ \ power}. \quad (1.4)$$

Indirect evaporative cooling thermal efficiency ε_{ie}, is highly dependent on the process air wet bulb temperature. ε_{ni} is defined as:

$$\varepsilon_{ie} = 100 \frac{T_{in} - T_{out}}{T_{in} - t_s}, \quad (1.5)$$

where:
ε_{ie} – indirect evaporative cooling thermal efficiency, %
T_{in} –cooling fluid return temperature, °C
T_{out} –cooling fluid supply temperature, °C
t_s –intake air wet bulb temperature, °C.

Water consumption for evaporative cooling process, knowing the intake air and exhaust air parameters recalculated according to the equation:

$$m_{\mathrm{w}} = m_{air} (x_2 - x_1) 1000 \quad (1.6)$$

where:
m_w – water consumption, kg/h
m_{air} – air mass flow, kg/h
x_2, x_1 – Working air moisture content of the process end and beginning, respectively.

2. EXPERIMENTAL STUDIES OF EVAPORATIVE COOLING

2.1. Experiment plan

One of the goals of this thesis is to evaluate the economic aspects of indirect evaporative cooling application in Latvian climate. The information on device efficiency that is necessary for seasonal energy consumption calculations is very limited. Usually, EER of the device is available and the data of seasonal efficiency (ESEER) which are obtained during testing procedures according to the corresponding standards.

Laboratory experiment plan

The deficiency of technical information available causes difficulties in calculating seasonal energy. Consequently, it is necessary to carry out the research in laboratory conditions, bringing forward following objectives:

1. Data obtaining of the effectiveness of combined evaporative cooling–compression cycle device outside the technical printout range.
2. The evaluation of useful cooled water temperature availability using the evaporative cooling. Namely, at which outdoor air conditions it is possible to obtain water to be used in the cooling process;
3. The influence of water spraying in the heat exchanger air-water to the cooling process.

Research plan in experimental object

The next factor that needs to be considered is the amount of energy produced in the cooler at outdoor temperatures.

It is closely related to the heat-technical qualities of the segregating construction in the building, where the system is located, as well as the heat production intensity and building inertia.

In case of evaporative cooling, it is necessary to specify the influence of outdoor air humidity on the process efficiency. It is necessary to carry out analytical research in the experimental object which is equipped with operating indirect evaporative cooling system, putting forward following objections:

1. distribution of cooling energy after determination of outdoor air temperature in the cooling season perspective;
2. the influence of outdoor humidity on the combined cooling process efficiency in the long-term period.

2.2. Research methodology

As the object of experiment for this thesis, the historic Riga Bourse building which has been renovated in 2011 and where there currently is the Art Museum Riga Bourse. The analytical research gathers the results of evaporative water cooling system operation from August 2011 to October 2012. The data of electricity and water consumption, cooler operation and cooling system temperature data were gathered with one-minute interval. The duration of analysis periods was chosen, based on the building cooling demand. The data obtained were converted to approximate hour values after the analysis of errors. For this research, the data from outdoor air collector was used which is located about 400–600 m from the experiment object.

In the operation period in 2011 after the analysis of outdoor air parameters, the last week of August was selected as the hottest period in the cooling season. The most frequently observed temperature (within 1038 minutes) was detected, using the *Pivot* functions of *MS Excel* program, which constituted a range from 21.5 °C to 22.5 °C. Assuming that the accuracy of outdoor air temperature was constant with a precision of 22±0.5 °C, a graphic representation was performed in order to indicate the correlation between outdoor air humidity x and cooler efficiency.

In the analytical study of cooling season in 2012, the data on 8 month long system operation with the outdoor air temperature range from 11 to 34 °C were selected with 7 temperature value intervals with a step of 2 °C. The temperature values in these intervals were considered to be constant, and used to detect the further EER–x empirical correlation.

The laboratory research has been carried out in the energy efficiency laboratory of HGWTI in Riga Technical University Faculty of Civil Engineering. The research was carried out, using indirect evaporative water cooling laboratory equipment and systems in different modes:

1. without cooling load and without water spraying (dry cooling mode) in order to indicate the lower possible cooling water supply temperature;
2. without cooling load, running the water spray in intake air („wet" cooling tower mode);
3. with variable cooling load provided by the electric heater, without water spraying;
4. with variable cooling load, using water spraying in intake air.

In the research, data from data gatherers available in the laboratory have been used as well as data obtained using visualization instrument *BACnet/COSMOweb*. The outdoor air temperature has been measured with the assistance of the combined humidity/air temperature provider *PRODUAL*. Exhaust air parameter measurements have been performed separately, using thermo-hygrometer *Testo 605-H1* and multifunctional anemometer *TESTO 435-4*. For water temperature control measurements on pipes, a contact thermometer with *Ni Cr-Ni* thermo–couple was used, connectable to the multifunctional anemometer. Exhaust air parameter measurements were performed through the openings of the air duct, 3 m from the device (Figure 2.1.).

Figure 2.1. Measurement of experimental unit exhaust air parameters

The data obtained during the measurements have been processed in *EXCEL* and used in the analytical research after the evaluation of the errors.

2.3. Laboratory research

In order to evaluate the combined Freon cycle - indirect evaporative water cooling equipment operating efficiency in wider outdoor air temperature range, a series of experiments was carried out in laboratory. The studies have been conducted in Riga Technical University, Faculty of Civil Engineering HGWT energy efficiency laboratory. Experiments were carried out in two stages:

- during the summer period when operating the device at a constant simulated cold consumption;
- during the autumn period, when the device was operated at simulated variable cooling loads.

Laboratory equipment data are described in table 2.1:

Table 2.1.

Technical specifications of laboratory equipment

Nominal intake air flow, m^3/s	1,22	El. power of the pumps in adiabatic loop, kW	2·0.64
El. power consumed by the ventilator, kW	2.13	El. power of secondary loop free cooling pump, kW	0.44
Water–water heat exchanger type	Aluminium plates	El. power of secondary loop condenser pump, kW	0.44
Water flow to the system, kg/s	0.83	El. power of compressor, kW	17.9

Laboratory device is equipped with a plate evaporation heat exchanger water-air with water spray nozzles on air intake side. The heat exchanger is a double element, the work air passes moistened by the cooling water flow crosses twice in a cross-flow direction. The plates are made of polypropylene, and they are ribbed on the water side, creating a square cross-section water channels (Figure Figure 2.2).

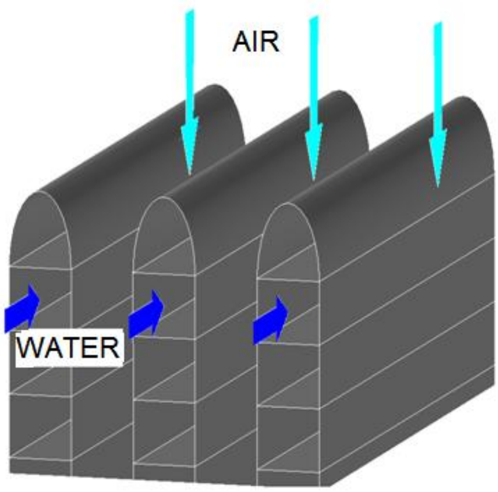

Figure 2.2. The diagram of laboratory device air-water evaporative heat exchanger

The heat load for the device was provided by the electric flow water heater with a nominal electrical capacity of 24 kW. To ensure the consumption, the existing hydraulic circuit was modified by looping the cooling and heating circuits.

The key components of cooling devices are: water-to-air heat exchanger with water spray nozzles, circulation pumps, water-to-water and water-Freon heat exchangers, centrifugal ventilator with frequency converter, air condenser and compressor. The laboratory device (diagram shown in Figure 2.4) is equipped with a water-to-air heat exchanger (8) which cools the adiabatic secondary loop with adiabatically cooled outdoor air. Outdoor air is moved with the help of a centrifugal ventilator (5), evaporative cooling is provided with water supply nozzles (9). Freon–air (1) and freon-water (2.2) heat exchangers utilize the heat produced in the compressor (4). Compression cycle heat is transferred from the primary loop evaporator (2.1) to the condenser.

Cooler performance studies in autumn outdoor air conditions suggest that the transition from dry to wet cooling tower operating mode, the cooling capacity, as well as the overall efficiency EER remains practically unchanged. In this stage of the research, the capacity in stable stages in both modes reached 29.7kW, with minor variations, and EER from 15.0 to 18.0. Significant EER changes were observed at the mode turnover due to the differences in supply and return temperatures. Switching on the water spray, the thermal cooling efficiency ε_{ni} increases significantly – from 30.0 to 45.0%, which is 50%, switching off – falls from 30.0 to 20.5%, equal to 30%. Duration of both deviations is approximately 60 minutes (Figure 2.3).

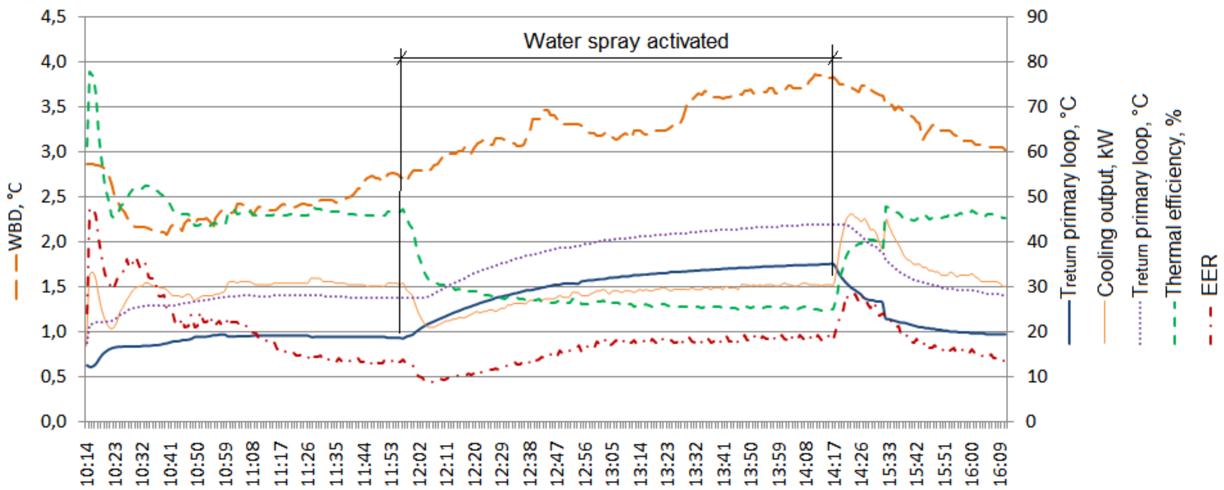

Figure 2.3. Experimental system $T_{supply.}$,T_{return}, cooling load, WBD, EER and thermal efficiency; 31 Oct, 2013.

Cooling T_{supply} and T_{return}, unlike the EER at different modes, varies considerably maintaining the same difference ΔT = 9.0 °C. In dry cooler mode the average T_{supply} = 34.0 °C, in wet cooling tower mode T_{supply} = 19.5 °C. This is important in terms of application, because temperatures higher than +22 °C virtually cannot be no used in building cooling systems, but up to 20 °C can be used in high-temperature systems, such as chilled ceilings.

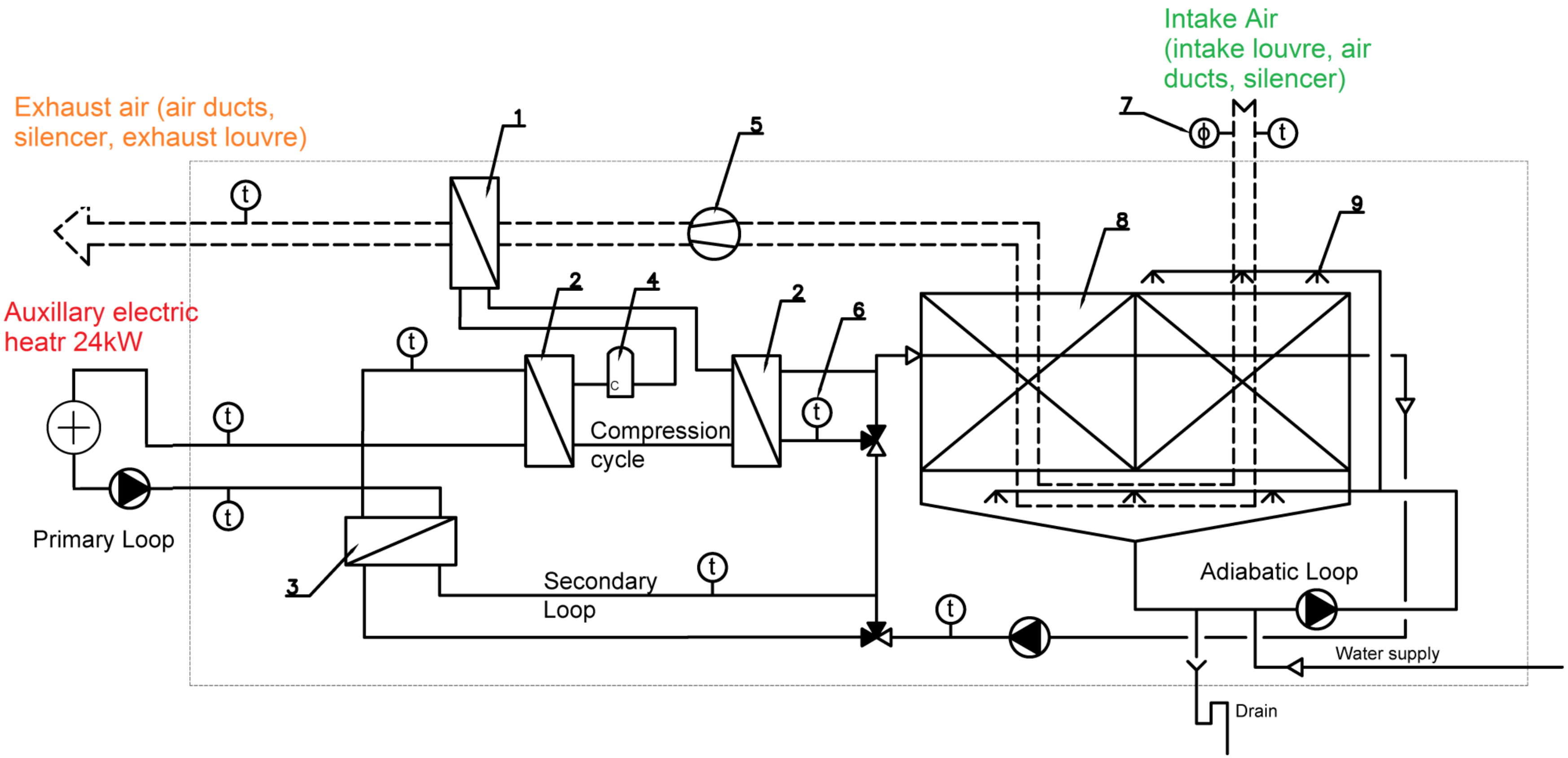

Figure 2.4. IEC – vapour compression combined system, where:

1 – freon–air heat exchanger;
2.1 and 2.2 – freon–water heat exchanger;
3 – water-water heat exchanger;
4 – compressor;
5 –centrifugal fan;
6 – temperature sensor;
7 – air humidity sensor;
8 – air-water heat exchanger;
9 – water spray nozzles.

2.4. Research in the experimental site

To determine the distribution of cooling energy in the existing facility depending on the outdoor temperature during the cooling season, several studies have been carried out in experimental facility. As the object for experiment of this research, a recently renovated Riga Bourse building has been selected; it was built in 19th century and re-opened in 2011, and is currently the Art Museum Riga Bourse (Figure 2.5). The analytic research gathers the results of evaporative water cooling system operation from August 2011 to October 2012. By using the aforementioned methods, three analytical studies have been carried out for three different periods.

Figure 2.5. Indirect evaporation cooler in experimental object Art Museum Riga Bourse

Assuming that the outdoor air temperature range is constant with an accuracy of 22±0.5 °C, a graphical visualization was carried out in order to detect the connection between air humidity content and cooler efficiency. Approximation of the data points to a very flat direct connection between outdoor air humidity and device efficiency, and this connection can be expressed by the equation $y = 0{,}0002x + 1.2024$, where y = the average 5–minute *EER*, x - outdoor air moisture content g/kg, which is filtered in ascending order. The research results on the experimental object cooling system in 2011, in the period of two and a half months starting from the system launching, shows a very weak direct connection between outdoor air humidity content and cooler efficiency. After analyzing this phenomenon, we have come to the conclusion that the device evaporative cooling function was not adjusted in the beginning, and the cold capacity was secured with the help of built-in compressors. With the increase of air humidity content, at the same temperature, the density of the air increases as well, thus increasing the heat capacity of air, which contributes to the increase of Freon-air effectiveness eventually the efficiency of all the equipment.

In experimental object cooling system study in 2012, the data regarding 8 month long system operation period was gathered. 7 temperature value intervals were chosen for outdoor air temperature range from 11 °C to 34 °C with a step of 2 °C. The temperature values in these intervals were considered to be constant, and used to detect the further *EER*–*x* empirical correlation (Figure Figure 2.6).

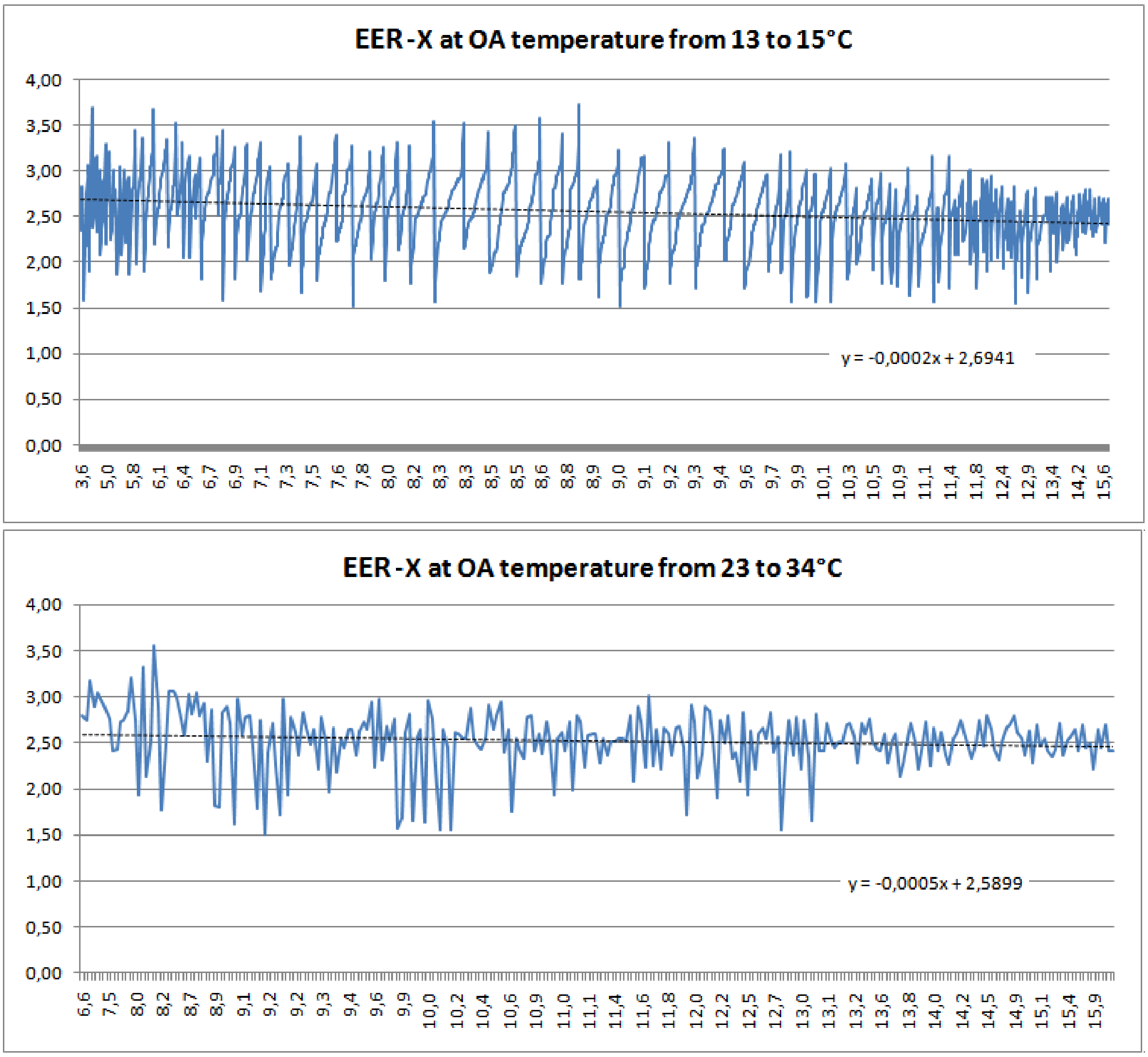

Figure 2.6. *EER (y)* and OA moisture content (*x*, g/kg) within temperature ranges 11..13 °C and 23..34 °C

At lower outdoor temperatures, EER-x correlation is more obvious than at higher temperatures. Temperatures in the range from 13 to 15 °C were registered in 1434 hours, and the humidity content increased from 3.6 g/kg to 15.6 g/kg, EER reduced by 10.0%. On the other hand, *EER–x* correlation in outdoor air temperature range from 23 °C shows that the average cooler *EER* is quite independent from the outdoor air humidity. Outdoor air heat capacity c_p and humidity content is proportionally straight connected. So it can be concluded that the highest, above 24 °C outdoor temperature range, the evaporative cooling efficiency drop due to the high humidity level is compensated with the increase of freon-air heat exchanger efficiency.

3. CALCULATIONS OF ENERGY CONSUMPTION AND ECONOMY IN COOLING SYSTEMS

3.1. Evaluation of seasonal operation efficiency

In the thesis, there is a comparison of various water cooler types provided; the schematic algorithm of cooler payback calculation is developed. Different Latvian climate data models have been analyzed. Because of its accuracy and data arrangement, the typical Riga meteorological year model, developed by M. Zariņš in the Latvia University of Agriculture; this model has been used in seasonal energy consumption calculations. A combined evaporation-compression cycle cooler operation was analyzed in Riga Bourse site during the cooling season in 2012. The application of ESEER calculation methodology has been evaluated in accordance with EN14511:3-2011 in Latvian climate conditions. After analyzing operational characteristics of the cooling system in the experimental object, distinct differences in capacity - outdoor air temperature have been noted from the method defined by ESEER (Figure 3.1.) Because of this, a proportional distribution calculation method is offered which can be used for other historical objects in similar climatic conditions.

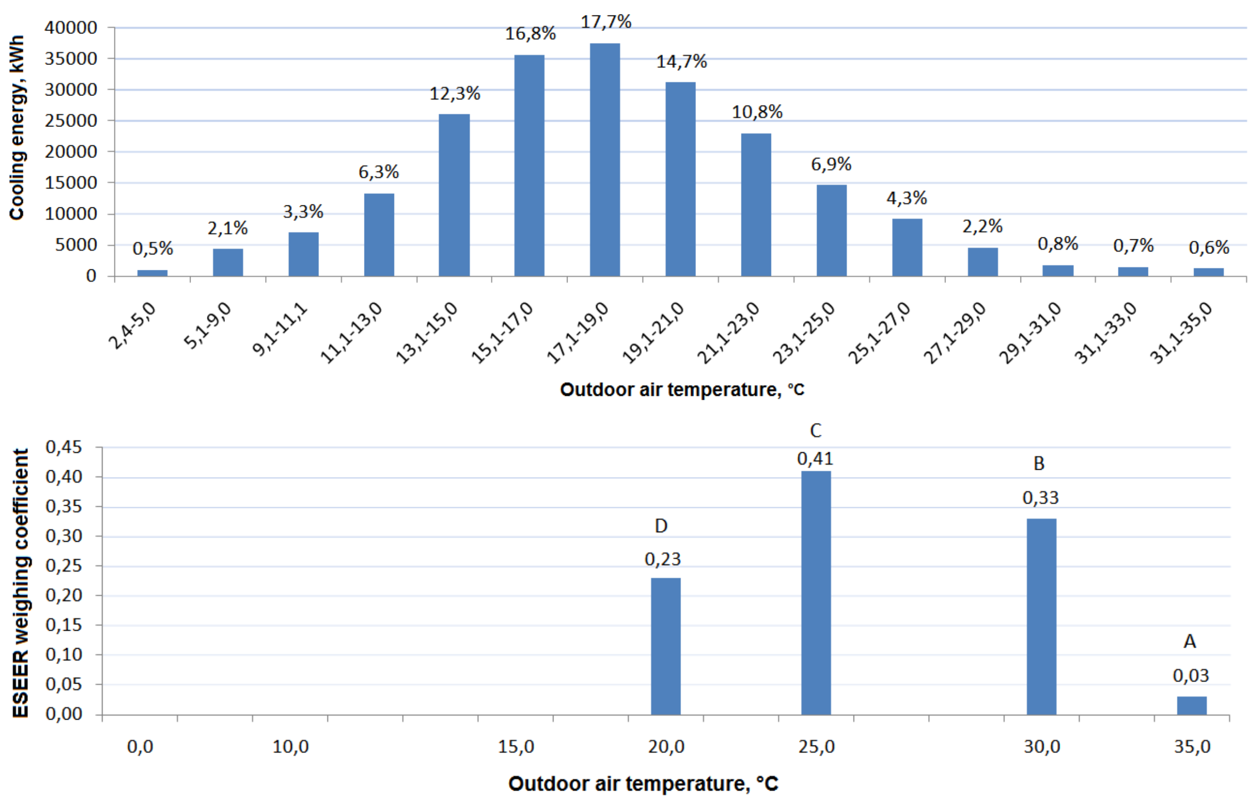

Figure 3.1. Distribution of cooling energy produced in outdoor temperature range (top) and influence factors of ESEER calculation according to EN14511:3-2011

Using the proportional distribution method, seasonal energy consumption calculations are performed for following device types: compact compression cycle air–cooled chiller (KCD), compression cycle water cooled chiller – dry cooling tower (KCD-DT), and combined compression cycle - evaporative chiller.

Seasonal electricity consumption was calculated using the equation:

$$Q_{el.seas.} = \sum_{\Delta T_n} \left(\frac{Q_{c.nom.}}{EER_{\Delta T_n}} DS_{\Delta T_n} GS_{\Delta T_n} \right) + Q_{el.st} \qquad (3.1)$$

$Q_{el.seas.}$– electricity consumption during cooling season, kWh
ΔT_n – outdoor air temperature interval
$Q_{c.nom.}$ – nominal cooling load of the device in standard conditions, kW
EER –energy efficiency ratio at a give 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

Efficiency EER data at certain outdoor air temperatures and output load in the temperature range from 20 to 35 °C were taken from the manufacturer software. At outdoor temperatures below + 20 °C EER data were used in laboratory studies. An example of EER data is shown in FigureFigure 3.2:

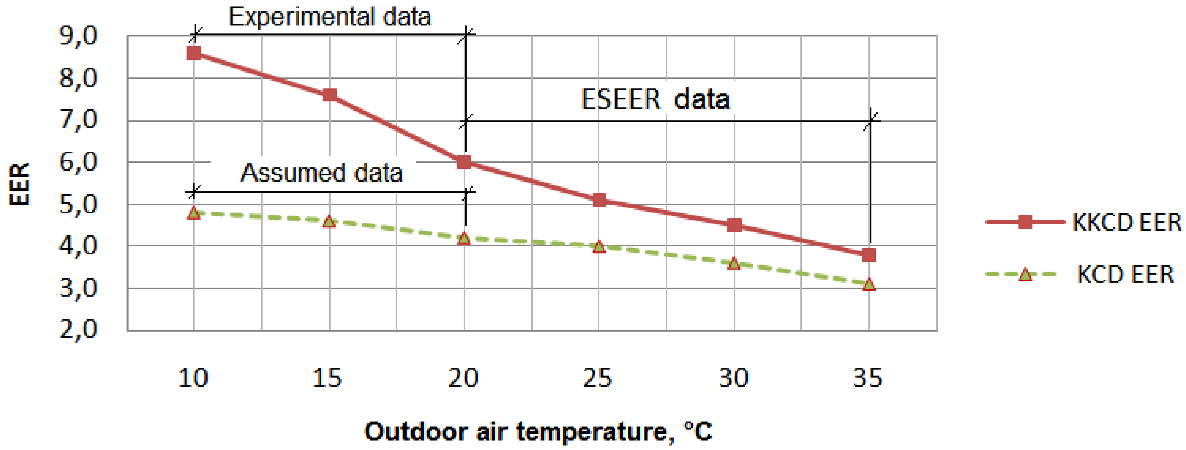

Figure 3.2. EER data for 16/20 °C and KCD KKCD devices

Overall efficiency of KCD-DT systems in full load was calculated by dividing the cooling capacity achieved in the chiller for the sum of electric load of all the equipment (chiller, pump, cooling tower). System efficiency values at lower cooling loads and the outdoor air temperature were assumed to be similar to seasonal EER values of the chiller in relation to EER_{100}.

$$EER_{KCD-DT} = \frac{Q_{dz}}{P_{DZ} + P_s + P_{DT}} \qquad (4.3)$$

where:
EER_{KCD-DT}– total efficiency for the system cooler-dry cooling tower
Q_c – cooling load, kW
P_C – electric load of the cooler, kW
P_P – circulation pump electric power, kW
P_{CT} – electric load of the cooling tower, kW

3.2. Economic aspects of choosing a cooler type. Payback time

For economic calculations the electricity rate is assumed to be 0.15 EUR/kWh, for T2 connection entering switches over 40A. Annual expenditure on service is assumed to comprise 600 EUR, water consumption – 500 EUR (historical for year 2012 from experimental facility Riga Bourse). Water rate assumed – 0,514 EUR/m^3. Annual expenditure for KCD service is assumed to constitute 300 EUR (TableTable 3.1).

Table 3.1.

Expenses assumed in payback time calculations, EUR

Device	Initial cost	Service/operational costs per year
KKCD	90000	600 + 500 (water consumption)
KCD	45000	300
KCD-DT	59500	450

In payment period calculations, at a discounted cash flow the discount rate of 5% is assumed. The discount factor for each operating year is calculated:

$$df = \frac{1}{(1+p)^n}, \quad (4.4)$$

where:
d f– discount factor,
p – discount coefficient, %
n – year, according to which calculation is performed.

Net present value determines the present value of the cash flow, discounting it with a necessary return rate using the following equation:

$$TTV(project) = A_o + \sum_{t=1}^{n} \frac{F_t}{(1+k+p_t)^t}, \quad (4.5)$$

where:
F_t – net cash flow in period *t*,
k – a set return rate,
A_o – initial cost (negative value because it is the outflow of cash)

Payback time calculations are performed for KCD and KCD-DT cooling devices, 7/12 °C and 16/20 °C cooling temperature modes, considering the advantages of their replacement by KKCD. Calculations for KCD-DT system replacement with KKCD is shown in Figure 3.3.

Currently on the market, there are several software tools that can be used to evaluate seasonal energy consumption in buildings and engineering systems. They are basically focused on thermal analysis and heat consumption/calculations of cooling load. Some of the most well-known energy calculation programs are: *RETScreen 4*, *RIUSKA*, *EnergyPlus*, *TRNSYS*, etc. Depending on the price and size, these programs allow the user to perform various calculations of different complexity, starting with a fast evaluation of cooling advantages (*RETScreen 4*) to detailed thermal process simulations influenced by external factors (*TRNSYS*).

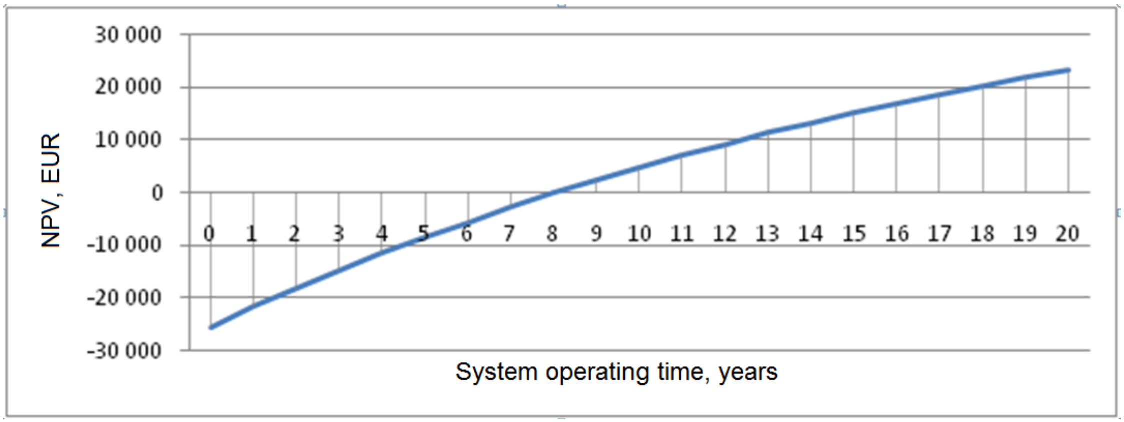

Figure 3.3.Payback schedule for temperatures regime KKCD 7/12 °C compared with KCD-DT cooling system

With the aim of comparing the calculation results of the proposed method, economical calculations were performed for cooling system types in computer program *RETScreen 4*. As a result of calculations, offline for KCD-CT system replacement by KKCD has been established with identically entered parameters within 18%; in KCD case offline comprised 28%. This significant deviation indicates that the use of standard ESEER efficiency parameters with cooling degree hours relatively inaccurate method for Latvian climate conditions, aggravated by the lack of correction factors for different types of objects.

CONCLUSIONS

This thesis seeks to evaluate the existing methods of calculating the seasonal cooling energy consumption, and it has been found that they cannot be directly used in Latvian climate conditions. Due to this reason, calculation methodology is proposed which provides significantly more accurate results during approbation period in experimental object.

Economic calculations have been performed for indirect evaporative water cooling system application combined with compression cycle in comparison with other cooling principles/systems. It has been concluded that in case of discounted cash flow, not taking into consideration grants/subsidies, the application of IEC method is economically justifiable because it payback time is within 8 years (Figure 3.3).

In order to increase the accuracy of economic and energy consumption calculations, it is proposed to introduce changes in European standard 14511:3–2007 which provides seasonal efficiency ESEER calculation procedure, taking into consideration peculiarities of various object types and conditions of cooler climate.

IEC method is tested in action in experimental object Art Museum Riga Bourse during the cooling season. There is a set proportional distribution of percentage of the produced cooling energy depending on the outdoor air temperature during the cooling season, and it is recommended to use it for calculating the cooling system energy consumption in similar historical buildings.

Using the data obtained in the object, correlation between combined indirect evaporative cooler efficiency and outdoor humidity in outdoor air temperature range from +11 °C to +34 °C has been noted. It has been established that at the outdoor air temperature above 24 °C moisture content is not significant, and this correlation approaches constant EER value. At a lower outdoor temperature, the influence of moisture content to the efficiency is more important (Figure 2.6).

The useful temperature availability of the water cooled with IEC method has been evaluated during experiments. It is concluded that at the outdoor air temperature +15 °C and lower, the water temperature in the primary circuit is decreased to 19 °C and it can be used in high temperature cooling systems such as cooled ceiling.

The outcomes of the research can be used by HVAC designers, architects and real estate developers in order to evaluate sustainable solutions of building engineering systems.

LIST OF PUBLICATIONS

1. Brahmanis A, Frīdenbergs G., Borisova V. Economical aspects of water–mist assisted air–cooled chillers usage in the temperate climate of Latvia. Proc. 13th SCANVAC Int. Conference on Air Distribution in Rooms. Sao Paulo, Brazil, 19–22.10.2014. – 8 p [accepted].
2. Frīdenbergs G., Brahmanis A., Lešinskis A., Experimental device modelling for IEAC thermal performance study. Proc. 13th SCANVAC Int. Conference on Air Distribution in Rooms. Sao Paulo, Brazil, 19–22.10.2014. – 8 p [accepted].
3. Brahmanis A., Pelīte U. Investigation of Combined Indirect Evaporative Ducted Cooling equipment efficiency in Historical Building in Temperate Climate. *Construction Science,* vol. 15, 2014. – 6 p.
4. Brahmanis A., Lešinskis A., Krūmiņš A. Case Study of Indirect Adiabatic Cooling System in Historical Building. Journal of Energy and Power Engineering, vol. 8,. 2014. - p. 313-317
5. Pelīte U., Krūmiņš, A., Brahmanis A. Energoefektīvas ēkas simulators RTU. Latvijas būvniecība, Nr. 2, 2013. - lpp. 92-93.
6. Brahmanis A., Lešinskis A., Krūmiņš A. Case study of indirect adiabatic cooling system in historical building. In: 11th REHVA World Congress and 8th International Conference on IAQVEC "CLIMA 2013", Prague, Czech Republic, 2013 – 7 p.
7. Brahmanis A., Lešinskis A., Indirect Evaporative Pre-Cooled Compressor Cooling System Performance under Various Outdoor Air Humidity Conditions. In: Conference "Civil Engineering `13", Jelgava, Latvia, 2013– 7 p.
8. Brahmanis A. Mikroklimats peldbaseinos. Eneģija un Pasaule, Nr. 2, 2011. - lpp. 43-44.
9. Brahmanis A., Pelīte U., Lešinskis A., Kona D., Kon Tai Bui. Extract air energy utilization using heat pump in buildings with indoor swimming pools. Proc. Int. The 8th International Conference of Young Scientists on Energy Issues "CYSENI2011", Kaunas (Lithuania), 26.-27.05.2011. – 9 p.
10. Brahmanis A., Pelīte U., Lešinskis A., Krūmiņš A. Energy efficient indoor climate model for public buildings with high humidity gains and spectator areas. – Proc. Int. Conference "Clima 2010", Antalya (Turkey), 9-12.05.2010. – 8 p.
11. Kona D., Kon Tai Bui, E.Dzelzitis, A.Lesinskis, A.Brahmanis. Weather data for indirect evaporative cooling equipment simulations. Proc. Int. Conference 41st International Congress & Exhibition on Heating Refrigeration and Air Conditioning, Belgrade (Serbia), 01.-03.12.2010. – 8p.
12. Krumins, A., Pelīte U., Dzelzītis E., Lešinskis A., Brahmanis A. Case Study of Ventilation System Development of Archive Premises. In: 6th Annual Conference of Young Scientists on Energy Issues „CYSENI 2009", Kaunas, Lithuania, 2009. – 7 p.
13. Krūmiņš A., Pelīte U., Dzelzītis E., Lešinskis A., Brahmanis A. Optimal control strategy of air handling unit for different microclimates in working and swimming areas of a swimming pool hall. - Proc. Int. Conference „Indoor Air 2008", Copenhagen (Denmark), 17-22.08.2008. – 8 p.