Budapest University of Technology and Economics
Faculty of Mechanical Engineering Doctoral Council
Doctoral Thesis Book

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Analysis of energy consumption of air handling units based on probability theory

titled topic,

from which he completes for to be awarded Ph.D. decree.

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1. ANTECEDENT OF THE RESEARCH WORK

The population and residential buildings represent almost 40% of the total energy consumption in Hungary. Their share is similar in the EU countries and if the buildings used in the industrial and transport sector are also taken into consideration, this figure even reaches 50%. The major part of this 50% is used for air conditioning. From the point of view of sustainable development and international agreements (Kyoto protocol) the reduction of carbon dioxide emissions and energy consumption is an important issue. The energy consumption of air handling units can be calculated in two ways. In the case of working air handling units the actual consumption data can be exactly determined by measurement. But according to Directive 2002/91/EC on the energy performance of buildings (EPBD) it is also important to determine the expected energy consumption of buildings in the designing phase. The timeliness of this research theme shows that the actual available calculation procedures are only rough estimates for analysing the energy consumption of air handling units. There are not exact and unambiguous methods. The aim of the actual calculation procedure is the classification and they take not into consideration the heat- and humidity load of the conditioned space.

2. GOALS

In our time the explosive spread of the air conditioning systems herein the air handling units is a global phenomenon. With the help of them such air states can be supplied in the spaces of the building which can provide the pleasant comfort sensation of the people or the easy operation of the installed technology. Previously the main consideration of the tenders for the reviewing of air-conditioning system designings and constructings was the investment cost. In the international circles the energy efficient operation and quality management gain bigger and bigger ground. One of the ways to beating down the investment cost is the abandonment of the supplementary costs, the low quality of the material consumption and the installation of the not expedient elements. All these raise the energy consumption and the opportunity of the uneconomical operation. To supplant the unwanted effects the „Life Cycle Cost” principle is taken into consideration during the reviewing of the tenders. On this wise the investment and operation costs are together taken into consideration for the whole operation term of the equipment. The operation costs include the energy consumption of the air handling unit, the maintance costs, the cost of the preservation and the annuity cost. In this case the importance of the quality management and the energy efficient operation is higher than the exclusive application of the investment cost. The spread of this attitude is specially important, because in the immediate future come to fore the „low energy buildins”, the „super low energy buildins” and the „passive buildings”.

In additional the statistical data attest that the active cooling is applied by residental and public buildings on much boareder front. By these buildings the ventilation proportion is significantly increased in the whole energy consumption. There are similar problems by the operation of posterior thermal insulated buildings. In this case the energy consumption of the ventialtion system is a major proportion of the energy consumption of whole building services [Magyar Tamás, 2003; Mikko Nyman, Carey J. Simonson, 2005; Kjell F., William L., 2005]. My research work is linked with this theme, in which I set myself an aim to work out a calculation procedure to determine the energy consumption of air handling units.

3. METHODS OF INVESTIGATION

During the building energetic calculations the building and the building servies have to be estimated. The energy consumption of the air handling units has to be determined among others. The solution of the problem is harder task, because the energy consumption changes steady during the year. Therefore simply equations can be not used. In my research work I aspired to the real energy consumption of the air handling units. I used the method based on the probability theory, because this procedure takes into consideration the most efficiently the changing of the ambient air state during the year, which changing determine above all the whole energy consumption of the bulidings and building services.

I worked out new physical and mathematical models to determine the energy consumption of representative constructed air handling units. For my research work I used the the ambient temperature and enthalpy duration curves (Figure 1.). The correctness of the developed new scientific method was attested by two years energy consumption of three building complexes (altogether six data), where the energy consumption of the air handling units is the part of the whole energy consumption of the buildings.

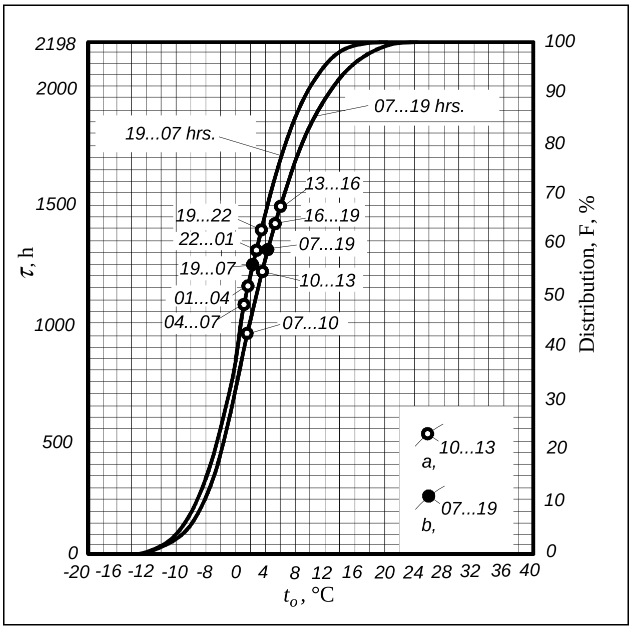

Figure 1. Ambient temperature duration curve from October until March (Budapest, measured temperatures between 1964-1972) [Kiss Róbert, 1980]

4. NEW SCIENTIFIC RESULTS

- 1. Thesis -

I worked out new physical models to determine the energy consumption of the air handling units.

I took into consideration the changing of the ambient air state by the ambient temperature and enthalpy duration curves. The developed new method is suitable to determine the energy consumption of the air handling units that include preheater, rehetaer, cooler, heat recovery unit, adiabatic humidfier. With the developed method there is possibility from the air handling combination built air handling unit to determine the annual, monthly energy consumption in continous working, daytime (07-19 hours) and nightly (19-07 hours) operation.

The publications for the thesis: [P2, P3, P4, P6, P8, P10]

Physical model of fresh air supplied air handling unit can be seen in the heating period on Figure 2. and in the cooling period on Figure 3.

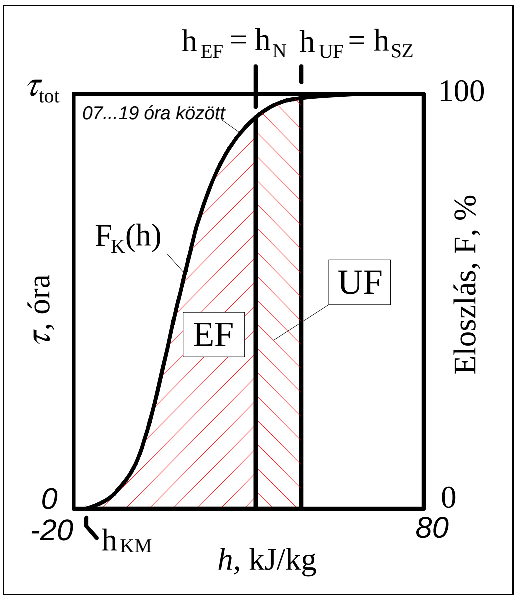

Figure 2. Areas on ambient enthalpy duration curve that represent the energy consumption of the preheater and reheater

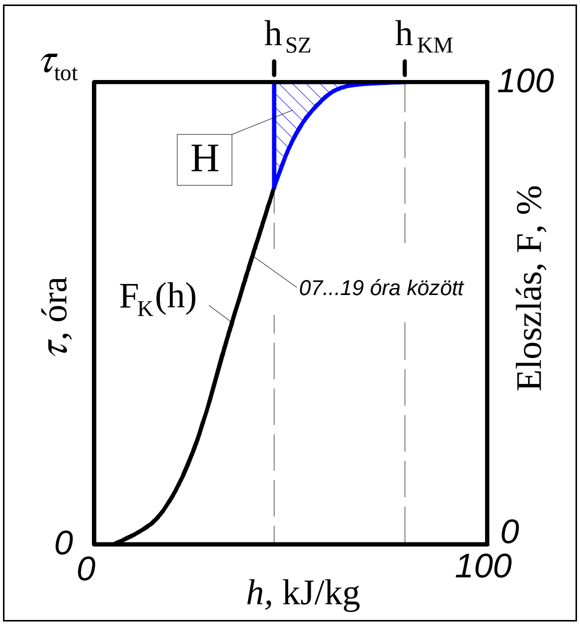

Figure 3. The area on ambient enthalpy duration curve that represents the energy consumption of the cooling coil

Physical model of saved energy with the heat recovery unit can be seen in the heating period on Figure 4. and in the cooling period on Figure 5.

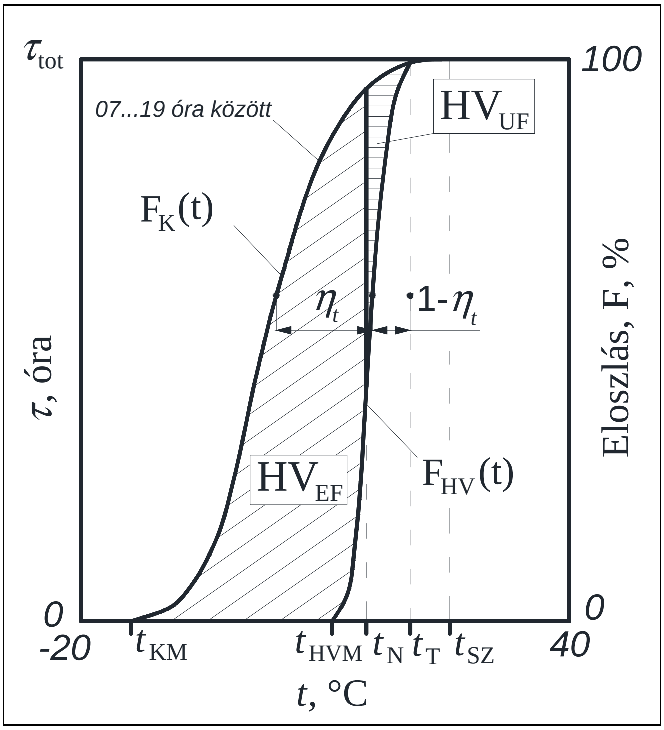

Figure 4. The areas on ambient temperature duration curve that represent the energy saved of the heat recovery unit, in the heating period

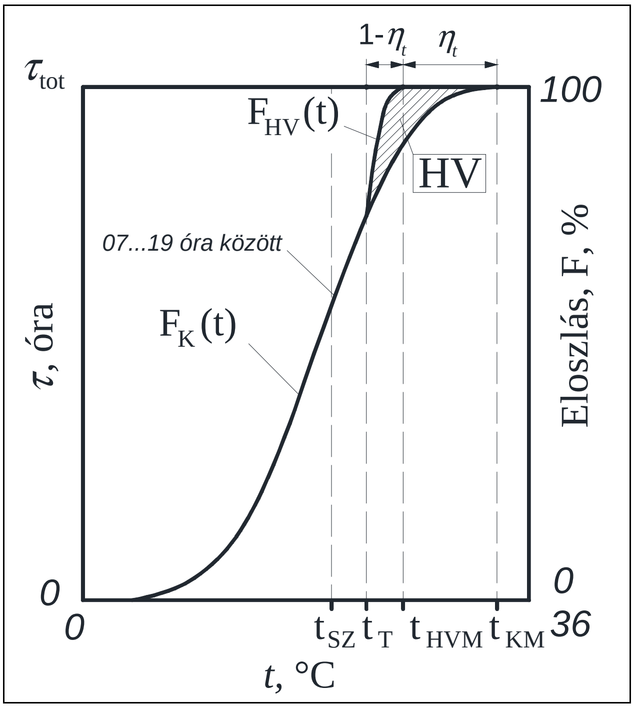

Figure 5. The area on ambient temperature duration curve that represents the energy saved of the heat recovery unit, in the cooling period

Physical model of the air handling unit with energy recovery operation can be seen in the heating period on Figure 6. and in the cooling period on Figure 7.

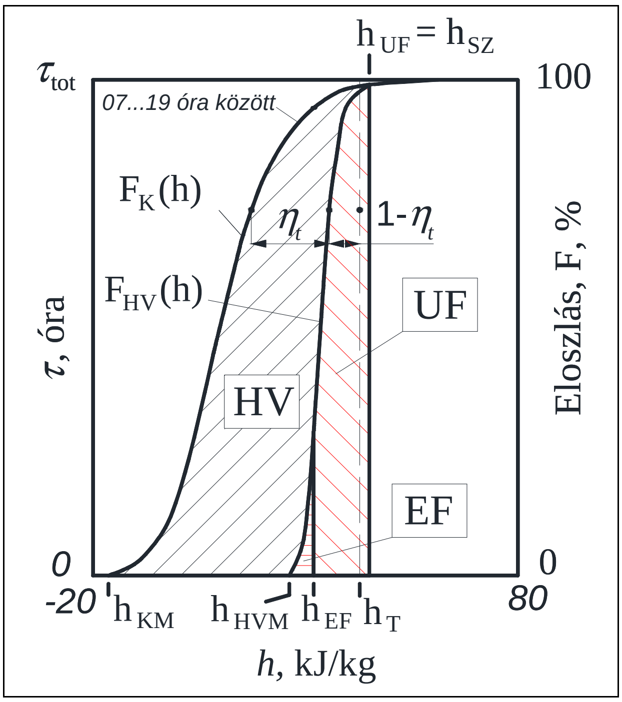

Figure 6. The areas on ambient enthalpy duration curve that represent the energy consumptions in the heating period

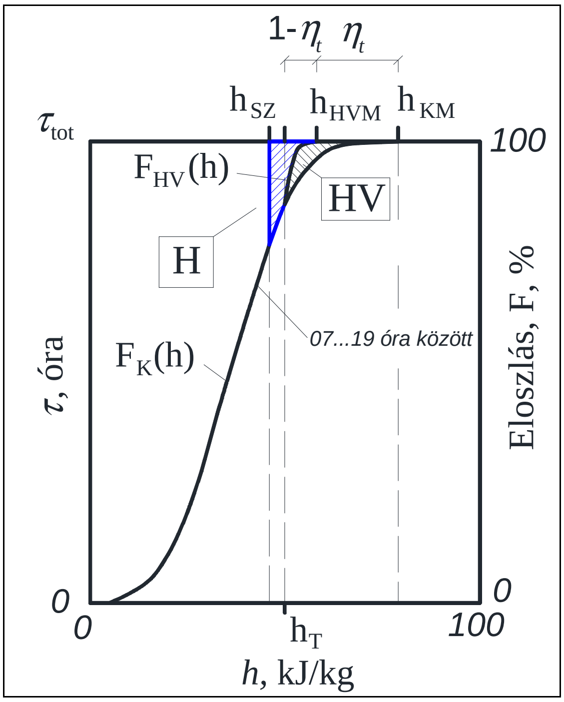

Figure 7. The areas on ambient enthalpy duration curve that represent the energy consumptions in the cooling period

Physical model of the air handling unit with air recirculation operation can be seen in the heating period on Figure 8. and in the cooling period on Figure 9.

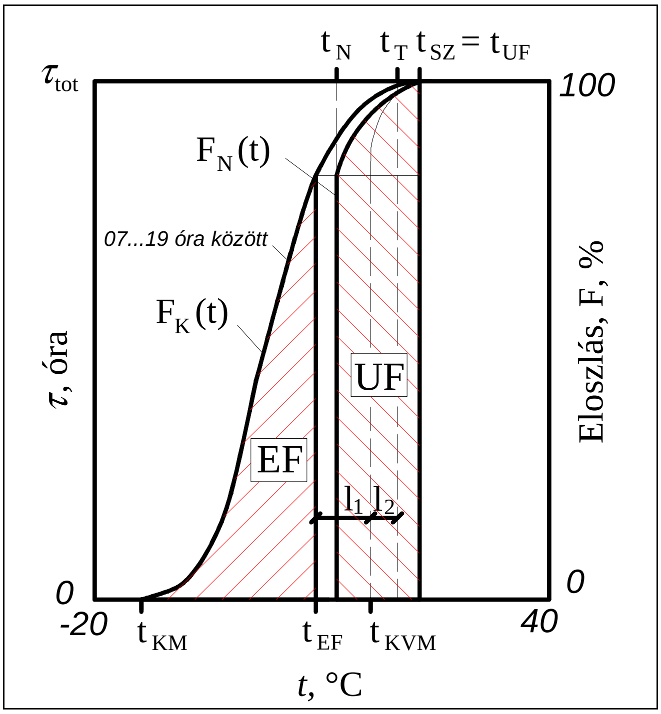

Figure 8. The areas on ambient temperature duration curve that represent the energy consumption of the preheater and reheater

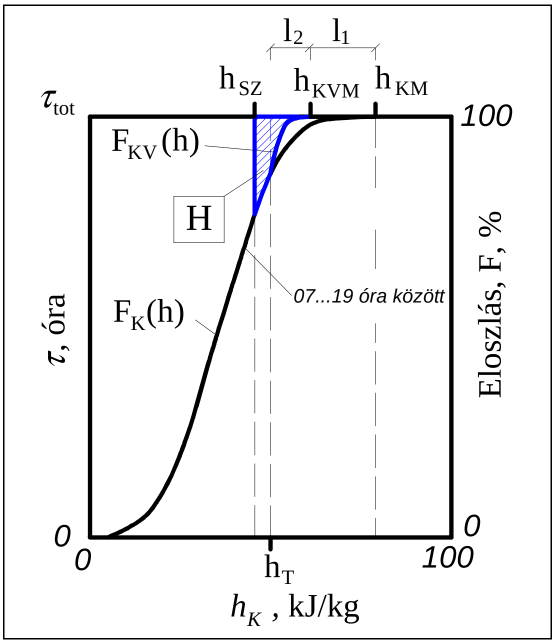

Figure 9. The area on ambient enthalpy duration curve that represents the energy consumption of the cooling coil

- 2. Thesis -

Based on the physical models I worked out new mathematical models to determine the energy consumption of the various constructed air handling units.

On the basis of the ambient temperature and enthalpy duration curves to determine the areas that represent the energy consumption and energy saved of the analysed air handling units I used approximation mathematical procedure (spline-interpolation), and based on the consequently so determined areas I developed the mathematical equations. I worked out the mathematical modells on the basis of all physical modells.

The publications for the thesis: [P13, P14, P15]

<u>The mathematical models of the energy consumption of the fresh air supplied air handling unit:</u>

The energy consumption of the preheater:

$$Q_{EF} = \rho \cdot \dot{V}_{EF} \cdot \int_{h_{KM}}^{h_{EF}} F_K(h)dh \text{ [kJ/year]} \tag{1}$$

The energy consumption of the reheater:

$$Q_{UF} = \rho \cdot \dot{V}_{UF} \cdot \int_{h_{EF}}^{h_{UF}} F_K(h)dh \text{ [kJ/year]} \tag{2}$$

The energy consumption of the cooling coil:

$$Q_{H} = \rho \cdot \dot{V}_{H} \cdot \int_{h_{SZ}}^{h_{KM}} [1 - F_K(h)]dh \text{ [kJ/year]} \tag{3}$$

The *electrical energy consumption* of the compressor in the light of the energy consumption of the cooling coil:

$$W_H = \frac{Q_H}{SEER} \text{ [kJ/year] or [kWh/year]} \tag{4}$$

<u>The mathematical models of the energy consumption of air handling unit with heat recovery system:</u>

The energy consumption of the preheater:

$$Q_{EF} = \rho \cdot \dot{V}_{EF} \cdot \int_{h_{KM}}^{h_{EF}} F_K(h)dh - c_{pl} \cdot \rho \cdot \dot{V}_{EF} \cdot \left[\int_{t_{KM}}^{t_N} F_K(t)dt - \int_{t_{HVM}}^{t_N} F_{HV}(t)dt \right] \text{ [kJ/year]} \tag{5}$$

The energy consumption of the reheater:

$$Q_{UF} = \rho \cdot \dot{V}_{UF} \cdot \int_{h_{EF}}^{h_{UF}} F_K(h)dh - c_{pl} \cdot \rho \cdot \dot{V}_{UF} \cdot \left[\int_{t_N}^{t_T} F_K(t)dt - \int_{t_N}^{t_T} F_{HV}(t)dt \right] \text{ [kJ/year]} \tag{6}$$

The energy consumption of the cooling coil:

$$Q_{H} = \rho \cdot \dot{V}_{H} \cdot \int_{h_{SZ}}^{h_{KM}} [1 - F_K(h)]dh - c_{pl} \cdot \rho \cdot \dot{V}_{H} \cdot \left[\int_{t_T}^{t_{KM}} [1 - F_K(t)]dt - \int_{t_T}^{t_{HVM}} [1 - F_{HV}(t)]dt \right] \text{[kJ/year]} \tag{7}$$

The negative sign term on right side of the (5-7) equations mean the heating and cooling energy saved with the heat recovery unit. The electrical energy consumption of the compressor can be calculated by the (4) equation.

The mathematical models of the energy consumption of air handling unit with energy recovery system:

The energy consumption of the preheater:

$$Q_{EF} = \rho \cdot \dot{V}_{EF} \cdot \int_{h_{HVM}}^{h_{EF}} F_{HV}(h)dh \text{ [kJ/year]} \tag{8}$$

The energy consumption of the reheater:

$$Q_{UF} = \rho \cdot \dot{V}_{UF} \cdot \int_{h_{EF}}^{h_{UF}} F_{HV}(h)dh \text{ [kJ/year]} \tag{9}$$

The energy consumption of the cooling coil:

$$Q_{H} = \rho \cdot \dot{V}_{H} \cdot \left[\int_{h_{SZ}}^{h_{T}} [1 - F_{K}(h)]dh + \int_{h_{T}}^{h_{HVM}} [1 - F_{HV}(h)]dh \right] \text{ [kJ/year]} \tag{10}$$

The electrical energy consumption of the compressor can be calculated by the (4) equation.

The mathematical models of the energy consumption of air handling unit air recirculation operation:

The energy consumption of the preheater:

$$Q_{EF} = c_{pl} \cdot \rho \cdot \dot{V}_{friss} \cdot \int_{t_{KM}}^{t_{EF}} F_{K}(t)dt \text{ [kJ/year]} \tag{11}$$

The energy consumption of the reheater:

$$Q_{UF} = c_{pl} \cdot \rho \cdot \dot{V}_{SZ} \cdot \int_{t_{N}}^{t_{UF}} F_{N}(t)dt \text{ [kJ/year]} \tag{12}$$

The energy consumption of the cooling coil:

$$Q_{H} = \rho \cdot \dot{V}_{H} \cdot \left[\int_{h_{SZ}}^{h_{T}} [1 - F_{K}(h)]dh + \int_{h_{T}}^{h_{KVM}} [1 - F_{KV}(h)]dh \right] \text{ [kJ/year]} \tag{13}$$

The electrical energy consumption of the compressor can be calculated by the (4) equation.

<u>The moisture consumption of the steam humidifer:</u>

$$m_g = \rho \cdot \dot{V} \cdot \int_0^{\tau} [x_{ki} - x_{küls\H{o}}(\tau)] d\tau = \rho \cdot \dot{V} \cdot \int_0^{\tau} [x_{ki} - \overline{x}_{küls\H{o}}] d\tau \text{ [kg/year]} \quad (14)$$

If the amount of the moisture in the air before the steam humifidier is not equal with the ambient air moisture (for example: because of air recircuation):

$$m_g = \rho \cdot \dot{V} \cdot \int_0^{\tau} [x_{ki} - x_{be}] d\tau \text{ [kg/year]} \quad (15)$$

<u>The energy consumption of the steam humidifer:</u>

$$Q_G = m_g \cdot h_g = m_g \cdot (r_o + c_{pg} \cdot t) \text{ [kJ/year]} \quad (16)$$

<u>The energy consumption of the ventilator:</u>

$$W_{vent} = \int_0^{\tau} \frac{\dot{V}_{vent} \cdot \Delta p_{ö}}{\eta_{vent} . \eta_{mot}} d\tau \text{ [kWh/year]}, \quad (17)$$

<u>The energy consumption of the pump:</u>

$$W_{sziv} = \int_0^{\tau} \frac{\dot{V}_{sziv} \cdot H}{\eta_{sziv} . \eta_{mot}} d\tau \text{ [kWh/year]}, \quad (18)$$

- 3. Thesis -

I controlled the developed new scientific method with measured energy consumption data of operating air handling units. For the controlling I used measured energy consumption data of separated years (2002, 2005 and 2006) in the case of two hotel building complexes and an office building. In the selected years the operation characterictic and the caseload of the buildings was average correlate with the building type. On the basis of the underlying six independent measured energy consumption data the difference of the calculated and the measured energy consumption values was between -11,7 and +11,7 %. During the controlling I used data of 30 pieces of various constructed air handling units.

The publications for the thesis: [P7, P9, P13]

During the energetic evaluation I compared the calculeted and measured energy consumption of separated years (2002, 2005 and 2006) in the case of three building complexes.

	Measured value	Calculated value	Difference [(C-M)/M]
	[kWh/m^{2}year]	[kWh/m^{2}year]	[%]
Office building (2002)	426	476	11,7
Office building (2005)	539		-11,7
Hotel 1 (2005)	437	455	4,1
Hotel 1 (2006)	444		2,4
Hotel 2 (2005)	441	422	-4,3
Hotel 2 (2006)	418		0,9

Table 1. The measured and the calculated energy consumption

In Table 1. can be seen that on the basis of the underlying six independent measured data the difference of the calculated and the measured energy consumption values was between -11,7 and +11,7 %. During the energetic analysis the difference of the calculated and the measured energy consumption values poved that the new theoretical procedure is right.

- 4. Thesis -

The new developed calculation procedure, based on the probability theory, is also suitable for comparative energetic analysis and the saved energy analysis of various constructed air handling units. On this wise there is possibility to make comparative energetic analysis, energetic optimization in the case of the worked up different conceptions by the buidling service engineer.

With the developed new scientific method there is possibility to evaluate the operation cost, each energy saving method and by those the amount of energy saved. The results that are determined by the new calculation method, are important not only for the designing engineers with respect to the energy conscious designing and the making of the energy performance certificate of buildings, but also for the investor, because the operating cost influneces the rent cost. On the basis of the investment and operation costs there is also method to make evaluation by „Life Cycle Cost". On the basis of the scientific results till now the annual energy consumption of the air handling units could be estimated only approximately, in this manner there was also not possibility for Life Cycle Cost analysis.

The publications for the thesis: [P11, P12]

- 5. Thesis -

I estimated the actual applied national method to evaluate the energy consumption of air handling units. I analysed the energy consumption determining procedure of the actual method. On the basis of the new scientific results, I worked out, I determined the necessary correction factors (k_1; k_2). In this manner the corrected sizing procedure is the following:

$$E_{hű} = \frac{Q_{hű} \cdot k_1 \cdot e_{hű}}{k_2 \cdot A_N}; \quad [\text{kWh/m}^2\ \text{year}]$$

where:

k_1 [-] the relationship of the sensible heat and total heat load ($k_1 = \dot{Q}_{total} / \dot{Q}_{érezhető}$); the value of it depends on the type of the air conditioning system, in the case of the analysed air conditioning system it can be determined (in general it is between 1,2-1,5).

k_2 [-] the seasonal energy efficiency ratio of the air conditioning system (SEER) a the value of it depends on the type of the air conditioning system, in the case of the analysed air-conditioning system it can be determined (in general it is between: 2,5-4,5).

The values of the above mentioned two factors are exactly determinable in the case of the applied air conditioning system. In this manner, the value of the energy consumption is only the 0,25-0,6 fold of the value according to the actual applied national method. It is in evidence that the difference is significant.

The publications for the thesis: [P5, P7]

- 6. Thesis -

I made an energetic comparison of the new scientific method and the actual applied international analyser calculation procedures. The results showed that the actual applied international methods are suitable for determining the energy consumption only in some cases.

The publications for the thesis: [P1, P5]

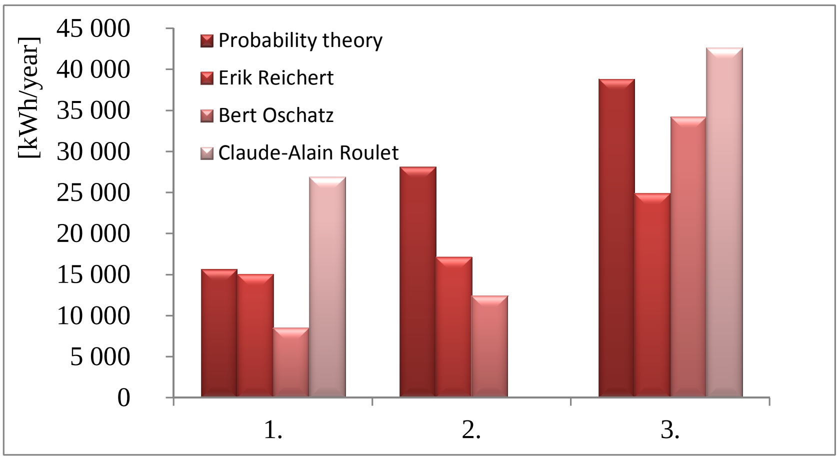

Figure 10. The net heating energy consumption of the analysed air handling units

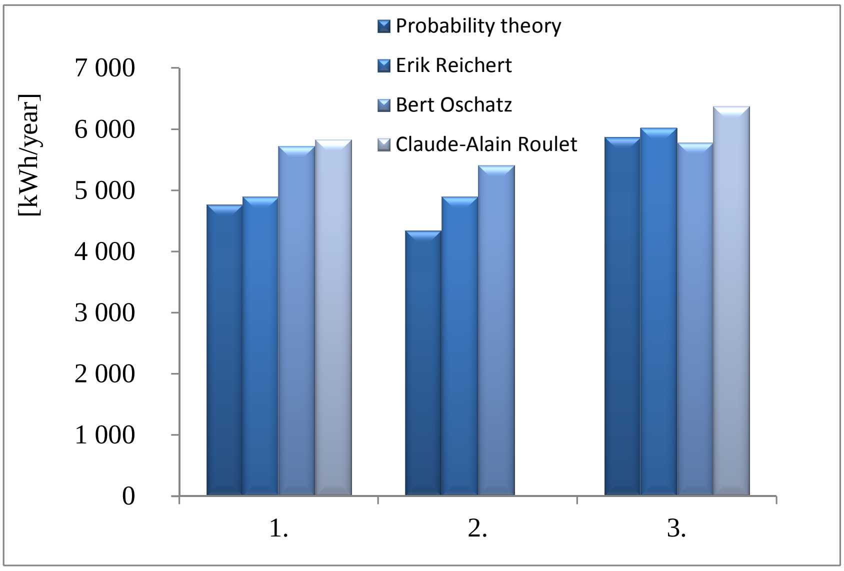

Figure 11. The net cooling energy consumption of the analysed air handling units

5. SUMMARY, UTILIZATION OF THE RESULTS

During my research my objective was to work out a generalized calculation procedure which is suitable for the analysis of the energy consumption of air handling units based on the probability theory. Considering that the construction of the air handling units and the air handling processes are very complex, I worked out the physical and mathematical models that describe exactly the complex air handling processes. The new method was applied in case of 30 pieces of different operating air handling units. The comparison of the calculated and the actual energy consumption proved that the new theoretical procedure is right. Based on the new calculation method I worked out proposal for the actual national method to specify the herein applied procedure.

With the developed energetic analysis procedure can already be determined the exact annual energy consumption of the air handling unit in the design phase before the investment realization. The new method is also suitable for analysing the energy saving of the various constructed air handling units. In this manner an optimal decision can be made in the design phase. By choosing the lowest energy consumed air handling unit, a significant energy saving (30-60%) can be achieved during the whole lifetime of the system.

To apply the results of the research work additional researches might be done in this field. To analyse the energy consumption of the air handling units fast, exact and efficiently, a computerised simulation PC program was made by Dr. László Kajtár and József Gräff. After the development of the marketable version of the PC program, the application of the new calculation method will be come possible also for the designing engineers.

The list of the own scientific publication for the thesis

a. Foreign language edited journal article in Web of Science vagy Scopus database:

[P1] László Kajtár - Miklós Kassai: A new calculation procedure to analyse the energy consumption of air handling units. Periodica Polytechnica, Mechanical Engineering, ISSN: 0324-6051 (2010). (A cikk közlésre elfogadva, szerkesztés alatt áll, igazolás mellékelve.)

[P2] László Kajtár - Miklós Kassai: Analysis of energy consumption of air handling units based on probability theory. Periodica Polytechnica, Mechanical Engineering, ISSN: 0324-6051, 52/2, p. 61-66. (2008).

b. Further foreign language edited journal article:

[P3] László Kajtár - Miklós Kassai: Analýza potreby energie pre centrálnu klimatizačnú jednotku. TZB HAUSTECHNIK, 2010/6, ISSN 1210-356X, p. 32-35. (2010).

[P4] István Barótfi, László Kajtár, Miklós Kassai,: Calculation Method for Energy Consumption of Air Handling Units. Mechanical Engineering Letters, Szent István University, HU ISSN 2060-3789, Vol. 3, p. 209-221. (2009).

c. Publication in hungarian (journals):

[P5] Kajtár L. – Kassai M.: Levegőkezelő központok energiafelhasználásának elemzése hazai és külföldi eljárások alapján. Magyar Épületgépészet, 2010/12. szám, 3-8 o., HU ISSN 1215-9913 (2010).

[P6] Kajtár L. – Kassai M.: Passzívház szellőzési rendszerének energetikai elemzése. Magyar Installateur, ISSN: 0866 6024, 46-49.o. (2010).

[P7] Kajtár L. - Kassai M.: Klimatizált épületek energetikai elemzése. Magyar Épületgépészet, HU ISSN 1215-9913, 2008/7-8. szám, 3-7.o. (2008).

[P8] Kajtár László - Kassai Miklós: Levegőkezelő központ energiafelhasználásának elemzése valószínűségelméleti módszerrel. Magyar Épületgépészet, 2007/4. szám, HU ISSN 1215-9913, 3-7 o. (2007).

d. Foreign language publications, which were appeared in international conference proceedings:

[P9] L. Kajtár, J. Gräff, M. Kassai, J. Szabó: New Calculation Method for Energy Consumption of Air Handling Units, The 12th International Conference on Indoor Air Quality and Climate, (2011). (A cikk közlésre elfogadva, igazolás mellékelve.)

[P10] Kajtár L., József G., Kassai M.: Energetic analysis of ventilation system of passive house. 16th "Building Services, Mechanical and Building Industry Days", International Conference, Debrecen, ISBN 978-963-473-121-5, pp. 5-11. (2010).

[P11] L. Kajtár - M. Kassai: Energy Consumption of Air Handling Units. Clima 2010 – 10th REHVA World Congress, Antalya, pp. 37-39. (2010).

[P12] L. Kajtár - M. Kassai: Analysis of energy consumption of air-conditioning systems. Gépészet 2010 Konferencia, Budapest, ISBN 978-963-313-007-0, pp. 439-450. (2010).

[P13] L. Kajtár - M. Kassai: Analýza spotreby energie Hotelov. 18. medzinárodnej konferencie VYKUROVANIE 2010, Pozsony ISBN 978-80-89216-32-1, s. 473-477. (2010).

[P14] Kajtár L. - Kassai M.: Analysis of air treatment equipment using the probability theory. 14th "Building Services, Mechanical and Building Industry Days", International Conference, Debrecen, ISBN 978-963-473-124-5, pp. 127-134. (2008).

[P15] László Kajtár - Miklós Kassai: Evaluation of energy demand of air-conditioning systems based on probability theory. The 6th IASME/WSEAS International Conference on Heat Transfer, Thermal Engineering and Environment, Rhodos, ISSN 1790-5095, ISBN 978-960-6766-97-8, pp. 266-270. (2008).

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[2] Magyar Tamás: *Légcsatorna rendszerek tervezési és alkalmazási irányelvei*, 3./23-24.o (2003).

[3] Mikko Nyman, Carey J. Simonson: *Life cycle assessment of residential ventilation units in a cold climate*, Building and Environment, p.15-27. (2005).

[4] Kjell Folkesson and William Lawrance: *Calculate ventilation Life Cycle Cost and Count on Savings*, Business Briefing: Hospital Engineering & Facilities Management, (2005).

SYMBOLS IN THE THESIS BOOK

c_{pg}	[kJ/kgK]	specific heat capacity of water vapor at constant pressure,
c_{pl}	[kJ/kg°C]	specific heat capacity of air at constant pressure,
EF	[-]	sign of the preheater,
UF	[-]	sign of the reheater,
$F_{HV}(h)$	[-]	air enthalpy curve after the heat recovery unit, which can be drawn by the efficiency of the heat recovery, the outgoing air and the ambient air enhaply curve,
$F_{HV}(t)$	[-]	air temperature curve after the heat recovery unit, which can be drawn by the efficiency of the heat recovery, the outgoing air and the ambient air temperature curve,
$F_K(t)$	[-]	duration curve of the ambient air temperature,
$F_{KV}(h)$	[-]	air enthalpy curve after the air recirculation, which can be drawn by the the air recurculation ratio, the enhaply of the outgoing air and the ambient air enhaply curve,
$F_N(t)$	[-]	temperature curve of the preheated, recirculated and humidified air,
h_{EF}	[kJ/kg]	the enthalpy of the air after the preheater,
h_{HVM}	[°C]	the enthalpy of the air after the heat recovery unit az sizing state,
h_{KM}	[kJ/kg]	the ambient enthalpy in sizing state,
h_{KVM}	[kJ/kg]	the enthlapy of the air after the air recirculation at sizing state,
h_N	[kJ/kg]	the enthlapy of the air after the adiabatic humidifier
h_{SZ}	[kJ/kg]	the enthalpy of the supply air,
h_T	[kJ/kg]	the enthalpy of the outgoing air,
h_{UF}	[kJ/kg]	the enthalpy of the air after the reheater,
H	[Pa]	lift of the pump
H	[-]	sign of the cooling-coil,
HV	[-]	sign of the heat recovery unit,
k_1	[-]	the relationship of the sensible heat and total heat load,
k_2	[-]	the seasonal energy efficiency ratio of the air conditioning system,
l_1	[mm]	the arm that proportionals with the temperature difference of the recirculated air and preheated air,
l_2	[mm]	the arm that proportionals with the temperature difference of the recirculated air and outgoing air,
r_o	[kJ/kg]	specific latent heat of water vaporization (value of it is if $t = 0$ °C temperature $r_0 = 2501$ [kJ/kg]),
t_{EF}	[°C]	air temperature after the preheater,
t_{HVM}	[°C]	air temperature after the heat recovery unit at sizing state, which value depends on the efficiency of the heat recovery, the outgoing air and the ambient air temperature,
t_{UF}	[°C]	the tamperature of the air after the reheater,
t	[°C]	the air temperature,
t_{HVM}	[°C]	the temperature of the air after the air recirculation at sizing state,

t_{KM} [°C]	ambient air temperature at sizing state,
t_N [°C]	air temperature after the adiabatic humidifier,
t_T [°C]	the temperature of the outgoing air,
t_{SZ} [°C]	the temperature of the supply air,
$\dot{V}_{friss}$ [m^3/h]	the fresh air volume flow,
$\dot{V}_{EF}$ [m^3/h]	the air volume flow in the preheater,
$\dot{V}_{UF}$ [m^3/h]	the air volume flow in the reheater,
$\dot{V}_{H}$ [m^3/h]	the air volume flow in the cooling coil,
$\dot{V}_{SZ}$ [m^3/h]	the supply air volume flow,
$\dot{V}_{sziv}$ [m^3/s]	the water volume flow by the pump,
$\dot{V}_{vent}$ [m^3/s]	the air volume flow by the ventilator,
x_{be} [gr/kg]	the amount of the moisture in the air that enters into the steam humidifier,
x_{ki} [gr/kg]	the amount of the moisture int he air after the steam humidifier,
$x_{külső}$ [gr/kg]	the amount of the moisture in the ambient air. The average value of it in heating period based on the ambient duration curves in the daytime and also at night is: 2,99 gr/kg,
$\Delta p_{ö}$ [Pa]	the pressure losses of the air handling system,
ρ [kg/m^3]	the air density,
η_{mot}	the efficiency of the motor (ventilator, pump),
η_{sziv}	the efficiency of the pump,
η_{t}	the efficiency of the heat recovery unit,
η_{vent}	the efficiency of the ventilator,
τ [h]	the operation time of the pump and ventilator.