Budapest University of Technology and Economics
Faculty of Architecture

Zoltán Magyar
Mechanical Engineer, MsC

Air change rate in the energy balance and structure protection of the buildings,

with special attention to minimize the thermal energy consumption of buildings ensuring the required comfort conditioning

Thesis of PhD dissertation

Budapest
2008

1. Introduction

Buildings mainly give us aesthetic experience also, but occupant getting pleased with environment and comfort – say wellbeing – we have to prepare good building and HVAC systems. We have to consider the world-wide ambitions for energy saving. European Union set the target reducing the energy consumption of buildings. Based on this requirement member states accepted the directive 91/2002/EC on energy performance of buildings and prepared the long term objective of common energy politics and the energy performance action plan of European Union (October 2006).

Effect of high spontaneously air change not only the higher energy consumption but also the control problem of heating and air conditioning system: the design parameters (temperature, humidity, air change rate) of indoors can't achieve. Reducing the spontaneously air change range has risk from the protection of building structure, safe and health. The very air tight building structure together with the non-conscious occupant behaviour could results the impairment of the building structure. The goal to prepare, balance and operate of the heating and air conditioning systems using minimum energy consumption while the buildings have more and more insulated walls, windows and doors, ensuring the excepted comfort parameters and the minimum level of necessary air change rate. The properly balanced air conditioning system could be better to reduce the spontaneously air change as the air tight building structure. The air conditioning system with electrical consumption is more energy efficient as the spontaneously air change. In consequence of non-controlled air movement we can't achieve the comfort requirements, in the same time the energy consumption of the building could be much higher as accepted. Balancing the waterborne and airborne systems, doing energy optimisation could reduce the annual energy consumption of building stock. The well balanced and operated HVAC system as important that the properly design.

We have to prepare an energy audit to come to know the energy consumption of buildings. The goal of the audit is to calculate the used energy sources and their cost, than to work out measures and suggestions to reduce the energy consumption. Part of the audit is the analysis of the existing situation and suggestions reducing the energy consumption technical and economical point of view.

2. The goal of the dissertation

Topic of the dissertation is connected to the directive 91/2002/EC on energy performance of buildings of European Union. During the calculation of energy consumption of buildings we determine the integrated energy performance of buildings, which is the annual specific amount of energy consumption of HVAC system associated with a standardised use of the building expressed in kWh/(m^2·a). The integrated energy performance of buildings contains the energy consumptions of heating, air conditioning, domestic hot water and lighting system, including the efficiency and self-consumption of these systems. The energy came from active solar, photo-voltaric, CHP with the own building could be reduce from the total energy consumption.

Based on the directive 91/2002/EC on energy performance of buildings of European Union the 7/2006 TNM decree gives requirements for the new and the existing buildings with major renovations. Using the decree we can calculate the energy consumption of the investigated building. The directive 91/2002/EC specifies the energy certificate of the existing buildings. The certificate can be done, the buildings can be classified, so it is possible to compare the different building energy consumption point of view. The certificate valid for standard use of the building, takes no notice of the behaviours of occupant, balancing of the operating building, real setting of control devices, set parameters of building management system, and a lot of other factor, which determine the real energy consumption of the given building. The target in the buildings that the occupant should be satisfied with his/her environment and comfort. The comfort and the energy consumption are connected with each other. Keeping a given parameter for example the operative temperature in a small range gives different system connection, control solution.

I would like to present and justify my thesis in two different areas, which logical connected to each other. The presented investigations, different hydronic connections, balancing of air borne and water borne systems all are very important in the energy balance of buildings influencing air change of buildings. My goal was to develop a new method for energy audit of buildings which is not only suitable for certificate of buildings, also exactly determines the energy consumption of the given building taking into consideration the comfort and indoor climate requirements of occupant. Knowing the energy consumption of existing building is important in itself, but to suggest energy saving measures, to offer better indoor climate is relevant for the scientific research and the daily practice. In my thesis I developed the method and process of the energy audit, I demonstrated the energy consumption of existing public buildings via case studies. I suggested different measures involved building structure, HVAC and lighting systems for reduce energy consumption and achieve better indoor climate. In separate chapter I investigated the energy consumption and energy audit of hospital buildings.

3. New method of investigation

In the last 12 years I made a lot of measures insuring the indoor climate and comfort in the buildings, I balanced many water borne and air borne systems, in the last 5 years I prepared more than 100 energy audits. Using the experience of the last years I developed a new method of investigation including the commissioning, energy auditing and optimization.

I developed the basic model of commissioning (Figure 1), publishing in the different national and international conferences and journals.

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One HVAC system contains several subsystems. One subsystem is for example the heating system; During commissioning the first step is always to set up some system equipments like boilers, chillers, water chillers, valves, pumps. Commissioning of the large equipments is made by a specialist delivering companies or their service contractors.
After this each subsystem’s commissioning takes place. This process includes the balancing of heating, domestic hot water, chilling, and HVAC system. Balancing is a process in which the previously set up equipments, valves, pumps, shutter and vents get in a position to let the designed mass flow through the air ducts. The imbalanced system even in its designed stage cannot cover the demanded indoor climate besides its energy consumption is larger than optimal. It is a frequent problem that even the correctly chosen and designed equipments are not working properly because of missing balance of the subsystemanother is a domestic hot

water. The common element of the two subsystems is the calorific /heat producer which needs to satisfy both the heating and domestic hot water demands. One subsystem of the air conditioning system is the air duct grid the element of which is the cooling and heating exchanger in the air handling unit. These heat exchangers are elements of the heating and cooling system as well. During the commission the common elements need to be controlled, after commissioning each subsystem, they need to be commissioned and compared to each other.

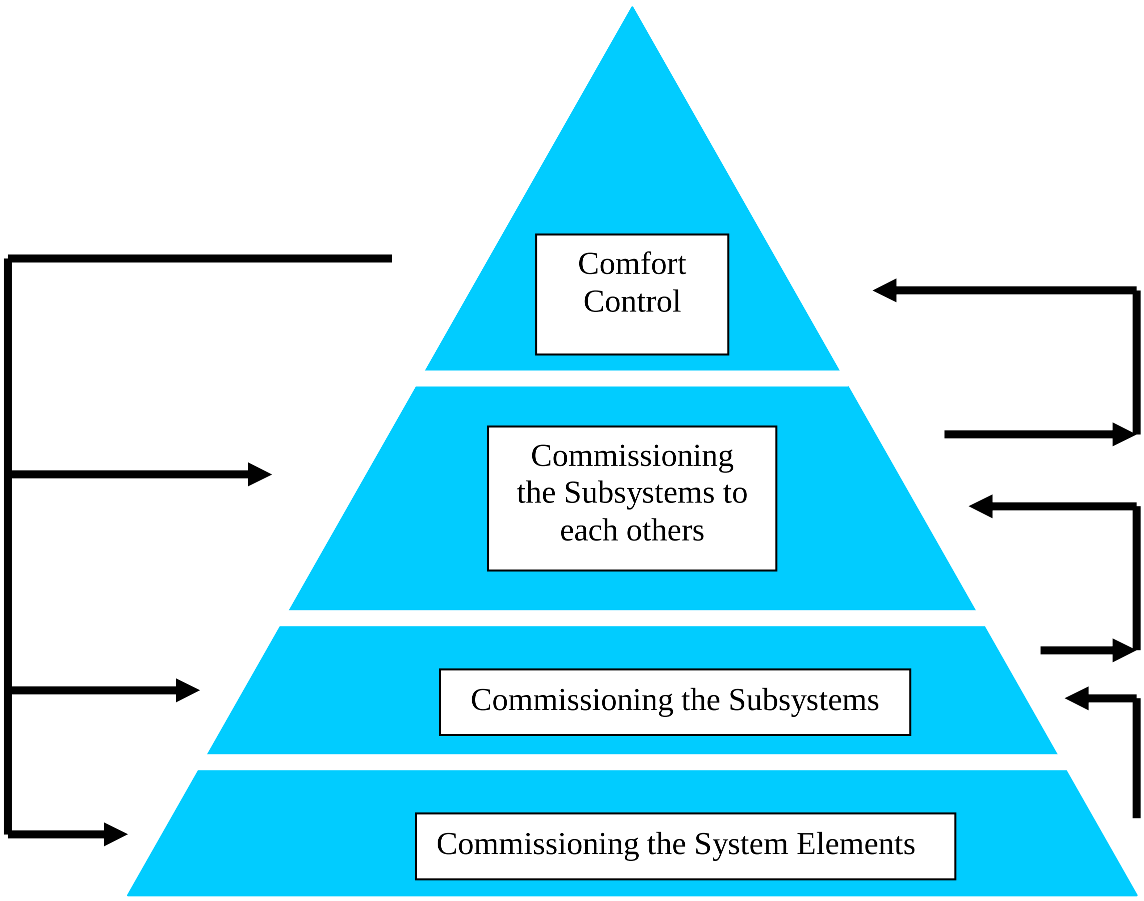

Figure 1.
Comissioning Model

When the subsystems commissions are ready then the whole system's commission is ready, the indoor climate values according to designed values need to be checked. Here belong the following measurements: room's temperature, humidity and noise; occupant zone's air velocity (draft). As long as the indoor climate is between designed and expected rate, we have finished the commissioning. In the contrary case an iteration process will start until we will not achieve desirable parameters which correspond to the category of the demanded conception. The commissioning's model is a pyramid, as we advance in the process from the lower lever to the higher in more complicated phase. In case if it is necessary we need to return to the lower levels too.

In the commissioning model I analyzed in detail the commissioning of the subsystems as well. The volume flow of the heating and chilling systems has an influence over the heat transmission. I defined the radiator's performance variation in function with the volume flow. I proved that with hydronic balancing not only we can improve the indoor climate but also we can save energy.

During the planning process the designer engineer chooses the heating and chilling system's pump and finds the working point of that as well. I demonstrated the optimal working point of the pump can be achieved after hydronic balancing with measuring. The pump operating on the optimal working point consumes minimal energy .

Using my work experience with energy audits helped me define those general measures which can lead to energy savings and better indoor climate.

4. The new scientific results and thesis of the dissertation

1. Thesis

I developed the new model of commissioning of proper indoor climate and the model's application method and I was the first to publish these results in related technical literature as well. In the 6th point of the dissertation I introduced the goal, the importance of the process, and the connections of each level. Publications to the thesis: [2],[4],[12].

The commissioning and application of the new model is the examined method of the dissertation, but in the same time it is my scientific achievement as well.

During the commissioning the first step is always to install the system elements. Working functioning of the given element needs to be checked. The elements of the system form system which in regards of the whole building can be considered a subsystem. Next step in the commissioning will be the commissioning of these subsystems.

When the subsystems commissions are ready then the whole system's commission is ready, the indoor climate values according to designed values need to be checked. As long as the indoor climate is between designed and expected rate, we have finished the commissioning. In the contrary case an iteration process will start until we will not achieve desirable parameters which correspond to the category of the demanded conception. The commission's model is a pyramid, as we advance in the process from the lower lever to the higher in more complicated phase. In case if it is necessary we need to return to the lower lever too as it shows on the figure 3.

2. Thesis

The building's comfort providing system is not working correctly because the designer was not applying the right hydronic connection. Hydronic connections, which I investigated, can be found in heating, chilling systems, in air handling units of the air borne systems, water systems and in applications of renewable energy; heat pumps and solar panels. I grouped my developed connections according to their roles in the applications, I introduced their working principles and operational misstates that can be made very often. This can be found in technical journals as well. The basic condition for a correctly working system for all the time is to use a proper connection.

For designing all the balancing circuits I worked out a connections collection. I gave a method, for different assignments and for the desired indoor climate- optimal in regards with energy consummation-to apply in connections. (Dissertation 7.1)

In the model I introduced in thesis 1. we will examine, during the comfort audit in the given building, the indoor climate. The indoor climate should correspond to normative MSZ CR 1752. To use this model, namely to keep the wanted parameters of the indoor climate reached with iteration between a given limit, it is a necessary condition to apply the proper hydronic connection.

In the last decades my experience in design and expert examinations lead me to the conclusion that the improper indoor temperature, air change rate, building deterioration, and higher than expected energy consume was caused by the wrongly designed and made unbalanced hydronic connection. According to the professional expectations, designers apply the “well working“ connections even for the new technologies like heat pumps.

Normative MSZ CR 1752 defines clearly what are the intervals for each parameter for each given indoor category. With the same hydronic connection and same balancing circle the different demands cannot be satisfied. In accordance with the demands it was a need for a technical manual, which helps in design and planning balanced HVAC circles.

3. Thesis

3/a I determined the radiator’s heating performance in function with mass flow. In my calculations I used an iteration mode, the smallest squares and spline interpolation (third degree estimation) . I calculated the radiator’s energetic efficiency in relation with mass flow (Dissertation 7.2).
3/b I proved that with hydronic balancing besides improving the indoor climate we can save energy too. Other than theoretic calculations I made two case studies concluding energy savings with hydronic balancing. (Dissertation 7.3).Publications related to this thesis: [1],[3],[5],[6],[7],[8],[9],[10],[11].

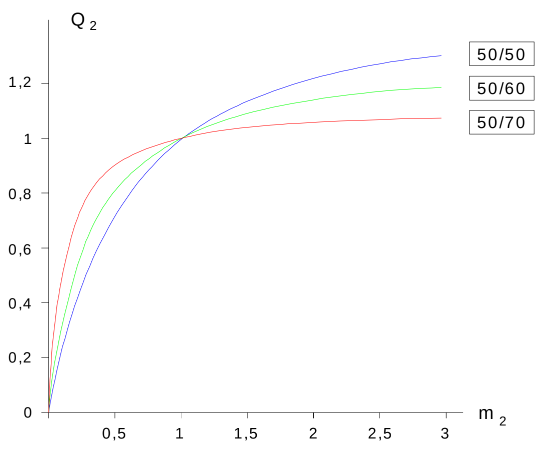

Figure 2.
Heat performance in function with mass flow

In the modeling of commissioning the HVAC systems, after commissioning the system equipments, comes the next level, commissioning the subsystems. (figure 1.). Between the subsystems I analyzed in details the hydronic balancing. During hydronic balancing the goal is to supply all the consumers with the designed volume flow meanwhile all the balancing valves are fully opened and in the same time the pump will work with maximam speed.

From (1) non linear equation in case ma →∞ we get (2) that values of Qa will not get larger than a certain level, or with the increase of the mass flow the heat transmission would increase just until a defined value.

$$Q_a = \left(\frac{Q_a \ln\left(\frac{t_{e0} - t_{b0}}{t_{v0} - t_{b0}}\right)}{m_a \ln\left(\frac{t_{e0} - t_{b0}}{-\frac{Q_a\,(t_{e0} - t_{v0})}{m_a} + t_{e0} - t_{b0}}\right)} \right)^{(1+M)} \quad (1)$$

where:

Qa - delivered (momentary)/designed heat performance
te0 - designed temperature of the flow water (°C)
tb0 - designed room temperature (°C)
tv0 - designed temperature of the return water (°C)
ma - momentary/ designed mass flow
M - radiator exponent

$$\lim_{m_a \to \infty} Q_a = \left(\frac{t_{e0} - t_{b0}}{t_{v0} - t_{b0}}\right)^{\left(\frac{1+M}{2}\right)} \quad (2)$$

The figure 2. was prepared with the numeric solution of the non linear (1) equation. I calculated the numeric solution with iteration using the algebraic computer system Maple, the interval ma = [0,3]was divided for 100 equal part. Using the the value pairs (ma, Qa) – which we received after the numeric calculations based on the Graphs on figure 2 – I searched for the appropriate function in (3).

$$\mathrm{f}(m_a) = \frac{-1 + (1 + A\,m_a^{\,2})^B}{((1+A)^B - 1)\,m_a^{(2\,B)}} \quad (3)$$

As a result of my calculation I defined in analytical form the radiator's heat performance in relation with mass flow. For example for a water heating system 80/60 °C and the indoor temperature 20 °C, the approximate equation of the function:

$$\mathrm{f}(m_a) = \frac{0.31891002305067170578\,(-1 + \sqrt{1 + 16.103854740397040026\,m_a^{\,2}})}{m_a} \quad (4)$$

In general we always talk about energy savings and energy consumptions but the truth is that we need to speak about exergy. The energy has two components, one is the exergy and the other is the anergy.

Energy= exergy +anergy

The exergy is a part of the energy which can be transferred for any kind of energy source. The anergy is the part that cannot be transferred. The exergy is the system's real working capacity, the maximal reversible work.

The energetic efficiency compared to the indoor temperature in function with the all time mass flow:

$$\eta^x = \frac{Q_a\left(1 - \dfrac{t_b}{-\dfrac{Q_a\,(t_{e0} - t_{v0})}{m_a} + t_e}\right)}{1 - \dfrac{t_b}{t_{e0}}} \tag{5}$$

Staying with our example, a water heating system 80/60 °C and the indoor temperature 20 °C, the energetic efficiency can be expressed with the mass flow:

$$(\eta^x)(m_a) = \frac{4\,Q_a(m_a)\,(Q_a(m_a) - 3\,m_a)}{3\,(Q_a(m_a) - 4\,m_a)} \tag{6}$$

Main purpose of the hydronic balancing is getting the system's designed performance the way shown on figure 2 . along with 100% designed volume flow. In this way we can ensure the demanded parameters of indoor climate. Hydronic balancing never have been examined before in regards with energy savings. The main purpose of hydronic balancing was mostly reaching the proper indoor climate. I made the analysis of hydronic balancing based on exergy point of view, which means a new approach.

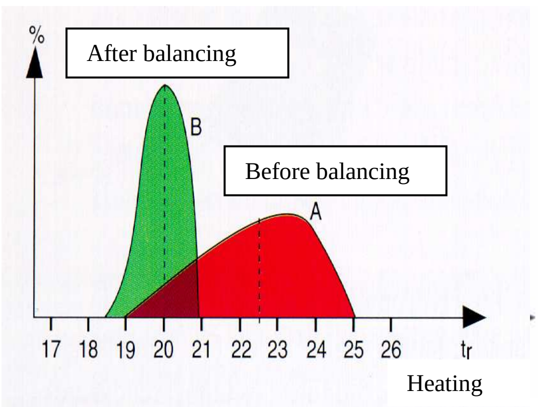

Figure 3.
Indoor temperature variation before and after hydronic balancing

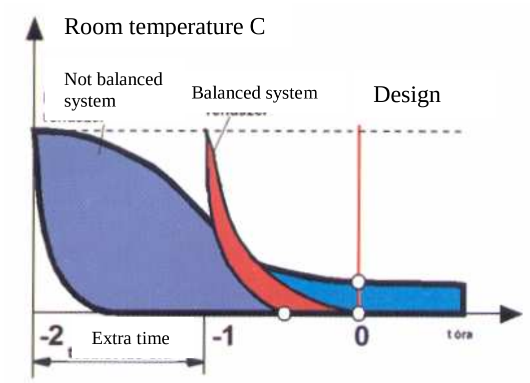

Figure 4.
Achievable energy savings in periodic run

After hydronic balancing, we can keep the indoor temperature in the range of ± 1 C° (this will correspond to "A" category of the standard MSZ CR 1752), which can lead to decrease of the average building temperature. According to the case studies, 1 C° decrease of the

building's temperature would result in 6-7% energy savings. A inside temperature decrease of 2-3 C° is reachable in the studied buildings.
Case studies are proving, that under the Budapest, IX. Bornemissza tér 8-9. sz. in the case of a 20 flats building, after hydronic balancing the building's energy savings was 19%.
Under the Budapest, IX. Kérő u. 18-20. sz. in case of a 130 flats building, after hydronic balancing the building's energy savings was 14%.
I gave the energy savings in regards of 50 years average outdoor temperature of Budapest.

4. Thesis

Targeting the convenient/good comfort, it is necessary insure a distribution of air velocity and operative temperature in a proportion that each point of the occupant zone to create the expected parameters of microclimate.
The above mentioned thesis can be ensured only with control of the air conditioning system. I developed the new routine to control the air conditioning. I gave a step by step method for work problems of air conditioning control. (Dissertation point 7.4.). Publications related to this thesis : [15],[16].

The purpose of the process is to satisfy all time demands of human living, working indoor.
The process of balancing the air borne system is different and more complicated from the hydronic one, because of the large numbers of air inlets.

We need to control the air conditioning:
to ensure the required and expected parameters (operative temperature, air velocity in the occupant zone, indoor air quality);
to reduce the energy cost;
to prevent the sick building syndrome.

I developed and I worked out the details of air conditioning control, the basis of which is the law of proportionality.

In a case study level I examined the comfort parameters of the given premises. I checked the measurements with CFD simulation and I determined the distribution of air velocity and temperature in the measured premises. Following my instructions and executing CFD simulation repeatedly, after finishing the control of air conditioning, parameters of the comfort improved a lot, their distributions became uniform.

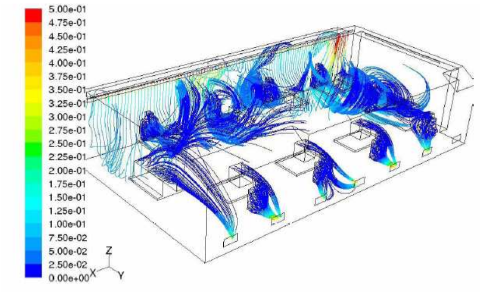

Figure 5.
Air velocity distribution before control

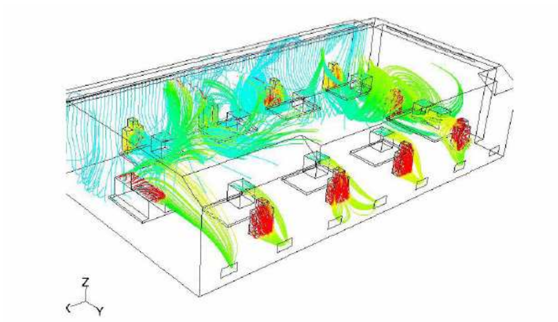

Figure 6.
Temperature distribution before control

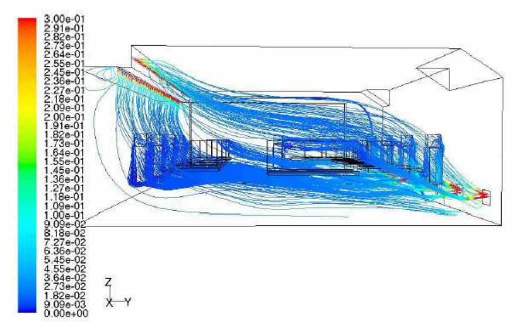

Figure 7.
Air velocity distribution after control

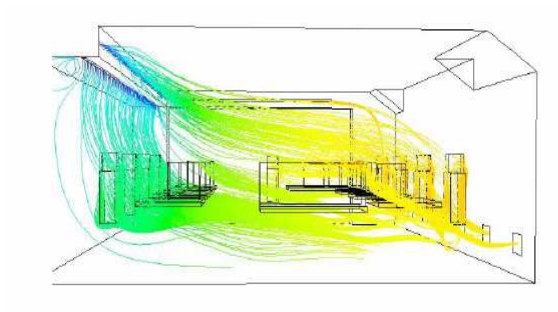

Figure 8.
Temperature distribution after control

5. Thesis

To determine the comfort parameters of the indoor we need to use an expert system since we have a large numbers of possible solutions. In this case we will get the best results. I developed an algorithm and based on that a knowledge based system. This system introduces input parameters, or those combinations, which can change the desired comfort level. (Dissertation 7.5.). Publications related to this thesis: [17],[23].

A given level of comfort can be achieved (PMV, PPD) with the influence of several compound values of the parameters. In case the investigated premises will not reach the expected level of the comfort, we need to change one of the parameter or combinations of the parameters.
My developed algorithm and computer program is an expert system - within which it is knowledge based one as well - that shows the consumers the heat-comfort related potential solutions.

I made an experimental system to study the indoor air quality in premises. The goal of the computer supporting is to solve the appearing conflict between different criteria and to examine and to line up the hypotheses to harmonize the architect’s building service’s and electrical engineer’s work. Another advantage of logical programming’s point of view is the knowledge base representation. This program will provide automatic problem solving for logically well described problems, including the research and all the alternative solutions too.

6. Thesis

Influenced by Directive on Energy Performance of the Buildings for every country of the European Union must introduce the legal conditions and requirement-systems which apply to verifications of: building's control, building's audit, boilers and HVAC. The 7/2006 TNM Decree gives requirements and algorithms that need to apply during our investigations. Between the values of requirements the expected value of specific heat transfer coefficient is listed which is independent from the operation of the building.

6/a. Based on energy audits of several hospitals I determined the specific heat transfer coefficients for hospital's buildings. Comparing the results with the requirement's values, I got the conclusion that the effective values of specific heat transfer coefficients are generally lower with 68%. The real specific heat transfer coefficients of the hospital's buildings can be expressed with the following equation: q = 0,0717 + 0,9189 (ΣA/V). (Dissertation 7.5.). Publications related to this thesis: [19],[20],[21],[22],[24].

The specific heat transfer coefficient it is the algebraic sum of transmission heat flows and the proportion of the radiation (passive) heat used during an average heating season, calculated based on a indoor -outdoor temperature difference and a heated volume unit. This coefficient depends from the parameters of the building and only the characteristics of the building, independent from the designation of the building. Equation of specific heat transfer coefficient in the function with surface/volume can be calculated with the following formula, according to 7/2006 TNM decree:

$$\Sigma A/V \le 0,3 \qquad q_m = 0,2 \qquad W/m^3K \qquad (7)$$

$$0,3 \le \Sigma A/V \le 1,3 \qquad q_m = 0,086 + 0,38\,(\Sigma A/V) \qquad W/m^3K \qquad (8)$$

$$\Sigma A/V \ge 1,3 \qquad q_m = 0,58 \qquad W/m^3K \qquad (9)$$

where ΣA = the sum of the wall's surface
V = the heated building's volume (heated air volume)

I determined the real values of specific heat transfer coefficient and I draw a regression diagram with obtained results. The equation is :

$$q = 0,0717 + 0,9189\,(\Sigma A/V) \qquad W/m^3\,K \qquad (10)$$

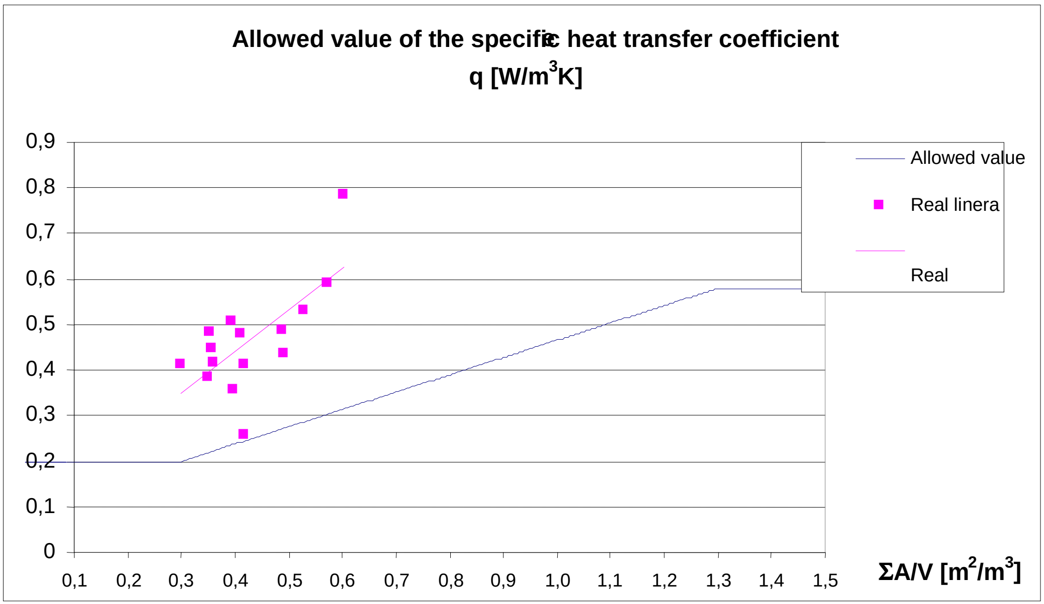

Figure 9.
The requirement of the specific heat transfer coefficients of the buildings and in case of the hospital buildings the values of the real specific heat transfer coefficients

Based on consumer dates I determined the values of real indoor energy gain of the hospital buildings. With these dates I determined the allowed values of the primer heating energy consumption in consideration with the decree TNM in regards with the buildings and HVAC systems.

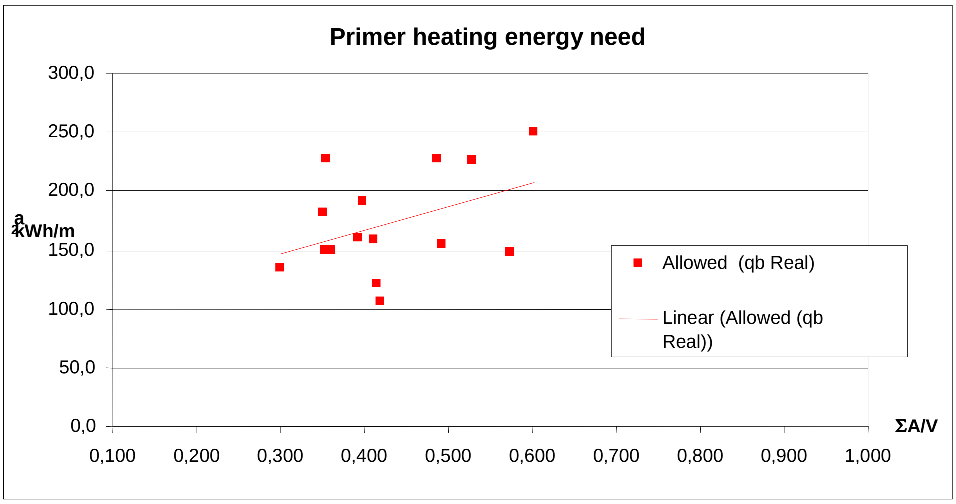

Figure 10.
Primer heating energy needs of the studied buildings

6/b. I studied the real heating consumption of several hospital building. Based on the utility bills I took in consideration the following: facts dependents from the consumer, the given building service system, consume of the different subsystem and other factors related to the energy use. After executing the necessary corrections I made a proposal for primary and secondary retrofitting. I determined for the secondary retrofitting another retrofitting that can be executed consideration 8 years of return.

During the hospital buildings system's energy audit I examined the effect of the different measures for the primer heating system's energy needs. One part of the measures are related to the structure of the building (external thermal insulation, retrofitting or changing fenestration and glazing), another part was related to the building service system (build in TRV, hydronic balancing, boiler replacement to condensing or low temperature one). Figure 11 repersents the effects on the primer suggested primer energy consume of the heating system after the suggested retrofittings.

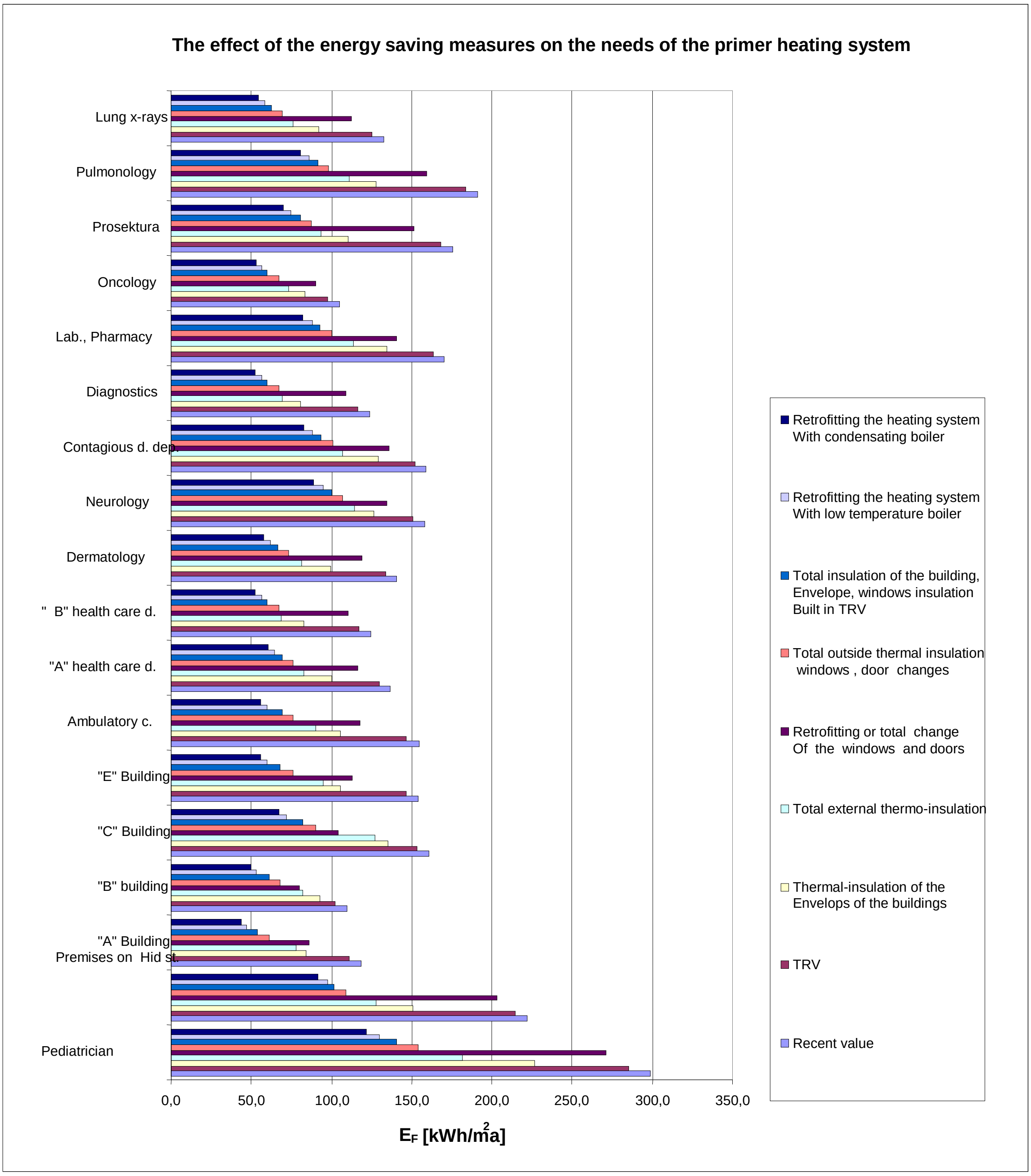

Figure 11
The studied hospital's primer energy consume of the heating system after the suggested retrofittings

My goal was-after the energy audit of the studied buildings-to determine allowed values the total primer energy use of the hospital buildings.
According to decree TNM I gave the results in a similar way for the differently used buildings, and I compared them with those published results. Figure(12.).

6/c. Based on hospital's buildings energy audit; on measurement of indoor heat gain and on heating energy requirements of the buildings I determined the required values of the cumulative energy parameters suggested for hospitals. The result of the research is the required value of the cumulative energy parameters for the hospital's buildings.

$\Sigma A/V \leq 0,3$	$E_P=189$	$kWh/m^2\ a$	**(11)**
$0,3<\Sigma A/V \leq 1,3$	$E_P=173*\Sigma A/V + 120$	$kWh/m^2\ a$	**(12)**
$1,3<\Sigma A/V$	$E_P=345$	$kWh/m^2\ a$	**(13)**

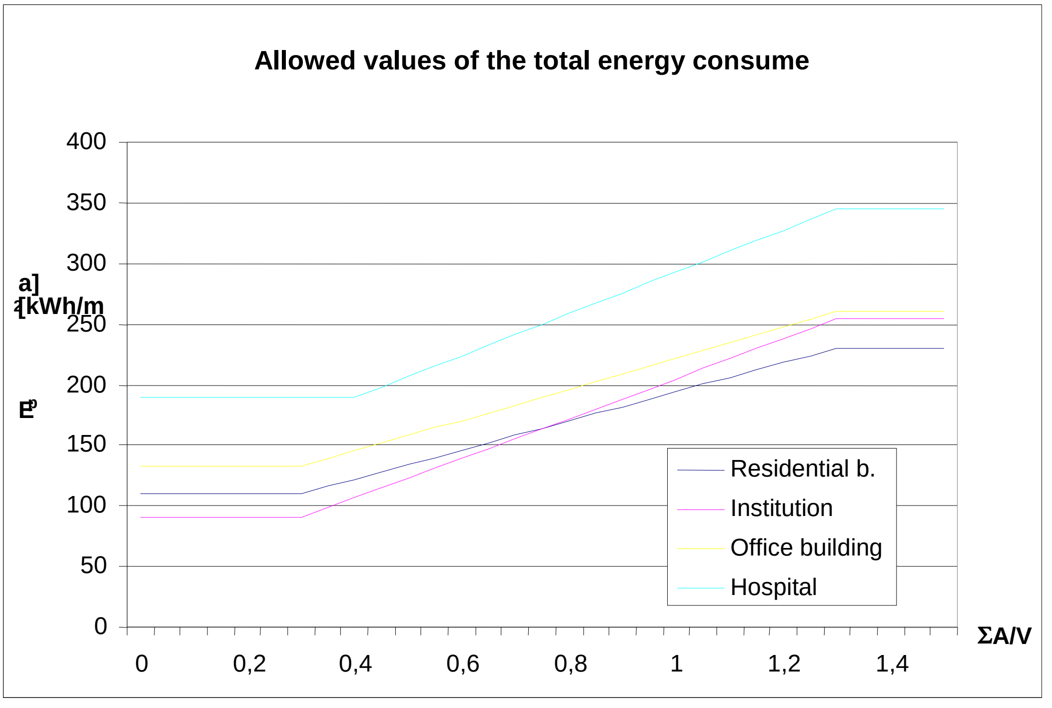

Figure 12.
Suggested required values of the cumulative primer energy exploitation
for the hospital's buildings and those connection with differently used buildings

5. Usefull posibilities of the dissertation's results

1. For designing all the balancing circuits I worked out a connections collection. I gave a method, for different assignments and for the desired indoor climate- optimal in regards with energy consummation-to apply in connections. Earlier such a collection was never at building service engineer's disposal.

2. Targeting the convenient/good comfort, is necessary to insure a distribution of air velocity and operative temperature in a proportion that each point of the occupant zone to create the expected parameters of microclimate. The above mentioned thesis can be insured only with control of the air conditioning system. I developed the new routine to control the air conditioning. I gave a step by step method for work problems of air conditioning control that can be used well in practice.

3. Decree 7/2006 TNM defines those requirements and algorithms that can be used for the inspection in our country. Between the given designations of the buildings there are no hospital types of buildings, at the present, we can count them under "other designation buildings" category. I developed the suggested required values of the cumulative primer energy exploitation for the hospital's buildings which can be directly used by engineers during the process of design and audit.

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