Energy Consumption and Indoor Climate Analysis of Office Buildings

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Keywords: - office buildings, energy consumption, simulation, indoor climate, energy efficiency

Abstract—This article introduces energy consumption and indoor climate analysis of two office buildings. Several indoor climate and energy consumption simulations with different parameters of building envelopes and HVAC systems were made of both buildings. The results showed that in modern office buildings approximately 1/3 of consumed energy is heat and 2/3 electricity. The effective means of reducing energy consumption are using efficient indoor climate control, energy-efficient electrical equipment (lighting, office equipment) and HVAC systems

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I. INTRODUCTION

Rising energy costs and environmentally friendly thinking have brought attention to the energy efficiency of buildings. Energy performance requirements have been set to new and renovated buildings in the EU [1]. In Estonia new buildings must also meet these requirements [2]. Research was carried out by Tallinn University of Technology to create these minimum requirements [3]. Also several analysis of buildings' energy consumption and indoor climate have been carried out by Tallinn University of Technology [4], [5], [6], [7]. Furthermore numerous studies of buildings' energy consumption have been carried out in several countries, for example in Sweden [8] and Finland [9]. The present study covers two office buildings that are located in Tallinn, Estonia at the latitude of 59° N on the shore of the Baltic Sea. It is studied what are the components of office buildings' energy consumption and how it can be affected.

II. ENERGY EFFICIENCY OF BUILDINGS

The energy efficiency of buildings is characterized by the amount of energy consumed to ensure required indoor climate parameters in a building. These parameters are air temperature, operative temperature, relative humidity, air speed, noise level, illuminance, air quality etc. To maintain the required values of the parameters in most cases heating, ventilation, air conditioning and lighting systems are used. The energy consumptions of listed systems are affected by architecture, construction types of building envelope elements, the parameters of HVAC systems, quality of construction works and reasonability of operating.

III. INITIAL DATA OF THE STUDIES

A. BUILDING 1

Building 1 is an 8-storie office building with heated area of 6458,8 m2. 40% of its facade is glass area. There is a bank hall and some offices on the ground floor, next 5 floors consist mainly of office rooms and there are garages on two floors underground. The heat source is a gas boiler and the heating units are steel panel radiators. The ventilation systems use rotary heat exchangers with temperature efficiency of 80% and supply air is either heated or cooled according to necessity. The cooling source is cooling station with free cooling and the cooling units are passive chilled beams and fan-coils. Domestic hot water is heated with electric boilers. The measured average indoor air temperature during heating period is +23 °C and average ventilation air flow ±1,6 l/(s*m2). The thermal transmittance of the building 1 envelope elements is given in Table 1, the windows of building 1 are described in Table 2 and measured indoor air temperatures in several offices are given in Figure 1.

Table 1: U-values of building 1 envelope elements

Building 1 envelope elements	**U-value, [W/(m^{2}K)]**	**Area, (m^2)**
Exterior walls	0,31	1353,1
Roof	0,21	1598,5
Walls in the ground	0,41	230,0
Windows	1,7	1283,5
Non-transparent part of glass facade	1,7	259,3

Table 2: Building 1 windows' description

Direction (description)	Area, (m^2)	U-value, [W/(m^2K)]	Solar factor g, -
South (transparent)	143	1,82	0,55
South (mirror)	103,7	1,19	0,27
West (transparent)	592,7	1,82	0,55
West (mirror)	46,8	1,19	0,27
East	264,2	1,82	0,55
Roof	133,1	1,82	0,55
Sum/Weighed average	**1283,5**	**1,74**	**0,52**

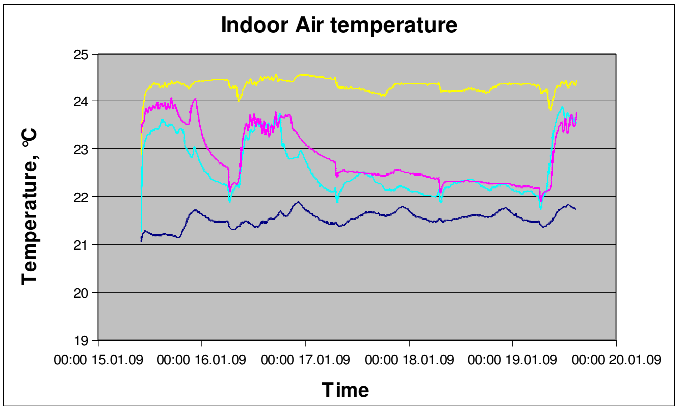

Figure 1: Measured indoor air temperatures of Building 1

The information about heat loads in Building 1 were gathered by observations in several offices and bank hall. The number of people in offices is 0.1 persons per m^2. The electrical power of lighting and equipment in offices is 12.0 and 19.5 W/m^2 respectively. The time of usage is 9 hours on weekdays and 7 hours on Saturdays and the simultaneousity is 60%. Internal heat loads in bank hall are similar to the offices. Detailed gathered information about heat loads is given in Table 3.

Table 3: Heat loads in building 1

Office room	Occupants, (persons/m^2)	Equipment, (W/m^2)	Lighting, (W/m^2)
1	0.150	22.17	21.3
2	0.077	8.25	15.8
3	0.118	8.39	21.3
Average	**0.10**	**12.9**	**19.5**

B. BUILDING 2

Building 2 is an 8-storie office building with heated area of 8105,7 m^2. 21% of its facade is glass area. The heat source is a gas boiler and the heating units are steel panel radiators. The ventilation systems use rotary heat exchangers with temperature efficiency of 70% and indirect recuperative heat exchangers with temperature efficiency of 40%. The measured heat recovery temperature efficiencies of building 2 are given in Figure 2. Supply air is either heated or cooled according to necessity. The cooling source is cooling station with free cooling and the cooling units are passive chilled beams. The measured average indoor air temperature during heating period is +23 °C and average ventilation air flow ±2,4 l/(s*m^2). The thermal transmittance of the building elements is given in Table 4, the windows are described in Table 5 and measured indoor air temperatures in several offices are given in Figure 3.

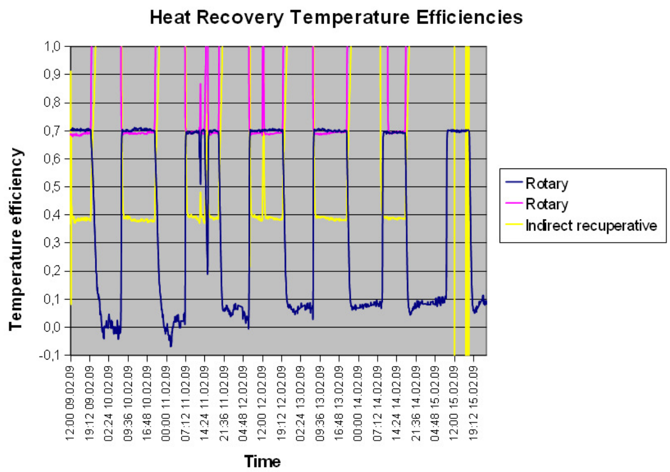

Figure 2: Heat recovery temperature efficiencies of building 2 ventilation systems

Table 4: U-values of building 2 envelope elements

Building 2 envelope elements	**U-value, [W/(m²K)]**	**Area, (m²)**
Exterior walls	0,28	3567
Roof	0,22	2135
Walls in the ground	0,31	708
Windows	1,8	955

Table 5: Building 2 windows' description

Direction (description)	**Area, (m²)**	**U-value, [W/(m²K)]**	**Solar factor g, -**
South	230	1,82	0,35
North	677	1,82	0,35
West	20	1,82	0,35
East	28	1,82	0,35
Sum/Weighed average	**955**	**1,82**	**0,35**

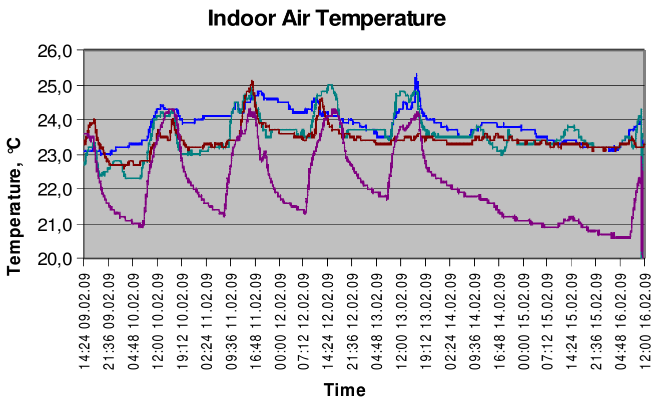

Figure 3: Measured indoor air temperatures in building 2.

The information about heat loads in Building 1 was gathered by observations in several offices and bank hall. The number of people in offices and bank hall is 0.1 persons per m². The electrical power of lighting and equipment in offices and bank hall is 15.0 and 12.8 W/m² respectively. The time of usage is 10 hours on weekdays with simultaneousity of 50% and 7 hours on Saturdays with simultaneousity of 25%. Detailed gathered information about heat loads is given in Table 6.

Table 6: Heat loads in building 2

Office room	**Occupants, (persons/m²)**	**Equipment, (W/m²)**	**Lighting, (W/m²)**
1	0.072	8.3	5.0
2	0.152	18.1	12.8
3	0.150	18.6	21.3
4	0.131	15.0	12.1
Average	**0.128**	**15.0**	**12.8**

IV. CALCULATIONS

The software used in the study was IDA ICE [10], which is a recognized Swedish indoor climate and energy consumption simulation programme. The climate file of Estonian test reference year [11] was used. The programme enables to create 3D models of buildings, model the performance and energy consumption of HVAC systems and also indoor climate. Building can be inserted into the programme either as a single zone or multiple zones. Due to complexity of studied buildings, several models of each building with multiple zones were made. The models of buildings are characterized in Figure 4, Figure 5, Figure 6 and Figure 7.

To validate the model, the energy consumption of both buildings was simulated and then it was compared to the actual energy use.

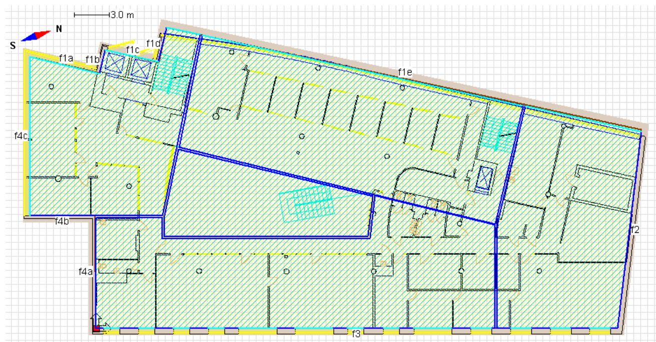

Figure 4: Building 1 1st floor plan

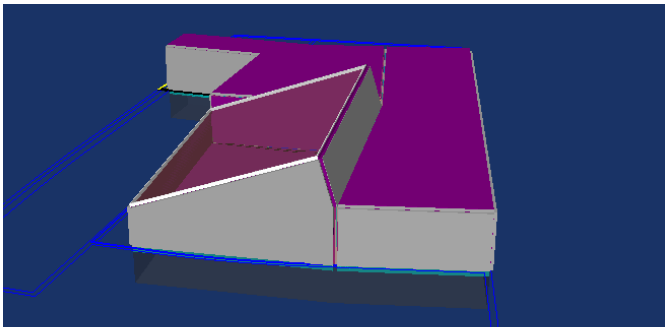

Figure 5: Building 1 6th floor model

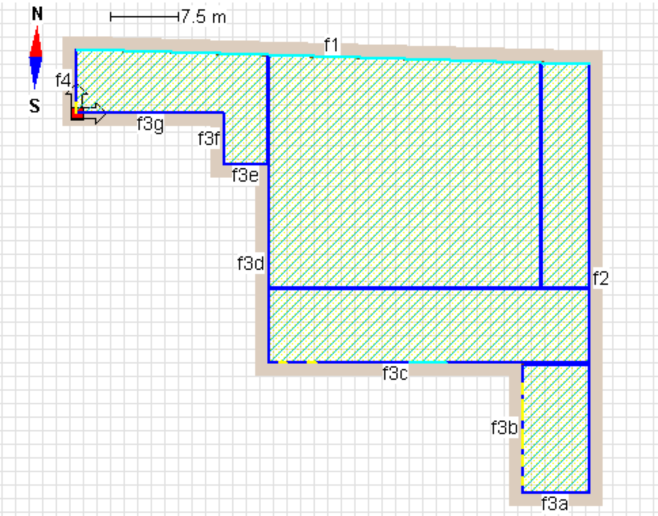

Figure 6: Building 2 ground floor plan

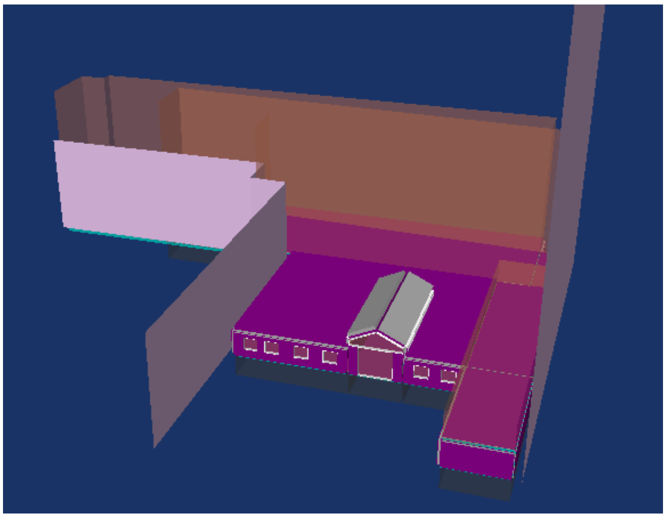

Figure 7: Building 2 1st floor model

A. DESCRIPTION OF BUILDING MODELS

After the validation of building models 4 addional variants of each building with different building envelope and HVAC system parameters were made. Only the energy consumption of buildings' office floors was calculated. Internal heat loads, air exchange rates and the parameters of indoor climate were taken from the Estonian energy-efficiency regulation [2]. The number of people in offices was 0.06 persons per m^2. The electrical power of lighting and equipment in offices was 15.0 and 18.0 W/m^2 respectively. The building is occupied 11 hours on weekdays and the simultaneousity is 55%. The ventilation air flow was ±2.0 $l/(s*m^2)$, the indoor air temperature of heating was +21 °C and of cooling +25 °C.

In variant A the actual buildings were calculated.

In variant B the thermal transmittance of building envelope was higher, plate heat-exchangers were used in ventilation systems and no free cooling was used.

In variant C the thermal transmittance of building envelope was taken from Estonian standards [12] and rotary heat exchangers were used in the ventilation system. This variant is slightly better than variant A.

In variant D the thermal transmittance of building envelope was taken from Finnish regulation C3(2010) [13] and free cooling was used. Rotary heat exchangers were used. This is the most energy-efficient variant.

More specific descriptions of building 1 and building 2 variants are given in Table 7 and Table 8 respectively.

Table 7: Building 1 variants description

	A	**B**	**C**	**D**
U-values, $[W/(m^2*K)]$				
Exterior walls	0,31	0,35	0,24	0,17
Roof	0,21	0,25	0,19	0,09
Walls in the ground	0,41	0,41	0,31	0,16
Windows	1,7	2,0	1,7	1,1
Non-transparent part of glass facade	1,7	1,7	1,7	1,1
Weighed average U-value	0,70	0,75	0,66	0,41
Heat recovery temperature ef.	0,8	0,6	0,8	0,8

Table 8: Building 2 variants description

	A	**B**	**C**	**D**
U-values, $[W/(m^2*K)]$				
Exterior walls	0,28	0,35	0,24	0,17
Roof	0,22	0,25	0,19	0,09
Walls in the ground	0,31	0,4	0,31	0,16
Windows	1,8	2,0	1,8	1,1
Weighed average U-value	0,47	0,54	0,44	0,27
Heat recovery temperature ef.	0,8	0,6	0,8	0,8

V. RESULTS

The results of the study show that approximately 2/3 of office buildings' energy consumption is formed by electricity and 1/3 by heat energy. The largest heat energy consumer is space heating and the largest electricity consumers are lighting, office equipment and ventilators. The specific energy consumed by different systems in building 1 and building 2 are given in Table 9 and Table 10 respectively. The amounts of consumed electricity and heat energy are Figure 8 given in and Figure 9. Although current study focused on analyzing heating energy consumption, it can be assumed that reducing energy consumption of electrical equipment, helps reduce office buildings energy consumption considerably.

Table 9: Building 1 simulation results

	Space heating*, (kWh/m^2)	Space cooling**, (kWh/m^2)	Vent. air heating*, (kWh/m^2)	Vent. air cooling**, (kWh/m^2)	Ventilators&pumps**, (kWh/m^2)	Equipment&lighting**, (kWh/m^2)	Hot water, (kWh/m^2)	Total energy, (kWh/m^2)
A	60	4,7	5,0	1,7	23	60	5,2**	160
B	62	7,9	23,9	1,8	25	60	5,2**	186
C	55	7,7	5,8	2,3	24	60	5,2*	161
D	36	5,9	5,3	2,0	25	60	5,2*	140

* - Heat

** - Electricity

Table 10: Building 2 simulation results

	Space heating*, (kWh/m^2)	Space cooling**, (kWh/m^2)	Vent. air heating*, (kWh/m^2)	Vent. air cooling**, (kWh/m^2)	Ventilators&pumps**, (kWh/m^2)	Equipment&lighting**, (kWh/m^2)	Hot water*, (kWh/m^2)	Total energy, (kWh/m^2)
A	45	0,4	35	2,1	31	60	6,8	176
B	48	2,3	28	2,1	26	60	6,8	174
C	42	0,6	7,9	2,4	26	60	6,8	146
D	26	0,3	7,6	2,1	26	60	6,8	129

* - Heat

** - Electricity

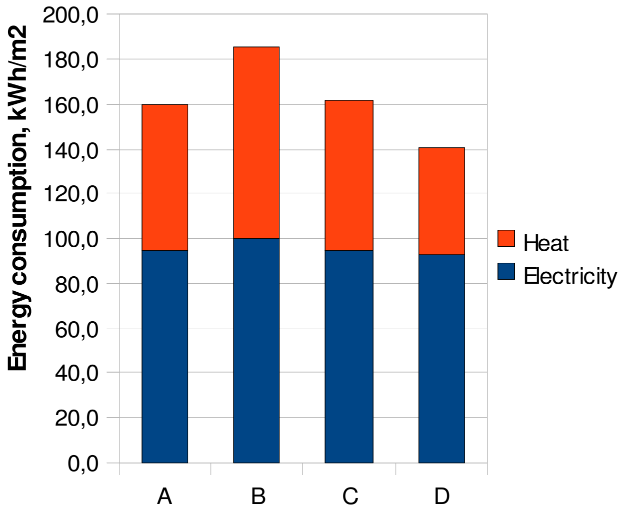

Figure 8: Building 1 specific energy consumption

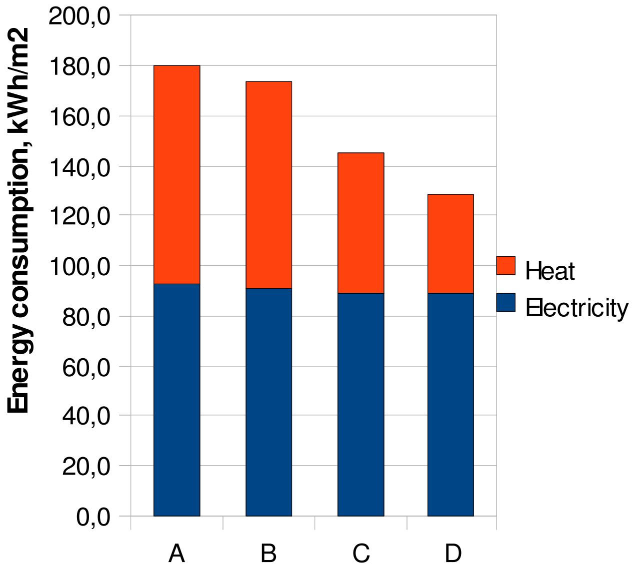

Figure 9: Building 2 specific energy consumption

The amounts of heat consumed by different systems is given in Figure 10 and Figure 11.

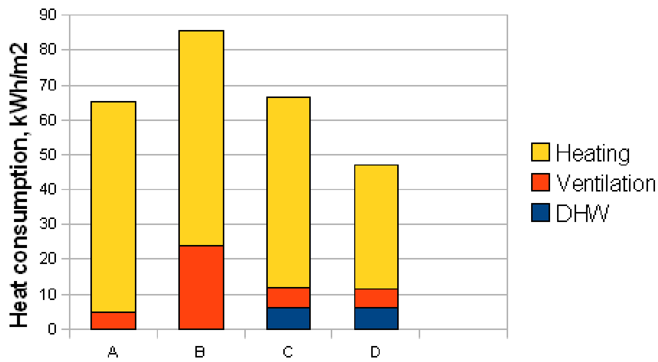

Figure 10: Building 1 specific heat consumption

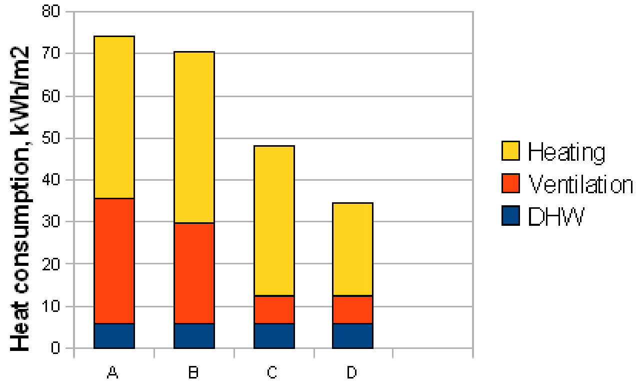

Figure 11: Building 2 specific heat consumption

The amounts of electricity consumed by different systems is given in Figure 12 and Figure 13.

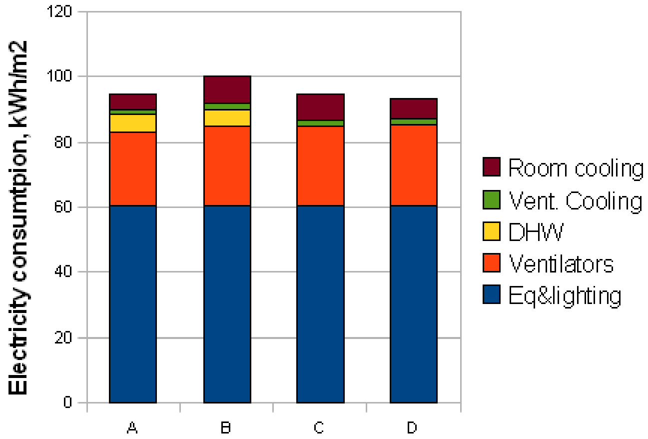

Figure 12: Building 1 specific electricity consumption

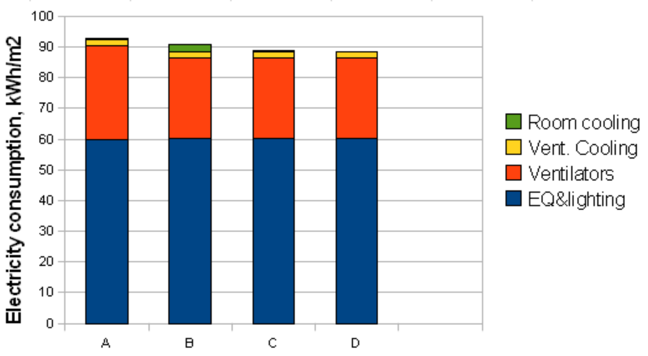

Figure 13: Building 2 specific electricity consumption

The relation between building envelope U-value and space heating energy consumption in practically linear. Reducing the U-values by 50% reduces buildings space heating energy consumption by 45 % and total energy consumption by 12,5 %. The relations between building envelope average weighed U-values and space heating energy consumption are given in Figure 14 and Figure 15.

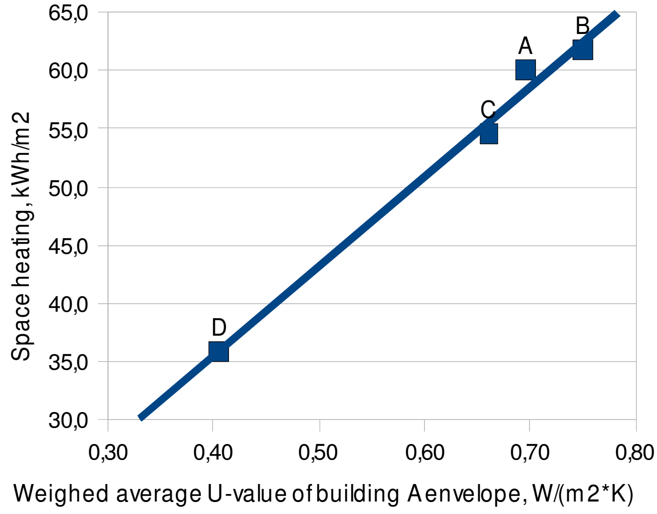

Figure 14: Building 1 space heating specific energy consumption

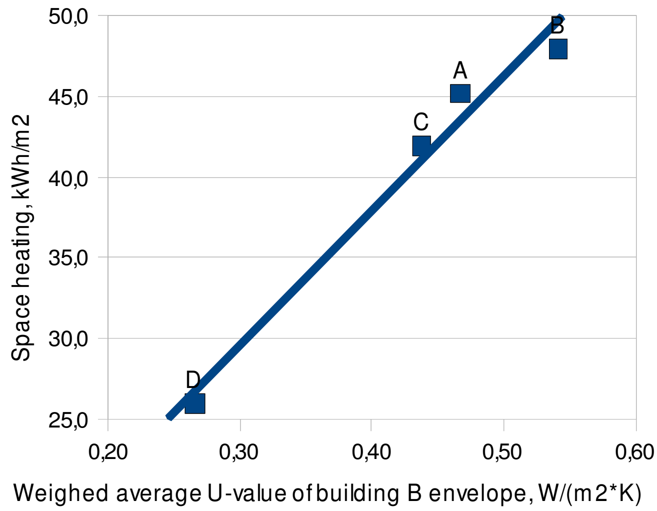

Figure 15: Building 2 space heating specific energy consumption

In case of ventilation heat exchangers' temperature efficiencies of 60% and 80%, the heat recovery energy efficiencies are 75% and 95% respectively. The additional ventilation air heating consumption is 4 times smaller in case of using rotary heat exchangers compared to plate heat exchangers. Also in that case buildings total energy consumption is 10% smaller. The relations between ventilation temperature efficiency and consumed additional ventilation air heating energy are given Figure 16 in and Figure 17.

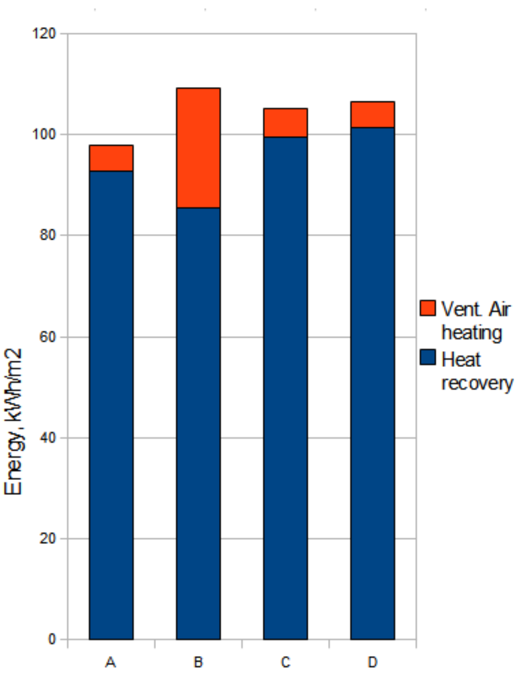

Figure 16: Building 1 ventilation system specific heat consumption

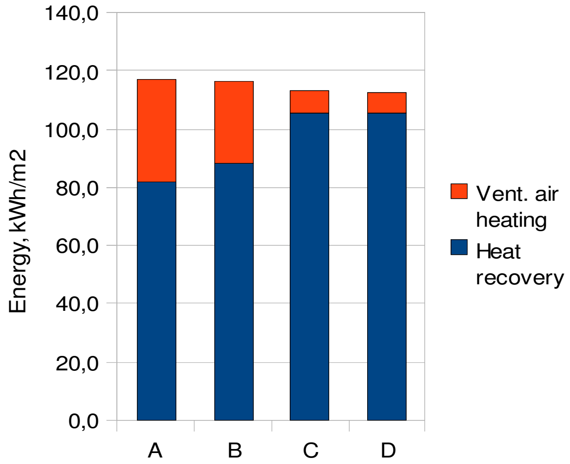

Figure 17: Building 2 ventilation system specific heat consumption

A. ANALYSIS OF ACTUAL SITUATION

As seen in Figure 1 and Figure 3, the actual indoor air temperature was approximately +23 °C instead of +21 °C, which causes considerably higher space heating energy consumption. In building 2 the temperature efficiencies of ventilation systems' heat exchangers were measured and in case of rotary heat exchangers it was 70%, which differs from values given in Estonian energy efficiency regulation, which differs from the values given in the Estonian energy-efficiency regulation [2]. Also the energy consumption of ventilation systems, lighting and office equipment were higher compared to simulation variants. This was caused by longer working hours and using offices on Saturdays. This means that depending on the characteristics of the office building and the work done in offices, the specific energy consumption of office buildings can vary within relatively large borders. Furthermore, in the current study, the energy consumption of outside lighting, elevators, servers (and their cooling), etc was neglected from the results of energy consumption of the buildings. This increases the diversity of office buildings energy consumption even further.

VI. CONCLUSIONS

The results of the study show that about 2/3 of office buildings energy consumption formed by electricity and 1/3 by heat. Electricity consumption is mainly formed by, lighting office, equipment and ventilators. There are smaller amount of electricity consumed by room and ventilation air cooling, also domestic hot water, if it is heated with electrical boilers. However the energy consumed by cooling system may be increased if the room temperature setpoint is lowered (e.g. +21 °C), but this situation was not simulated in the current work. Most of the heat is consumed by room heating and smaller amounts by ventilation air and hot water heating.

The study also shows that the most effective way of lowering heat consumption of office buildings is using effective ventilation heat recovery and in Estonian climate also reducing U-values of building envelope elements. Although the electricity consumptions of lighting, office equipment and ventilation fans was not changed while making the simulations in the study, it can be said that attention must be paid to these energy consumers. If it is possible natural daylight and energy-efficient office equipment should be used. Also while designing ventilation systems, the pressure drop of the systems should not be too high and energy efficient fan motors should be used.

Finally, it must also be reminded, that indoor air temperature must not be too high during heating period.

To conclude the energy efficiency of office buildings should be paid serious attention to, because it is a common type of building and generally its consumes more energy per area unit than for example residential buildings.

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