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How Energy Efficiency Measures Influence and Simplify the HVAC Design at Austria´s biggest Plus-Plus-Energy Office Building

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Abstract

Due to the precisely optimization of up to 9300 building components and an optimized passive house envelope, the primary energy demand has been reduced to a minimum. The consequent implementation of plenty of energy efficiency measures enables less HVAC efforts by simultaneously maintaining high level thermal quality requirements. Therefore, an optimized heating, cooling and ventilation demand simplifies the entire HVAC system to meet all challenges and requirements regarding a comprehensive refurbishment towards a plus-plus-energy office building. The implementation of a CO_2 driven and real occupation based ventilation system with a variable and optimized air rate, is only one key element towards user satisfaction, HVAC simplification and integral planning stages. Furthermore, an interdisciplinary team of experts, including a scientific team of the TU Wien, have been used the instruments of holistic planning approaches and a simulation based decision making process during all stages. The primary energy balance at Austria's biggest plus-plus-energy office building covers not only the energy demand for it´s entire operation, but also for the energy demand caused by all it´s occupancies. As a result of the reduced area for the HVAC distribution and generation, this building benefits of an additional conference room at the top of this building as well as an additional night ventilation system. By considering the general issue of complex refurbishments within a city, the concept and the approach of this plus-plus-energy office building can be seen as a best practice example in terms of facing future urban challenges.

Keywords – efficiency arrangments; HVAC design; Plus-Plus-Energy Office-Building

1. Introduction

In the course of an ambitious initiative within the TU Wien (Vienna University of Technology), an over 40 years old high rise building has been refurbished comprehensively to Austria´s biggest plus-plus-energy office building. This building is located in the very center of Vienna and originally consists of a two level basement and 12 upper stories. Before it´s refurbishment, the building was occupied by the faculty of chemistry, including chemical laboratories.

Fig. 1 - Plus-plus-energy office building before the refurbishment [1]

The entire building has a net floor area of approximately 13500m^2 and occupies roughly 500 employees of the faculty of mechanical engineering. The building is operating since September 2014. This research focuses on how energy efficiency measures influence and effect the design of the entire HVAC system, with respect to the general aim of achieving a plus-plus-energy office building.

While the plus-energy office building standard usually describes an on site positive primary energy balance for the buildings operation within one year (HVAC, controlling system, etc.), the plus-plus-energy office building standard also considers the primary energy demand for the entire office equipment, kitchens, elevators, lighting as well as other appliances such as switches, routers and copy machines.

The main focus was to manage this massive reduction of the entire energy demand for all sections and components within this building. Therefore, more than 9300 components within 280 categories have been registered, improved and approved during all stages.

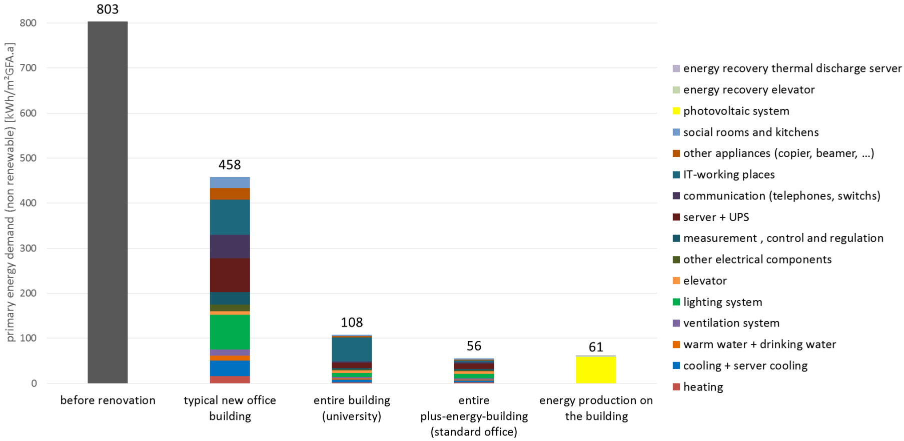

Fig. 2 – simulated primary energy balance of the plus-plus-energy office building compared to the old stock and to a typical office buidling [2]

Fig. 2 represents the results before and after the comprehensive refurbishment. Due to the building was used as a chemical laboratory which is completely different to the current office occupation, a before and after comparison would not be very meaningful. Therefore, all results have been compared to a state of the art office building. By considering a typical new office building (according to the current Austrian standards), the primary energy demand decreases from 458 kWh/m^{2}a to 108 kWh/m^{2}a, respectively to 56 kWh/m^{2}a by focusing only on the office space according to chapter 2. In order to achieve a plus-plus energy office building, the building benefits not only from Austria´s biggest building integrated photovoltaic power plant, but also from an energy recovery of it´s 3 elevators as well as from a waste heat recovery of all IT-servers within it´s server room.

2. Constraints and Aims

The constraints for the plus-plus-energy office building (primary energy, non renewable) consider only the building and its surface over an observation period of one year for all energy flows based on Fig. 3. This is including the energy demand for both, operation (heating, cooling, ventilation, lighting and domestic water) and usage (computers, servers, all kitchens as well as all electronic appliances) within the 3rd and 10th floor, which are occupied as office use. The basement, ground floor, 1st and 2nd floor as well as the 11th floor are not occupied as office space and therefore not addressed within this research. By considering the urban neighborhood of the plus-plus-energy office building, space for photovoltaics is limited. This led to the approach, that energy efficiency measures are not only influencing the cooling, heating and electrical loads, but also decreasing necessary area for photovoltaics towards a plus-plus-energy office building. This fact is not only an issue for the technical feasibility, but also effects the overall costs.

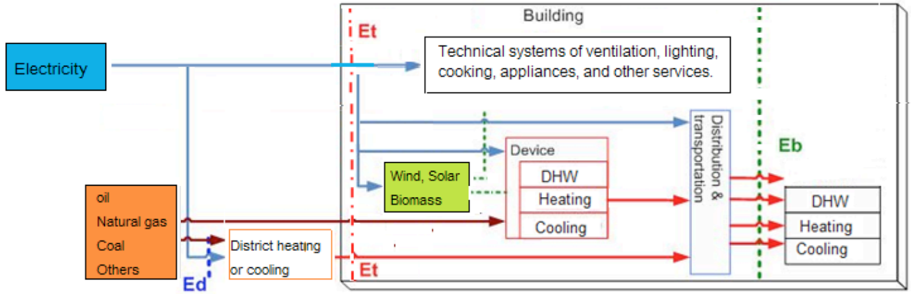

Fig. 3 - Energy boundaries Eb and Et based on [3] for the primary energy non renewable

3. Method

By considering all framework conditions, the team of planners was set up differently. Besides the traditional roles of an architect, HVAC planner, building physics planner, building owner and operator, the entire team was supported by external experts (e.g. photovoltaic specialist) and by a scientific team of the TU Wien. This led to a comprehensively interdisciplinary and holistic approach within all stages, including the planning, construction and commissioning. Therefore, all important decisions have been made by the entire team in the course of workshops and meetings. Moreover, every single component has been undergoing through an intensive approval process by external experts as well as by the scientific team. All decisions regarding different concepts and feasibilities have been made based on continuous building simulation results using BuildOPT_VIE [4, 5]. This enabled a decision making process based on dynamic and quantified simulation results, which is unlikely for conventional projects within all planning stages. Furthermore, interdisciplinary impacts due to mayor changes, could be identified within these stages.

4. Results

This chapter presents some selected and significant results within the planning process of the plus-plus-energy office building. Therefore, each optimization process will be explained and the effects on the overall aim are highlighted. In order to make all results comparable, most of the results are referencing to the specific primary energy demand – kWh/m^{2}a.

Ventilation

The entire office space is supplied by fresh air, using three different ventilation systems. Two ventilation systems are dedicated to the office space and one is dedicated to all restrooms within the office space. The optimization process focused mainly on the air rate, optimized pressure losses due to the distribution, occupancy scenarios, heat recovery, the specific fan power of all fans as well as on the set up of the ventilation system.

Table 1 – Comparison: specific to total air flow rate q_{tot} (q_P=7 l/s Person; q_B=0.35 l/m^2s)

Office Room (A)	Occupation (n)	Total air flow m^3/hr	Specific air flow m^3/hr Person	for 500 occupants m^3/hr
10 m^2	1	37.5	37.5	18750
10 m^2	3	88.2	29.4	14700

$$q_{tot} = n \; x \; q_P + A \; x \; q_B \qquad (1)$$

Based on Table 1, (1) and [6], the air volume is depending on the occupation and the room size. In terms of air rate, office rooms with a higher occupation perform more efficiently. Using only big office rooms, the overall air rate will decrease by 20%, but in fact there is an equal share between bigger and smaller office rooms. The examples of Table 1 are strengthening the approach to focus on the level of an individual room in order to calculate the overall air rate for an entire building. Assuming that the occupancy is decreasing to 55% [7] compared to a maximum occupancy scenario, the maximum air flow rate can be optimized to the real fresh air demand. Considering the probability of the the real occupation, it is reducing not only the specific air flow rate by 45%, but also the space for it´s distribution. In order to take advantage of a real fresh air supply, instruments such as motion detection and continuous CO_2 measurements have been installed. Furthermore, fans with a specific fan power of 0.45 W/m^3 instead of 0.8 W/m^3 have been used [6]. Those energy efficiency measures enabled a variable and occupation based fresh air supply within the entire office space.

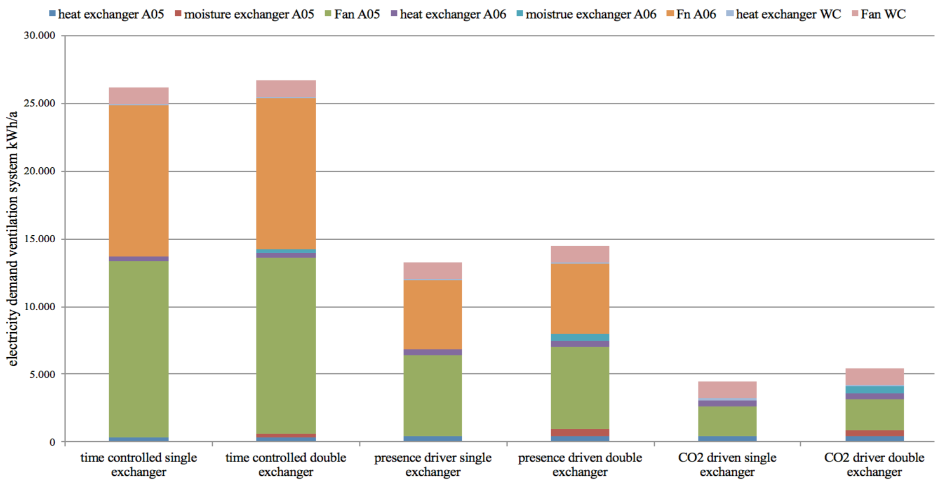

Fig. 4 - Optimization process for the final energy demand of the ventilation system

The results of this optimization process can be seen in Fig. 4. Comparing a time controlled ventilation system with a CO_2 driven ventilation system, the electricity demand to run the entire ventilation system decreases by 80%. Fig. 5 highlights the effects on the overall primary energy demand.

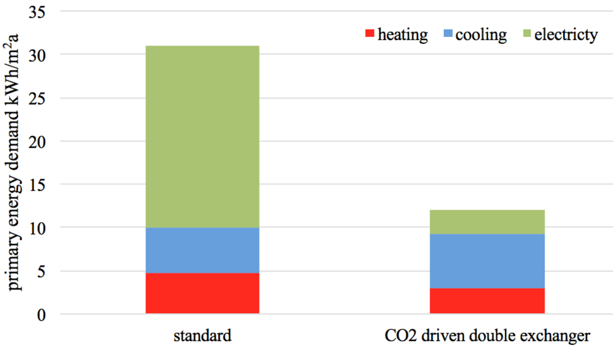

Fig. 5 - Optimization process for the primary energy demand of the ventilation system with respect to the heating, cooling and electricity demand

In conclusion, the total savings for the ventilation systems end up with 18.89 kWh/m^{2}a primary energy. When talking about refurbishments, the size and the number of installation shafts is usually fixed. An additional result, which can hardly be quantified using primary energy demand, is the reduction of distribution efforts due to the optimized air rate. Not only in terms of pressure losses, but also the space for the installation. Due to the results of all energy efficiency measures, one former installation shaft is now free of any installations. This shaft is now dedicated for night ventilation purposes only. The night ventilation is decreasing the cooling demand by using only automatically open windows in each floor, thus, enables less distribution efforts for the cooling system. The results on the effects for the night ventilation regarding the cooling demand are part of the ongoing monitoring process and can't be published yet.

Lighting

Talking about plus-plus-energy office buildings, the energy demand for lighting is usually a big issue. The aim was to ensure an illumination intensity of up to 500 lux, by taking advantage of an optimized daylight factor. Using 24W LED with an efficiency of 110 lm/W, decreases the installing power for lighting to 3.7 W/m^2 for the office space. The operation conditions of the lighting are similar to the ventilation system. Only occupied offices will be supplied with light. Furthermore, the controlling system distinguishes between the preferred natural light and the lighting demand by LED using up to four lux meters for each room as well as automatic external shading devices. Fig.

6 highlights the difference between a non LED scenario and two LED scenarios with respect to effects on the primary energy for heating cooling and electricity demand. The primary energy demand for lighting decreases by 57% (28.24 kWh/m^{2}a). By considering only the share of electricity, it's decreasing by 69%.

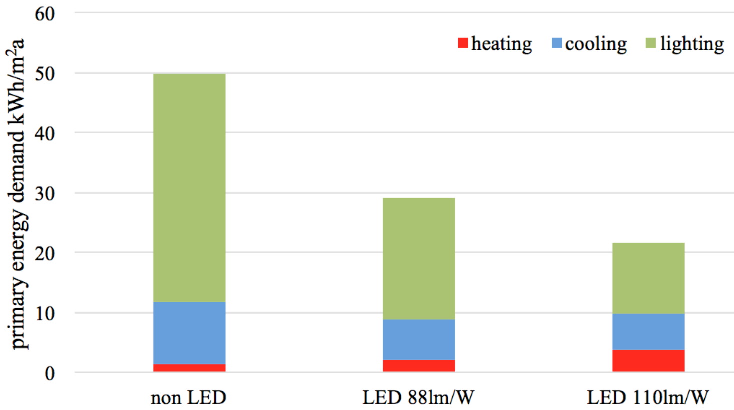

Fig. 6 - Optimization process for the primary energy demand of the lighting system with respect to the heating, cooling and electricity demand

Electrical Appliances

The plus-plus-energy office building focuses not only on the operation, but also on the energy demand caused by the occupancies. In this case, the main focus was on the entire IT equipment and infrastructure, kitchen appliances as well as phones, coffee machines and copy machines. The first step was to relocate IT intensive processes, such as for computing and simulation purposes, to the dedicated server room of this building. Using a dedicated server room, enables a centralized cooling and thus, a more efficient cooling process. The second step was to substitute old IT hardware such as monitors and computers by initializing an exchange program towards to more efficient hardware within the office space. This ends up in a workspace using a less or equal 10W computer and a 15W monitor. By using a remote connection to it's server room, all intensive applications are still available, but the computing efforts are not anymore within the office rooms. Besides the massive reduction of cooling energy, the office rooms benefit from a less noise level. For all other appliances, only triple A labelled devices have been used.

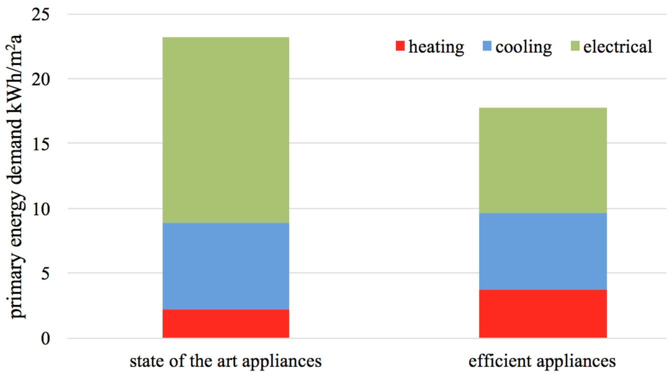

Fig. 7 - Optimization process for the primary energy demand of all occupancy based appliances with respect to the heating, cooling and electricity demand

The effects on the efforts for more efficient appliances can be seen in Fig. 7. Due to less power for appliances, the heating demand is increasing by 1.5 kWh/m^{2}a, while the electrical share of the primary energy demand is decreasing by 6.25 kWh/m^{2}a. Due to the cooling effort is shifted to the server room, the primary energy demand for cooling decreases by 0.7 kWh/m^{2}a.

Heating and Cooling

The optimized passive house envelope reduces the influences of the ambient temperature and solar radiation dramatically [2]. Thus, the internal loads become a mayor importance regarding all comfort parameters. The symbiosis of this well insulated envelope and optimized internal gains leads to low heating and cooling loads and thus, the plus-plus-energy office building is taking advantage of a single change over floor heating and cooling system within the screed. Due to constraints in terms of floor surface temperature, this system is limited regarding it´s power. Therefore, the temperature level for the heating system ranges from 24-30°C. Due to the small share of heating loads for the office space compared to the entire building and buidling neighbourhood, the effects on the temperature level for the district heating system can´t be quantified, respectively are insignificant. Considering a room temerature set point of 22°C during the winter, the operative temperature will drop to 18.6°C to 20°C by using the change over heating system without an passive house optimized envelope. By considering the baseline scenario during the summer periode (standard refurbishment), the operative temperature will rise to 35.2°C to 36.2°C. The operative temperature during the summer time within the plus-plus-energy office building performs in a range from 26.1°C to 26.5°C [2]. In addition, the combination of the floor heating system with low heating loads, enables the use of low temperature waste heat from it´s server room for heating the entire office. This makes the server room to the primary heating system within the office space, backed up by the district heating system. Table 2 summarizes the key facts regarding the envelope, heating and cooling system.

Table 2 - key facts regarding the envelope, heating and cooling system comparing a standard refurbishment with the plus-plus-energy office building

	Standard Refurbishment	Plus-Plus-Energy Building
Ventilation	No	Yes (0.902 recovery)
Heating system	Radiator	Change over floor heating ($15W/m^2$)
Cooling system	No	Change over floor cooling ($35W/m^2$)
lighting	$10W/m^2$	$<5W/m^2$
Shading device	External	External
Window	U=1.1 W/m^2K; g=0.6	U=0.85 W/m^2K; g=0.57
External wall	U=0.35 W/m^2K	U=0.088 W/m^2K
Air tightness	1.5 1/hr	0.3 1/hr

Due to the high share of waste heat, the primary energy factor for the heating system is very low and thus, the influence of the heating demand on the overall primary energy demand is almost insignificant. Unlike the heating demand, the cooling demand inpacts the primary energy significantly. Table 3 indicates the differnce between a state of the art chiller and a high efficient chiller [8] with regards to the saisonal performance factor (SPF) and energy demand.

Table 3 - Comparison of the energy demand on the example of two chiller scenarios

	SPF	Energy Demand
Standard screw compressor	4.26	42138 (kWh/a)
Magnetic bearing turbo chiller	9.22	19486 (kWh/a)

Taking advantage of high efficient chiller technologies such as [8], does only come along with an optmized operation strategy, reduced cooling loads and therefore, high temperature levels for the entire cooling supply within this buiding. Due to the comprehensive energy efficieny measures, a 20-24°C temperature level is sufficient to cover the cooling loads within the office space and also enables the economical benefit of a single change over system for both, heating and cooling. This can be seen as an another significant result on how energy efficiency measures inpact the HVAC design.

Conclusion

One of the key elements was to reduce the energy demand for all working places. This is including all computers, screens, telephones, printers and all network devices. Furthermore, different scenarios for the ventialtion system, lighting system, heating and cooling system emphazises the massive impact on the HVAC system. Only this step by step optimization enables less HVAC efforts for both distribution and generation. Therefore, only a single low temperature change over floor heating and cooling system was installed in the entire office area. Two CO_2 driven ventilation systems supplies the entire office area with fresh air, using only a double rotary heat exchanger. Additionally, a natural night ventilation system which is located in a former utility shaft, is reducing cooling loads during the transition periods. These systems are getting complemented by Austria´s biggest building integrated photovoltaic power plant. Besides the achievment of a plus-plus-energy office standard, the building benefits from an additional confrence room on the 11th floor, which was used before as a HVAC room.

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