IMPACT OF CLIMATE ON ENERGY-EFFICIENCY OF BUILDINGS IN NORWAY

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Abstract

In order to realize energy performance requirements of a higher standard according to today's and future Technical Regulations, it is necessary to develop new design strategies without sacrifices in other performance codes, standards or guidelines. Prior experience related to the introduction of new energy performance requirements has shown that the design energy performance levels are either not met, or they are fulfilled at the expense of indoor climate, technical quality (e.g. moisture related problems), or architectural quality. Therefore it seems appropriate to determine the parameters of building design that have the biggest influence on energy consumption of buildings.

There is a lack of information about cost effective measures to reduce energy consumption in existing buildings in Norway. The aim of this work was to determine the design parameter of a typical office building which have the biggest influence on monthly energy consumption.

With the help of dynamic computer simulations of energy and indoor environment for various building concepts, the impact of different parameters on energy use and indoor environment was analyzed. Local sensitivity analysis has been applied in order to evaluate the influence of those different parameters on monthly heating energy consumption.

The results show that during periods with higher outdoor temperatures the sensitivity is reduced compared to the annual average. At the same time, during periods with lower outdoor temperatures the sensitivity is increased compared to the annual average. This should be taken into account when trying to optimize a design parameter. In this respect it is also interesting to look at the monthly cooling energy consumption. Since this was not part of this work it should be further analysed.

1. Introduction

This work is part of the project "Climate Adapted Buildings" (CAB) run by SINTEF Building and Infrastructure. The project's principal objectives are to develop more energy-efficient building envelope assemblies and new methods for the design of building envelopes in harsh climates, resulting in more accurate and geographically dependent design guidelines. The project includes analyses of building envelopes applied in different kinds of climates, different uses, and different construction methods.

In order to realize energy performance requirements of a higher standard according to today's and future Technical Regulations, it is necessary to develop new design strategies without sacrifices in other performance codes, standards or guidelines. Prior experience related to the introduction of new energy performance requirements has shown that the design energy performance levels are either not met, or they are fulfilled at the expense of indoor climate, technical quality (e.g. moisture related problems), or architectural quality. Therefore it seems appropriate to determine the parameters of building design that have the biggest influence on energy consumption of buildings. Special focus has been put on the building envelope and some parameters that have an influence on the building load (Andresen et al. 2005). A lot of work has been done for residential buildings and thus this paper focuses on office buildings (Dokka and Hermstad 2006).

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1.1 New building projects

The New Norwegian building regulations (TEK07) describe two ways to fulfil the new energy regulations for a building; the Energy measure method and the Energy target method (TEK07 2007).

The target method is based on net specific energy demand per year, thus the efficiencies of the energy systems are not taken into account. Passive measures that reduce the net cooling demand will contribute to satisfy the energy frame. This puts an extra focus on utilizing passive measures to decrease the total energy use in buildings. The regulations still contain minimum requirements concerning the U-values and air tightness of the building envelope, which help to maintain a good insulation standard (TEK 2007).

1.2 Existing building stock

Some work has been done to analyze the existing building stock. Sartori and Wachenfeldt (2007) focused on the energy performance, but found that reliable data only exists for buildings not older than 1983 (Sartori and Wachenfeldt 2007). They found that energy intensity (kWh/(m^2a)) decreased slightly in the residential sector and increased slightly in the service sector (that is all non-residential buildings) over the last two decades. There is more research needed in order to be able to fully analyze the potential for an energetic refurbishment of the existing building stock in Norway.

There is no official definition of specific goals and figures for low energy buildings. Some attempts have been made to define a low-energy building. In general, it refers to a building built according to special design criteria aimed at minimizing the building's operating energy (Sartori and Hestnes 2007).

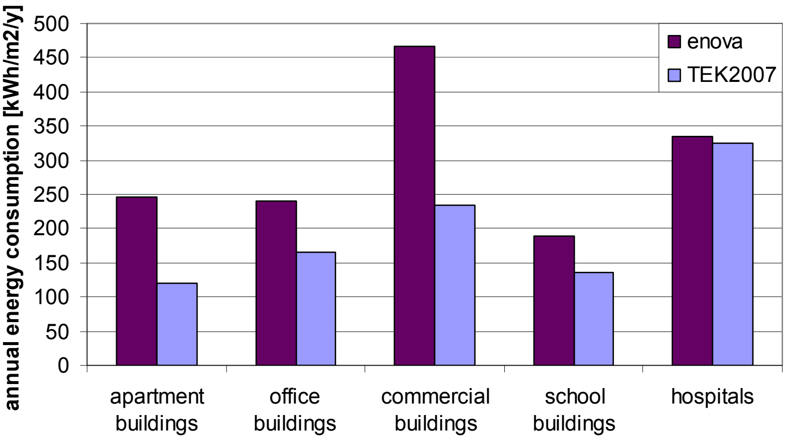


Fig. 1. Energy consumption in the present building stock and according to the new energy targets (Enova 2007; TEK 2007)

Figure 1 gives an overview of the estimated energy consumption of the building stock and the energy target for aggregate net energy demand for different building types in kWh/(m^2 a) (Enova 2007; TEK 2007). It shows that the new building regulation requires a drastic reduction in energy consumption (i.e. 50% in commercial buildings and 31% in office buildings). In Germany, the 'lean building' has been defined with specific primary energy consumption of 100 kWh/(m^2 a) (Voss et al. 2006). The new energy labelling system will help to categorize the levels of energy use in buildings (Wigenstad et al. 2005).

Although the construction standards for existing buildings vary, some research indicates that the energy consumption remained almost stable over the past decades (Enova 2007). Measures to reduce the energy consumption are therefore very much dependent on the age and type of construction (Sartori and Wachenfeldt 2007). Assuming that constructions have been built according to the existing regulations at that time, there still remain many influencing factors with great uncertainty.

1.3 Climate in Norway

The climate is determined by the amount of solar radiation and mean outside temperature that a building is exposed to. The climate also constitutes the amount of energy that is used for heating and cooling but also the amount of energy that is used for lighting. There is solar excess which determines the amount of solar energy that is not wanted in the building. With growing amounts of glass and a glazing system that allows large solar heat gains, the impact of orientation is substantial. The New Norwegian standard for calculating energy consumption in buildings uses Oslo weather data for all locations in Norway (TEK 2007).

The monthly temperatures vary for different locations throughout Norway. Haase and Andresen (2008) give an overview of the monthly mean temperature distribution for the different locations analyzed in the study. It showed that Oslo weather data has the highest summer temperatures and the highest solar radiation data (Haase and Andresen 2008a). Table 1 lists the annual and monthly outdoor temperature for 13 different locations spread over Norway and covering almost all climatic zones (except zone 5).

Table 1 Monthly temperature in different cities in Norway

	Rygge	**Oslo**	**Horten**	**Stavanger**	**Bergen**	**Hamar**	**Røros**	**Levanger**	**Trondheim**	**Narvik**	**Tromsø**	**Vardø**	***Karasjok***
year	5,8	5,7	6,5	7,6	7,7	4,1	1,0	4,9	3,8	3,7	2,9	1,4	*-2,6*
Jan	-4,6	-4,4	-3,2	1	1,5	-8,1	-11,4	-3,4	-3,6	-4,3	-3,7	-5,2	*-15,9*
Feb	-4,2	-4,3	-2,9	0,8	1,5	-7,4	-8,8	-2,9	-3,4	-4	-3,7	-5,4	*-16,2*
Mar	0,2	-0,1	-0,1	2,6	3,3	-2,8	-4,1	-0,7	-0,8	-1,7	-2,2	-3,6	*-10,8*
Apr	4,4	4,4	5,1	5,6	5,8	3,1	0,4	3,2	2,2	2,1	0,7	-1	*-3,5*
May	10,3	10,8	10,7	10	10,6	9,2	7	7,9	7,3	7,2	5,1	2,6	*3*
Jun	14,8	15,1	14,8	12,4	13,3	13,8	11,1	11,3	10,2	10,8	9,1	6,1	*8,9*
Jul	16,5	16,5	17,4	14,9	14,6	16,5	12,7	14,4	11,7	13,5	12,3	9,8	*13,3*
Aug	15,6	15,3	16,1	14,8	14,4	15	11,7	13,3	11,5	12,4	10,9	9,1	*10,5*
Sep	10,8	10,6	11,8	12,2	11,4	10	7,2	9,5	8,1	8,2	6,7	6,5	*5,8*
Oct	7,3	6,4	6,8	8,4	8,8	4,6	2,3	5,1	4,7	3,9	3,2	2,4	*-2*
Nov	1,2	0,6	2,4	5,3	4,7	-0,4	-5,1	1,5	0	-0,5	-0,6	-1,3	*-10,1*
Dec	*-2,6*	*-3*	*-0,4*	*3*	*2,8*	*-4,4*	*-11,1*	*-1*	*-2,2*	*-2,7*	*-2,6*	*-3,7*	*-14,3*

2. Objectives

There is a lack of information about cost effective measures to reduce energy consumption in existing buildings in Norway. The aim of this work was to determine the design parameters of a typical office building which have the biggest influence on monthly energy consumption. With the help of detailed dynamic simulations of a typical office building in Norway, combined with a sensitivity analysis, it is possible to obtain results for a number of design parameters that have the biggest potential to reduce heating energy consumption with special focus on the façade design.

3. Methodology

With the help of dynamic computer simulations of energy and indoor environment for various building concepts, the impact of different parameters on energy use and indoor environment was analyzed. The following parameters were considered:

- Annual outdoor temperature
- Air tightness of the building envelope
- Thermal insulation of the building envelope
- U-value of roof, wall, and floor
- U-value of windows
- Window-to-Floor-Ratio (WFR)
- Type of shading system (no, external, internal)
- Efficiency of heat recovery system

For each parameter a number of different input data were altered and the results for monthly heating energy consumption (MHEC) were plotted in scatter plots.

3.1 Computer simulation

The office building was simulated using SCIAQ Pro, a dynamic simulation software that calculates hourly energy consumption for heating, cooling, lighting and equipment. It is based on hourly weather data provided by Meteonorm (Dokka and Dokka 2004). Although the software has been validated, the simulation results have been compared with measured data in order to get higher confidence in the simulation results (Haase and Andresen 2008c).

The building construction details are described in Table 2. It is a typical three storey high office building located in Fredrikstad, around 100 km south of Oslo.

The input parameter have been taken and stepwise changed in order to find the sensitivity of the single input parameter towards the monthly heating energy consumption (MHEC) (Lam and Hui 1996; Lomas and Eppel 1992).

TABLE. 1: Building description; office building

Location:	Fredrikstad (latitude 59.2"N, longitude 10.5"E)
Building type and storeys:	Office building, 3 storeys above ground
Floor areas:	Total heated floor area = 6,300 m^2
Dimensions and heights:	118 m x 18.1 m; floor-to-floor = 3.5 m ; window height = 1.5 m ; window-to-wall ratio = 0.33
Constructions of building envelope: (a) External walls (spandrel portion of curtain wall) U-value: 0.2 W/m^{2}K (according to Norwegian building code 1997) - Absorption coeff. outside: 0.4; Thermal cap. outside: 5 Wh/m^{2}K; emissivity outside surface: 0.85 (b) Roof U-value: 0.2 W/m^{2}K (according to Norwegian building code 1987) - Absorption coeff. outside: 0.5; Thermal cap. outside: 4 Wh/m^{2}K; emissivity outside surface: 0.85 (c) Floor U-value: 0.2 W/m^{2}K (according to Norwegian building code 1987) (d) Windows Two panes, 4 mm clear glass + 4 mm Optitherm S, 15 mm argon, wood/vinyl frame - U-value: 1.4 W/m^{2}K; glazing factor: 0.75; dir. solar transm. factor pane: 0.47; total solar gain factor pane: 0.59 - Solar shading system: Venetian blinds, outside, light color, automatic	
Constructions of internal structure : - Medium weight furniture; medium weight partition construction; Thermal capacity: 12 Wh/m2K Operating hours : Mon. to Fri.-0800 to 1600 hr Sat. and Sun. and Easter and Christmas holidays-closed	
HVAC design parameters : (a) Building load - Occupancy density = 0.1 person/m^2 (seated working (1.2 Met); normal office clothing (1 clo)) - Lighting load = 10 W/m^2 ; equipment load = 10 W/m^2 - Infiltration = 0.15 ach - Heating set point temperature 22 °C during operating hours (20 °C outside operating hours) - Cooling set point temperature 26 °C (off outside operating hours) (b) HVAC system Minimum 3.6 m3/hm^2; maximum 10 m3/hm^2 - Throttling range = 1 °C - operating hours 0600 hr to 1800 hr - HVAC system type = VAV Ventilation (c) Heating - capacity: 50 W/m^2; convective share delivered heating: 0.5 - operating hours 0600 hr to 1800 hr (d) Cooling - capacity: 40 W/m^2; convective share delivered heating: 0.5 - operating hours 0600 hr to 1800 hr	

3.2 Sensitivity

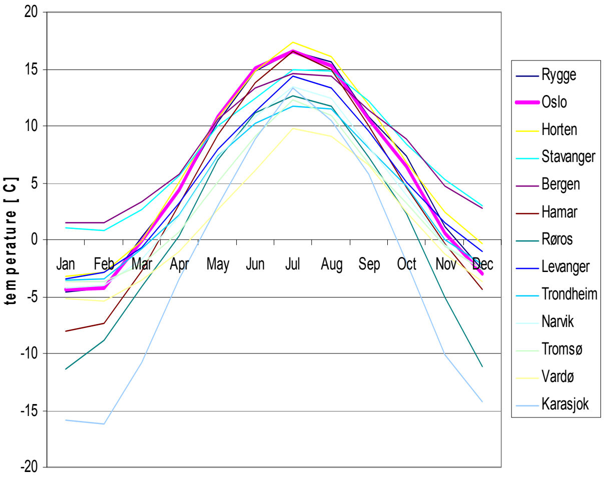
In this respect it was interesting to estimate the uncertainty in the input parameters. A sensitivity analysis of eight different design parameters for an office building has been carried out and detailed results have been reported (Haase and Andresen 2008b; Haase and Andresen 2008c). The technologies suggested for upgrading the buildings from one category to another were determined by sensitivity analysis and were summarized. The New TEK07 tightens the requirements for U-values of the building envelope and air tightness.

4. Results

The results are shown for annual and for monthly sensitivity in the following paragraphs.

4.1 Annual sensitivity

Monthly heating energy consumption was plotted for the reference building put in different locations all over Norway. Figure 3 shows the results and illustrates that monthly energy consumption is strongly linked to monthly outdoor temperature. A polynomial fitting curve was put in with an R^2 = 0,989 indicating a very good fit.



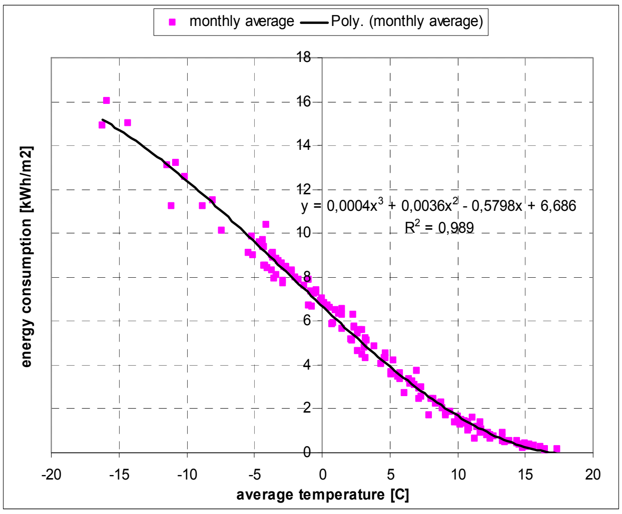


Figure 2 Monthly outdoor temperature distribution

Figure 3 Monthly heating energy consumption (MHEC)

4.2 Monthly sensitivity

Since outdoor temperature has such an important influence on the heating energy consumption, the different parameters have been examined with focus on the monthly energy consumption. Figure 4 gives the result for the base case as described in Table 2. It can be seen that the share of MHEC which consists of Room heating and Heating coil is very high in the winter month (up to 72% in January) and low in the summer months (down to 2% in July).

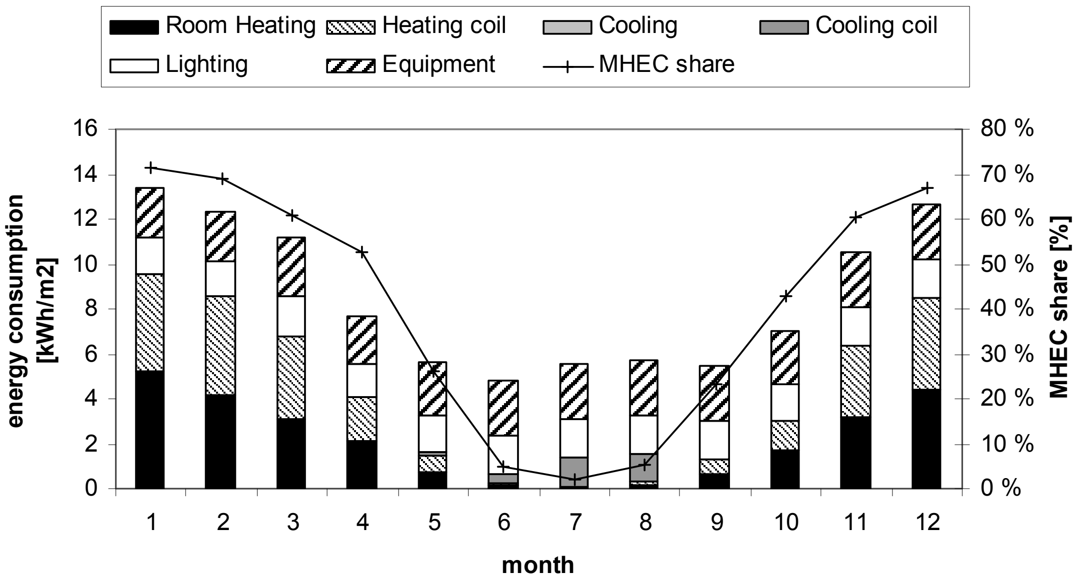


Figure 4 Monthly energy consumption (with MHEC = Room heating + Heating coil)

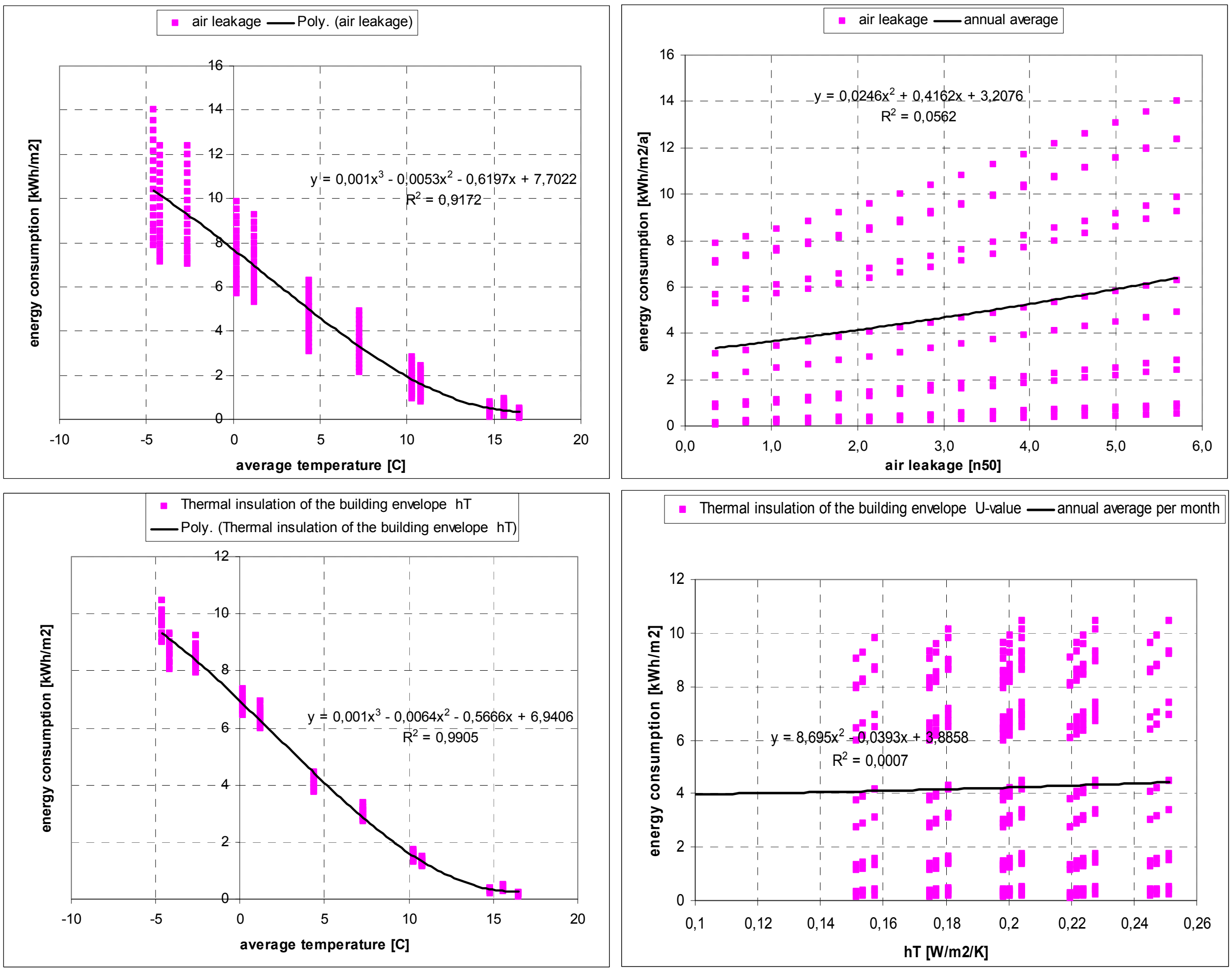
Figure 5 gives the results for the different parameters as described above, with respect to outdoor temperature (on the left) and a commonly used sensitivity plot of the design parameter but with monthly values (on the right).

4.2.1 Sensitivity over outdoor temperature

Each design parameter has been altered and MHEC was plotted over the monthly outdoor temperatures. This results in 12 different columns, one for each month's average outdoor temperature. It can be seen that the cooler the outdoor temperature, the higher MHEC. But, the range of the design parameter also gets bigger with cooler outdoor temperatures. The sensitivity of the design parameter is bigger with cooler outdoor temperatures. This is indicated by the larger output range at cooler temperatures.

4.2.2 Sensitivity of input parameter

The annual average indicates the average, i.e. annual sensitivity distribution with very good R^2 values divided by 12 months. The very low R^2 indicates a poor fit of the curve over the monthly values. This is not surprising since all design parameter have an influence on MHEC. But it can be seen that during periods with higher outdoor temperatures the sensitivity is reduced compared to the annual average. At the same time, during periods with lower outdoor temperatures the sensitivity is increased compared to the annual average.



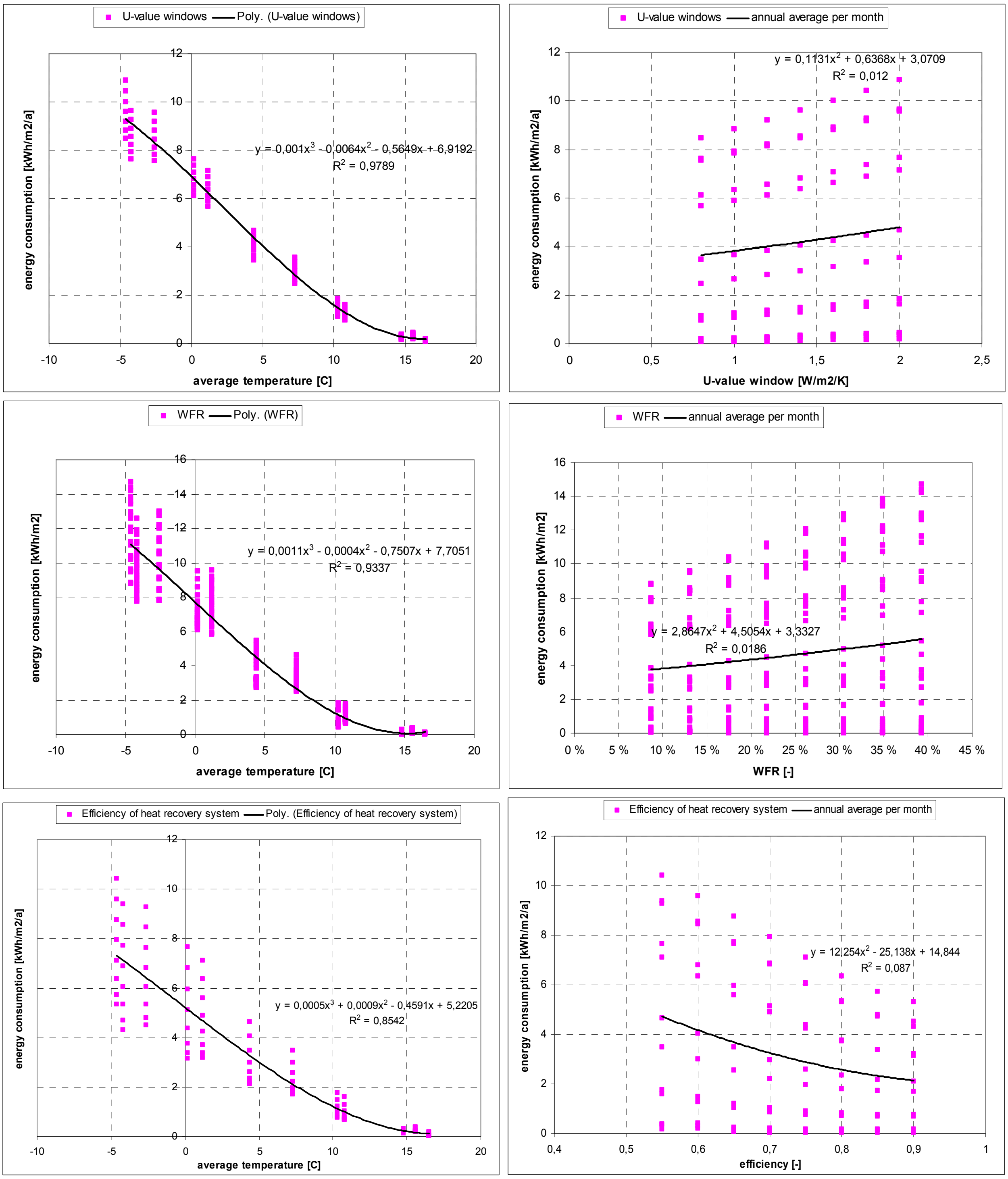


Figure 5 Sensitivity analysis results for different design parameters

5. Conclusions

Since outdoor temperature has such an important influence on the heating energy consumption, the different parameters have been examined with focus on the monthly energy consumption. The share of MHEC on total energy consumption is high in the winter months and low during the summer which has an influence on the seasonal sensitivity of design parameters.

During periods with higher outdoor temperatures the sensitivity is reduced compared to the annual average. At the same time, during periods with lower outdoor temperatures the sensitivity is increased compared to the annual average. This should be taken into account when trying to optimize a design parameter. In this respect it is also interesting to look at the monthly cooling energy consumption. Since this was not part of this work, it should be analysed further.

The climate has a large influence on the energy performance and should therefore be taken into consideration. Expected climate change over the next 50 years will influence the energy consumption. A sensitivity analysis could be applied in order to evaluate the parameters with the biggest influence on building monthly heating energy consumption. A change in annual mean temperature of less than 3 degrees, as projected by the IPCC, can cause great uncertainty in future energy consumption of office buildings.

The local sensitivity analysis gives only results for changing one parameter at the time. Synergy or other effects of changing more than one parameter could not be analyzed in this work. Future work will focus on this aspect and apply a global sensitivity analysis to the problem. It is hoped that these findings will assist in setting up future analysis work.

More work is needed in order to accurately quantify the consequences and to develop envelopes that are capable of adapting to the changing climate.

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