ENERGETICAL, ECOLOGICAL AND SUSTAINABLE OPTIMIZATION OF SKYSCRAPERS ALL OVER THE WORLD

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ABSTRACT

The climate protection is one of the greatest challenges of our time. Different countries face this problem with an ambitious climate policy and climate goals, especially in reducing CO_2-emissions. The building sectors plays a crucial role. At international conferences with the goal of climate protection, different targets were defined. The Brundtland-Report “Our Common Future” (1987) characterized the term “sustainability” and indicates, that it is important to save resources and to act climate friendly. Also the Kyoto-Protocol, which came into effect in 2005, defined strategies for reducing CO_2-emissions. In Germany nearly 30% of the final energy demand is used for the conditioning of buildings. As a consequence there is a large quantity of emissions for example of CO_2. The European directive 2002/91/EG adopted by the European Parliament and Council in December 2002 regulates the energy demand of buildings in the different member states of the European Union. This balancing of the energy demand includes the demand for heating, ventilation, cooling, lighting and the supply of hot water. But it is not only important to decrease the energy demand, it is also necessary to reduce impacts on the environment. Additionally the indoor air quality is important for the users of an office building. This paper investigates the energy optimization for an exemplary office skyscraper. The building will be evaluated for different locations all over the world, including the specific climate conditions. Different energetic standards will be examined for the same building. In addition to the influence of the energetic standard, the proportions of the window area will be examined. To address all dimensions of sustainability next to climate comfort and ecological impacts also costs are considered during the operation period of the building. Different variations of construction will be assessed energetically with particular attention to the thickness of the insulation and the energetic quality of the windows. Therefore special cities with different climate boundary conditions in various countries and continents will be investigated. Furthermore indoor comfort criteria will be studied – also with regard to the different constructions and locations. As a result the inner temperature and humidity will be compared. Based on the outcome of the final energy demand the environmental expenses and effects and also the costs will be calculated for the period of operation. Special attention is paid to renewable and non-renewable primary energy input as well as the global warming and the acidification potential. Results consider the relation between climate regions and the minimum insulation as wells as the indoor air quality.

Keywords: climate comfort, comparison worldwide, ecological, energetic balances, sustainability.

1. INTRODUCTION

For this office building different energetic standards and climate boundary conditions will be analyzed regarding the final energy demand, the operating costs, the environmental expenses and effects and the indoor climate.

1.1. Exemplary office building

The exemplary office building is a skyscraper with 30 floors, a width and a depth of 20 m and a height of 90 m. On the one hand it is assumed that the building has a high energetic standard regarding the thermal envelope – for German conditions – and on the other hand it is assumed that the building is not insulated. Another point of variation of the building is the percentage of the window area – this is either 30, 50 or 80 % or 80 % with electrical sun protection.

The exemplary office building is shown in Figure 1. Table 1 shows the different heat transfer coefficients (U-values) of the thermal envelop of the edifice.

Table 1. U-values of the exemplary office building

Building component	Uninsulated building	Insulated building
Outer wall	3,150 W/(m²K)	0,166 W/(m²K)
Flat roof	1,540 W/(m²K)	0,150 W/(m²K)
Base plate	1,463 W/(m²K)	0,250 W/(m²K)
Window	3,157 W/(m²K)	0,780 W/(m²K)

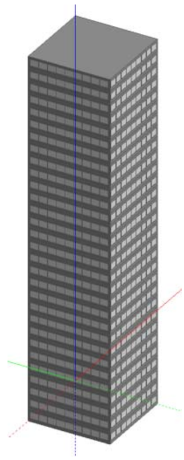

Figure 1: Exemplary office building with a window area of 50 %

1.2. Climate boundary conditions

Figure 2 shows the different climes of the world. For this computation one town of each temperate zone was chosen and based on the different boundary conditions the final energy demand for heating, cooling, ventilation and lighting was calculated.

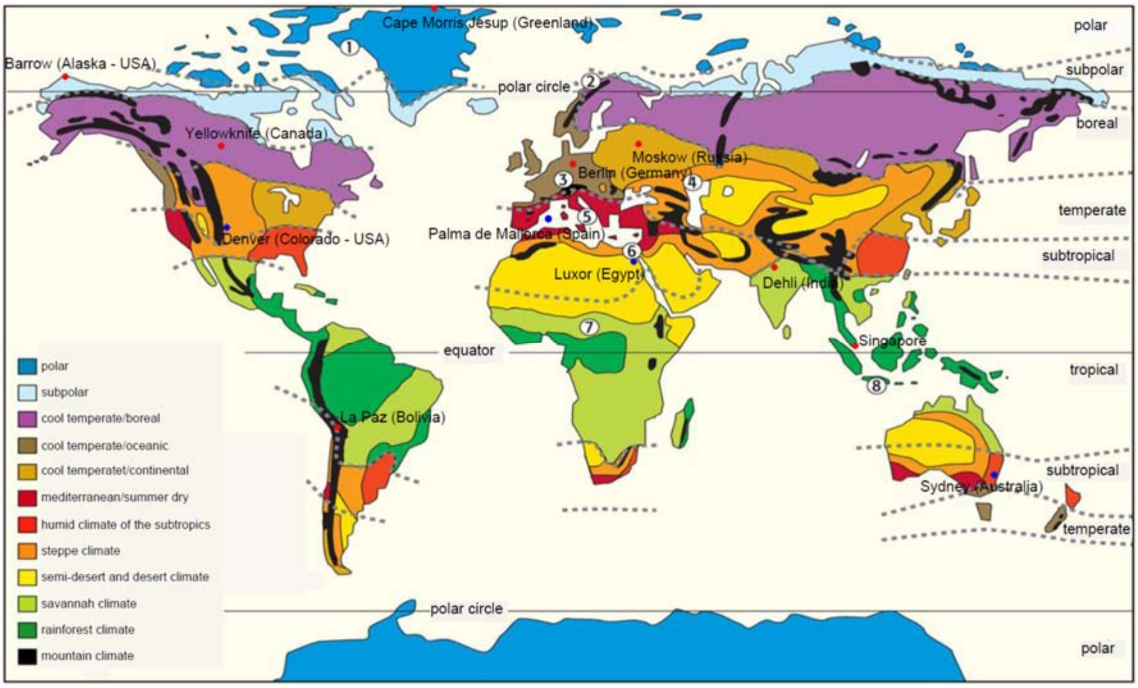

Figure 2: Climate map [1]

1.3. Investigations

The energetic balances of the building were conducted with the software Design Builder – Energy Plus [2]. This program is based on the fundamentals of computation ASHRAE 90.1. By means of the building geometry, the thermal envelop and the building technology the final energy demand to operate the building was calculated.

Due to the final energy demand the operating costs were determined. For this edifice it is the assumption that it will be heated with district heating and for cooling, ventilation and lighting electric energy is used. In Germany the costs for electric energy per kWh are 0.17 Euro and for district heating 0.09 Euro. The foundation of the operating costs are the specific values from the Characteristic 2.1.1. of the Evaluation System of Sustainable Building of the Federal Ministry of Transport, Building and Urban Development [3]. This evaluation system is a German standard to certificate edifices regarding sustainable building.

To calculate the environmental expenses and effects – especially the primary energy input (PEI_{ges}), the global warming potential (GWP) and the acidification potential (AP) – the specific values were taken from the program Legep [4]. The ökobau.dat is deposited to this program [5]. These values are summarized in Table 2.

Table 2. Ecological values per kWh final energy in Germany

Energy source	PEI_{ges} in kWh	GWP in kg CO2 Eq.	AP in g SO2 Eq.
District heating	0.953	0.256	0.316
Electric energy	3.463	0.654	0.974

2. ENERGETIC CONSIDERATION

Figure 3 shows the final energy demand for heating for the different variants of the edifice and climates.

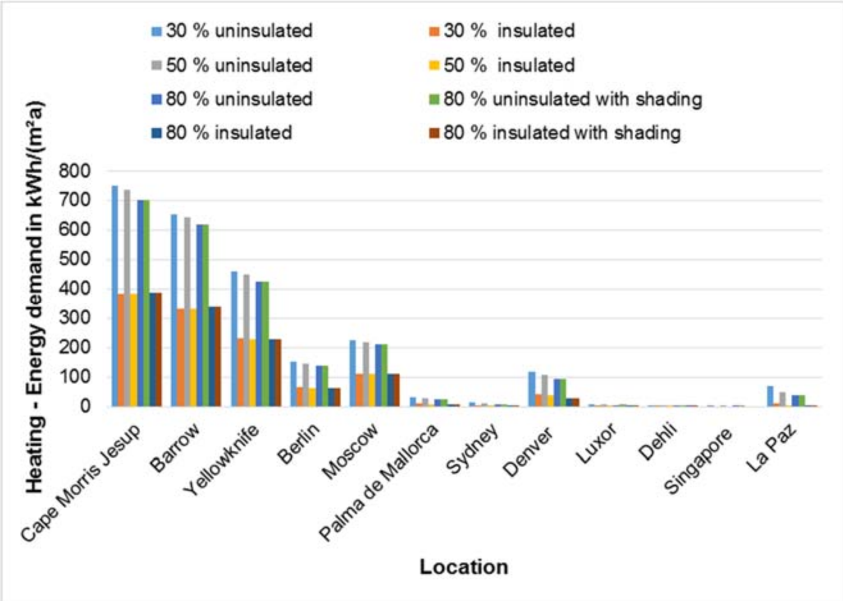

Figure 3. Final energy demand for heating in kWh/(m²a)

If the building is insulated the final energy demand is much lower. For the uninsulated building the final energy demand decreases with the expansion of the window area. The reason are the solar gains. In the colder climes the final energy demand of the uninsulated building will go down by changing the window area from 30 to 50 %. By increasing the window area to 80 % the final energy demand will expand. The reason are on the one hand the solar gains and on the other hand the higher losses of the windows compared to the outer wall. In the warmer climes the final energy demand for heating will go down by the increase of the window area.

Further this figure clearly shows the regional differences of the climate boundary conditions. As expected the highest final energy demand for heating is reached in the polar, subpolar and cool temperate boreal regions. Furthermore the energy demand is higher for the cool temperate continental climate zone (Moscow) as for the cool temperate ocean climate zone (Berlin). In the mediterranean, the subtropical and tropical clime zone but also in the savannah or desert a very low up to zero energy demand for heating is reached. Whereas the steppe region shows a higher energy demand, reasoned by the cooler climate.

For the mountain climate (La Paz) the uninsulated skyscraper shows a relatively high energy demand compared to the insulated building. The shading of the big window areas (80 %) does not have a big influence to the final energy demand.

Figure 4 shows the final energy demand for cooling of the edifice. The demand for cooling increases with the proximity of the equator – this is as expected the opposing trend to the final energy demand for heating. If the skyscraper is insulated and the window area is 80 % in the polar regions the demand for cooling is very low – for the other variants of the building no energy for cooling is necessary. In the cool temperate zones the final energy demand for cooling – still low –increases by expand of the window area and the level of insulation. The energy demand for cooling rises for the mediterranean, subtropical and steppe climates. The highest demand is reached for the desert, savanna and rainforest area. In general the demand for cooling increases with a higher level of insulation and a higher percentage of the window area of the building. By using an outer shading of the windows, which is controlled by the solar radiation, the final energy demand for cooling can be reduced up to 20 % - especially in the warmer climes.

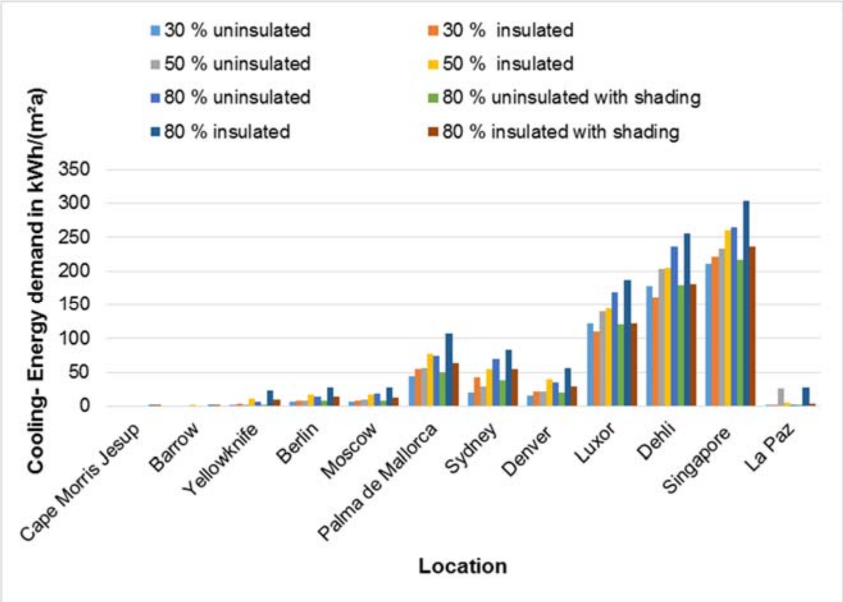

Figure 4. Final energy demand for cooling in kWh/(m²a)

The final energy demand for lighting of the skyscraper amounts to between 280.000 and 310.000 kWh. This depends on the percentage of the window area and the shading. In general the demand decreases with nearing the equator.

Based on the results above the total final energy demand is shown in Figure 5.

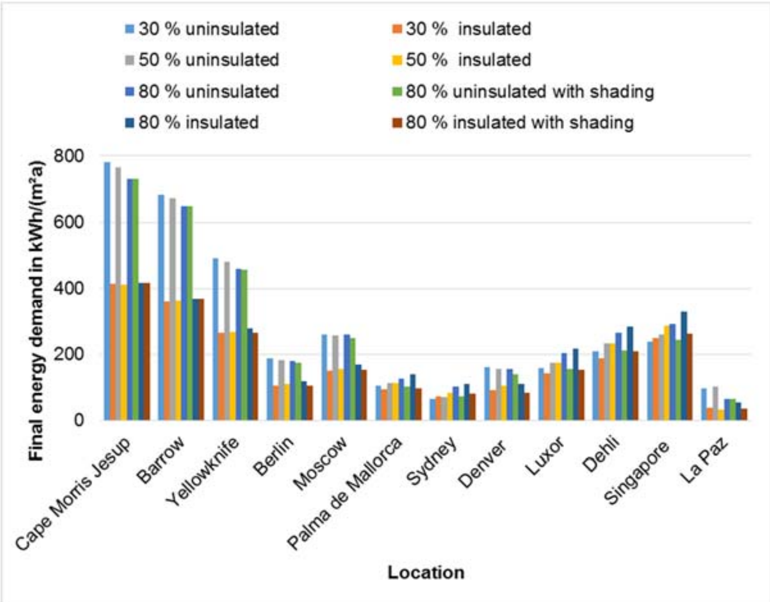

Figure 5. Final energy demand (total) in kWh/(m²a)

Especially in the cooler regions the differences between the insulated and the uninsulated building are conspicuous. The highest energy demand is needed in the polar regions for the uninsulated building. For the insulated building the final energy demand for the cool temperate boreal clime is nearly the same as for the rainforest clime, this is reasoned by the higher demand for cooling. Regarding the other climate zones the final energy demand is relatively balanced, because of the demand for heating and cooling.

3. ECONOMIC AND ECOLOGIC CONSIDERATION

Figure 6 shows the annual operating costs and Figure 7 the global warming potential for the different variants of building and climes.

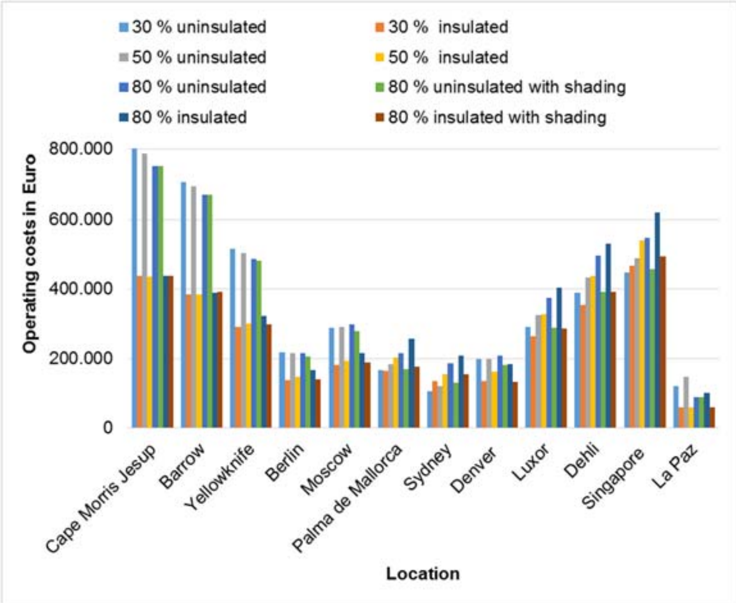

Figure 6. Operating costs in Euro

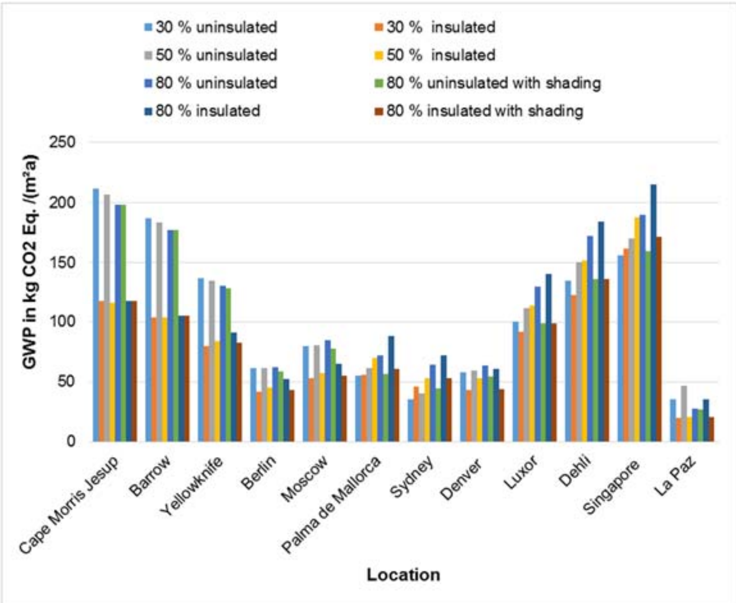

Figure 7. Global warming potential – Period of operation – in CO2 Eq./(m^2a)

Under the assumption of the German energy costs the operating costs account for between 60.000 and 800.000 Euro per year. They are calculated based on the final energy demand. Therefore the different costs for district heating and electric energy have to be considered. As expected the highest operating costs are reached for the uninsulated building in the polar clime. In this case a decrease of the costs is shown for the increase of the window area. The cool climate, the mediterranean and the subtropical area shows related tendencies for the operating costs, because of the different energy demand for heating and cooling of the skyscraper. In the desert and the tropical area the demand for cooling is very high, so the operating costs are the highest for the location of Singapore for the insulated building.

The global warming potential changes corresponding to the final energy demand. Based on the different values for the global warming potential for district heating and electric energy a big difference of the potential is shown for the diversity locations. In the cooler climes the energy demand for heating strongly influences the environmental expenses and effects. In the warmer climes the demand for cooling plays a crucial role, so the global warming potential is very high for the tropical and desert regions. The same tendencies are also given for the primary energy input and the acidification potential.

4. INNERCLIMATE CONSIDERATION

For the consideration of the inner climate only the outer climate – especialy the air temperatur – will be taken into account.

The mean inner air temperature will rise with nearing the equator, but also with the higher level of insulation. Another point is a higher proportion of the window area. Especially in the warmer regions the shading of the windows has a strong influence on the inner temperature. Particular for the polar climate, also in the cool temperate zones, a mean temperatur of 20 degree can not be reached in the uninsulated building. In contrast the mean temperature in the desert and tropical climate amounts to 25 degree.

Based on the reduction of the temperature in the night and on the weekend the minimal temperature amounts to 12 degree nearly in each region – with the exeption of tropical regions, but also the insulated building in the subtropical or desert region. In the tropical zone – specially in Singapur – no temperatures below 22 degree are noted.

Normally the maximal temperature inside the building increases with the higher level of insulation and higher proportion of the window area. Due to this fact the maximal temperature in the tropical and subtropical climate reaches 50 degree. But also in the cool climate there are maximal temperatures of about 40 degree for the insulated building with a window area of 80 %. By shading the windows the maximal temperature can be reduced.

5. SUMMARY

In summary the comtemplation of the same skycrapper under different influences of the climate shows that it is not wise to build an edifice with the same energetic standard in different regions. The climate has a big influence on the necessary type of construction – espacially the level of insulation – and has to be adapted. Furthermore the percentage of the window area and the thermal envelop in general has a big influence on the final energy demand for heating and cooling of the building. The insulation has a special effect on the energy needs for cooling – especially in the warmer climate zones, as the warm air will be save inside the room and more energy for cooling is necessary.

The environmental expenses and effects develop accordingly to the final energy demand for heating, cooling, ventilation and lighting. Reasoned by the high electric energy demand for cooling the building – for example in tropical regions – the environmental expenses and effects can be the same as for the insulated building in polar regions, which are only heated.

As a conclusion the construction of the thermal envelope depends on the climate. An internationl unitary architecture is not productive.

6. REFERENCES

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