

Energy Performance of Buildings in Urban Areas

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ABSTRACT: The urban setting influences the energy performance of buildings, as mutual shading of buildings increases the heating and lighting energy demand, but reduces cooling loads. The work tries to quantify the overall urban impact on primary energy demand for both residential and commercial urban districts. For a given urban form and building structure, different building use profiles are compared, for example occupation hours, required heating and cooling set points, lighting levels etc., which vary strongly between commercial and residential buildings. Mainly high rise buildings are considered with varying site coverage, building standards and user profiles.

To combine heating, cooling and lighting energy evaluation of buildings in an urban context, different software tools such as EnergyPlus and Radiance are used. Especially for lighting simulations, the location of window surfaces and sky view factors are very important, less so for heating and cooling simulations. The simulation accuracy required for each tool has been evaluated in detail. To validate the different simulation tools used, a case study was carried out in an urban area near Stuttgart/ Germany, where energy consumption data are available for both residential and commercial buildings. The simulation methodology was applied to high rise buildings in different climatic zones (Germany and China) to study the impact of the urban form on the overall energy performance of the buildings. In climates with dominance of cooling energy, denser urban forms reduce the energy demand, as shading lowers the unwanted solar gains. In moderate climates, density increases the energy demand for heating and cooling by about 10 to 20%. Lighting electricity increases in both cases with increasing density, which is mainly important for commercial districts.

Keywords: building energy demand, urban impact, housing density, heating and cooling

1. INTRODUCTION

Rapid population growth leads to a growing necessity for built-up areas which cause a number of problems of modern cities. Most of the time, this problem is solved with high-rise buildings or compact settlement structures, instead of expanding the city boundaries. Energy planning and energy supply of these settlement areas are important issues. Knowledge of the patterns

of energy consumption and energy flow in the urban settlement structure are essential for the energy management of urban areas.

Many studies on individual buildings relating their energy and environmental performance are neglecting the importance of the urban scale. Here influences of environmental, technical, social and economic factors have to be considered.

These factors might be categorized as below:

- Geometrical properties of the urban structure such as height and width of the buildings, density of the area with street dimensions
- Thermal and optical characteristics of the built environment
- Land use configuration of the settlement such as activity level or schedule of the area
- Living standards of the society

The effect of these factors on heating, cooling and lighting energy demand of the areas is different and their influences are changing according to climatic conditions. The effects caused by urban design and

their influences are summarized in the Table I. The patterns of energy use are varied according to occupation type of the area. The time schedule of occupation in the residential areas differs from the working areas. The comfort levels also depend on the occupation type of the buildings and it has a major influence on heating and cooling demand of the areas. Besides that, energy intensities fluctuate within commercial areas, industrial areas and residential areas.

In the context of this paper the impacts of measurable factors are quantified for urban designers and energy management planners, who then can estimate the energy demand of the different urban quarters.

Table I: Urban effects on heating, cooling and lighting demand

	HEATING	COOLING	LIGHTING
Height and Width of Buildings	-Multi-storey buildings and compact forms reduce the heat losses from the building envelope. - Heating and cooling systems might be used more efficiently in multi-storey buildings.	-Multi-storey buildings and compact forms reduce the heat gains from the building envelope.	-Shading impact increases with increasing height to width ratio causing higher artificial lighting requirement. -Daylighting performance should be evaluated considering only useful daylight illuminance levels
Street Configuration	-Density of the area increases the mutual shading and reduces the solar gains. -Central or district heating and cooling systems might be used efficiently in dense areas. -Efficiency of solar heating and cooling systems decreases because of the shading effect of other buildings on the solar collecting area.		-High density causes more daylight-controlled artificial lighting energy consumption at lower floors than upper floors.
Thermal and optical properties of buildings	-Low U-value reduces the heat losses from building envelope. -High albedo and absorbance of the building envelopes increases the urban heat island effect.	-Low U-value reduces the heat gains from building envelope.	-High reflection causes high illuminance levels and results in less electric consumption. -High visual transmission of glass provides high illuminance levels and results in less electric consumption.

2. APPROACH TO ASSESS THE BUILDINGS' ENERGY USE IN THE URBAN CONTEXT

The real urban texture is highly complex to compute. In order to limit these complexities some archetypes from Martin

and March classification of urban forms were applied and configured on the site with different densities [1].

Three dimensional urban quarter simulation was done for different generic urban forms for business and residential districts. The floor by floor daylight

illuminance was calculated by using the ray tracing program Radiance [2]. The daylighting performance has been evaluated according to the useful daylight illuminance (UDI) scheme which is based on a survey of occupant preferences [3]. Daylight illuminances in the range 500 to 2000 lux are mostly perceived either as desirable or at least tolerable and called UDI autonomous (UDI-a). The change of the illumination level is sensitive to building orientation and height of the floor. The annual electricity consumption with a daylight responsive control system was simulated with Radiance using the lighting program Daysim [4]. To evaluate the total energy demand of the building, the heating and cooling demand including the internal gains from electricity consumption with daylight responsive lighting control was calculated in the energy+ simulation program [5].

Performing sets of experiments is important in order to develop a reliable methodology for validating the urban effect on the measured energy performance of residential buildings. To quantify the impact of the surrounding buildings on the energy performance of the case study buildings in the urban context, daily measurements of heating and electricity consumption were taken from Stuttgart, Germany.

In this study, measurements of 10 single family houses from Scharnhäuser Park, Stuttgart were compared with simulation results of those buildings. Figure 1 shows site plans and 3D drawings of the case study buildings. Daily electricity consumption for summer and winter season was evaluated according to weekend and weekday's conditions and typical weekly summer and winter electricity consumption was defined.

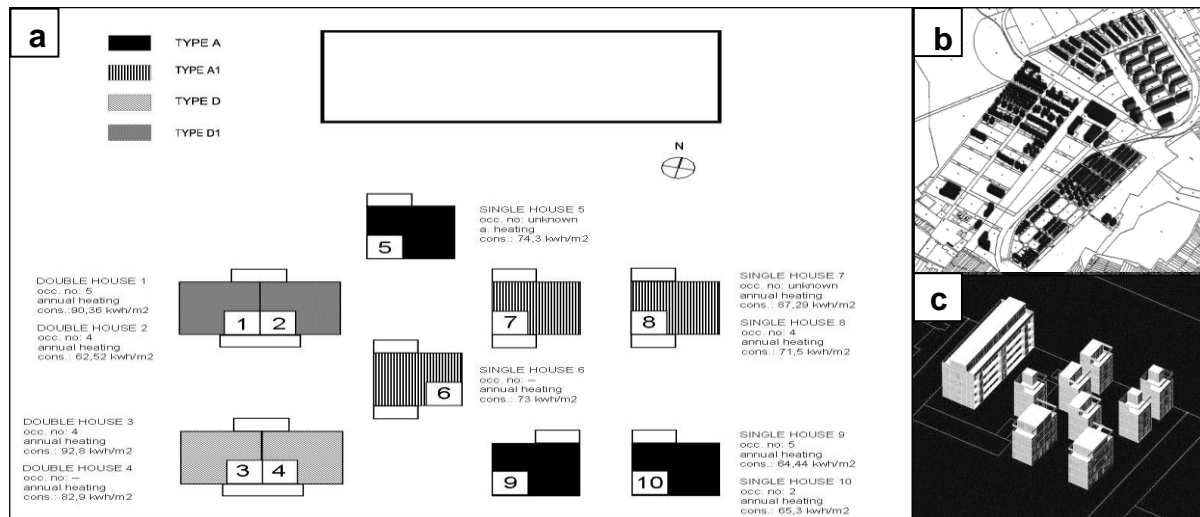


Figure 1a: The location of 10 case study buildings on the area and their properties. **Figure 1b:** The case study area in the Scharnhäuser Park settlement. **Figure 1c:** 3D drawings of the case study buildings

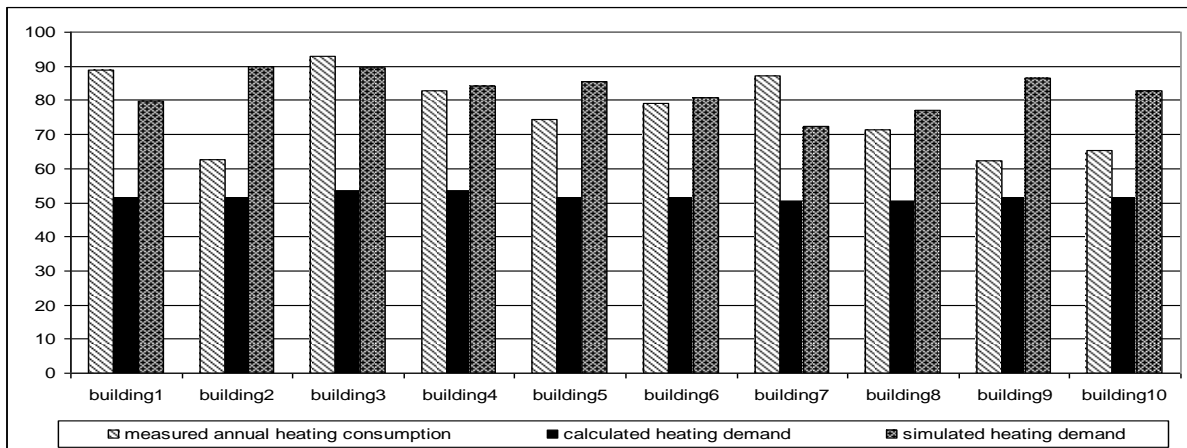


Figure 2: Measured, calculated and dynamically simulated heating demands for case study area in Stuttgart/Germany

In a first approach, the heating demand was calculated using a monthly energy balance method. The calculated heating demand is significantly lower than measurements for all buildings, as monthly energy balances are based on constant room temperatures and air changes. The dynamic building simulation results are quite close to the measured building energy consumption data, because shading effects and more realistic user schedules are implemented.

In order to analyse energy and especially daylight performance of office buildings in an urban context, measurements were also taken from a test room office in Stuttgart – Germany, of which plans are shown in Figure 3. The façade is oriented towards South-Southeast (154.5 degree from north).

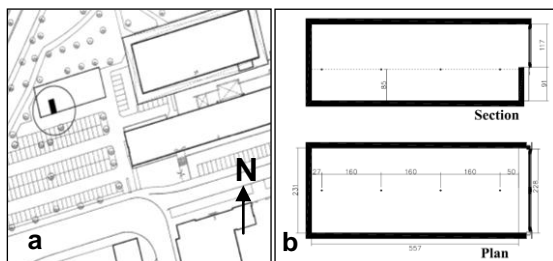


Figure 3: a. Site plan (test room in circle)
b. Floor plan and section of the test room

The test room dimensions are 2.31 x 5.84 m deep x 2.08 m high. The comparison of heating calculations and measurements can

be seen in the Figure 4. The heating measurement was taken from 8 o'clock until 18 o'clock of February 2010 with a weekend break. The calculation of the heating energy demand is a simple energy balance with transmission and ventilation losses as well as solar and internal gains following the calculation procedure from European standard DIN V 18599 [6]. A reasonable agreement between demand calculation and consumption is obtained, although additional heating up energy demand after heating system switch off cannot be modelled. The illuminance was measured at four points on the middle axis of the test room and the Radiance software was used to simulate the interior space illuminance. Comparisons were done in two different sky conditions such as clear and overcast. Figure 5a indicates a comparison of illuminance measurement between the test room and simulation model under clear sky conditions. Deviations are mainly due to shading effects on sensors with a non negligible surface area, whereas the simulation tool calculates illuminance at a point. When no direct light is incident, the deviation between measurements and simulation models is very small. This means that under overcast conditions good agreement between simulation and monitoring can be achieved.

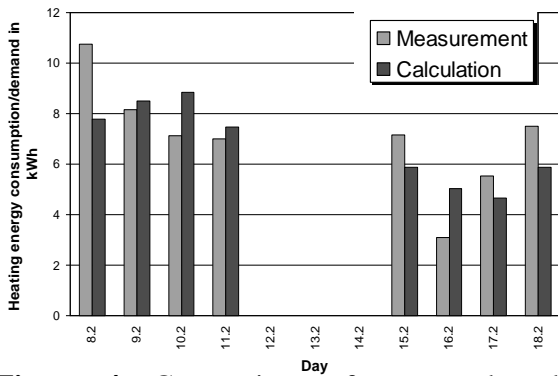


Figure 4: Comparison of measured and simulated of heating energy consumption

The accuracy of the thermal simulation depends mainly on the quality of the input data. Solar gains are important for the calculation. Under Stuttgart climatic conditions this simulation method gives good results during most of the year. Daylight simulation program validation is another challenging task. Due to the dynamic nature of light, sudden changes on sky-sun relations cause complexities for the measurements. Ashmore and Richens found 30% of difference between the software and test models in their physical accuracy analysis and they indicated the experimental error between 25% - 40% depending on the location of the room [7]. Recent studies of Mardaljevic on validation of lighting programs for illuminance modeling shows errors about 10% to 25% [8]. Comparing our results with previous studies on daylight simulation program accuracy, the test results are in a reasonable error range.

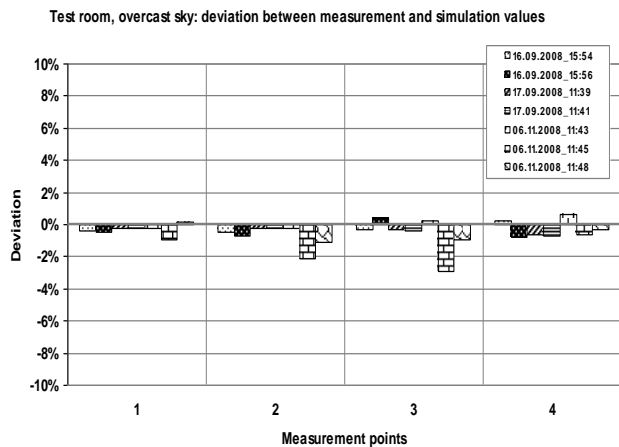
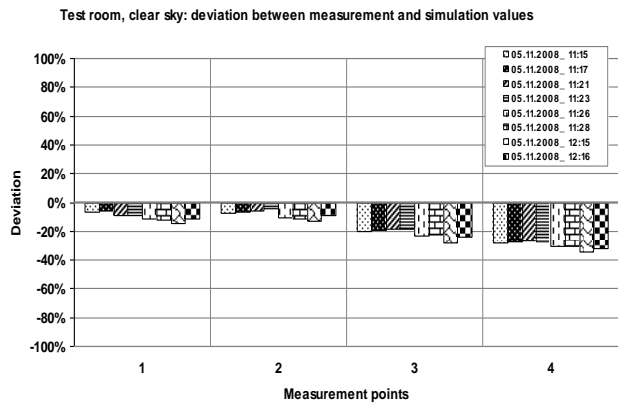


Figure 5a: Deviation between measurements and simulation under clear sky conditions as a function of room depth.

5b: Deviation between measurements and simulation under overcast sky conditions.

3. RESULTS AND DISCUSSIONS

In the residential building configuration the daylighting simulation space is considered as a living room presented in Figure 6. In order to get the minimum lighting levels for residential spaces, the living room illumination level should be 300 lux.

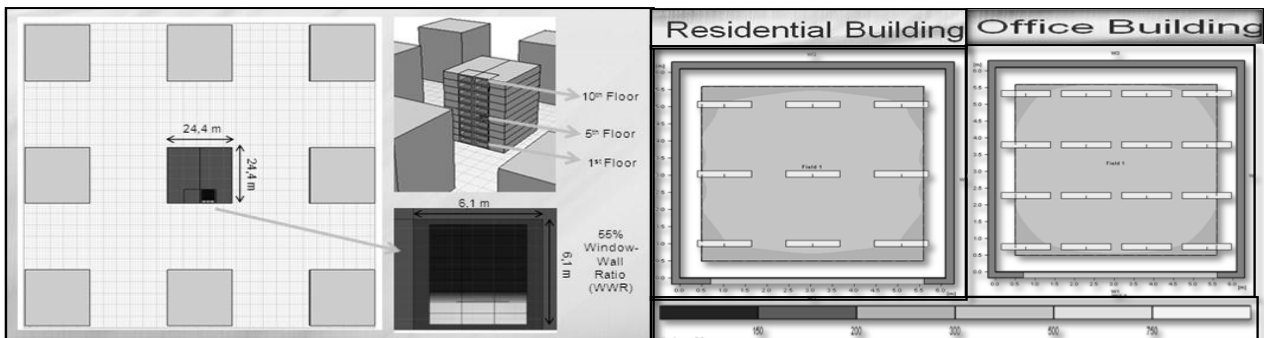


Figure 6: Urban configuration (left) and luminary placement for residential and office buildings.

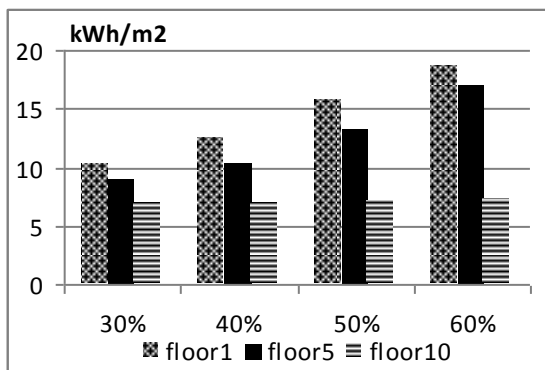


Figure 7: Daylight responsive electrical lighting energy demand of office buildings in Stuttgart/Germany within different urban densities for different levels of buildings.

The case study room is equipped with an artificial lighting system. The placement of the artificial lighting system in the living room and the luminary lamp properties can be seen in Figure 6. Total luminous fluxes of the lamps are 2600 lm and the efficiency is 72.8%. Each luminary power is 32 W. Without the implementation of a daylight responsive system in the space, the energy consumption due to artificial lighting is 19,6 kWh/m². In a residential building the usage of the lighting system is restricted as defined in the daily schedule according to occupancy. When a daylight responsive dimming system is integrated into the model, the electricity consumption drops to 16,9 kWh/m² or by 15.3%.

In a similar urban configuration with similar site coverage, the energy consumption of the office buildings' daylight-controlled artificial lighting was evaluated. The required illumination level of office room is 500 lux and the artificial lighting system was designed to supply this level. In the first case the lighting consumption was calculated considering all working hours during the day without dimming system and surrounding effects. In this scenario the electricity consumption is 35.8 kWh/m². With a manual on/off system the consumption drops to 27.7 kWh/m². When the daylighting responsive

control system was applied in the urban configuration, the consumption dropped to between 18,6 and 6,8 kWh/m² according to the elevation of the floor (see Figure 7).

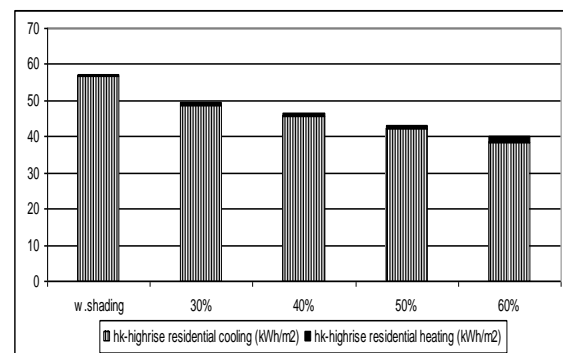
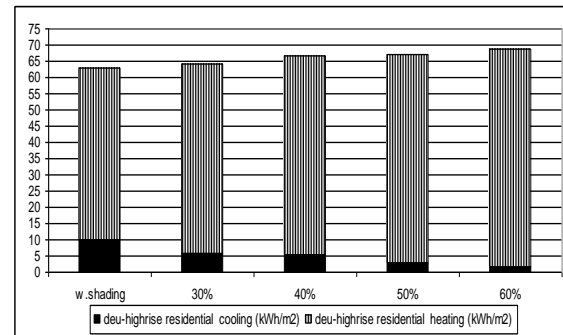


Figure 8a: Heating and cooling demand of high-rise residential blocks for different settlement densities in Stuttgart climate **8b:** Heating and cooling demand of apartment blocks for different settlement densities under Hong Kong climatic conditions.

High-rise residential blocks with different site coverage are simulated for Stuttgart and Hong Kong climatic data (see Figure 8). The dominating building energy demand is cooling for Hong Kong climate. In Hong Kong, high rise residential blocks are very common in residential areas and the density of these blocks highly affects the cooling energy demand. The cooling demand of a well insulated high-rise block with 54 kWh/m² decreases to 37 kWh/m² with 60% site coverage in Hong Kong. On the other hand the heating demand of 53 kWh/m² for high-rise buildings in Stuttgart increases to 67 kWh/m² with increasing site density.

4. CONCLUSION

The presented paper shows exemplary results of simulations and measurements which aim to investigate the effects of urban structure and building types on the energy performance of the urban quarters. The goal of the work is to quantify lighting, cooling and heating energy demand for different residential and business urban quarters.

Many aspects of the urban design, from the layout of the roads to the building shape crucially affect the energy performance of the buildings. On the other hand, the urban configuration of the business district has significant effects on the site energy performance. Especially the lighting electricity demand can be decreased by the urban design strategy and daylight responsible artificial lighting system. Therefore first the possible solar gains for the site design need to be investigated and then building construction and envelope design have to be optimized by considering this analysis.

Combined detailed daylighting analysis and dynamic thermal simulations show that in a moderate to cold climate, the total heating and cooling energy demand increases with site coverage by about 10%, heating alone by 27%. In a hot climate the energy consumption decreases with increasing site coverage by about 30%, as the cooling demand diminishes.

Increasing the site density from 30 to 60% in commercial districts the lighting electricity demand increases by 60%. If no daylight responsive strategy is used, the effect is even higher at 73%. In residential districts the effect of density on lighting electricity density is smaller with 14%.

Lighting and thermal energy demand should be investigated together and the overall energy consumption should be optimized considering primary energy.

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