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The Impact of the Urban Form on Building Energy Demand

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ABSTRACT*: It is hard to quantify the impact of the urban form on the energy demand of the buildings. Only very few software tools are available that calculate the influence of mutual shading of buildings and topography on the energy demand. If lighting electrical energy is also considered, the simulations become more complex, as the sky models need to be realistically represented. In this work, the classification of generic urban forms is combined with the site thermal properties and the building types. For selected forms and typology detailed simulations of heating, cooling and daylighting for different parameters (site coverage, building age and thermal standards) were carried out on building level to consider precisely the shading situation from neighbouring buildings. To validate the different simulation tools used, a case study was choosen from the urban area Schärnhauser Park near Stuttgart. As a result this research gives the quantified detailed energy demand for different settlement types for urban designers and energy management planers, who then can estimate the energy demand of the different urban quarters without socio economic context. In the paper the different energy performance of urban forms will be compared for different climates with varying heating, cooling and daylighting situations.*

Keywords*: urban, heating, cooling, lighting, energy.*

1. INTRODUCTION

Although energy demand of the cities is related to the daily activities of people in the cities, it has a big interaction with the urban structure configuration which contains urban building forms and their organization on the land area. The influence of the urban forms can be evaluated without the socio-economic context. To quantify the effect of urban design and urban forms supports to improve the urban energy performance and to minimize the environmental problems.

The basic problem on this theme is the analysis of complexities of urban environment and some archetypes were defined for daylighting or thermal energy performance studies to surmount that difficulty. The fundamental study on this subject was done by Leslie Martin and Lionel March [1]. For evaluating the daylighting ability, the urban forms are classified as pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts. Many studies which based on this classification have done but none of them considered the irradiance on the facade and daylight responsive energy demand. In the last decade, the urban energy performance of archetype forms was evaluated with image processing techniques for the real case study area [2]. The urban forms and their possible 30 design variables were used for estimating the energy usage of building by Steemers [3]. Nevertheless this study assessed only the building energy consumption not urban quarters and also just for possible 30 variations. Heating and daylighting performance of six configurations of courtyard typology urban blocks were calculated by Eugenio et al. with the daylighting factor and daylight autonomy [4]. Mardeljevic and Rylatt used the ray tracing method to resolve the irradiation in complex urban environment [5]. R. Compagnon produced irradiation results with a periodic solar radiation distribution method to find out the viability of solar energy technologies in the urban context [6]. EEP (Energy and Environment Prediction) model is applying the individual building as a starting point and gives some estimation result for a group of buildings [7]. Another relevant urban energy modelling approach is the Sustainable Urban Neighbourhood modelling tool (SUNtool) [8]. It simulates the

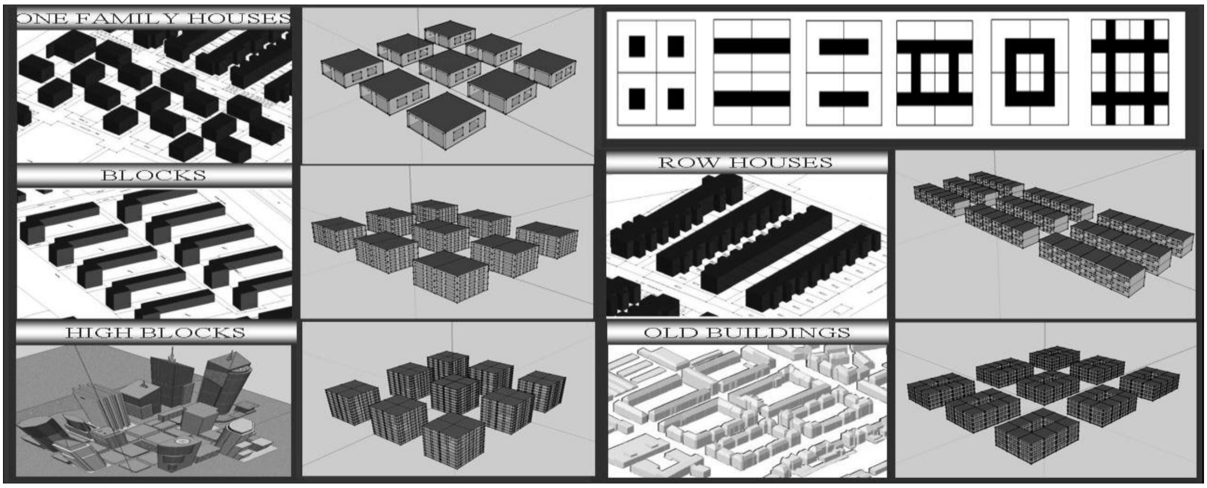

Figure 1:Residential settlement types with face to face design according to building type

hourly urban energy, water and waste flows with a simplified dynamic thermal model, based on a radiation model, which calculates solar and thermal radiant exchanges for the building envelope with stochastic occupancy models. Another important urban scale site design program Gosol, consider just the direct sunlight and the shading. It does not calculate the reflactance from surrounding buildings [9].

In this study, urban generic forms and residential building types are combined for setting up the building stock thermal and visual properties data. According to these datasets, heating, cooling and daylighting performance of different residential urban quarters were simulated a floor by floor level to consider precisely the shading situation from neighbouring buildings. This research aims to derive detailed energy demand profiles for residential urban quarters which can be used by urban designers and energy management planers to estimate the energy demand of the different settlements without socio economic context.

2. ANALYSIS APPROACH FOR ASSESSING THE URBAN EFFECT ON THE ENERGY PERFORMANCE OF RESIDENTIAL BUILDINGS

In the context of this research, settlements are considered as several districts and those districts are classified according to their main using types as residential, commercial or industrial. After this classification, the main research area is focused on the residential part. The data input is carried out on three levels considering occupancy, building and urban form in relation to energy flow. The thermal properties of these districts have been determined according to characteristics of radiative, thermal, moisture, and geometric properties which are based on the thermal climatic zone classification for urban heat island effect [10]. In this assessment three generic urban types were chosen: pavilion, terraces and pavilion courts. These types are configured on the site with different densities. For the second level of data, the building properties are defined according to typology made by Institute for Housing and Environment-Germany [11]. The building stock was explored on the basis of energy demand properties according to construction years in this typology and it is categorized as single family houses, row houses, multifamily houses, large apartments and high-rise blocks. For each class the representative building is chosen for urban settlement types and it gives typical values for the thermal insulation characteristics and building geometry. The residential settlement types are configured as the pavilion settlement type of one family houses, apartment and high-rise blocks, the terrace settlement type of row houses and the pavilion courtyard settlement type of old houses. The building types can be seen in Figure 1. Three dimensional urban quarter model was prepared for different generic urban forms. The representative urban quarter constitutes of 9 generic building blocks from each building type and the distance between the buildings varies according to site densities. In the simulations, the German statistic data and measurements from site were applied for estimating the occupancy scenario. According to that, all types of residential buildings were simulated for two identical family scenario. The first scenario is based on a family with 4 people and all of them do not use the flat during daytime except at the weekends. The second scenario is with 5 people and one of them is always at home. Every house is equipped with a television, computer, washing machine, dishwasher, oven, fridge, and microwave. The usage was determined as the average time taken from the German household statistic [12].

Daylighting research part of this study carries out daylight analyses and electricity consumption of daylight response artificial lighting for residential building spaces with different urban geometry configurations in different height level. For the calculation of the floor by floor daylight illuminance the ray tracing program Radiance was used [13].The daylighting performance has been analyzed using the so called useful daylight illuminance scheme. Daylight illuminance in the range 500 to 2000 lux are often perceived either as desirable or at least tolerable and called UDI autonomous (UDI-a). In order to compute internal daylight distribution, results were evaluated with daylighting metrics. The change is sensitive to building orientation and height of the floor. Annual UDI-a distribution of residential spaces can be seen in Figure 2.

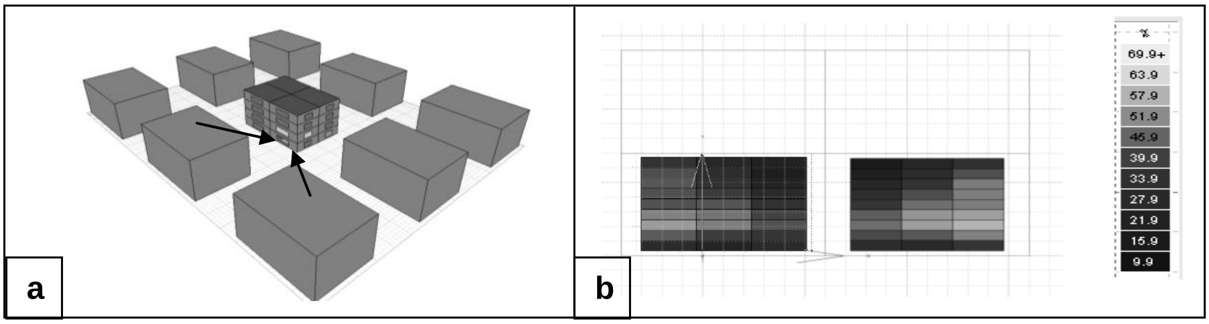

Figure 2: a-residential building spaces with south-west facades and south east facades b- Useful daylight illuminance autonomy performances comparison on the entrance floor working level (80cm height)

In the entrance floor level, the annual UDI-a of left building space, which has south and west oriented windows, is 35.82% and right building space, which has south and east oriented windows, is 33.42%. According the daylight performance of two residential spaces, daylighting responsive artificial lighting system was designed. The space was equipped with artificial lighting which provides 300 lux minimum illuminance in the space. The annual electricity consumption with a daylight responsive control system was simulated in radiance based on the lighting program Daysim [14]. To see the total energy demand of the building, heating and cooling analysis including the annual electricity consumption with daylight responsive control was calculated in the Energyplus simulation program [15].

2.1. Simulation validation with case study

In order to quantify the impact of the surrounding buildings on the energy performance, the daily measurements of heating and electricity consumption from the case study area in the Scharnhauser Park, Stuttgart/Germany were evaluated. The multyfamily apartments, row houses and some commercial and administrative buildings are placed in the area and it has 7000 inhabitants . In this study, 10 single family houses from Scharnhauser Park were measured and simulated. Site plans and 3D drawing of buildings are shown in Figure 3..

The shading effect of one another building was defined in EnergyPlus with three dimensional site model. For the energy plus model the energy consumption data from many residential houses were collected from monthly energy readings and for some specific cases they were measured with smart metering system. According to collected consumption and daylighting simulations, the building equipment schedule was defined in the EnergyPlus program. The same design sets are used in the simulations with different air change rates and heating set temperature for houses according to different user scenarios. The calculated energy demand in Figure 4 is based on DIN V 4108-6:2003-06 standard. When comparing measured and simulated results with dynamic simulation tool with Energyplus, which is shown in Figure 4, it is not possible to separate the shading effect from the user behaviour effect, which clearly dominates consumption. In the building detailed simulation, the building energy consumption and simulated values are quite close in most cases. The monthly energy balance results are always lower than the dynamic simulations.

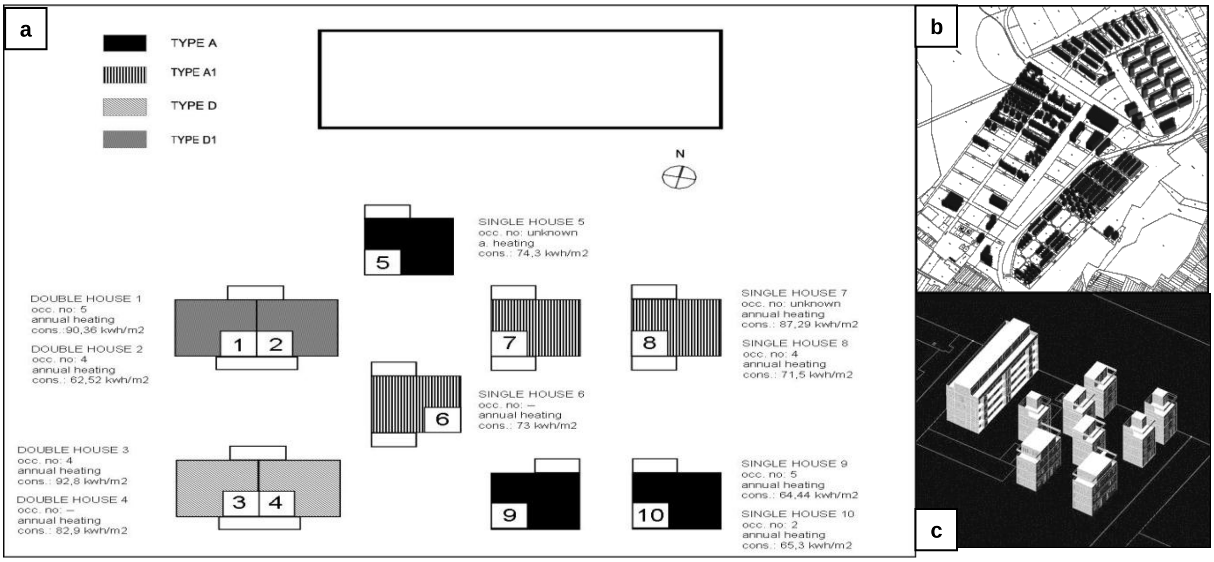

Figure 3: a-The location of 10 case study buildings on the area and their properties, b- The case study area in the Scharnhauser Park settlement, c- 3D drawings of the case study buildings

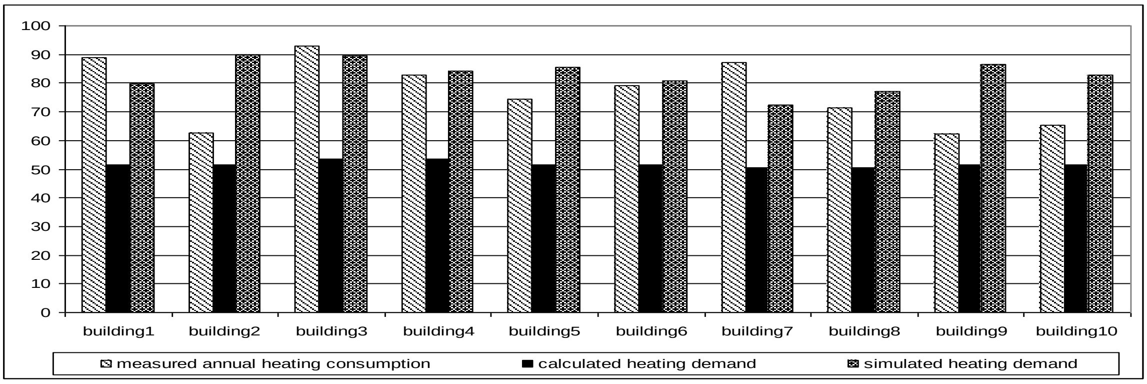

Figure 4: Measured, calculated and simulated heating demands for case study area.

3. RESULTS

The lighting electricity is scheduled according to that system; between 08:30-18:00 – the space lighting system works with daylight responsive system, between 18:30-22:30 artificial lighting systems works at 75% of installed power and between 22:30-24:00h artificial lighting system power is reduced to 25%. It has been observed that the useful daylight illuminance autonomy tends to increase in higher levels of the building. Figure 5 represents the sensitivity of the electricity consumption with respect to orientation and building level. Floor by floor analyses results in approximately 10% electric energy saving between entrance floor and last floor.

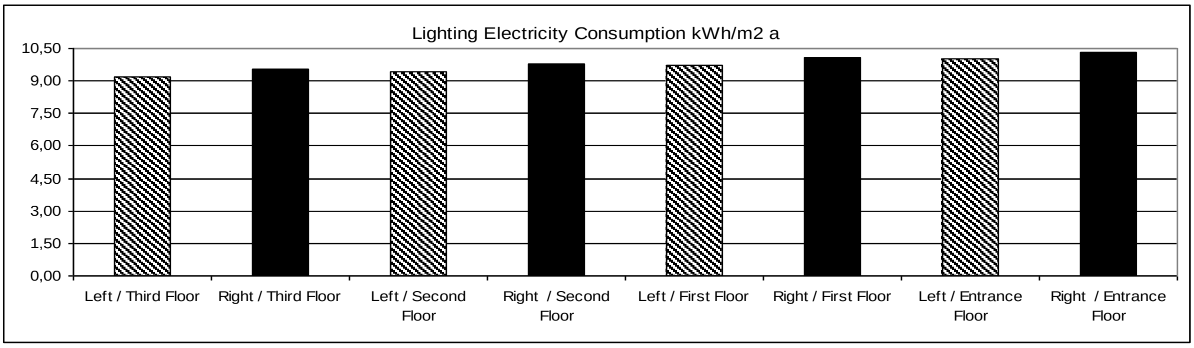

Figure 5: Lighting demand as a function of floor level for apartment biıldings area with 40% site coverage.

The place of the building in the settlements has an important influence on the building energy demand. In order to quantify this factor, each 9 buildings from evaluation area was simulated with different densities. The results can be seen in Figure 6. It shows that the buildings which have no shading effect on the south facade is not affected by the site density. Although the place of the building is not magnitude in the less dens areas, in the high dens areas the highly shaded building has 20% more heating demand than the building in the first row. The heating demand of building 9, which locates in the middle of the area, is 44.75 kWh/m^2 and cooling demand is 11.3 kWh/m^2. Depending on the shading on the site, the heating demand can be 18% higher more for same building. The building 6 which have shading effect on south, east and west facade got the second bigger ifluence from the site density. The reflection has the minor effect on the building heating demand and the influence would be higher with large and reflective window areas.

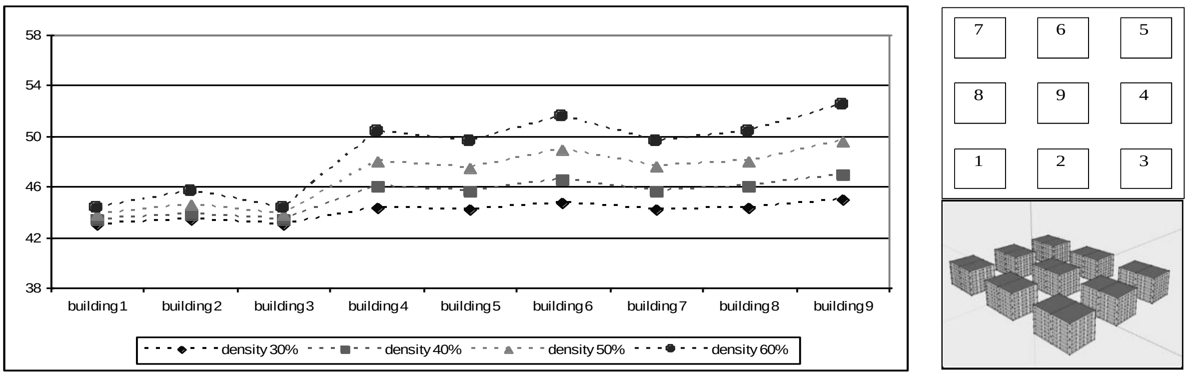

Figure 6: Heating demand of the appartment blocks with different site coverage.

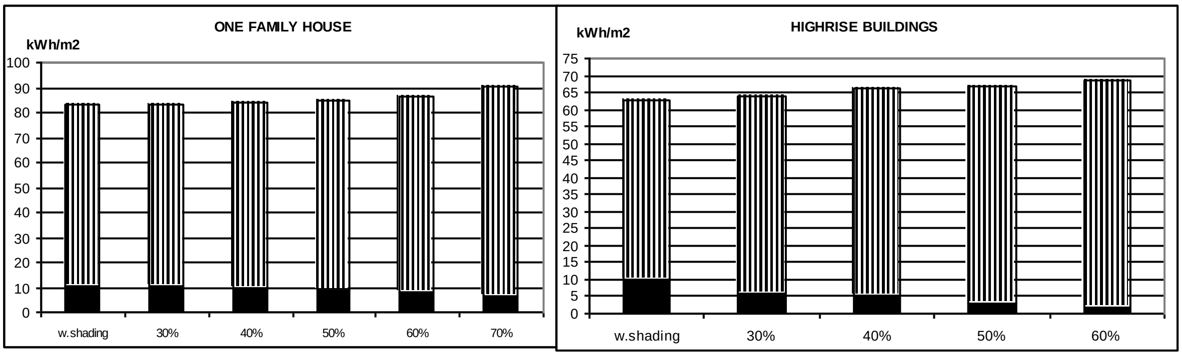

Figure 7: a-Heating and cooling demand of a one family house for different settlement densities in Stuttgart climate, b-Heating and cooling demand of highrise blocks for different settlement densities in Stuttgart climate.

Figure 7 shows the heating and cooling demand of a one family house and highrise blocks in different dense areas which were constructed in between 1995 and 2001. Without any shading effect the heating consumption of one family house is 72 kWh/m^2 and depending on the shading of the area the heating consumption can be 17% higher than the buildings which are simulated without surrounding. When albedo is 0.7 for the surroundings with actual glazing areas, the heating demand of one family house is 79 kWh/m^2 in the 60% site coverage. The energy demand per square meter of highrise blocks is less than one family house. The heating consumption of the highrise blocks is 53 kWh/m^2 and cooling demand is 10 kWh/m^2. Depending on the shading on the site, the heating demand can be 25.5% higher more. It shows that the shading effect is relevant within the highrise dense areas.

The heating consumptions of row houses are changing as a function of the total heated surface area to the surface area exposed to the ambient condition. The heating consumption of corner houses are 17% high than the other buildings in the middle of the row as shown in Figure 8a. Depending on the density on the site, the heating demand increases 11-13%. The reflection effect with density does almost not influence the heating demand of the row houses. The figure 8b shows the heating and cooling demand of the old blocks within the courtyard urban form. The old house has very high overall heat transfer coefficient for the building envelope.

The apartment blocks are simulated with Stuttgart, Ankara and Hong Kong weather data (Figure 9). The dominating building energy demand is cooling for Hong Kong climate. In Hong Kong, the density of the blocks highly affects the cooling energy demand. The heating demand of a well insulated apartments with 39,25 kWh/m^2 in Stuttgart increases to 49,8 kWh/m^2 with increasing site density. The optimization of the site density is highly important in Ankara climate and it should consider the primary energy consumption of the building.

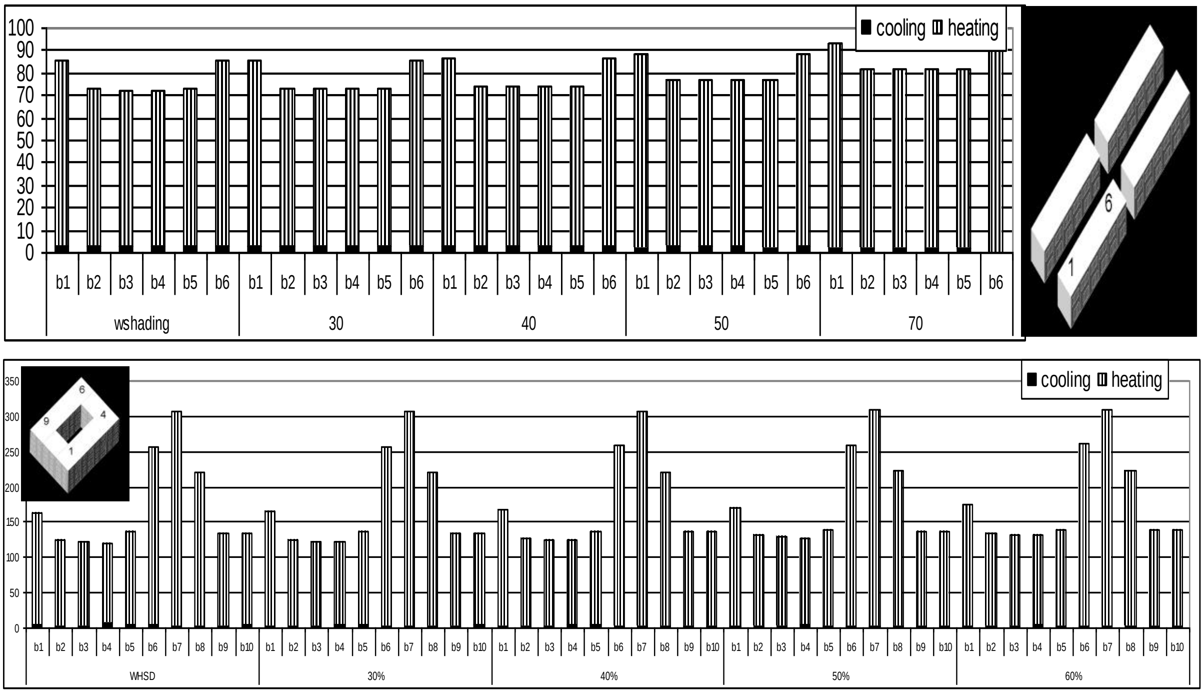

Figure 8: a-Heating and cooling demand of row houses for different settlement densities in Stuttgart climate, b-Heating and cooling demand of old houses in the courtyard urban form for different settlement densities in Stuttgart climate.

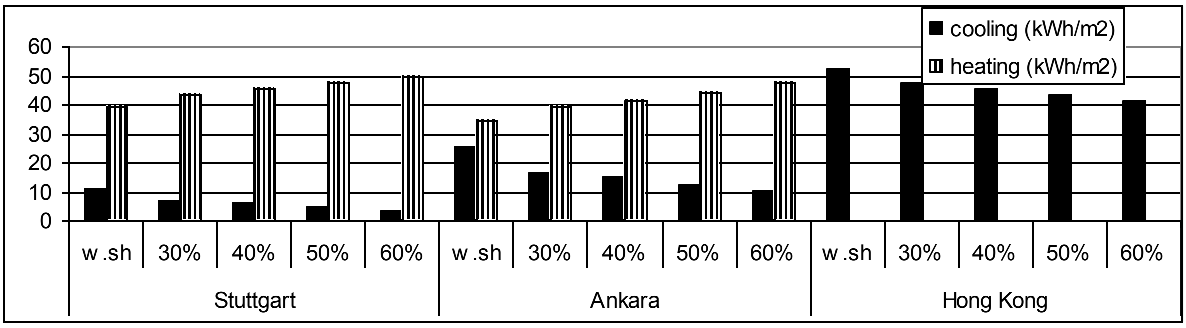

Figure 7: comparison of Heating and cooling demand of apartment blocks with U-value according to EnEV 2009 for different settlement densities in Stuttgart, Hong Kong and Ankara climate.

4. CONCLUSION

The presented paper shows exemplary results of simulations and measurements which aim to investigate the effects of urban structure and building forms on the energy performance of the urban quarters. This part of the research aims to carry out quantified lighting, cooling and heating energy demand calculations for different residential urban quarters. The total energy consumption of the cities is crucially influenced by early urban design decisions. In the early step of the design when the layout of the roads to the building shape is formed, the site energy performance should be considered an the possible solar gains for the site design need to be investigated. According to primary energy demand, the building placement, shape and envelope design have to be optimized . Combined detailed daylighting analysis and dynamic thermal simulations show, that 10-20% heating and cooling demand may be saved by an energy aware site structure. When we consider the used primary energy, the lighting and the thermal energy demand should be investigated together and the overall energy consumption optimization for operating the building has to be considered.

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