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## A Calculation Method on the Energy Demand of Urban Districts

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**ABSTRACT:** According to climatic conditions the structure of the urban quarters has a big influence on the lighting, heating and cooling energy demand of the buildings. The study aims to derive a method to estimate the performance of urban quarters. To quantify the energy performance of city quarters the buildings have to be dynamically simulated and the influence of the surrounding urban form, for instance the street distance or height of the neighbour buildings has to be considered. In this work, the lighting, heating and cooling performance of urban districts with different urban forms are calculated with simulation programs such as EnergyPlus, Radiance and Daysim. 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, lighting levels etc., which differ strongly between commercial and residential buildings. Mainly high rise buildings are considered with varying site coverage, building standards and user profiles. Interrelations between those effects are analyzed with respect to thermal and visual comfort condition. The analyses show that the site thermal performance depends on the arrangement of the urban geometry according to solar gains and there is a strong correlation between energy savings and efficient urban design.

**Keywords:** Building energy performance, urban impact, heating-cooling and lighting demand

### 1. INTRODUCTION

The design of a low-energy building does not answer alone the point of energy efficiency, meaning that the design should consider the effects from the surrounding urban structures. The urban spatial structure and building forms shape the requirements and living standards of citizens. Another degree of urban design is related to energy efficiency. The heating, cooling and lighting energy demand of buildings have been affected from the structure of the urban quarters according to the dominant climatic conditions. The urban structure contributes to the total energy demand of the city in various ways and the effects are complex and conflicting [1]. It is not easy to quantify those influences on the energy demand but it might be analysed in two dimensions considering daylighting and thermal behaviour.

Daylighting contributes to reduce electrical energy demand for lighting and decrease internal gains of the building for cooling. The daylighting performance of the building considers not only the direct and diffuse sunlight and also reflected light from neighbour facades and ground. The distance between buildings, the height of the facing building, the orientation of and the reflectance from the facing buildings, the size of openings and the size of the shading device have an influence on the building daylighting performance [2]. The solar irradiation on the façade and the illuminance level inside the buildings are important for understanding the building energy performance. There is some research on this topic which tries to evaluate daylighting performance of the buildings at the urban scale. P.J. Littlefair provided a design tool which deals with where the global solar irradiation and the global illuminance reaching the buildings envelopes [3]. R. Compagnon generated the irradiation map with a periodic solar radiation distribution method to find out the viability of active and passive solar energy technologies in the urban context [4]. All researches show that accuracy and validation of the modelling of urban solar availability and energy performance is significant to complete the building energy performance investigations in urban context. The shading on the façade and the solar reflectance from surrounding environment influence the building solar gain potential. In cold climate conditions solar gains are

helpful for decreasing the heating consumption, but in hot climate conditions the basic strategy for reducing the cooling load is avoiding the solar gains before reaching the envelope.

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 the 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 1. 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

It is important to combine energy use and comfort in the design phase of urban planning. This study describes a methodology to evaluate the mainly daylight responsive electric lighting consumption considering the thermal performance of the building in specific distance-height-length ratios. The real urban texture is highly complex to compute with software. In order to limit these complexities some archetypes were defined and these simplified types are used especially for energy use studies [5]. In this assessment the separated generic urban type was chosen. The separated units were defined by site coverage.

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 [6]. The daylighting performance has been evaluated according to the useful daylight illuminance (UDI) scheme which is based on a survey of occupant preferences [7]. 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 [8]. 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 EnergyPlus simulation program [9]. The simulation sets are summarized in Tables 2 and 3.

In the residential building configuration the daylighting simulation space is considered as a living room presented in Figure 1. In order to get the minimum lighting levels for residential spaces, the living room illumination level should be 300 lux. 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 1. Total luminous fluxes of the lamps are 2600 lm and the efficiency is 72.8%. Each luminary power is 32W.

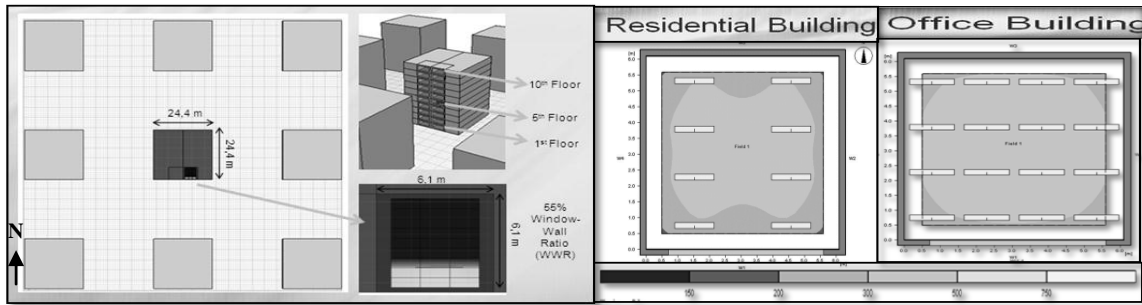


Figure 1: Urban configuration (left) and luminary placement for residential and office buildings.

**2.1. High-Rise Office Building Energy Demand in Urban Context**

To see the total energy demand of the high-rise office building, heating and cooling analysis including the annual electricity consumption with daylight responsive control was calculated by theEnergyPlus simulation program. The building type is a cellular (private) plan office and the working schedule is weekdays from 08:30 till 18:30.

In Germany, the Energy Saving Ordinance (EnEV) regulates energy performance in buildings. EnEV 2009 requires energy demand to be reduced in new buildings by 30 per cent (up to 46 kWh/m<sup>2</sup> per annum). The envelope was designed according to EnEV 2009. The basic set points are described in the Table 1. High-rise office blocks with different site coverage are simulated for Stuttgart, Germany. The 10 storey reference building has 24.4m depth, 24.4m length and 30m height. The dimensions of the reference office are 6 m width, 6m depth, 3m height and it has % 50 windows to wall ratio. The energy consumption of the office buildings’ daylight-controlled artificial lighting was evaluated for different site coverage. The required illumination level of the office room is 500 lux and the artificial lighting system was designed to supply this level [10].

When the shading effect due to the surrounding buildings is included to the evaluation, less amount of electric lighting energy savings was observed from the simulation results. The cooling energy demand is also affected by daylight responsive controlled artificial lighting fixtures. It results in less heat gain generated by artificial lighting and a small fall in heating energy demand concerning to internal gains. In the figure 2, the effects caused by external obstructions can be observed. Shading effect is increased in order to growth of site coverage ratio and it results in less cooling requirement by reason of a decrease in solar gains. On the other hand, more daylight decreases the electric lighting consumption and leads to less cooling demand due to a reduced amount of artificial lighting usage.

Table 2. The simulation sets for Office Building

Use of Building: cellular (private) plan office				
Daily profiles: Weekdays from 08:00 till 18:00 (without lunch breaks for internal gains point of view)				
People sensible gain:150W/person, Occupancy density:10m2/person, Appliances sensible heat gain:10 W/m2				
Infiltration maximum flow: 0,2 h-1 (air exchange)				
Auxiliaire ventilation: Natural ventilation maximum flow: 0,8 h-1(air exchange)				
Construction details	U value (W/m2K)	Thickness (mm)	Reflectance (%)	Visible light transmittance
Exterior Walls	0,24	0,34	0,3	
Roofs	0,24	0,36	0,3	
Ground Floors	0,24	0,36	0,3	
Internal ceilings / Floors	-	0,15	0,3	
Windows	1,31	0,04		0,55
Heating set points time schedule			Cooling set points time schedule	
Monday-Friday 00:00- 08:30 = 16 °C 08:30- 18:30 = 21 °C 18:30- 24:00 = 16 °C			Monday-Friday 00:00- 07:00 = off 07:00- 18:00 = 25 °C 00:00- 24:00 = off	
Weekend 00:00- 24:00 = 16 °C			Weekend 00:00- 24:00 = off	
Summer Period Off			Winter Period Off	
Lighting time schedule (with daylight responsive control system application)				
Weekdays 00:00 - 08:30 = off 08:30 - 18:30 = on 18:30 - 24:00 = off			Weekends 00:00 - 24:00 = off	

Table 3. The simulation sets for High-Rise Residential building

Use of Building: High-rise Residential building				
Daily profiles: 4 People: 2 parents and 2 children.				
People sensible gain: 120W/person(daytime-light working), 100W/person(sleeping)				
Infiltration maximum flow: 0,2 h-1 (air exchange)				
Auxiliaire ventilation: Natural ventilation maximum flow: 0,6 h-1(air exchange)				
Construction details	U value (W/m2K)	Thickness (mm)	Reflectance (%)	Visible light transmittance
Exterior Walls	0,24	0,34	0,3	
Roofs	0,24	0,36	0,3	
Ground Floors	0,24	0,36	0,3	
Internal ceilings / Floors	-	0,15	0,3	
Windows	1,31	0,04		0,55
Heating set points time schedule		Cooling set points time schedule		
Monday-Friday 00:00- 08:30 = 15 °C 08:30- 18:30 = 21 °C 18:30- 24:00 = 15 °C		Monday-Friday 00:00- 07:00 = 30 °C 07:00- 18:00 = 25 °C 00:00- 24:00 = 30 °C		
Summer Period Off		Winter Period Off		
Lighting time schedule (with daylight responsive control system application)				
Weekdays 07:00 - 09:00 = on 09:00 - 16:30 = off 16:30 - 24:00 = on		Weekends 07:00 - 24:00 = on		

The simulated thermal and electricity energy performances of the office with different site coverage ratios were investigated in terms of total annual consumption (loads, kWh/m<sup>2</sup>). The simulated annual heating demand differs from 35.65 kWh/m<sup>2</sup> to 40.12 kWh/m<sup>2</sup> with daylight responsive artificial lighting system. In 60% site coverage situation, the annual cooling loads decrease to 17,47 kWh/m<sup>2</sup> which is about 36% less than 30% site coverage position.

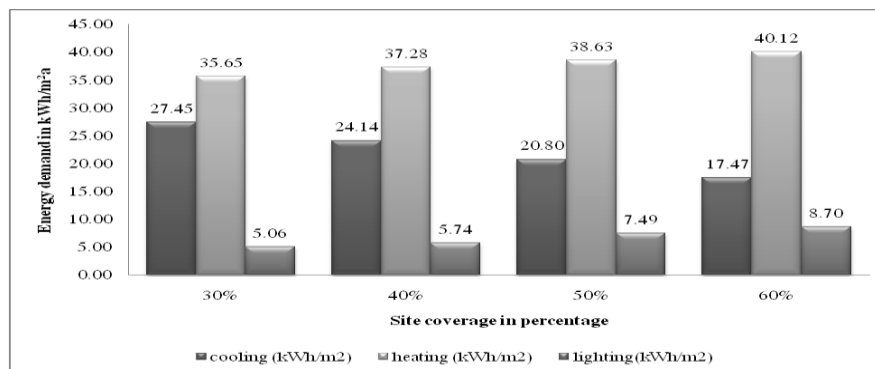


Figure 2: Heating, cooling and lighting demand of high-rise office blocks for different settlement densities in Stuttgart climate.

## 2.2. High-Rise Residential Building Energy Demand in Urban Context

High-rise residential blocks with different site coverage are simulated for Stuttgart climatic data (see Figure 3). The identical 10 storey reference building (with equal dimensions) was used for evaluation of the energy demand. The same sized reference space defined as living room and the annual electricity consumption with daylight responsive control was calculated. The occupancy, lighting and equipment schedules were differed compare to the high-rise office building. The envelope's components of the residential building as well as the office building were designed according to EnEV 2009.

Total energy consumption of the residential buildings was assessed under different site coverage with daylight-controlled electric lighting. In order to required illumination level of 300 lux for a living room the supplementary artificial lighting system was designed (see Figure 1) [11].

Figure 3 shows the annual heating, cooling and lighting electricity consumption per m<sup>2</sup> variation in settlement densities for high-rise residential blocks. The dominating building energy demand is heating for the Stuttgart climate. The heating energy demand increases depending on the range of density. On the other hand,

the cooling demand of a well insulated high-rise residential block with 6.59 kWh/m<sup>2</sup> decreases to 1.95 kWh/m<sup>2</sup> with 60% site coverage.

Especially from artificial lighting requirement point of view the daytime usage of the residential building is less than the daytime usage of office buildings.. Therefore, daylight responsive artificial lighting demand has not been changed depending on site coverage.

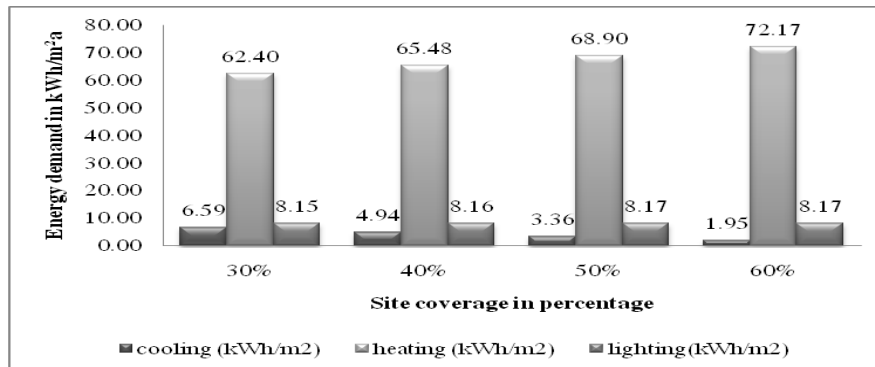


Figure 3: Heating, cooling and lighting demand of high-rise residential blocks for different settlement densities in Stuttgart climate.

### 3. DISCUSSIONS

This study examines the energy performance of high-rise residential and office buildings in the urban context with separated urban generic form in different site coverage ratios. The cases deals with daylight responsive controlled electricity lighting consumption and thermal performance of buildings. The results from simulation analysis indicate the energy savings under the impact of nearby obstructions.

For the sample office room and the sample living room spaces, the annual electricity lighting demand was evaluated in each site coverage percentage as a function of the floor height. In the office building lighting energy demand was affected by daylight availability during the daytime. Hence the daylight responsive artificial lighting system decreases the total consumption of electric lighting energy. This decreasing effect can be seen more clearly on first and fifth floor (Figure 4b). On the top floor, the effect cannot be observed because of the neighbourhood building obstructing position. In the living room space, lighting demand is basically not directly depending on the daylight availability of the room. The occupants use the room mostly between 18:30-22:30. Thus, in this time period the artificial lighting system cannot be supported by daylighting (Figure 4a).

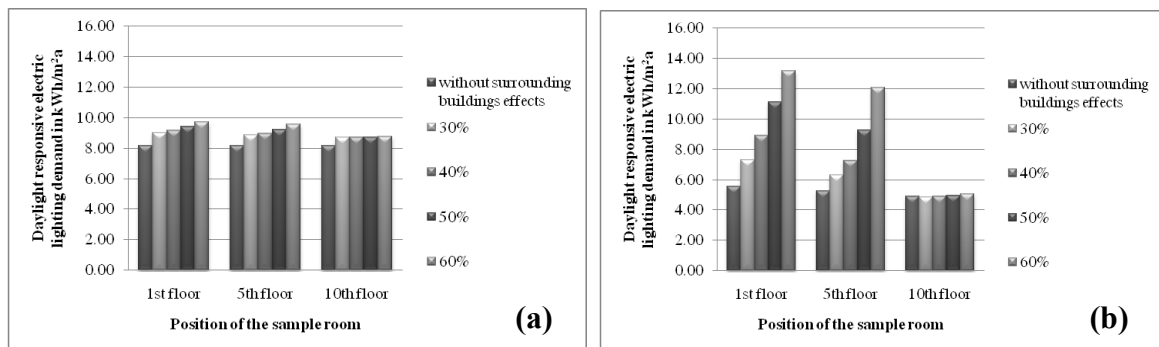


Figure 4: Daylight responsive artificial (electric) lighting demand of high-rise residential (a) and office (b) blocks for different settlement densities and different floor levels.

### 4. CONCLUSIONS

The presented paper shows exemplary results of simulations 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 office 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 the 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 of high-rise office buildings show that in a moderate to cold climate, the heating energy demand increases with site coverage by about 12 % and the

cooling demand drops by 36%. The daylight responsive electric lighting demand rises from 5.05 kWh/m<sup>2</sup> in 30% of site coverage to 7.49 kWh/m<sup>2</sup> in 60% of site coverage. If no daylight responsive strategy is used, the electric lighting demand is 35.75 kWh/m<sup>2</sup> which means 5 times as much in the worst case.

Increasing the site density from 30 to 60% in residential districts the heating demand increases by almost 15% (from 72.17 kWh/m<sup>2</sup> to 62.40 kWh/m<sup>2</sup>) and cooling demand decreases by 70% (from 6.59 kWh/m<sup>2</sup> to 1.95 kWh/m<sup>2</sup>) In residential buildings districts the effect of density on lighting electricity density is much smaller with only 1%.

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

The calculations showed, especially in high rise office building districts, up to 35 % of electricity consumption could be prevented by the site design. On the other hand the heating and cooling consumption can be optimized in the same time. If solar access is taken into account at the earliest planning stages, it is usually possible to ensure that the majority of buildings on a site are orientated to have good solar access for daylighting and reducing the heating demand. On this type of settlements, the cooling load can be minimized by optimized shading devices. For summer dominated climate conditions, the site design can be helpful to reduce the cooling load but in the design phase always the daylighting situation and the lighting loads should be considered. By taking early focus on site design, many business districts can reduce their energy demand significantly.

## REFERENCES

1. Givoni, B., (1998). Climate Considerations in Building and Urban Design. *Van Nostrand Reinhold, United States of America*.
2. Santamouris M., D. N. Asimakopoulos, (2001). Energy and climate in the urban built environment. ISBN-13:9781873936900
3. Littlefair P., (2001). Daylight, sunlight and solar gain in the urban environment. *Solar Energy, Volume 70, Issue 3, , Pages 177-185*
4. Compagnon R., (2000). Assessment of the Potential for Solar Energy Applications in Urban Sites. *Ecole d'ingénieurs et d'architectes de Fribourg*
5. Martin, L. and L. March, (1972). Urban Space and Structures. *Cambridge Urban and Architectural Studies, No.1. Cambridge University Press*.
6. Larson, W, Shakespeare. (1998). Radiance Lighting Simulation System.
7. Nabil, A, and J. Mardaljevic, (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings, 38(7):905-913*.
8. Reinhart, C.F., (2006). Tutorial on the use of daysim simulations for sustainable design. *Institute for Research in Construction, National Research Council Canada: Ottawa, Canada*.
9. Drury, C, B, Lawrie, L, K, Pedersen, C, O, Liesen, R, J, Fisher, D, E, Strand, R, K, Taylor, R, D, Winkelmann, F, C, Buhl, W, F, Huang, Y, J, Erdem, A., (1999). EnergyPlus: A New Generation Building Energy Simulation Program. Proc. Renewable and Advanced Energy Systems for the 21st Century, Maui, Hawaii, April 1999. New York: ASME.
10. CEN. (2002) EN 12464-1:2002, Light and lighting—lighting of work places—Part 1: indoor work places. *Brussels, Belgium: Comité Europe' en de Normalisation*.
11. CIE. 1986. Guide on Interior Lighting, International Commission on Illumination (CIBSE), *Vienna, Austria: CIE, Publication no. 29.2, 1986*.