Published in:
Proceedings of the 7th International Conference on Indoor Air Quality, Ventilaton and Energy Conservation in Buildings (IAQVEC 2010), August 15-18,2010, Syracuse, New York USA

A Method to Quantify the Energy Performance in the Urban Quarters

Dilay Kesten[1,*], Aysegül Tereci[1] and Ursula Eicker[1]

[1]Centre of Applied Research - Sustainable Energy Technology (zafh.net), Stuttgart University of Applied Sciences, Stuttgart, Germany

[*]*Corresponding email: dilay.kesten@hft-stuttgart.de*

ABSTRACT
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 has to be considered; for instance the street distance or height of the neighbour buildings. 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. Interrelations between those effects are analyzed with respect to thermal and visual comfort condition. Electricity lighting consumption is calculated and the thermal effect of artificial lighting is set as an input to the heating and cooling performance calculation. 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. The simulation results are validated with measured data from a case study in Stuttgart, Germany.

KEYWORDS
Energy performance, urban quarters, simulation tools

INTRODUCTION
The cities with their structures and organizations shape the requirements and living standards of citizens; on the other hand the cities supply the energy, sanitation, water, housing and transportation requirements of their citizens with the same structures and organizations. The design or plan of those structures can be an advantage or a disadvantage for the urban development and the life quality of residents. Another magnitude of urban design is related with energy requirements of the buildings themselves. 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. In the sustainable city development, less energy demand for the buildings is a first step for energy conservation and combined with green energy supply it can be the right solution for the future of the cities.

The physical form and spatial structure of the cities have an influence on energy demand as well as the building design itself. The urban structure contributes to the total energy demand of a city in different ways and the effects are complex and conflicting (Givoni, B. 1998). It sometimes can bring benefits, but it can also create extra loads and undesirable effects according to the dominant climatic conditions. The influence on energy demand can be analysed in two dimension considering daylighting and thermal behavior.

Natural illumination will reduce the demand of electrical energy and decrease in electrical energy demand reduces also internal gains of the building. This performance is related to direct and diffuse sunlight and also to reflected light from neighbor facades and ground. The

main factors that affect the daylight on buildings are listed by M. Santamouris, D.N. Asimakopoulos (2001) as 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. P.J. Littlefair (2001) provided a design tool which deals with where the global solar irradiation and the global illuminance reaching the buildings envelopes. R. Compagnon (2004) produced irradiation results to determine viability of passive and active solar energy technologies in urban context. The previous researches related to the modelling of urban solar availability and energy performance shows, the application of existing technical concept and/or implementation of new theories difficulties. Accuracy and validation of the tool is important to fulfil the building energy performance investigations in urban context.

The solar heat gains also relate to the solar irradiation on the facade. The shading of the façade, the solar reflectance according to albedo of the surrounding buildings and the irradiation on the façade determine the building solar gain potential. In the winter condition more solar heat gain is helpful for reducing the heating consumption, but on the other hand for summer conditions the shade from the surrounding is helpful to reduce the cooling load. For this reason lighting, cooling and heating should be investigated together and the overall energy consumption optimization for operating the building has to be considered. In this context site design according to daylighting opportunity is recognized as a useful strategy in energy-efficient building and site operation. The daylighting performance is especially significant for office buildings which are characterized by a big amount of lighting energy consumption and where the productivity of the employees is highly affected by lighting conditions. This paper presents the effect of the external factors which are related to the quality and quantity of natural light entering a building. The energy consumption of the building is calculated and the surrounding effect is discussed.

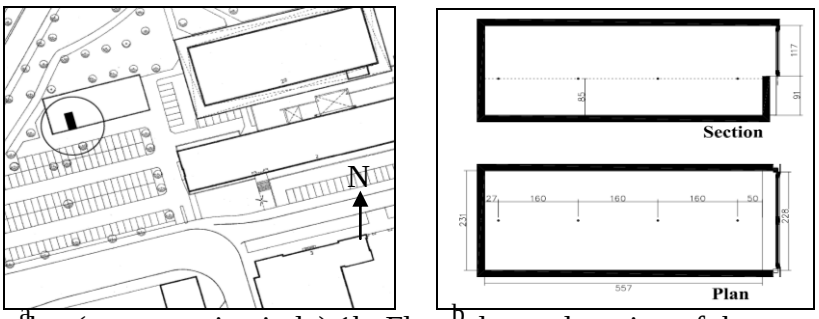
METHODS

Performing set of experiments is important in order to develop a reliable methodology for assessing the urban effect on the energy performance of office buildings. This process evaluates whether simulation tools complies the requirements.

Simulation validation with measured Data

To quantify the impact of the surrounding buildings to the energy performance of the office building in the urban context, simultaneous measurements were taken from a test office. The work plane illuminance, heating – cooling energy consumption and lighting electricity consumption (with daylight dimming system) measurements were done.

The test space is located in an office building near the city centre of Stuttgart – Germany. The façade is oriented towards South-Southeast (154.5 o from north). The test room dimensions are 2.31 x 5.84 x 2.08 m (width x depth x height). Floor plan and sections of test room are shown in the Figure1.



a b

Figure 1: 1a. Site plan (test room in circle) 1b. Floor plan and section of the test room

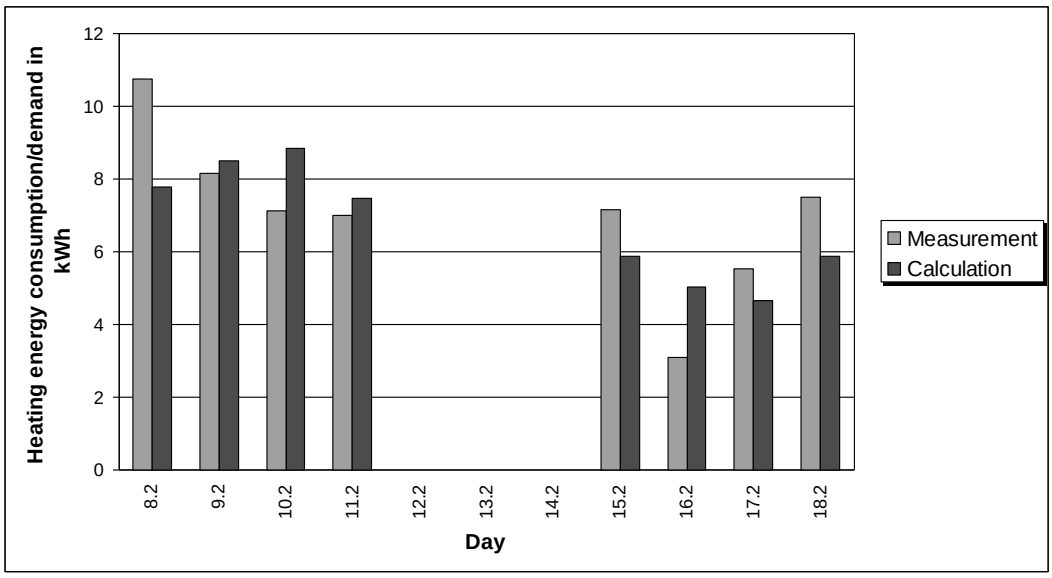


Figure 2: Comparison of measured and simulated heating energy consumption

The calculation results and measurement comparison can be seen in the figure. The heating measurement was taken from 8th (12 o'clock) until 18th (12 o'clock) of February 2010 (with a weekend break). The calculation of the heating energy demand considers the whole energy balance with transmission and ventilation losses as well as solar and internal gains following the calculation procedure from European standard DIN V 18599 [Strzalka, 2010]. Comparison of the daily calculated and measured values for the heating energy consumption/demand has a quite good reasonable agreement. The deviations are due to the static calculation method used. Therefore, there will be a need for the use of the dynamic simulation model to calculate the heating energy demand in the future.

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 3a indicates a comparison of illuminance measurement between 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 small point. When no direct light is incident, the deviation measurements and simulation models is small. This means that under overcast conditions good agreement between simulation and monitoring can be achieved.

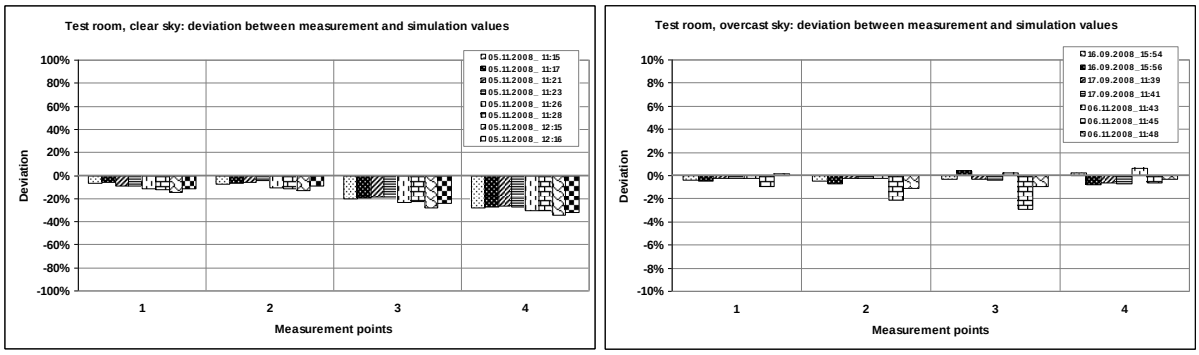


Figure 3a: Deviation between measurements and simulation under clear sky conditions. 3b: Deviation between measurements and simulation under overcast sky conditions.

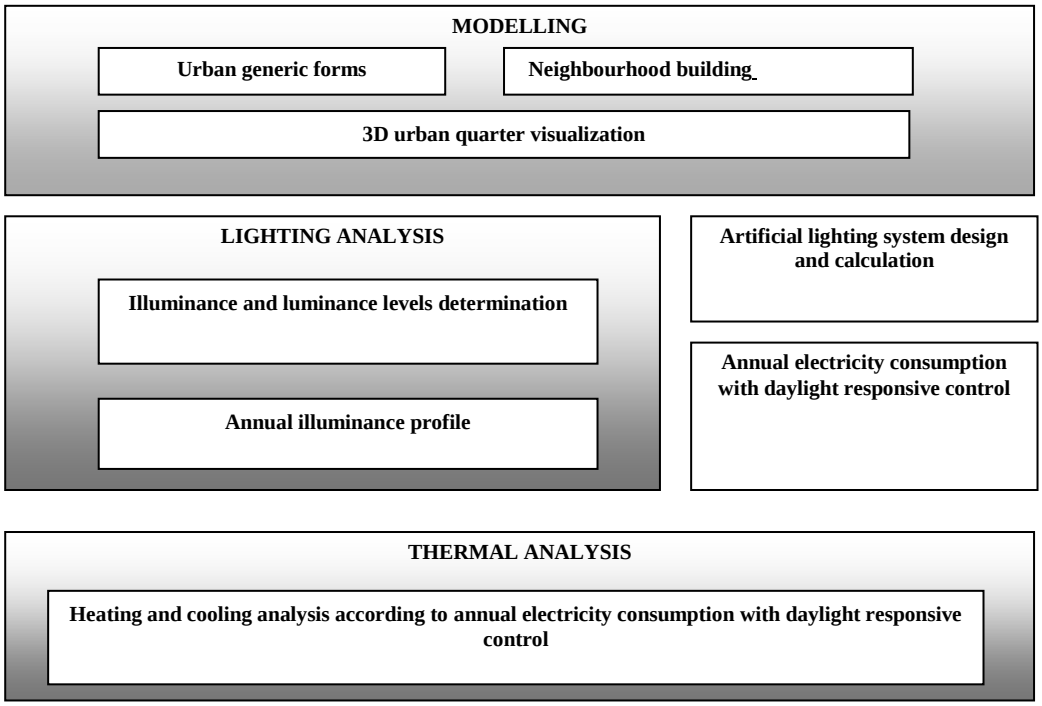


Figure 4: Analysis model for energy performance of the building

Simulation models can be used to asses the annual energy consumption for electric light or the impact of daylighting on the thermal behavior of the building. The accuracy of the thermal simulation depends mainly on the quality of the input data. Solar gains are important for the calculation. In Stuttgart climate simulation method usually gives good results during most of the year. Daylight simulation program validation is also important. Due to the dynamic nature of light, sudden chances 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 (Ashmore and Richens, 2001). Recent studies of Mardaljevic on validation of lighting programs for illuminance modeling shows significant errors about 10% to 25% (Mardaljevic, 2004). Comparing our results with previous studies on daylight simulation program accuracy, the test results seem to be in a reasonable error range.

Approach to assess the office 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 (Ratti et al., 2003). In this assessment two generic urban types were chosen: separated and continuous units. The separated unit, defined by geometrical ratios, can be seen in figure 5. Sixty different building configurations were analyzed, corresponding to five levels of spacing distance (L1/L2), three levels of building depth (D/L2), and four levels of aspect ratios (H/W).

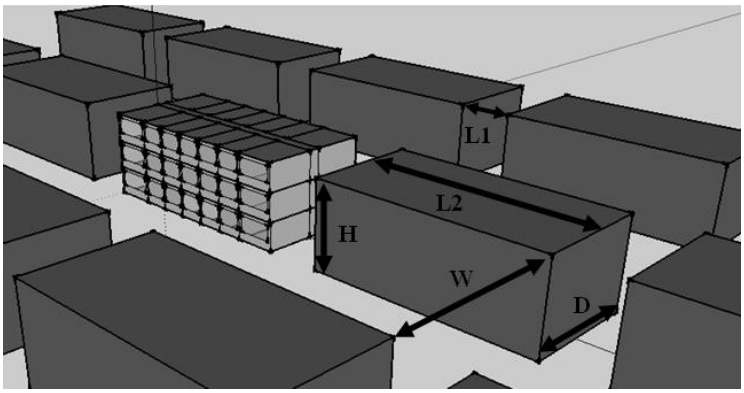


Figure 5: The separated form structure H, D, L2, refer to the height, depth, frontal length of each unit, L1 refers to the spacing between the units and W refers to the width of the street (Shashua-Bar L, Hoffman ME, Tzamir Y).

Three dimensional urban quarter simulation was done for different generic urban form and geometrical ratios. To calculate the daylight illuminance the raytracing program Radiance was used. The room was also equipped with artificial lighting. The placement of the artificial lighting system in the test office and the luminary lamp properties can be seen in the figure 6. Total luminous fluxes of lamps are 2600 lm and efficiency is 72.8%. Each luminary power is 32 W. A daylight responsive dimming system is integrated into model. The annual electricity consumption with a daylight responsive control system was simulated in radiance based on the lighting program Daysim (Reinhart, 2006).

Table 1. The simulation sets for EnergyPlus calculation

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:10m^2/person,Appliances sensible heat gain:10 W/m^2				
Infiltration maximum flow: 0,2 h-1 (air exchange)				
Auxiliary 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	Monday-Friday	00:00- 08:30 = Off
	08:30- 18:30 = 21 °C		08:30- 18:30 = 25 °C
	18:30- 24:00 = 16 °C		00:00- 24:00 = Off
Weekend	00:00- 24:00= 16 °C	Weekend	00:00- 24:00= Off
Summer Period	Off		

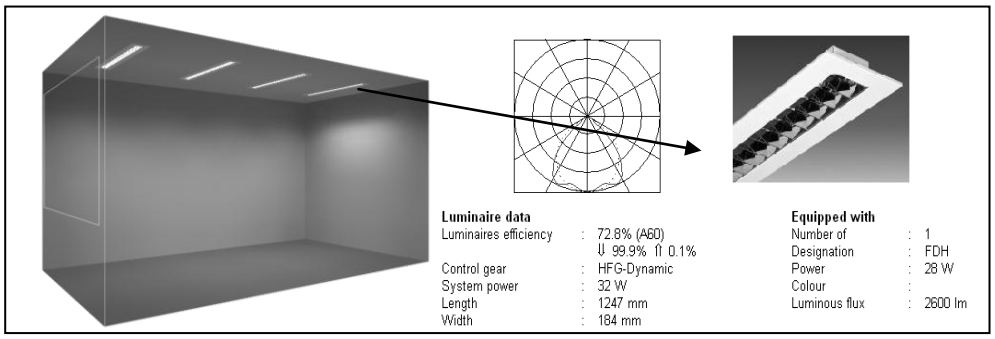


Figure 6: Artificial Lighting System Placement

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 Energyplus simulation program. The building type is a cellular (private) plan office and the working schedule is weekdays from 08:30 till 18:30. The envelope was designed according to EnEV 2009. The basic set points are described in the Table 1.

The separated form from urban generic forms was selected to serve a base case for comparison and evaluation. The base case was evaluated in order to distance between office buildings (L1/L2 - Figure 5). The 3 storey reference building has 10m depth and 20m length. The reference office is located in the first floor - middle axis of the building and facing to the south. The dimensions of office are 2.5 m width, 4.5m depth, 2.5m height and it has % 50 windows to wall ratio.

The simulated thermal and electricity energy performances of the office with different L1/L2 ratios were investigated in terms of total annual consumption (loads, kWh/m2). The simulated annual electricity lighting consumption without daylighting control is 29.58 kWh/m^2. With daylighting control, annual electricity loads decrease to 6,14 kWh/m^2 which is about 20% of total lighting consumption without any shading effect from neighboring.

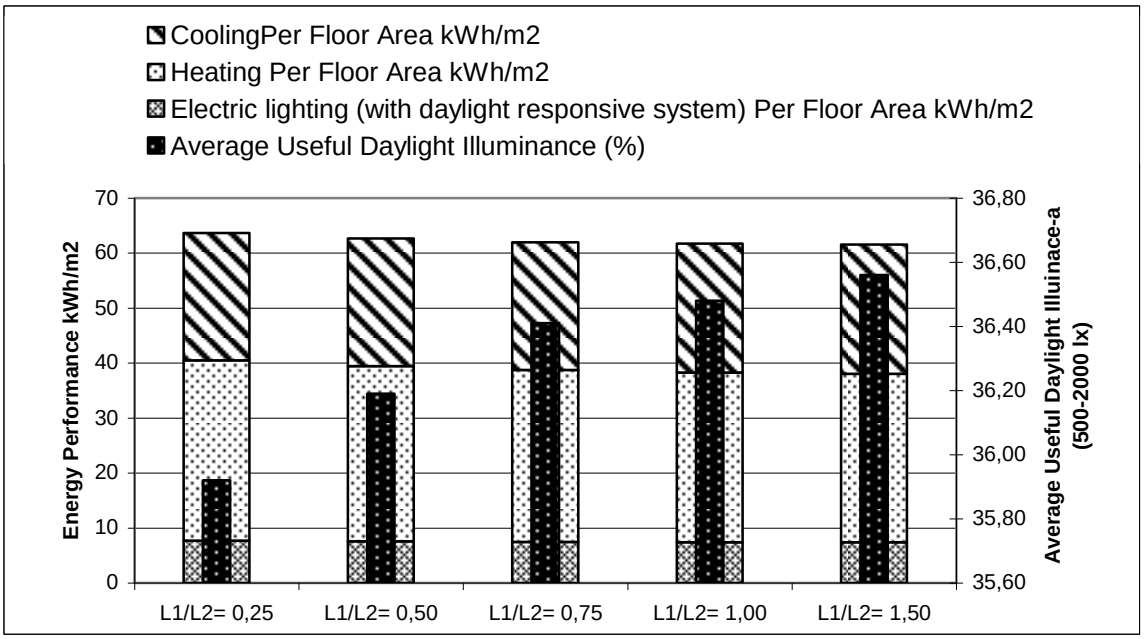


Figure 7: The energy performance (demand) calculation results as a function of the in built form t (spacing distance to the frontal length (L1/L2)

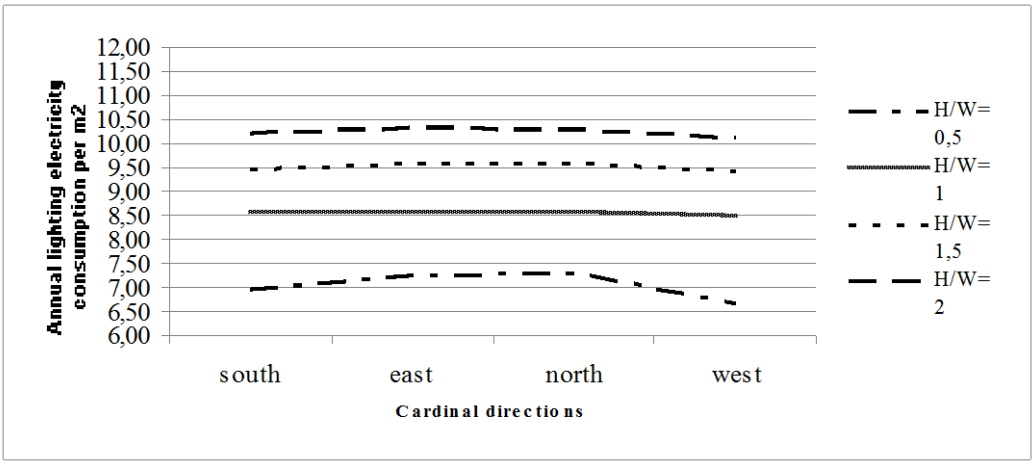


Figure8: Annual electricity consumption per m2 in different aspect ratios (H/W)

When the shading effect due to the surrounding buildings is included to the evaluation, less amount of electric lighting energy savings was observed from simulation results. The cooling energy demand is also affected by daylight responsive controlled artificial lighting fixtures. It results less heat gain generated by artificial lighting and small fall in heating energy demand concerning to internal gains. In the figure 7 the observed affects was caused by external obstructions. Shading affect is decreased in order to growth of L1/L2 ratio and it results cooling requirement by reason of decrease in solar gains. On the other hand, to receive more daylight decrease the electric lighting consumption and relatively the cooling demand due to artificial lighting usage. Figure 7 shows also average useful daylight illuminance level which is the degree of occurrence of illuminances in the range of 500 to 2,000 lux on the working level of the office room (80cm height) in order to distance between buildings (Mardaljevic, 2004)

Figure 8 shows the annual lighting electricity consumption per m^2 variation both in cardinal direction and three levels of aspect ratios (H/W). The electricity energy reduction due to daylighting for is more apparent than L1/L2 affect. The range of aspect ratio effect is about 3,7 kWh/m^2 in the south facing office however the spacing distance to the frontal length ratio effect (L1/L2) is just 0,57 kWh/m^2. The building depth to frontal length ratio (D/L2) effect on annual electricity lighting consumption can be seen in Figure 9.

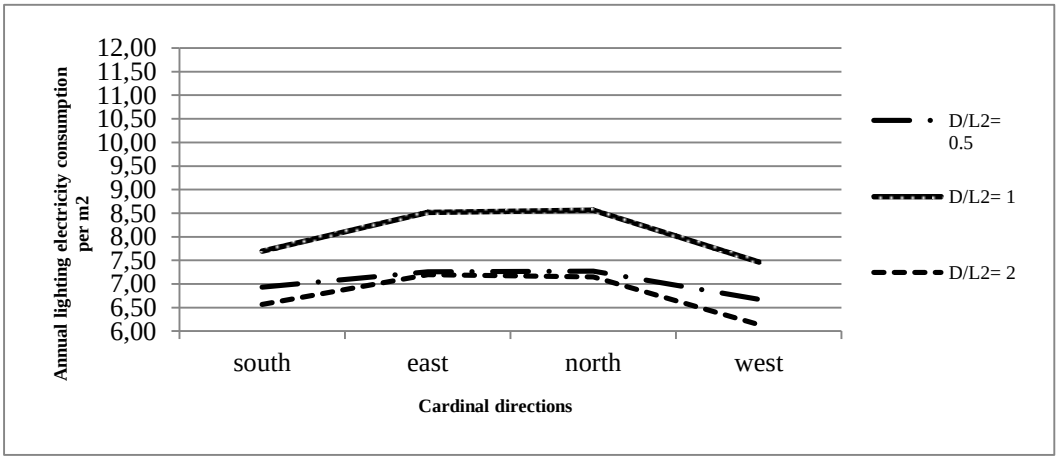


Figure 9: Annual electricity consumption per m2 in different building depth to frontal length ratios (D/L2)

DISCUSSIONS

This study examines the energy performance of office buildings in urban context with different dimensional ratio in separated urban generic form. 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 a sample office room the annual electricity lighting saving increases from 0,41 kWh/m^2 to 3,48 kWh/m^2 as a function of the dimensional ratios between urban structures. Within this work, the thermal performance of building under which is the L1/L2 ratios effect was evaluated. Further analysis will be extended to investigate the whole building energy performance under H/W ratios and D/L2 ratios.

CONCLUSIONS

The first calculation showed that between 4.5 % and 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. Many aspects of the urban design, from the layout of the roads to the building shape, will crucially affect the energy performance of the buildings. 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 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.

ACKNOWLEDGEMENT

The authors hereby thank the European Commission supported Marie Curie Program “Citynet” which assisted and supported this work in an outstanding manner.

REFERENCES

Ashmore, J., Richens, Paul, 2001. “Computer Simulation in Daylight Design: A Comparison”, *Architectural Science Review*, 44, pp 33-44, (UK).

Azza N., Mardaljevic J. ,2006, Useful daylight illuminances: A replacement for daylight factors *Energy and Buildings*, Volume 38, Issue 7, July 2006, Pages 905-913 Special Issue on Daylighting Buildings

Compagnon R., 2000, “Assessment of the Potential for Solar Energy Applications in Urban Sites”, *Ecole d'ingénieurs et d'architectes de Fribourg*

Givoni, B. 1998,.“Climate Considerations in Building and Urban Design”, *Van Nostrand Reinhold, United States ofAmerica*

Littlefair P., 2001,“Daylight, sunlight and solar gain in the urban environment ”,*Solar Energy*,Volume 70, Issue 3, , Pages 177-185

Mardaljevic, J., 2004. “Verification of Program Accuracy for Illuminance Modeling: Assumptions, Methodology and an Examination of Conflicting Findings”, *Lighting Research and Technology, 36(3), pp. 217-242, CIBSE (UK).*

Reinhart CF, 2006, “Tutorial on the use of daysim simulations for sustainable design”, *Institute for Research in Construction, National Research Council Canada: Ottawa, Canada.*

Shashua-Bar L., Hoffman M. E. and Tzamir Y., 2006, “Integrated thermal effects of generic built forms and vegetation on the UCL microclimate”, *Building and Environment,Volume 41, Issue 3.*

Santamouris M., Asimakopoulos D. N. (2001) Energy and climate in the urban built environment, ISBN-13:9781873936900

Strzalka A., Bogdahn J., Eicker U. (2010) 3D City Modelling for Urban Scale Heating Energy Demand Forecasting, Proceedings, IAQVEC 2010, Syracuse, New York