Slobodan Djordjevic[1)]
Milorad Bojic[1)]
Dragan Cvetkovic[1)]
Jovan Malesevic[1)]
Marko Miletic[1)]

1) Faculty of Mechanical Engineering, University of Kragujevac, Serbia
sdjordjevic@energetika-kragujevac.com

INFLUENCE OF HOUSE SHADOWING TO THE CONSUMPTION OF PRIMARY ENERGY FOR HEATING, COOLING, AND LIGHTING

Abstract: *The optimization of dimensions of concrete horizontal roof overhangs in relation to the consumption of primary energy for heating, cooling, and lighting of houses. Then, the energy that spent to build a overhangs is taken into account. The simulation is carried out for the house is located in Belgrade, Serbia throughout the year. The overhangs are horizontally placed to provide shading of all exterior walls and windows of the building. To create the model, the building energy simulation software package was used called EnergyPlus. The overhang size optimization was performed by using Hooke Jeeves algorithm and plug in GenOpt program. The simulation results show that in the optimal case, 4.64% energy is spent less than that of the primary energy for heating, cooling, lighting and general consumption compared to the house without overhangs.*
Keywords: *Roof overhangs, optimization shadowing, heating, cooling, lighting, GenOpt, EnergyPlus*

1. INTRODUCTION

Of the total energy consumed by a household consumes in a year, more than three-quarters of the energy is spent on heating, cooling and lighting, while the rest is spent on household electrical appliances (electric equipment). Reducing energy consumption is of great importance not only for the individual, but also globally, as the burning of fossil fuels into the atmosphere emit significant amounts of greenhouse gases, primarily carbon dioxide. It also fossil fuels are a limited resource, which in nature is less and it should be used very cautiously. By applying the principles of building with passive energy elements which include elements of shading horizontal roof overhangs that is improving the indoor comfort, reduces the consumption of primary energy and hence reduce greenhouse gas emissions. When designing strive to (aspire to) better insulation of the building from outside influences, to reduce energy exchange, on the other hand it is necessary in the best way to utilize energy from the environment in order to achieve even better results. The implementation of these principles in the stage of designing buildings, is the most effective way to achieve good results in reducing the energy required for heating, cooling and lighting. Many studies have been carried out analysis of the impact of shading elements in relation to energy consumption, and most authors come from a reduction in energy consumption for cooling due to shadowing. Cooling load due to solar gain represents about half of the total cooling load of residential buildings. By placing shading devices on the exterior side of the window reduces the influence of solar radiation through the windows. [1] Sciuto S, Model Development Subgroup Report, vol. 2 solar control, Conphoebus S.C. RI, Catania, Italy, in 1994. Also I Skias and D. Kolokotsa studying the effects of shadowing and reduce energy consumption for cooling. The study involved 10 office buildings, which are located in Athens. Each object is modeled in TRNSYS 16 By applying the horizontal roof overhangs on the south side of the building, depending on the analyzed building energy savings ranged from 7.2% to 17.5%. G. Kim and others have used the program IES_VE to evaluate energy saving cooling device for applying shading to the building, which is located in Seoul, South Korea. By applying the horizontal roof overhangs on the south facade of the building, length 1.53m, achieved energy saving cooling system by 11%. Also, research has shown that external shading devices are more efficient than any internal shading devices. S.Raeissi and M.Taheri examined the influence of horizontal roof overhangs size as a passive cooling option, the total energy consumption for heating and cooling. The study was carried out on the family home of 140.55m^2 located in Shiraz, Iran, at an altitude of 1491m, latitude 52.53^{0}N and longitude 29.6^{0}E. Testing was performed for four days during the summer (cooling period) and winter (heating period). By optimizing the primary energy consumption for cooling and heating the building achieved a reduction in energy consumption for cooling by 12.7% and on the other hand increased energy consumption for heating by 0.63%. [4]. In the published works that explore the impact of installing roof overhangs on the energy consumption was not investigated how installation roof overhangs influence on the common consumption of energy for heating, cooling and lighting. In this paper, the effect of shadowing by horizontal roof overhangs was investigated on the primary energy consumption for heating, cooling and lighting of the residential building throughout the year. Optimization is performed with the simultaneous operation of the program EnergyPlus and GenOpt to optimize the obtained optimal size horizontal roof overhangs placed over all four walls (east, west, north and south). This is performed with respect to the primary energy consumption for heating, cooling and lighting, and at the same time takes into account the energy that is spent for the construction of concrete horizontal roof overhangs (embodied energy) of the appropriate dimensions [5].

2. DESCRIPTION OF A HOUSE

A model home that is used for housing was made, a total internal area of 116.64 m2, of which 92.88 m2 air-conditioned and heating. The shell of the building is shown in Table 1.

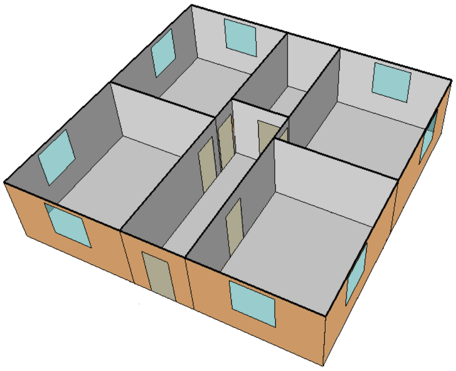

Figure 1. Horizontal cross section of the house model

The ratio of glass to the surface of the outer wall layer is 13.96%, and the total area of exterior walls is 112.32 m^2 and window area is 15.68 m^2. To be more correct to dull the impact of shadowing object is properly divided into 4 rooms of per 23 m^2, which are air-conditioned and illuminated by an average brightness of 500 lux. This is achieved by setting the appropriate settings and the corresponding parameters in EnergyPlus. Model of house is shown in Figure 1.

3. LOCATION AND CLIMATIC CONDITIONS OF THE OBJECT

Within EnergyPlus software package was used meteorological file SER Belgrade 132720 IWEC.epw describing Meteorological characteristics of Belgrade, Serbia [6]. The average elevation of Belgrade is 99m, and is latitude 44^o82N and longitude 20^o28E. Belgrade has a moderate continental climate with four seasons of winter, spring, summer and autumn. In table 2. presents the main meteorological parameters.

4. THE MODEL

To simulate the energy performance of a building EnergyPlus software was used, in which architecture is shaped himself and set all system parameters corresponding to his physical condition (thermal, lighting condition, etc.) and energy exchange with the environment in a given period of time. Finding the optimal size horizontal roof overhangs was made with Hooke Jeeves optimization method with the help of GenOpt, so that the objective function that minimizes the consumption of primary energy for heating, cooling and lighting of the building and when it is taken in the calculation of the energy expended to build a horizontal roof overhangs. The program works by GenOpt is coupled with the two programs EnergyPlus one of them with fixed parameters, and the other with variable parameters in which the optimization is performed. The Ini file defined the objective function and all necessary parameters and variables that are required for optimization as well as input, output and configuration files. The command file is given as the pattern of the traits that are necessary for the execution of the optimization algorithm (in this case Hooke Jeeves Algorithm).

To ensure adequate thermal comfort in winter, electric heaters was used. Heating thermostat is used to set the appropriate temperature in winter mode. In summer mode to maintain proper thermal comfort in rooms is used room air conditioners with the appropriate thermostat. Room air conditioners are also supplied with electricity. To maintain an appropriate light level the combined impact of daylight and electric lighting, using DayLightingControls function (this function is implemented in EnergyPlus), which is available by entering the appropriate parameters set dimmer room in a given time interval [6].

The simulation results are obtained in the output file, and that the optimum horizontal roof overhangs size and power consumption of heating, air conditioning, lighting and total consumed primary energy.

5. ENERGY

5.1. Primary energy consumption

Primary energy consumption of the analyzed object is calculated by the following equation:

$E_{prim} = (E_{ac} + E_{eh} + E_{eq} + E_{el})K_{ec}$

Where the E_{ac} stand for electricity consumption in the indoor air conditioners, E_{eh} - electricity consumption of the electric heating, E_{eq} - electricity consumption for the electric equipment, E_{el} electricity consumption for lighting and K_{ec} - primary energy factor (PEF). This factor is defined as the ratio of total primary energy consumption by energy sources (hydro, coal, oil, hevy oil and natural gas) and the total supplied electricity when not taking into account the imported electricity. For Serbia, the value of manufactured and supplied electricity on average in 2010th and 2011th amounts K_{ec}= 3.04 [7] (this value varies from year to year and depends on the season hydrological situation).

$$K_{ec} = \frac{(m_{c1}H_{d1} + m_{c2}H_{d2} + m_{c3}H_{d3})}{E_{ec,f}}$$

5.2. Embodied energy

Embodied energy for horizontal roof overhangs depends on size and type of material, given in the third equation

$E_{emb} = \rho\delta l\, h s_{ec}/f_n$

The optimization was performed in respect to the length of the exhaust horizontal roof overhangs h, where ρ stand for material density for roof overhangs (concrete, ρ = 2150 kg/m^3), l stand for the width of the roof overhangs that relies on the buildings wall (10.8 m), δ thick of roof overhangs (0.18 m) , h length of roof overhangs, s_{ec} roof overhangs specific embodied energy (1.924 MJ / kg) [8], f_n roof overhangs lifecycle (20 years).

5.3.Objective function

The total energy is equal to the sum of the primary energy and embodied energy as shown in Equation 4

$E_{tot} = E_{prim} + E_{emb}$

Equation 4 is the objective function

5.4. The achieved energy savings

Realized savings of primary energy for heating, cooling and lighting is calculated for the house with the roof overhangs set in relation to an object without roof overhangs installed

6. RESULTS

Optimal length of the roof overhangs when taking into account the impact of energy for lighting are shown in table 3. Optimal length of the roof overhangs when not taking into account the impact of energy for lighting are shown in Table 4.

$e_{p\%} = (E_{p0} - E_{popt})/E_{p0}$

Aannual electricity consumption intensity and infiltration are shown in Table 5

When we consider the influence of shadowing by horizontal roof overhangs the energy consumption for heating, cooling and lighting is consumed 4.78% less primary energy compared to an object when there are no overhangs.

By optimizing the consumption of primary energy for cooling, heating and lighting of the object is achieved reducing energy consumption for cooling for 37.16%, while on the other hand the energy consumption for heating has increased to 9.28%, and the energy consumption for lighting increased by 2.99%, while of course shading has no effect on overall consumption devices ($E_{eq}^{\#}$).

By placing the horizontal roof overhangs reduces the influence of solar radiation that passes through the windows for a total of 48% annually, which is shown in Table 6 and figure 2.

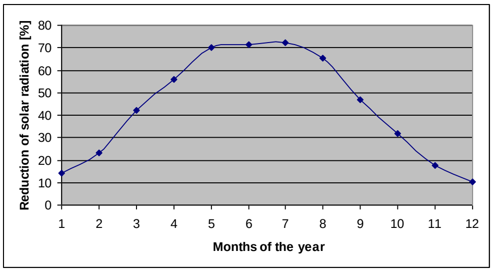

Figure 2. The percentage reduction of solar radiation that passes through the windows due to the influence of horizontal roof overhangs

From Table 6 and Figure 2 it can be seen that the optimal setting horizontal roof overhangs reduces the impact of solar radiation that passes through the windows, but not equally in all months. The decrease was significantly less in winter than in summer (in the geographical area of Belgrade), mainly due to reduced winter altitude (elevation) the sun, the length of the days and fewer sunny days than in summer, so that the beneficial effect used for the reduction of total energy consumption in heating, cooling, and lighting on an annual basis.

7. ENVIRONMENTAL PERFORMANCE IN TERMS OF ENERGY PAYBACK TIME (EPBT)

EPBT is defined as the duration (in years) needed to be converted to energy equivalent of primary energy needed to build a technical system (in the case of concrete horizontal roof overhangs) compensation due to reduction of primary energy consumption during its life cycle, including energy to build, transport, work , maintenance and recycling [10].

$EPBT = E_{emb}\ f_n/(E_{p0}-E_{popt})$

EPBT= 6,01 years

8. GREENHOUSE SUBSTITUTION TIME (GHGST)

GHGST is defined as the duration (in years) required to substitute the entire amount of CO2 emitted during the construction of a technical system (in the case of concrete horizontal roof overhangs) due to the effect of emission reductions resulting from operation of the system.

The amount of CO_2 emitted as a consequence of production, transportation, building and installation of a concrete horizontal roof overhangs

$G_{CO2} = \rho\delta l(h_E+h_S+h_W+h_N)\ GHG_c$

$G_{CO2} = 2{,}847t$

where GHG_c =0,13 t CO_2 / t CO_2 emissions intensity of the production of concrete ([9],[10]).

Applying horizontal roof overhangs emits a smaller amount of CO_2 annually to 1,834 t

$S_{CO2} = (E_{p0}-E_{popt})\ k_{CO2,ec} = 1{,}834t$

where $k_{CO2,ec}$ equivalent CO_2 emissions for EPS [7]

$GHGST = \rho\delta l(h_E+h_S+h_W+h_N)\ GHG_c/(E_{p0}-E_{popt})\ k_{CO2,ec} = 1{,}55$ godina

9. SENSITIVITY TO THE ACCURACY OF THE INPUT DATA CONCLUSION

Optimization is performed in horizontal roof overhangs that are made of concrete density ρ=2150 kg/m^3, for the manufacture and installation of specific energy is embedded s_{ec}=1,924 MJ/kg. These two parameters are sensitive input data in different conditions of production and placing concrete may be different. Here is an analysis of how these changes affect the data output simulation results. Sensitivity to the accuracy of the input data is shown in Table. 7. If specific embodied energy s_{ec} increase by 20% size of some roof overhang during optimization changes, that cause the effect of reducing primary energy consumption reduced by 5.64%. If specific integrated energy s_{ec} reduced by 20% size of some roof overhang during optimization changes, that cause the effect of reducing the primary energy increases by 0.84%.

10. CONCLUSION

By placing the horizontal roof overhangs reduces the influence of solar radiation that passes through the windows by 48% per annum, given that the effect is much less pronounced in winter than in summer in the geographical area of Belgrade, it has given us the ability to perform optimized length larmier separately for each side of the world thus reducing the total consumption of primary energy. Optimal dimensions marquee are Eastern 2.01m, 0.61m southern, western North 2.11 mi 0.51 m. By reducing the heat gains due to solar radiation, reduces the energy consumption for cooling for 37.16%, while increasing the consumption of energy for heating and lighting of 9.28 to 2.99%., And the total primary energy consumption is reduced by 4.78%.

TABLES:

Table 1.

Object	external wall	thickness [m]	conductivity [W/m-K]	density [kg/m^3]	specific heat [J/kg-K]
Outside Layer	lime mortar	0.015	0.81	1600	1050
Layer 2	stiropor	0.15	0.041	20	1260
Layer 3	clay block	0.19	0.52	1200	920
Layer 4	lime mortar	0.015	0.81	1600	1050
Object	inner wall	thickness [m]	conductivity [W/m-K]	density [kg/m^3]	specific heat [J/kg-K]
Outside Layer	lime mortar	0.015	0.81	1600	1050
Layer 2	clay block	0.19	0.52	1200	920
Layer 3	lime mortar	0.015	0.81	1600	1050
Object	roof panel	thickness [m]	conductivity [W/m-K]	density [kg/m^3]	specific heat [J/kg-K]
Outside Layer	cement screed	0.04	1.4	2100	1050
Layer 2	glass wool	0.08	0.04	50	840
Layer 3	monta	0.16	0.6	1200	920
Layer 4	lime mortar	0.015	0.81	1600	1050
Object	floor (parquet)	thickness [m]	conductivity [W/m-K]	density [kg/m^3]	specific heat [J/kg-K]
Outside Layer	sand	0.2	0.81	1700	840
Layer 2	concrete	0.15	0.93	1800	960
Layer 3	PVC foil	0.00015	0.19	1460	1100
Layer 4	stirodure	0.05	0.03	33	1260
Layer 5	cement screed	0.04	1.4	2100	1050
Layer 6	Parket	0.02	0.21	700	1670
Object	floor (tiles)	thickness [m]	conductivity [W/m-K]	density [kg/m^3]	specific heat [J/kg-K]
Outside Layer	sand	0.2	0.81	1700	840
Layer 2	concrete	0.15	0.93	1800	960
Layer 3	PVC foil	0.00015	0.19	1460	1100
Layer 4	stirodure	0.05	0.03	33	1260
Layer 5	cement screed	0.04	1.4	2100	1050
Layer 6	ceramic tiles	0.015	0.87	1700	920

Table 2. Mapping of the main meteorological parameters for Belgrade

Monthly		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry Bulb temperatures °C	Max	18.4	17.8	21	26.6	32	34	33.2	33.4	32.2	30	18	17
	Min	-10	-7.7	-3	0	4	8	10	10	8	-2.3	-3	-19
	Daily Avg	0	1.7	5.9	12	17.5	20.3	21.7	21.6	17.7	12.3	5.4	1.3
Relative Humidity %	Maxi	100	100	100	100	100	100	100	100	100	100	100	100
	Min	49	36	30	22	30	31	31	29	33	42	43	53
	Daily Avg	86	83	71	68	69	71	68	67	73	82	85	89
Solar Radiation Wh/m²	Direct Avg	1277	1962	3303	3324	4077	4321	5195	4641	3675	3002	2066	987
	Direct Max	5012	6612	7628	8148	8317	8963	8889	7642	7032	6527	5379	4621
	Diffuse Avg	793	1195	1639	2249	2780	3059	2588	2413	1864	1371	818	697
	Global Avg	1221	2044	3426	4394	5655	6172	6314	5582	4003	2814	1569	994

Table 3. Results of simulations with the implemented lighting control

with the implemented lighting control								
length of horizontal roof overhangs				Energy				
EAST (hE)	SOUTH (hS)	WEST (hW)	NORTH (hN)	E_{prim}	E_{ac}	E_{eh}	E_{eq}	E_{el}
m	m	m	m	GJ	GJ	GJ	GJ	GJ
0	0	0	0	136.63	11.18	20.08	9.23	4.46
2.010	0.610	2.110	0.510	130.10	7.03	21.94	9.23	4.78
Reduction of primary energy $e_{p\%}$			%	4.78	37.16	-9.28	0.00	-2.99

Table 4. Simulation results without light control implemented

without the implemented lighting control								
length of horizontal roof overhangs				Energy				
EAST (hE)	SOUTH (hS)	WEST (hW)	NORTH (hN)	E_p	E_{ac}	E_{eh}	E_{eq}	E_{el}
m	m	m	m	GJ	GJ	GJ	GJ	GJ
0	0	0	0	137.12	11.75	19.61	9.23	4.51
2.135	0.610	2.235	0.447	129.94	7.49	21.51	9.23	4.51
Reduction of primary energy $e_{p\%}$			%	5.23	36.27	-9.69	0.00	0.00

Table 5. Annual energy consumption intensity

Annual energy consumption intensity				
Air conditioning	Heating	Overall consumption#	Lighting	Infiltration and ventilation
kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2	air ch per h
21,43	65,42	27,61	13,73	0,7

Overall consumption are all consumers in the home that are not in use for heating, air conditioning and lighting.

Table 6.

Solar radiation passing through windows				
	Widhout overhangs	Widh an optimal length overhangs	difference	reduction
	GJ	GJ	GJ	%
January	0.430	0.370	0.060	14.014
February	0.578	0.443	0.134	23.266
March	0.942	0.545	0.397	42.186
April	0.784	0.346	0.438	55.882
May	0.804	0.241	0.563	70.058
June	0.779	0.223	0.556	71.355
July	0.995	0.274	0.721	72.450
August	1.012	0.352	0.660	65.231
September	0.963	0.510	0.452	46.982
October	0.929	0.634	0.295	31.772
November	0.665	0.547	0.117	17.669
December	0.333	0.300	0.034	10.156
Total	9.212	4.784	4.429	48.071

Table 7.

with the implemented lighting control										
S_{ec}	length of horizontal roof overhangs				Energy					
	EAST (hE)	SOUTH (hS)	WEST (hW)	NORTH (hN)	Eprim	Eac	Eeh	Eeq	Eel	Reduction of primary energy $e_{p\%}$
	m	m	m	m	GJ	GJ	GJ	GJ	GJ	%
	0	0	0	0	136.63	11.18	20.08	9.23	4.46	\
$S_{ec+20\%}$	1.666	0.610	1.954	0.010	130.47	7.37	21.75	9.23	4.57	4.51
S_{ecref}	2.010	0.610	2.110	0.510	130.10	7.03	21.94	9.23	4.59	4.78
$S_{ec-20\%}$	2.010	0.610	2.235	0.510	130.04	6.98	21.97	9.23	4.59	4.82

Nomenclature

E_{prim} -annual consumption of primary energy,
E_{ac} - annual electricity consumption of the air conditioners,
E_{eh} -annual electricity consumption of the electric heating,
E_{eq} -annual electricity consumption of the electric equipment,
E_{el} -annual electricity consumption of the electric lightting,
E_{emb} -embodied energy,
E_{tot} -total annual energy,
K_{ec} -primary energy factor (PEF),
h -length of roof overhangs,
ρ -material density for roof overhangs,
l -length of the exhaust horizontal roof overhangs,
δ -thick of roof overhangs,
s_{ec} -specific embodied energy,
f_n -roof overhangs lifecycle,
$e_{psav\%}$ -achieved primary energy savings in %,
E_{pmin} -primary energy consumed in house afther installation the roof overhangs,
E_{p0} -primary energy consumed in house without roof overhangs,
E_{popt} -primary energy consumed in house afther installation the roof overhangs optimal dimensions,
$e_{p\%}$ -reduction of primary energy,
EPBT -environmental performance in terms of energy payback time,
GHGST -greenhouse substitution time,

REFERENCES:

[1] Sciuto, S. (1994). Model development subgroup report, vol. 2 solar control, Conphoebus S.C. r.I., Catania, Italy.

[2] Skias, I., & Kolokotsa, D. (2007, September). *Contribution of shading in improving the energy performance of buildings*. 2nd PALENC Conference and

28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, Crete island, Greece.

[3] Kim, G., Lim, H. S., Lim, T. S., Schaefer, L., & Kim, J. T. (2012). Comparative advantage of an exterior shading device in thermal performance for residential buildings. *Energy and Buildings*, *46*, 105-111.

[4] Raeissi, S., & Taheri, M. (1998). Optimum Overhang Dimensions for Energy Saving. *Building and Environment*, *33*(5), 293-302.

[5] Dixit, M. K., Fernández-Solís, J. L., Lavy, S., & Culp, C. H. (2010). Identification of parameters for embodied energy measurement. *Energy and Buildings*, *42*, 1238-1247.

[6] EnergyPlus Energy Simulation Software. Retrieved from: http://apps1.eere.energy.gov/buildings/energyplus/on februar 2012.cfm/weather_data2.cfm/region=6_europe_wmo_region_6

[7] Bojic, M., Djordjevic, S., Malesevic, J., Cvetkovic, D., & Miletic, M. Interunit Heat Flows in a Residence during District Heating in a Multistory Residential Building.

[8] Peng, J., Lu, L., & Yang, H. (2012). Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems, Renewable Energy Research Group (RERG), Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China.

[9] Goggins, J., Keane, T., & Kelly, A. The assessment of embodied energy in typical reinforced concrete building structures in Ireland.

[10] Kim, H. C., & Fthenakis, V. M. (2006). *Life cycle energy demand and greenhouse gas emissions from an amonix high concentrator photovoltaic system.* Conference Record of the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion.