BUILDING SHADOW IMPACT TO THE PRIMARY ENERGY CONSUMPTION

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Abstract: *The application of the overhangs can yield energy saving during summer. This paper presents the optimization of the overhangs' length during the cooling season. The optimization is done with the objective to minimize the total energy consumption (the sum of the primary energy consumption for cooling during building lifecycle and the embodied energy of the overhangs and used air-conditioner). The analyzed residential house is located in Belgrade, Serbia. The overhangs face north, south, east, and west direction. For optimization of the overhangs, Hooke-Jeeves method is used with the help of GenOpt code. EnergyPlus software is used to simulate energy behavior of the house.The simulation results show that the house with optimally sized overhangs consumed 4.64% of primary energy less for heating, cooling, and lighting than that of the house without overhangs.*

Keywords: *Roof Overhangs, Optimization, Shadowing, Heating, Cooling, Lighting, GenOpt, EnergyPlus.*

1. INTRODUCTION

The building sector requires large amounts of energy both for cooling and heating. The cooling loads due to solar gains represent about half of the cooling loads for residential and non-residential buildings. The decrease in cooling loads to achieve energy conservation in buildings is very important.

An application of building with passive energy elements which include elements of shading by horizontal roof overhangs improves thermal indoor comfort, reduces the consumption of primary energy and hence reduces greenhouse gas emissions. Sometimes, a building design strives to insulate the building from outside influences, and thus to reduce energy exchange. On the other hand, in the best way, it is necessary to utilize energy from the environment in order to achieve even better results. The implementation of these principles in the stage of building design is the most effective way to achieve good results in reduction of the energy required for heating, cooling, and lighting.

Many studies were carried out to analyze the impact of shading elements to energy consumption, and most authors found 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. Placing shading devices on the exterior side of window reduces the influence of solar radiation through the windows [1]. Also, Skias and Kolokotsa studied the effects of shadowing to reduce energy consumption for cooling [2]. The study involved 10 office buildings, which were located in Athens. Each house was modeled in TRNSYS 16. The application of the horizontal roof overhangs on the south side of the building yielded the building energy saving ranged from 7.2% to 17.5%. Kim et al. used the program IES_VE to evaluate energy saving for cooling by applying shading to the building, which is located in Seoul, South Korea [3]. The horizontal roof overhangs on the south facade of the building (depth 1.53m), achieved energy saving for cooling of 11%. Also, research showed that external shading devices were more efficient than any internal shading devices. Raeissi and Taheri examined the influence of horizontal roof overhangs size to the total energy consumption for heating and cooling [4]. The study was carried out on the family home of 140.55m2 located in Shiraz, Iran, at an altitude of 1491m. Testing was performed for four days during the summer (cooling period) and winter (heating period). The optimization of 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 the energy consumption for heating by 0.63%.

In the literature, the investigation how an installation of roof overhangs influences the common consumption of energy for heating, cooling and lighting was not reported so far. This paper reports the investigations how shading by horizontal roof overhangs influences the primary energy consumption for heating, cooling and lighting of the residential house throughout the year. Optimization is performed with the simultaneous operation of the programs EnergyPlus and GenOpt to obtain the optimal size of horizontal roof overhangs placed over all four walls (east, west, north, and south). The optimization is performed to minimize the sum of the primary energy consumption for heating, cooling and lighting, and the primary energy spent for the construction of concrete horizontal roof overhangs (embodied energy) of the appropriate dimensions [5].

2. DESCRIPTION OF HOUSE

2.1 Basic assumptions

An investigated house had the total floor area of 117m^2, of which 93m^2 were air-conditioned and heated. The constructions used in the envelope of the house are shown in Table 1 – 5.

Table 1 – The construction of the exterior wall

Materials	δ [m]	λ [W/m-K]	ρ [kg/m^3]	c_P [J/kg-K]
lime mortar	0.015	0.81	1600	1050
stiropor	0.15	0.041	20	1260
clay block	0.19	0.52	1200	920
lime mortar	0.015	0.81	1600	1050

Table 2 – The construction of the interior wall

Materials	δ [m]	λ [W/m-K]	ρ [kg/m^3]	c_P [J/kg-K]
lime mortar	0.015	0.81	1600	1050
clay block	0.19	0.52	1200	920
lime mortar	0.015	0.81	1600	1050

Table 3 – The construction of the roof panel

Materials	δ [m]	λ [W/m-K]	ρ [kg/m^3]	c_P [J/kg-K]
cement screed	0.04	1.4	2100	1050
glass wool	0.08	0.04	50	840
monta	0.16	0.6	1200	920
lime mortar	0.015	0.81	1600	1050

Table 4 – The construction of the floor (parquet)

Materials	δ [m]	λ [W/m-K]	ρ [kg/m^3]	c_P [J/kg-K]
sand	0.2	0.81	1700	840
concrete	0.15	0.93	1800	960
PVC foil	0.00015	0.19	1460	1100
stirodure	0.05	0.03	33	1260
cement screed	0.04	1.4	2100	1050
parquet	0.02	0.21	700	1670

Table 5 – The construction of the floor (tiles)

Materials	δ [m]	λ [W/m-K]	ρ [kg/m^3]	c_P [J/kg-K]
sand	0.2	0.81	1700	840
concrete	0.15	0.93	1800	960
PVC foil	0.00015	0.19	1460	1100
stirodure	0.05	0.03	33	1260
cement screed	0.04	1.4	2100	1050
ceramic tiles	0.015	0.87	1700	920

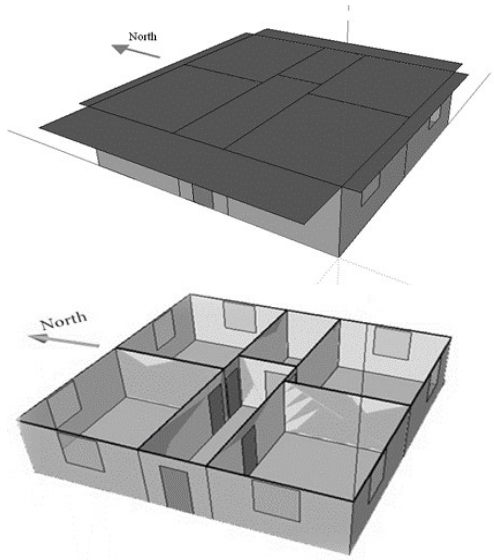

Figure 1 – The house with the with the optimized overhangs (up) and the cross section of the house (down)

The ratio of glass surface area to the area of the external wall is 13.96% where the total area of the exterior walls is 112 m2 and that of the windows is 16 m2. To be more correct the impact of shadowing, the house is divided into 4 rooms of per 23 m2, which are air-conditioned and illuminated by an average brightness of 500 lux. The model of the house in EnergyPlus is shown in Fig.1. The overhang geometrz is shown in Fig.2.

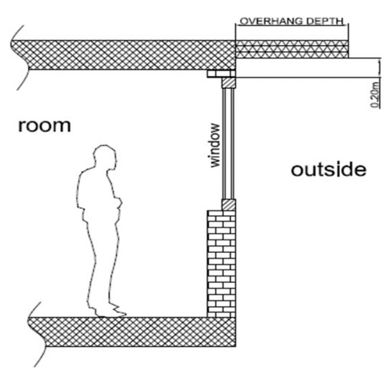

Figure 2 – Overhang geometry

3. LOCATION AND CLIMATIC CONDITIONS OF HOUSE

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

Table 6 – The main meteorological parameters for Belgrade

Monthly	*TDB* [°C]	*φ* [%]	I_{DIR} [Wh/m^2]	I_{DIF} [Wh/m^2]
Jan	0	86	1277	793
Feb	1.7	83	1962	1195
Mar	5.9	71	3303	1639
Apr	12	68	3324	2249
May	17.5	69	4077	2780
Jun	20.3	71	4321	3059
Jul	21.7	68	5195	2588
Aug	21.6	67	4641	2413
Sep	17.7	73	3675	1864
Oct	12.3	82	3002	1371
Nov	5.4	85	2066	818
Dec	1.3	89	987	697

4. MODEL OF HOUSE

To simulate the energy performance of a building, EnergyPlus software was used, in which the architecture and all system parameters are set that correspond to its 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. The objective function minimizes the consumption of primary energy for heating, cooling and lighting of the building and that of energy spent to build a horizontal roof overhangs. The program GenOpt operates with fixed parameters, and with variable parameters in which the optimization is performed. Its Ini file defines the objective function and all necessary parameters and variables that are required for optimization. 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 are used. Heating thermostats are set to the appropriate

temperature during winter. In summer to maintain proper thermal comfort in rooms air conditioners are used with the appropriate thermostats. The room air conditioners are also operated by electricity. To maintain an appropriate light level, the combined impact of daylight and electric lighting is investigated by entering the appropriate parameters in a given time interval (using DayLightingControls function implemented in EnergyPlus) [6].
The simulation results are obtained in the output file, and that of the optimum horizontal roof overhangs size and power consumption of heating, air conditioning, lighting and that of the total consumed primary energy.

5. ENERGY

5.1 Primary operating energy consumption

Annual primary operating energy consumption of the analyzed house is calculated by the following equation:

$$E_P = \frac{(E_{AC} + E_{EH} + E_{EQ} + E_{EL})K_{EC}}{F}$$

K_{EC} is defined as the ratio of the total primary energy consumption by energy sources (hydro, coal, oil, hevy oil and natural gas) and the total supplied electricity. For Serbia, on average in 2010th and 2011th, K_{EC}=3.04 [7] (this value varies from year to year and depends on the season hydrological situation).

5.2 Embodied energy

The annualized embodied energy (AEE) for horizontal roof overhangs depends on size and type of material is given as:

$$AEE = \frac{\rho \delta l h s_{EC}}{f_N F}$$

s_{EC} is the roof overhangs specific embodied energy (1.924 MJ/kg) [8],

5.3 Partial annualized primary energy consumption

The total energy is equal to the sum of the primary energy and embodied energy as shown in Equation 3:

$$E_{TOT} = E_P + AEE$$

This equation is the objective function for the optimization.

5.4 Operating 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 house without roof overhangs installed:

$$e_{PSAV} = 100(E_{P0} - E_{P,MIN}) / E_{P0}$$

5.5 Environmental performance in terms of energy payback time

Energy payback time ($EPBT$) is defined as the duration (in years) needed that primary energy savings compensate primary energy needed to build overhangs, given as [10]:

$$EPBT = \frac{E_{EMB} f_N}{E_{P0} - E_{POPT}} = \frac{\rho \delta l (h_E + h_S + h_W + h_N) s_{EC}}{E_{P0} - E_{POPT}}$$

The energy recovery (ER) is defined as number of time primary energy savings are generated during lifecycle more than the primary energy needed to build overhangs. ER is calculated by using the following equation:

$$ER = \frac{(E_{P0} - E_{POPT}) f_N}{E_{EMB}} = \rho \delta l (h_E + h_S + h_W + h_N) s_{EC} f_N$$

5.6 Greenhouse substitution time

$GHGST$ is defined as the duration (in years) required to substitute the entire amount of CO_2 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:

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

GHG_C stands for CO_2 emissions intensity of the production of concrete in t CO_2 / t

concrete. The annual decrease of the emission of CO_2 due to the application of horizontal roof overhangs is given as:

$$s_{CO2} = (E_{P0} - E_{POPT})k_{CO2,EC} = 1.834\ t\ CO_2$$

Then, CO_2 substitution time is given as:

$$GHGST = \frac{\rho\delta l(h_E + h_S + h_W + h_N)GHG_C}{(E_{P0} - E_{POPT})k_{CO2,EC}}$$

6. RESULTS

When taking into account the impact of energy for lighting, the optimal depths of the roof overhangs are shown in Table 7.

Table 7 – Results of simulations with the implemented lighting control

[kWh/m²]	h_E=0 m; h_S=0 m h_W=0 m; h_I=0 m	h_E=2.14 m; h_S=0.61 m h_W=2.24 m; h_I=0.45 m
E_{PRIM}	325.37	309.82
E_{AC}	26.62	16.74
E_{EH}	47.82	52.25
E_{EQ}	21.98	21.98
E_{EL}	10.62	11.38

When not taking into account the impact of energy for lighting, the optimal depths of the roof overhangs are shown in Table 8.

Table 8 – Simulation results without light control implemented

[kWh/m²]	h_E=0 m; h_S=0 m h_W=0 m; h_I=0 m	h_E=2.14 m; h_S=0.61 m h_W=2.24 m; h_I=0.45 m
E_{PRIM}	326.54	309.44
E_{AC}	27.98	17.84
E_{EH}	46.7	51.22
E_{EQ}	21.98	21.98
E_{EL}	10.74	10.74

In all calculations, the intensity of infiltration and ventilation in all areas of the house was 0.7 air changes per hour. When we consider the influence of shadowing by horizontal roof overhangs, the primary energy consumption for heating, cooling and lighting decreased by 4.78% compared to the primary energy consumption of an house when there are no overhangs. Then, the house reduced energy consumption for cooling by 37.16%, while the energy consumption for heating increased by 9.28%, and the energy consumption for lighting increased by 2.99%. The horizontal roof overhangs reduce solar radiation that passes through the windows for a total of 48% annually, which is shown in Table 9.

Table 9 – Solar radiation through windows

Monthly	No overhangs	With overhangs	Reduction
	[kWh]	[kWh]	[%]
Jan	119.44	102.78	13.95
Feb	160.56	123.06	23.36
Mar	261.67	151.39	42.14
Apr	217.78	96.11	55.87
May	223.33	66.94	70.02
Jun	216.39	61.94	71.37
Jul	276.39	76.11	72.46
Aug	281.11	97.78	65.22
Sep	267.50	141.67	47.04
Oct	258.06	176.11	31.75
Nov	184.72	151.94	17.74
Dec	92.50	83.33	9.91

From Table 5, it can be seen that the optimal setting horizontal roof overhangs reduce the impact of solar radiation through the windows, but not equally in all months. This decrease was significantly lower in winter than that 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.

The duration (in years) needed that primary energy savings compensate primary energy needed to build overhangs is $EPBT$ = 6.01 years. The number of time primary energy savings are generated during lifecycle by using the optimal overhangs more than the primary energy needed to build overhangs is ER = 3.33.

The CO_2 substitution time ($GHGST$) is the time required to substitute the entire amount of CO_2 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 during the construction of concrete horizontal roof overhangs is G_{CO2} = 2.847 $t\ CO_2$. Then, the CO_2 emissions intensity of the concrete production is taken as GHG_c = 0.13 $t\ CO_2$ / t concrete from [9, 10]. The CO_2 emission reductions resulting from the application of horizontal roof overhangs is annually S_{CO2} = 1.834 $t\ CO_2$ where equivalent CO_2 emissions for *EPS* $k_{CO2,EC} = 3.1$ taken from [7]. Finally, the CO_2 substitution time is *GHGST* = 1.55 years.

7. SENSITIVITY TO THE ACCURACY OF THE INPUT DATA

Optimization is performed of the horizontal roof overhangs. The overhangs are made by using concrete of the specific embedded energy due its manufacture and installation s_{EC} = 1.924 MJ/kg. As there are different conditions of production and construction of concrete, the specific embedded energy of concrete as input datum may be different in practice. Here, an analysis is given how these changes influence output simulation results. Sensitivity to the accuracy of the input data is shown in Table 10.

Table 10 – Sensitivity to the accuracy of the specific embodied energy

[kWh/m^2]	s_{EC}	$s_{EC+20\%}$	s_{ECREF}	$s_{EC-20\%}$
h_E [m]	0	1.666	2.01	2.01
h_S [m]	0	0.61	0.61	0.61
h_W [m]	0	1.954	2.11	2.235
h_W [m]	0	0.01	0.51	0.51
E_{PRIM}	325.37	310.72	309.82	309.68
E_{AC}	26.62	17.55	16.74	16.62
E_{EH}	47.82	51.8	52.25	52.32
E_{EQ}	21.98	21.98	21.98	21.98
E_{EL}	10.62	10.88	10.93	10.93
e_P [%]	-	4.51	4.78	4.82

During optimization, if specific embodied energy sec increases by 20%, the depth of east, west and north roof overhangs decreases, decreasing the primary energy consumption by 5.64%. If specific embodied energy sec decreases by 20%, only depth of west roof overhang increases, enlarging the primary energy consumption by 0.84%.

8. CONCLUSION

Placing of horizontal roof overhangs reduces influence of solar radiation that passes through the windows by 48% per annum. This 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 depth larmier separately for each side of the world thus reducing the total consumption of primary energy. Optimal dimensions of overhang depths are 2.01m facing east, 0.61m facing south, 2.11 m facing west and 0.51 m facing north. Reduction of heat gains due to solar radiation decreases the energy consumption for cooling by 37.16%, while increasing the energy consumption for heating and lighting by 9.28 and 2.99%, respectively. Then, the total primary energy consumption is reduced by 4.78%.

NOMENCLATURE

AEE annualized embodied energy,
E_{AC} primary energy consumption by air conditioners, kWh/m^2/a,
E_{EH} primary energy consumption by electric heating, kWh/m^2/a,
E_{EQ} primary energy consumption by electric equipment, kWh/m^2/a,
E_{EL} primary energy consumption by electric lighting, kWh/m^2/a,
E_{P0} primary energy consumed in house without roof overhangs, kWh/m^2/a,
K_{EC} primary energy factor (PEF),
E_{POPT} primary energy consumed in house after installation the optimal roof overhangs, kWh/m^2/a,
$E_{P,MIN}$ primary energy consumed in house after installation the roof overhangs, kWh/m^2/a,
E_P annual consumption of primary energy, kWh/m^2/a,
E_{TOT} total annual energy, kWh/m^2/a,
h, h_E, h_S, h_W, h_N depth of roof overhangs, m,
l length of the exhaust horizontal roof overhangs, m,
e_{PSAV} achieved primary energy savings, %,
e_P reduction of primary energy, %,
f_N roof overhangs lifecycle, a,
s_{EC} specific embodied energy, MJ/kg,
EPBT environmental performance in terms of energy payback time,
GHGST greenhouse substitution time,
δ thickness, m,
λ conductivity, W/mK,
ρ density, kg/m^3,
c_P specific heat, J/kgK,
φ relative humidity, %,
TDB dru bubl temperature, °C,
I_{DIR} direct solar radiation, Wh/m^2,
I_{DIF} diffuse solar radiation, Wh/m^2.

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