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THERMAL EFFICIENCY OF THE WINDOW SHADE

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ABSTRACT

The purpose of this paper is to find the efficiency of window shades regarding building energy performance and explore the possibility of developing a model that enables users to find proper shades for their specific conditions.

The paper investigates different options of shades and their related variables and finds the efficiency of the shades regarding energy load. Each variable was investigated for its effect on the heat loads. Results were used as input variables for neural network prediction model.

A prediction model was developed and trained based on the previous simulation results. Ten different shade cases were used to test the accuracy of the prediction model, and the outcomes of the prediction model were compared with energy simulation results to find its robustness.

KEYWORDS

Shade, Energy, Performance, Neural Network, Sensitivity

INTRODUCTION

Window shades are commonly used in buildings for blocking the direct sun to reduce glare indoors. Their function can be extended as a thermal buffer too. Shades can reduce direct solar radiation, which reduces the heat gain and heat loss as well.

Research concerning window shades were focused on the efficiency of light levels to reduce direct solar radiation and increase indoor light levels to reduce artificial lighting (Cheung and Chung, 2007; Ihm et al., 2009); other studies addressed automatic controllability of the shades as an operative management problem (Laha, et al., 2005).

The thermal performance aspect of shades was investigated at a basic level several decades ago (Olgyay, 1957); however, recently shades have been investigated relation to their specific project use. (Lee and Tavil, 2007; Tanaka, H. Et al., 2008; Ochoa and Capeluto, 2009; Baldinelli, 2009).

A comprehensive study for their effect on glass has not been fully investigated. This paper provides the being of such an investigation and sets frame work for further investigations.

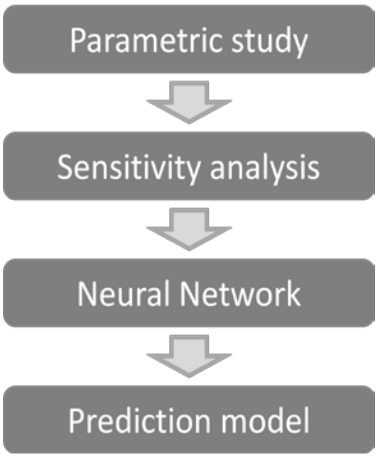
Shades need a low initial investment to install. If their thermal effectiveness is greater than the investment, shades can be the optimum solution for improving an existing poor performance of windows in the building.

This study investigated roller shades using transit energy simulation analysis to predict their impact on the energy performance of a building and investigate their efficiency and their sensitivity depending on variances between different materials.

The thermal behaviour of window shades is influenced by several variables including their geometry, the properties of the materials used, their orientation and location. Due to those influences, the study investigated different scenarios to capture all the variances of the shades. The resulting data was used to develop a prediction model that suggests different shades' thermal performance without generating complicated energy simulation models for different scenarios (Figure 1).

This study utilizes the Neural Network as the prediction model. Different scenarios of the shades' variation were predicted by the network model, and results were compared with the energy simulation. This verifies the accuracy of the prediction model and its limitation.

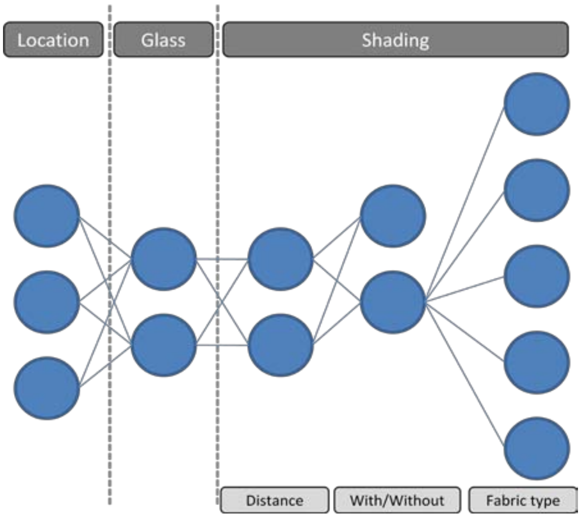
Figure 1. Overall process



WINDOW SHADE INVESTIGATION

Different geometric and physical properties of the elements of the window shade will affect its performance. To predict these effects, sixty-six tests were performed, with three locations, two glass types, with or without shades, two different shade distances from the window, and five different shade types. Each test was simulated for a year with hourly time steps (Figure 2).

Figure 2. Various conditions for simulation



A model with "typical" room dimensions was constructed (Depth 7790mm x Width 6700mm x Height 2850mm). It has one window (Width 6000mm x Height 2050mm) facing the south. Internal shading was constructed to perform a transit thermal simulation.

The simulations were conducted for different conditions regarding location, glass, and shade types.

Three locations were selected to represent different climate conditions that represent hot, temperate and cold climates. Table 1 and 2 shows the material properties of the two types of glass used for simulation. Five different types of shades were selected for the simulation (Table 3).

Table 1. Glass type A material properties

Layers	*Properties*	*Values*
Outside	Thickness {m}	0.0063
	Solar Transmittance at Normal Incidence	0.6
	Solar Reflectance at Normal Incidence: Front Side	0.1
	Solar Reflectance at Normal Incidence: Back Side	0.08
	Visible Transmittance at Normal Incidence	0.85
	Visible Reflectance at Normal Incidence: Front Side	0.102
	Visible Reflectance at Normal Incidence: Back Side	0.08
	IR Transmittance at Normal Incidence	0
	IR Hemispherical Emissivity: Front Side	0.84
	IR Hemispherical Emissivity: Back Side	0.87
	Conductivity {W/m-K}	0.9
Air	Thickness {m}	0.0127
Inside	Thickness {m}	0.0063
	Solar Transmittance at Normal Incidence	0.6
	Solar Reflectance at Normal Incidence: Front Side	0.1
	Solar Reflectance at Normal Incidence: Back Side	0.08
	Visible Transmittance at Normal Incidence	0.85
	Visible Reflectance at Normal Incidence: Front Side	0.102
	Visible Reflectance at Normal Incidence: Back Side	0.08
	IR Transmittance at Normal Incidence	0
	IR Hemispherical Emissivity: Front Side	0.84
	IR Hemispherical Emissivity: Back Side	0.87
	Conductivity {W/m-K}	0.9

Table 2. Glass type B material properties

Layers	*Properties*	*Values*
Outside	Thickness {m}	0.0095
	Solar Transmittance at Normal Incidence	0.381
	Solar Reflectance at Normal Incidence: Front Side	0.338
	Solar Reflectance at Normal Incidence: Back Side	0.468
	Visible Transmittance at Normal Incidence	0.662
	Visible Reflectance at Normal Incidence: Front Side	0.255
	Visible Reflectance at Normal Incidence: Back Side	0.211
	IR Transmittance at Normal Incidence	0
	IR Hemispherical Emissivity: Front Side	0.84
	IR Hemispherical Emissivity: Back Side	0.051
	Conductivity {W/m-K}	1
Air	Thickness {m}	0.0127
Inside	Thickness {m}	0.0063
	Solar Transmittance at Normal Incidence	0.381
	Solar Reflectance at Normal Incidence: Front Side	0.338
	Solar Reflectance at Normal Incidence: Back Side	0.468
	Visible Transmittance at Normal Incidence	0.662
	Visible Reflectance at Normal Incidence: Front Side	0.255
	Visible Reflectance at Normal Incidence: Back Side	0.211
	IR Transmittance at Normal Incidence	0
	IR Hemispherical Emissivity: Front Side	0.84
	IR Hemispherical Emissivity: Back Side	0.051
	Conductivity {W/m-K}	1

Table 3. Different shade fabric material properties

Type	*Properties*	*Values*
1	Solar Transmittance (T-sol)	0.12
	Solar Reflectance (R-sol)	0.42
	Visible Transmittance (T-vis)	0.1
	Visible Reflectance (R-vis)	0.4
	Openness (%)	22
	Thickness (mm)	1.8
2	Solar Transmittance (T-sol)	0.11
	Solar Reflectance (R-sol)	0.38
	Visible Transmittance (T-vis)	0.09
	Visible Reflectance (R-vis)	0.36
	Openness (%)	17
	Thickness (mm)	1.7
3	Solar Transmittance (T-sol)	0.11
	Solar Reflectance (R-sol)	0.56
	Visible Transmittance (T-vis)	0.09
	Visible Reflectance (R-vis)	0.54
	Openness (%)	11.5
	Thickness (mm)	2.3
4	Solar Transmittance (T-sol)	0.11
	Solar Reflectance (R-sol)	0.41
	Visible Transmittance (T-vis)	0.1
	Visible Reflectance (R-vis)	0.4
	Openness (%)	11.3
	Thickness (mm)	3.6
5	Solar Transmittance (T-sol)	0
	Solar Reflectance (R-sol)	0.65
	Visible Transmittance (T-vis)	0
	Visible Reflectance (R-vis)	0.65
	Openness (%)	8.9
	Thickness (mm)	1.8

PARAMETRIC STUDY

All simulations were based on a non-steady state thermal model conducted for the entire year on an hourly basis. The study utilized EnergyPlus (United States Department of Energy, 2007,1) as a thermal simulation engine. Heat transfer equations of conduction, radiation and convection (between glass and shades) were used, which allow robust thermal performance predictions. The study took into consideration the impact of the outdoor conditions. Indoor heat loads such as lighting, equipment, and occupants were assumed to be constant in order to focus the work on the relative impact of the shades on heat flow.

Weather data were based on the Typical Meteorological Year 2 (TMY) weather format. TMY2s are data sets of hourly values of solar radiation and meteorological elements for a 1-year period.

An important feature of the shading device thermal model in EnergyPlus is calculating the natural convection airflow between the shading device and the glass. This flow affects the temperature of the shading device and glazing and, for interior shading, is a determinant of the convective heat gain from the shading layer and glazing to the zone air. The airflow model is based on the ISO Standard 15099, "Thermal Performance of Windows, Doors and Shading Devices— Detailed Calculations" (ISO15099, 2001).

DISCUSSION

These simulations were compared to a reference study simulation (windows with no shades) and expressed as a percentage relative to the reference points.

The results are compared based on the average hourly heat surface heat exchange for the entire year.

Overall simulation results show that installing shades reduced the heat gain. Covering the window with shades also reduced the heat loss during the night time. The reduction rate of the energy is significant when glass performance is poor (Table 4 and 5).

Table 4. Heat Gain [W] (Hourly)

Location	*Glass*	*Shade*	*Heat gain*	*Reduction*
Hot	A	without	765.18	20.87%
		with	605.47	
	B	without	405.48	12.06%
		with	356.59	
Temperate	A	without	756.38	21.16%
		with	596.30	
	B	without	398.31	10.30%
		with	357.27	
Cold	A	without	737.72	21.18%
		with	581.48	
	B	without	398.31	11.75%
		with	351.49	

Table 5. Heat loss [W] (Hourly)

Location	*Glass*	*Shade*	*Heat loss*	*Reduction*
Hot	A	without	82.08	17.52%
		with	67.70	
	B	without	18.85	4.39%
		with	18.02	
Temperate	A	without	114.88	13.58%
		with	99.28	
	B	without	33.13	3.03%
		with	32.12	
Cold	A	without	123.53	11.80%
		with	108.95	
	B	without	39.29	3.36%
		with	37.97	

The study shows that, as shades are closer to the glass, heat reduction was increased. A maximum 2% reduction can be achieved if a shade is closer to the glass (Table 6).

Table 6. Heat reduction and shade distance

Climate	*Glass type*	*Shade distance multiplier*	*Reduction*	
			Heat Gain	Heat loss
Hot	a	0	21%	18%
		1	20%	16%
	b	0	12%	4%
		1	11%	3%
Temperate	a	0	21%	14%
		1	20%	13%
	b	0	12%	3%
		1	11%	2%
Cold	a	0	21%	12%
		1	20%	11%
	b	0	12%	3%
		1	10%	3%

Shade distance multiplier : Effective area for air flow at the top and bottom of the shade divided by the horizontal area between glass and shade (United States Department of Energy, 2007, 2)

SENSITIVITY ANALYSIS

Based on the previous parametric study, the paper investigated the effect of the glass and shade variables on the energy load.

The different properties of both glass and shades were investigated with three different locations. All the property values were modified one at a time and the ratios of changes from a baseline configuration were analyzed.

Table 7 and 8 show the amount of thermal load changes from the baseline configuration in different locations.

Table 7. Properties sensitivity (Heat gain)

Heat Gain	*Hot*	*Temperate*	*Cold*
Glass			
Solar transmittance and reflectance	29.82%	32.98%	34.89%
Visible transmittance and reflectance	0.00%	0.00%	0.00%
IR Hemispherical emissivity	-3.18%	-3.42%	-3.44%
Conductivity {W/m-K}	0.02%	-0.02%	-0.04%
Thickness	-0.04%	0.03%	0.06%
Shade			
Solar transmittance and reflectance	7.00%	7.35%	7.51%
Visible transmittance and reflectance	0.00%	0.00%	0.00%
Thermal hemispherical emissivity and transmittance	1.04%	0.94%	0.85%
Thickness {m}	-0.05%	-0.04%	-0.04%
Conductivity {W/m-K}	0.03%	0.03%	0.03%
Air flow permeability	-0.02%	-0.02%	-0.02%
Top opening multiplier	-0.42%	-0.41%	-0.42%

Table 8. Properties sensitivity (Heat loss)

Heat Loss	*Hot*	*Temperate*	*Cold*
Glass			
Solar transmittance and reflectance	28.66%	21.63%	18.20%
Visible transmittance and reflectance	0.00%	0.00%	0.00%
IR Hemispherical emissivity	14.10%	13.02%	12.71%
Conductivity {W/m-K}	0.79%	0.74%	0.72%
Thickness	-1.15%	-1.08%	-1.06%
Shade			
Solar transmittance and reflectance	4.94%	3.18%	2.80%
Visible transmittance and reflectance	0.00%	0.00%	0.00%
Thermal hemispherical emissivity and transmittance	0.53%	0.39%	0.40%
Thickness {m}	-0.08%	-0.05%	-0.04%
Conductivity {W/m-K}	0.06%	0.04%	0.03%
Air flow permeability	-0.01%	-0.01%	-0.01%
Top opening multiplier	-0.34%	-0.24%	-0.22%

In all location, for the glass properties, the result shows that solar transmittance, solar reflectivity, and infrared (IR) hemispherical emissivity were major variables that affect the heat loads. For the shade properties, solar transmittance, solar reflectance, thermal hemispherical emissivity, and thermal hemispherical transmittance were major variables. The conductivity of both the glass and the shade did not show significant change in the different locations.

These results made it possible to decide which variables were major contributors to the thermal performance of the shade. Results of the sensitivity analysis gave an in-depth view of which variables were needed more study than other variables, and later it allowed reduction of the input parameters for the neural network.

NEURAL NETWORK

The challenge of utilizing energy simulation to find optimum shades is that manipulating different variables and simulating energy load is time consuming. Therefore, it is necessary to reduce the computer power and simulation time by utilizing prediction algorithms.

For that reason, this paper investigates the possibility of utilizing the neural network as a prediction model.

The neural networks are non-linear statistical data modelling or decision-making tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. So once the relationship is established between initial data and conditions, it is easy to predict any shade’s efficiency on the energy load.

The neural network model Matlab (MathWorks, 2001) was used for the test. The neural network was coded in a m-file. The training set of inputs and targets are shown in Table 9.

There are 160 neurons in the first layer and two neurons in the second (output) layer. The transfer function in the first layer is “logsig”, and the output layer transfer function is “purelin.” The log sigmoid transfer function (logsig) takes the input, which may have any value between plus and minus infinity, and squashes the output into the range 0 to 1. The linear transfer function (purelin) is used as an approximation. For the training function, gradient descent with momentum was used. The parameters for training were also customized for the research.

Table 9. Neural network training input and output variables.

Input	*Location*	
	Glass	Solar transmittance Solar reflectance IR hemispherical emissivity
	Shade	Solar transmittance Solar reflectance Thermal hemispherical emissivity Thermal hemispherical transmittance
Output	Heat gain[W](Hourly) Heat loss[W](Hourly)	

Once the network was trained, ten cases were simulated with neural network. The range of cases is shown in Table 10.

Table 10. Neural network test case input variables range

#	*A*	*Glass*			*Shade*				
		B	C	D	E	F	G	H	I
1	0.4	0.60	0.09	0.86	0.12	0.42	0.7	0.22	1
2	0.4	0.60	0.09	0.86	0.11	0.38	0.7	0.17	1
3	0.4	0.60	0.09	0.86	0.11	0.56	0.7	0.12	1
4	0.4	0.60	0.09	0.86	0.11	0.41	0.7	0.11	1
5	0.4	0.60	0.09	0.86	0	0.65	0.7	0.09	1
6	0.4	0.38	0.40	0.45	0.12	0.42	0.7	0.22	1
7	0.4	0.38	0.40	0.45	0.11	0.38	0.7	0.17	1
8	0.4	0.38	0.40	0.45	0.11	0.56	0.7	0.12	1
9	0.4	0.38	0.40	0.45	0.11	0.41	0.7	0.11	1
10	0.4	0.38	0.40	0.45	0	0.65	0.7	0.09	1

A : Location, B: Solar transmittance, C: Solar reflectance,
D: IR hemispherical emissivity, E: Solar transmittance,
F: Solar reflectance, G: Thermal hemispherical emissivity
H: Thermal hemispherical transmittance, I: Distance multiplier

DISCUSSION

Comparison between the result of the prediction model and the energy simulation shows the difference within reasonable range of average 9% except the case number 5and 10(Figure 3 and 4).

Figure 3. Comparison between energy simulation (EP) and neural network(NNW) prediction (Heat gain)

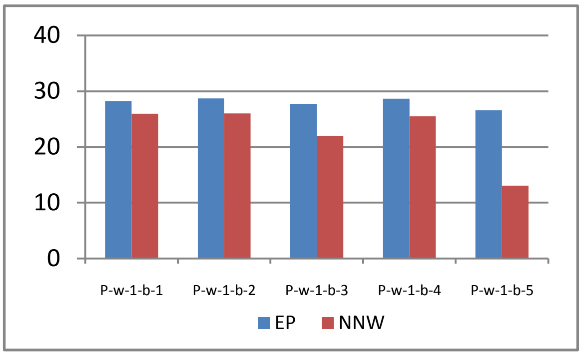
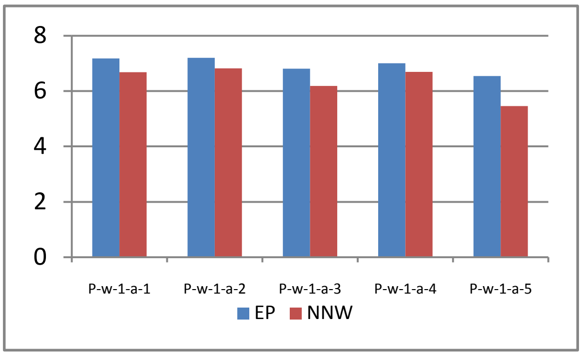


Figure 4. Comparison between energy simulation (EP) and neural network(NNW) prediction (Heat loss)



The result shows that in cases when the shades solar transmittance is zero, the difference between the prediction model and the energy simulation result increased compared to other cases. The relation between reflectance and transmittance was assumed to be the factor of difference. In the test case even when the transmittance value was zero the reflectance value was also low that creates a conflict relationship between the transmittance and the reflectance value.

CONCLUSION

The paper investigated the importance of shades regarding energy saving. The result shows that shades can reduce the energy load, and especially shows that the reduction of the energy load increases when the glass type is poor. This suggested that having shades in low energy performance buildings could benefit energy saving with comparatively low initial investment.

The sensitivity analysis result shows that solar and thermal transmittance, reflectance, and hemispherical emissivity were major variables that affect the heat loads compared to other variables.

The result of the neural network model was within reasonable range. The neural network model gives a possibility to extend the research to implement the optimization model to find the best shade option for different conditions.

The paper illustrated the initial development and further research is needed which include:

- The different orientation of the windows and its effects on the shades should be included.
- Even though the energy simulation is able to simulate the air convection between the glass and shades, its algorithm needs further study, which suggests integration with Computational Fluid Dynamics (CFD) to find better Convectional Heat Transfer Coefficient value.
- The neural network model needs to include relationships not only between transmittance and reflectance but also involving absorption of both glass and shades.

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