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Comparison of Methods for Modelling Complex External Shading in EnergyPlus and IESVE

Matthew Tee[1], Thajnu Rashid[2], Anna Ioannidou-Kati[1]
[1]Eckersley O'Callaghan, London, UK
[2]Skelly & Couch, London, UK

Abstract

Passive cooling measures, such as shading devices, offer a means of controlling overheating risk while reducing the energy use for cooling and subsequently operational carbon emissions. As such, shading devices are becoming increasingly common features of new building facades in the UK. Such devices may include detailed geometries and a range of materials, adding complexity to the solar performance analysis.

Modelling the performance of such devices is well suited to the parametric modelling environment Grasshopper and environmental plug-ins Ladybug and Honeybee. This allows the solar transmission of these devices to be calculated on an hourly basis also considering reflections within the device. However, it is currently unclear how to model the dynamic hourly performance most accurately in whole building energy simulations, which creates uncertainty for facade and building services engineers alike. This may lead to simplified geometries or static performance assumptions being made and errors in the estimated energy loads leading to a performance gap.

This study compares the solar performance of an example external shading device calculated using Radiance, with methods available in energy modelling software IESVE and EnergyPlus. A simplified 'shoe box' energy model has been used to compare the total solar energy transmission and energy loads calculated with each method.

It was found that while EnergyPlus offers more ways to model shading devices than IESVE, ApacheSim in IESVE results in more accurate dynamic performance calculations than the EnergyPlus methods 'Full Exterior' and 'Full Exterior with Reflections'. While EnergyPlus supports the use of BSDF IDF glazing definitions for energy simulations, unlike IESVE, this was found to consistently overestimate solar transmission compared to the Radiance shading coefficient method yet offered the most accurate method overall.

Background

For heating dominated climates, such as the UK, reduced thermal transmittance (U-value) and air permeability of building fabric typically produces a net reduction in overall Energy Use Intensity (EUI) for heating and cooling as the reduction in heating demand exceeds any consequential increase in cooling demand.

Therefore, in order to improve the energy performance of the UK building stock, there has been a gradual reduction of the minimum U-value requirements for external walls through subsequent revisions of the UK Building Regulations. In addition to regulations, there is a growing body of guidance suggesting lower fabric performance targets are voluntarily adopted in order to achieve more ambitious reductions in the operational carbon emissions of the future UK building stock. An example of such guidance is the Climate Emergency Design Guide (LETI, 2019). While improved U-value and air permeability performance tends to reduce heating energy demand in winter months, it may increase the severity of overheating in summer due to reduced dissipation of solar gain transmitted externally through the building envelope. This is particularly valid for South, South West, and West oriented facades.

To reduce the risk of overheating and energy demand for cooling, passive cooling measures are becoming increasingly important in building projects in the UK. Examples of passive measures include reduced window to wall ratio (WWR), lower solar transmittance (g-value) requirements for glazing, and the introduction of shading systems, such as blinds or external shading devices. Facade and mechanical engineers are assessing the performance of increasingly complex external shading devices as architects apply the same creativity of form and materiality to the shading device as would be expected for other components of the building.

Introduction

During the early design stages for facades incorporating complex external shading systems, it is necessary to analyse the performance of these systems rapidly to enable several design iterations to occur within reasonable project timescales.

Under these conditions, and when designing systems with complex geometry, it is advantageous to work in a parametric modelling environment such as Grasshopper. In combination with the environmental plug-ins Ladybug and Honeybee, it is possible to perform climate based annual radiation studies by raytracing using Radiance. Such analyses consider the effect of reflections within the shading system in addition to direct radiation. The performance of the shading system can be determined on an hourly basis using the shading coefficient (SC) method (Omidfar, 2011) (Zani et al., 2017). In this method, a screen of test points upon which the radiation distribution is measured is placed behind the shading system. By comparing the radiation with and without the presence of the shading system, the shading coefficient of the system can be determined. These shading coefficients can be combined with the solar energy transmittance (g-value) of a glazing construction to give the total solar energy transmittance (gtot) on an hourly basis across a typical year. The total solar energy transmittance (gtot) therefore represents the proportion of incident solar radiation transmitted through the glazing construction including the effect of the external shading system.

The shading coefficient method allows flexibility to rapidly create and iterate the design of complex shading devices using a performance-lead approach. However, current limitations of common energy modelling software, such as EnergyPlus and IESVE, mean it is not possible to incorporate the results of this method into energy simulations by specifying the g-value of glazing constructions on an hourly basis. This sometimes leads to uncertainty between facade and building services engineers when deciding how to incorporate complex shading devices in energy simulations in practice. This may commonly be resolved by taking alternative approaches, which may include:

- Modelling the geometry and material properties of the shading device within the energy modelling software and analysing the performance using integrated algorithms.

- Representing the performance of the shading system on a static basis by specifying the performance of a glazing construction using a single g-value corresponding to the combined performance of the shading and glazing. This simplified approach assumes constant performance, which may be derived from a single point in time or by taking a radiation weighted average for a period, such as on an annual basis (Kohler et al., 2017).

- Creating a Bidirectional Scattering Distribution Function (BSDF) definition of the shading system using the Radiance function genBSDF and combining this with the glazing performance in LBNL WINDOW. The resulting BSDF IDF file may be used to specify the combined performance of glazing and shading for energy simulations in EnergyPlus (Dartevelle et al., 2013) (Hauer et al., 2014), but it is not currently possible in IESVE.

This paper aims to assist with the choice of these methods by applying each to a simplified energy model containing a complex shading device and comparing the total solar energy transmittance results to those of the shading coefficient calculation method performed in Radiance. The use of the SC method as the baseline for comparison throughout the paper is not intended to suggest that it is the most robust method but that it is the method that is most often used in practice.

Methodology

The analysis methodology is shown diagrammatically in Figure 1.

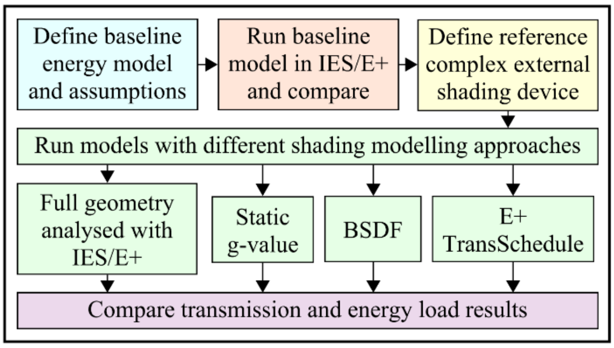

Figure 1: Analysis methodology flow chart.

To compare methods for modelling shading devices within energy simulations, a case study has been analysed using methods within EnergyPlus v9.2.0 and IESVE v2019.1.0.0. The EnergyPlus models were created in Grasshopper using Honeybee v0.065. The case study was comprised of a simplified 'shoe box' energy model consisting of a single thermal zone and representing a typical facade bay of an office building in the UK featuring a complex external shading device.

Baseline model definition

A baseline model without any shading device has been analysed in addition to the energy models representing each modelling method. This is intended to provide an indication of errors between each software prior to comparing each modelling approach.

This baseline model consists of a cuboid thermal zone of 6m width, 9m depth and height of 3.8m. The dimensions of the model have been chosen to represent a typical facade bay. There are five internal surfaces to which an adiabatic boundary condition is applied. The external elevation of the model consists of horizontal spandrels of height 0.35m at the top and bottom, with the remaining area consisting of glazing. The effect of thermal bridging is omitted for simplicity. The properties of the spandrel represent an insulated panel with 194mm of mineral wool between a 3mm aluminium panel externally and a 3mm steel panel internally, achieving a U-value of 0.175 W/m^2K. The glazing performance represents a double-glazed unit with a low-emissivity coating, achieving a U-value of 1.1 W/m^2K and g-value of 0.6. This is performance is specified directly in EnergyPlus using Honeybee, rather than by specifying an LBNL WINDOW IDF description of the glazing.

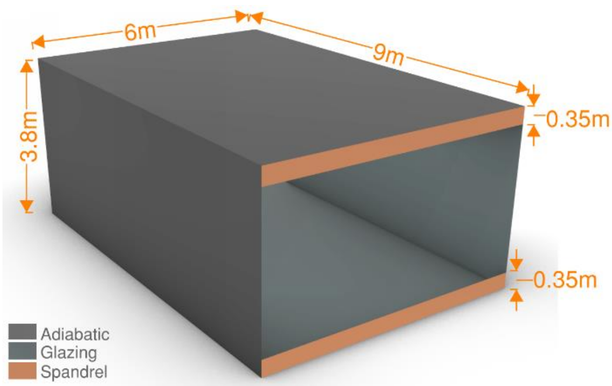

Figure 2: Baseline energy model geometry.

Shading system definition

The reference complex shading device used in this study consists of a grid of vertical and horizontal slats inspired by the arrangement of mortar joints in brickwork. The slats have a depth of 60mm and thickness of 10mm with a vertical spacing of 65mm between horizontal slats. The vertical slats have an alternating spacing of either 215mm or 100mm, as shown in Figure 3.

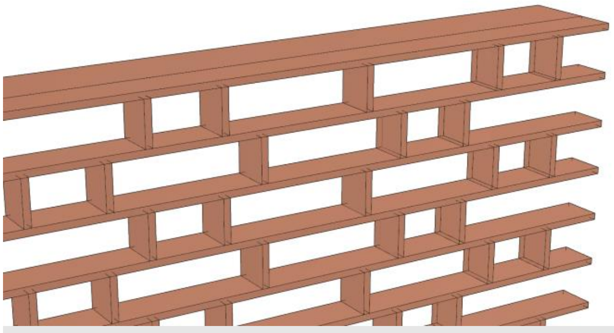

Figure 3: Shading system geometry.

The shading device has an overall width of 9m and height of 3.8m and is placed with a 100mm gap between the glazing and the shading. These dimensions provide a horizontal projection of 1.5m beyond the width of the thermal zone on each side to reduce the exposure of the glazing to direct radiation which may pass between the shading and glazing at the edges of the model. The gap between the glazing and shading at the top of the model has also been closed for this reason. The shading device has been assigned properties representing a bronze coloured metal with reflectance of 0.14, surface roughness of 0.2 and specularity of 0.3.

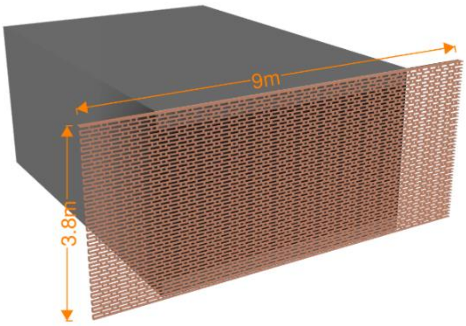

Figure 4: Shading system dimensions.

Energy model parameters

Each energy model has been run for a South and West orientation using IWEC EPW weather file 037760, which represents a typical year from climate data measured at London Gatwick airport. Heating and cooling demand has been calculated as ideal air loads with no free cooling, so ventilation shall be fixed to that specified. The modelling parameters are shown in Table 1.

Table 1: Energy model parameters

Parameter	Value	Notes
Occupant density	10 m^2/person	Applies Mon-Fri 7am-7pm according to the schedule in Figure 5. No occupancy assumed at all other times
Cooling set point	24 °C	Applies Mon-Fri 8am-6pm. No cooling assumed at all other times
Heating set point	21 °C	Applies Mon-Fri 5am-7pm
Heating set back temperature	12 °C	Applies all times when set point 1 not in use
Mechanical ventilation	10 l/s/person	Applies Mon-Fri 7am-7pm. No mechanical ventilation assumed at all other times
Facade air infiltration	0.15 ACH	Applies at all times

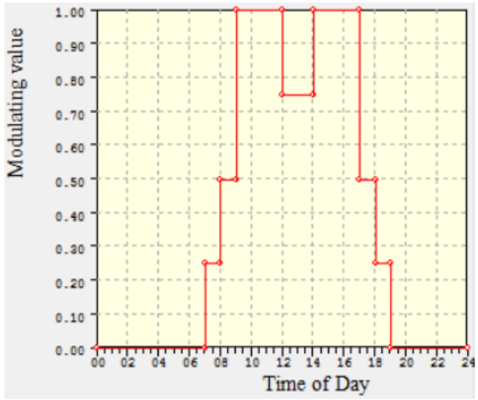

Figure 5: Occupancy profile.

Configuration definitions

An energy model has been analysed for each shading modelling method and these are referenced using the notation shown below in Table 2.

Table 2: Model configuration descriptions

Reference	Description
C0	Baseline (without shading device)
C1	Integrated analysis
C2	Static performance – design cooling day
C3	Static performance – annual average
C4	BSDF (EnergyPlus only)
C5	TransSchedule (EnergyPlus only)

For each configuration, the shading device has been modelled using the following methods.

C0: The shading is not be modelled in this configuration.

C1: The full geometry of the shading system is modelled in EnergyPlus and the solar gain is calculated using each of the integrated solar distribution calculation methods, ‘Full exterior’ (FE) and ‘Full exterior with reflections’ (FEWR) (EnergyPlus, 2019). The FE method determines the sunlit area of the glazing surface for each timestep and uses this to reduce the transmitted solar gain. Instead, the FEWR method performs raytracing for test points on the outside of the glazing surface to account for reflections in the shading device.

The geometry of the shading device has been transferred from Grasshopper, in which it was originally modelled, to IESVE using the gbXML file format. However, IESVE automatically simplified the geometry by removing the vertical elements due to the length being below an apparent threshold of 0.1m. Therefore, due to the number of shading surfaces in the device, the exact geometry cannot be easily modelled in IESVE and these models only contain the vertical shading elements. The shading geometry imported to IESVE is assigned as shading objects and analysed on an hourly basis with SunCast in ApacheSim, which determines the sunlit area of glazing.

C2: If the geometry of a shading device is too complex to be modelled directly in an energy simulation, a simplified approach may be to specify static performance of the shading device based on the results of the shading coefficient method for a single point in time. This configuration represents the shading by creating a glazing construction with total solar energy transmittance equivalent to the combination of glazing and shading averaged on the cooling design day of August 21st.

C3: In this configuration, the shading device is represented using static performance as per C2, however this is based on the radiation weighted annual average total solar energy transmittance (gtot) for the combination of shading and glazing (Kohler et al., 2017).

C4: This configuration represents the combined shading and glazing performance with a BSDF material definition. The shading geometry is exported from Grasshopper to a Radiance scene for genBSDF analysis. The resulting BSDF file is combined with an equivalent glazing construction in LBNL WINDOW 7.6. The resulting BSDF IDF file describes the performance of the shading and glazing based on the angle of incidence of the radiation (altitude and azimuth).

At the time of writing, it is only possible to use this method in EnergyPlus as IESVE is unable to account for the effect of BSDF on solar gain. The only effect of BSDF in energy models within IESVE is to determine the potential for reduced lighting energy consumption due daylight provision, which uses Radiance. Therefore, C4 has not been analysed in IESVE.

C5: While it is not possible to specify the g-value of a glazing construction using an hourly schedule in either modelling software, it is possible in EnergyPlus to simulate context shading surfaces with varying transmittance specified as an hourly schedule. This can be achieved using the Honeybee component ‘EP context surfaces’ and input ‘EPTransSchedule’. This configuration represents the shading by enclosing the full energy model within a larger cuboid geometry of which the solar transmittance is varied on an hourly basis to match the shading coefficient of the shading device as calculated with Radiance.

Results

The modelling methods can be compared most directly using the annual total solar energy transmittance (gtot) distribution measured from each energy model, which accounts for the combined shading and glazing. All other gains and losses remain constant between models, hence variations in energy loads are due to the different gtot distributions calculated by each modelling method. Therefore gtot is be compared prior to energy loads.

Total solar energy transmittance (gtot)

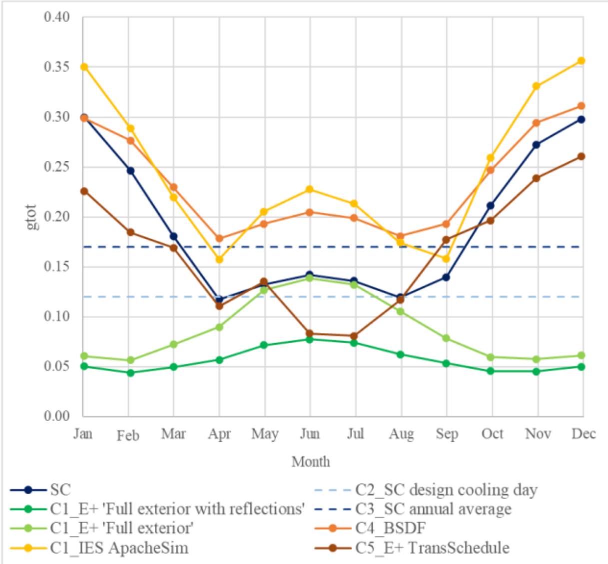

Figure 6: gtot distribution for South oriented models

The annual gtot distribution for each configuration is shown in Figure 6 for the South oriented models. Each data point represents a radiation weighted average value for each month and the results of each method are compared against shading coefficients calculated with Radiance, shown in blue.

The results of the shading coefficient method show peak solar transmission in winter, with a maximum gtot of approximately 0.3. The transmission during summer is considerably lower, between 0.12-0.14. This is expected as the shading device primarily consists of horizontal slats, which cast greater shaded area on the glazing for high sun positions (high solar altitude) than for lower sun positions. It should be noted that this shading performance trend is beneficial as solar gain serves to reduce heating energy consumption during winter but should be reduced to control cooling loads and overheating in summer. The annual average of this shading coefficient data, which has been used as the static g-value of the glazing in C2 is 0.17. Instead the average shading coefficient on the cooling design day is 0.12, which is used as the g-value in C3.

Considering C1, in which the geometry of the shading device was analysed directly by the energy modelling software, there is significant variation between the methods in EnergyPlus and that in IESVE. The EnergyPlus methods show an inverse trend to the shading coefficient distribution. Although the ‘Full exterior’ method shows correlation during the summer months, generally both of these methods show peak transmission in summer rather than winter. The transmission calculated using the ‘Full exterior with reflections’ method is consistently lower than the shading coefficient method. Instead, IESVE using ApacheSim for shadow calculation shows a similar trend to the shading coefficient method but consistently calculates higher solar transmission. This can be explained by the omission of the vertical shading elements from the IESVE models, which were removed automatically when importing the shading geometry from the gbXML file as previously described.

The two methods which most closely represent the shading coefficient distribution are those available for use in EnergyPlus but not IESVE. The BSDF IDF glazing construction (C4) shows a similar trend to the shading coefficent method but shows consistently higher transmission, with the offset greater in summer than winter. The transmittance schedule method also shows a similar trend to the shading coefficients with peak transmission in winter, however this method shows greatest correlation in the period of March to May and August to September while there are offsets for other periods. Although these methods are not closely correlated with the shading coefficent consistently, it is apparent that they generally show better correlation than other methods.

The annual gtot distribution for each of the West orientated energy models is shown in Figure 7.

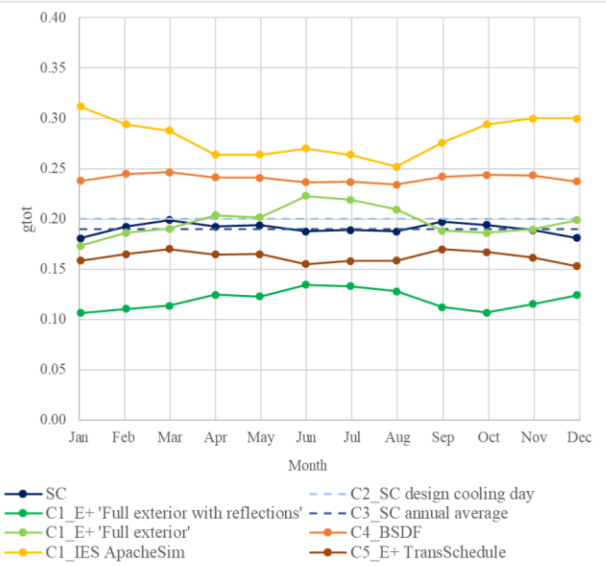

Figure 7: gtot distribution for West oriented models

It can be seen in Figure 7 that the annual shading coefficient distribution is significantly less variable for the West oriented models than for the South and that the coefficients are within the range 0.18-0.20 throughout the year. Due to the relatively low annual variation, the cooling design day and annual averages show little separation with gtot values of 0.19 and 0.20 respectively.

All methods, with the exception of ApacheSim in IESVE, show similarly low annual variation. There is significant difference however between the transmission calculated by the EnergyPlus shadow calculation methods, as while the 'Full exterior with reflections' method shows consistently lower transmission than the shading coefficient method, the 'Full exterior' method is very closely correlated for all but the period of May to August. It was similarly observed for the South orientations that the 'Full exterior' method is more closely correlated than the 'Full exterior with reflections' method.

The transmission calculated by ApacheSim in IES peaks during winter and shows both greater transmission and variation than any other method for this orientation. As previously described, this is likely to be caused by the lack of vertical shading elements in the IESVE model geometry, which is expected to have a more significant effect for the West orientation as the sun is typically to the South, from where shadow would be cast on the glazing by the vertical surfaces.

The two additional EnergyPlus methods show very similar trends to the shading coefficient method but similar offsets for the West orientation to those observed for the South. The BSDF method predicts consistently higher transmission than the shading coefficient method, whereas the transmittance schedule method consistently predicts lower transmission.

For the West orientation, the expected shading coefficient performance of the device is most closely represented by the 'Full exterior' method in EnergyPlus.

Energy loads

The calculated annual energy demand for heating and cooling corresponding to each model are shown below.

C0_Basline
C1_Integrated shading analysis
C2_Static - cooling design day
C3_Static - annual average
C4_BSDF
C5_EPTransSchedule

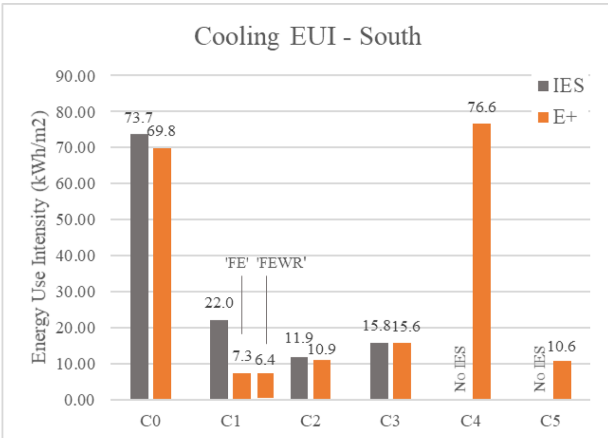

Figure 8: Cooling energy use for South oriented models

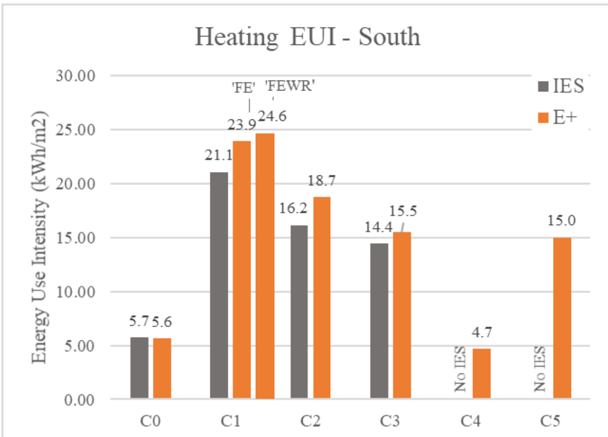

Figure 9: Heating energy use for South oriented models

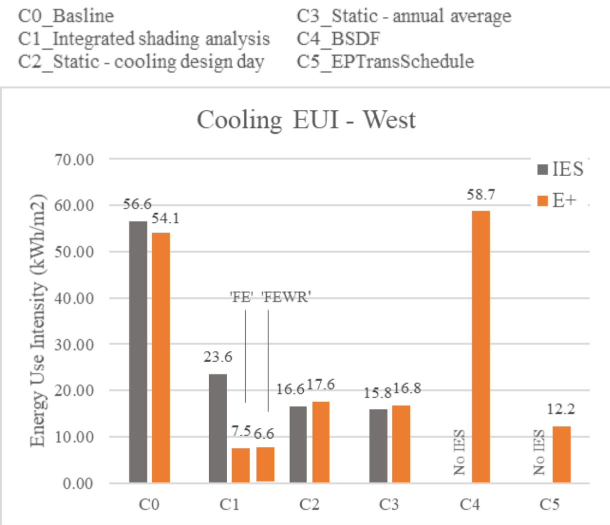

Figure 10: Cooling energy use for West oriented models

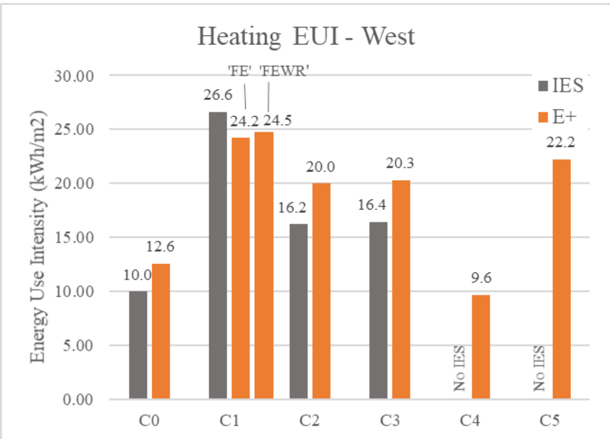

Figure 11: Heating energy use for West oriented models

Discussion

The results of this case study can be used to compare the energy modelling methods and between EnergyPlus and IESVE generally.

Comparisons for total solar energy transmission

The results presented in Figure 6 indicate that neither of the shadow calculation methods within EnergyPlus closely correlate with the results of the shading coefficient method for the South oriented models. Both EnergyPlus methods show an opposite trend to the shading coefficient method, with peak g-value occurring in summer, rather than winter.

This trend is unexpected, and the reason is not clear when studying the descriptions of the methods in the EnergyPlus Engineering Reference document. The 'Full Exterior' method calculates the sunlit fraction of the glazing using a shadow projection technique. The sunlight fraction is then used to factor the radiation intensity when calculating solar gain. For the shading device considered in this study, the area of the glazing obscured by the shading device is greater for the lower sun altitudes in Winter, than for the higher altitudes expected in Summer, hence a similar total solar energy transmittance trend to the shading coefficient method was expected.

The results show a similar total solar energy transmission distribution for the 'Full Exterior With Reflections' method, however the transmittance was found to be lower at all times and for all orientations that for the other methods. As described in the EnergyPlus engineering reference document (EnergyPlus, 2019), this method uses raytracing to determine the beam and diffuse irradiance of test points on the exterior surface of the glazing construction due to reflections from the ground or other obstructions, such as the shading device. While the use of raytracing may infer greater accuracy due to additional consideration for reflected radiation, in the case of 'Full exterior with reflections', the number of test points is equal to the number of edges of the receiving surface. For a rectangular window, such as that considered in this study, only four test points are used and the irradiance on the surface is taken as the mean of the four receiving points. By comparison, when performing the shading coefficient method using Radiance, a total of 1800 test points were placed on the exterior surface of the glass in order to capture the radiation distribution on the surface with increased resolution. This is beneficial when analysing a complex shading system, which may create regions of shade and irradiance much smaller than the test surface. In this study, it is possible that four test points provide insufficient resolution to measure the average irradiance on the glazing surface accurately and these may be shaded more than the glazing average.

Figure 7 shows good correlation between the shading coefficient method and the 'Full Exterior' method for West oriented models for all but summer months. Generally, the performance of the shading system is more consistent throughout the year than for the South orientation as indicated by all methods. It is not apparent why improved correlation is seen for the Full Exterior method for the West oriented models, while Full Exterior With Reflections maintains poor correlation.

It is notable that ApacheSim in IESVE performs better for the South orientation than both of these EnergyPlus methods and while the IESVE shows higher transmission than the shading coefficient method for both orientations, this can in part be attributed to the omission of vertical shading elements. For this reason, it appears that ApacheSim in IESVE is better suited for analysis of complex shading devices than the EnergyPlus 'Full Exterior' and 'Full Exterior With Reflections' methods.

Both the BSDF and EPTransSchedule methods in EnergyPlus include raytracing. In the case of BSDF, this is performed by genBSDF in Radiance, while the EPTransSchedule directly incorporates the shading coefficients calculated with Radiance in Honeybee. For this reason, the trends in transmission calculated by each of these methods closely align with the shading coefficient distribution. However, the BSDF method can be seen to consistently overestimate transmission, while EPTransSchedule tends to underestimate it. The reasons for these offsets are unclear.

Comparisons for energy consumption

The results of the baseline models, for which no shading effect was considered, show IES predicting 5% higher cooling energy consumption than EnergyPlus for both orientations, while for heating EnergyPlus predicted higher consumption by 2% for the South orientation and 25% for the West. These errors in the baseline model configuration have been considered when making comparisons between the software for other modelling methods.

Considering energy use for cooling, the effect on energy loads generally match the trends shown in the total solar energy transmittance results. For the South orientation, introducing the shading system by modelling the static performance based on the annual radiation weighted average reduces annual energy consumption by ~80%, while for static performance based on the design cooling day, the reduction is ~85%. For C1, there is a significant difference between IESVE and E+. The E+ methods produce a reduction of ~90%, while for IES, the reduction is ~70%. This can be explained by the omission of the vertical slat elements of the shading device from the model in IES, which would reduce the shading performance of the system. These elements were omitted by IES when importing the geometry of the shading device from Grasshopper using the gbXML file format. Similar trends are observed for the West orientation with energy reductions of between ~60% and ~90% depending on the modelling method.

It is clear however that the results of the BSDF model in EnergyPlus do not appear to show any shading effect, with increased cooling loads observed compared even to the baseline model. This is despite the total solar energy transmittance distributions shown in Figure 6 & 7 indicating a significantly reduced transmission compared to a static g-value value of 0.6, as would be expected for the baseline. This may be explained by the method of incorporating an external shading device within a glazing construction in LBNL WINDOW. When introducing a BSDF shading device as a layer within a glazing construction, a cavity is created between the exterior of the glazing and the shading layer. While in reality this cavity is likely to be ventilated, hence providing little or no improvement in the U-value of the glazing system, WINDOW is understood to assume that this cavity is unventilated, just as an internal cavity in a glazing construction. Hence, incorporating the external BSDF layer in this way may significantly reduce the U-value of the glazing construction unrealistically. This may result in increased cooling and reduced heating loads compared to the baseline despite the presence of the shading system. The difference in U-value between the BSDF model and the baseline model does not affect the transmitted solar radiation, hence Figures 6 & 7 correctly indicate the effect of BSDF on solar transmission. This finding may indicate that combining BSDF shading layers within glazing constructions in LBNL WINDOW may only be appropriate if the layer is within an internal cavity, however further analysis is required to investigate this.

Despite the possible issues creating BSDF with external shading in WINDOW and the possibility of poor implementation of BSDF in EnergyPlus, BSDF is generally expected to lead to robust results considering that both magnitude and directionality of transmission are accounted for in the energy simulation directly. On the other hand, while the SC method also accounts for both directionality and magnitude of transmission, directionality is introduced only during calculation of the coefficient by raytracing with Radiance and not in the energy simulation directly. It may be argued that BSDF should give more robust results however the shading coefficient method has generally been found to be reliable and widely used in practice considering limited implementations of BSDF in EnergyPlus and IESVE.

Considering energy use for heating, all modelling methodologies, except for BSDF, show increases in consumption, compared to the baseline. For the South orientation, introducing the shading system by modelling the static performance based on the annual radiation weighted performance increases annual energy consumption by ~265%, while for static performance based on the design cooling day, the increase is ~300%. For C1, the E+ methods produce an increase of ~430%, while for IES, the increase is ~370%. Again, similar trends are observed for the West orientation with increases of between ~140% and ~235% depending on modelling method. It should be noted that for all modelling approaches, the combined energy consumption of heating and cooling was reduced by the presence of the shading system.

Comparing IES and E+, generally there is good correlation between the different software for each modelling method. There is however poor correlation for the baseline model as previously described. It is also evident that heating loads are typically higher when calculated by E+ compared to IES, with an average increase of 12% for the South orientation and 20% for the West. While EnergyPlus offers more ways to model shading devices than IESVE, ApacheSim in IESVE results in more accurate dynamic performance calculations than the EnergyPlus methods ‘Full Exterior’ and ‘Full Exterior with Reflections’. While EnergyPlus supports the use of BSDF IDF glazing definitions for energy simulations, unlike IESVE, this was found to consistently overestimate solar transmission compared to the Radiance shading coefficient method yet offered the most accurate method overall.

Conclusion

For the shading system considered in this study, none of the modelling approaches available in EnergyPlus or IESVE closely correlated with the results of the shading coefficient method consistently for both orientations and for all times of year. However, on balance, some methods better represent the shading coefficients than others.

Of the two shadow calculation algorithms used to analyse the effect of shading geometries in EnergyPlus, the ‘Full exterior’ method performs favourably compared to the ‘Full exterior with reflections’ method. Both of these methods may be considered unsuitable for modelling complex shading systems however, as ‘Full exterior’ neglects reflections completely, while ‘Full exterior with reflections’ performs raytracing to consider reflections but using very few samples points. In the case of a rectangular glazing, only four sample points are used, which may be considered insufficient.

Two further methods are available in EnergyPlus but not currently in IESVE. The use of a LBNL WINDOW BSDF IDF definition to account for the combined performance of shading and glazing offers improved correlation with the shading coefficients compared to both EnergyPlus shadow calculation methods and ApacheSim in IESVE. However, the creation of BSDF IDF files in LBNL WINDOW may incorrectly model the thermal performance of the cavity between the glazing and external shading devices, hence further analysis is required to determine the suitability of this method.

While IESVE is limited by not supporting BSDF constructions for energy simulation, ApacheSim appears to give a good approximation of the performance of complex shading devices.

For the shoebox energy models considered here, the choice of method produces significant variations in the predicted energy loads, therefore the choice of modelling software and method is important when studying complex external shading devices.

Based on this study, EnergyPlus appears to be better suited for modelling the effect of complex shading devices on energy simulations compared to IESVE due to support for the BSDF and transmittance schedule methods. Despite this, ApacheSim in IESVE appears to give a good approximation when studying shading systems of simplified geometry.

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