# SENSITIVITY OF THE SOLAR HEAT GAIN COEFFICIENT OF COMPLEX FENESTRATION SYSTEMS TO THE INDOOR CONVECTION COEFFICIENT

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## ABSTRACT

Accurate estimation of the solar gain of a fenestration system is important in analyzing the energy performance of buildings. Recently, models were developed for complex fenestration systems – glazing systems with attachments such as venetian blinds and insect screens. These models use a three-node network for modeling heat transfer at the indoor-side of a glazing system. Empirical expressions based on observation and known limits were originally proposed for the corresponding convection coefficients. To address any ambiguity or error associated with these expressions, a research project is underway to develop techniques for evaluating these convection coefficients more accurately. The purpose of the current paper is to quantify the sensitivity of the U-value and solar heat gain coefficient of complex fenestration systems to the indoor-side convection coefficients. Configurations comprised of low-e glazings, roller blinds, venetian blinds, drapes and insect screens were examined in design summer and winter conditions using the window analysis software VISION5. Results show that the presence of an indoor-mounted attachment can significantly change the solar heat gain coefficient of a fenestration system. Nevertheless, the solar heat gain coefficient and the overall heat transfer coefficient are not sensitive to the indoor convection coefficient.

## INTRODUCTION

Design of energy-efficient glazing and shading attachments is a key component in the successful design of green buildings (*e.g.* [1,2,3]). The ability to control the solar gain through windows, usually the largest and most variable heat gain in a building [4], is particularly important because it allows heating by solar radiation when heating is needed, and eliminating the solar gain when cooling is required.

The solar optics and thermal characteristics of glazing systems are well understood. The total heat gain through the fenestration is the sum of the solar heat gain and the conduction heat gain. The solar heat gain is in turn the sum of the solar radiation transmitted through the fenestration and the portion of the absorbed radiation that is transferred inward. Three sections are typically considered when studying heat transfer through windows: centre-glass, edge-glass and the frame. The centre-glass region accounts for the majority of heat transfer through the window and is of primary interest [4].

Centre-glass heat transfer is usually modeled as one-dimensional. Nevertheless, nonlinearity and the coupling between different heat transfer modes can make the analysis of heat transfer through centre-glass complicated. Extra complications are encountered due to the spectral and directional dependence of the material properties and hence the solar heat gain. An overall heat transfer coefficient, the U-value, is used to characterize the conducted heat gain. A spectrally-averaged solar heat gain coefficient (SHGC), defined as the fraction of the incident solar radiation turned into heat gain, is used to characterize the solar heat gain.

An assessment of different fenestration models used in building energy simulation can be found in the study by Laouadi [5]. In the method developed by Wright and Kotey [6], the transmitted, absorbed and reflected solar fluxes at each layer are first calculated. The absorbed fluxes are then treated as source terms in the heat balance performed at each glazing layer, where both convective and longwave-radiative heat transfer are taken into account. This layer-to-layer approach was used [7,7,8] to create a comprehensive set of simulation models for complex fenestration systems (CFS), *i.e.* fenestration systems with attachments such as slat-type shades, drapes, roller blinds and/or insect screens. These models, known as the ASHWAT models [9,10], were implemented in the ASHRAE Toolkit (HBX version) and have since been incorporated in a number of building energy simulation software packages (see reference [11] for example). ASHWAT has also been used to generate tabulated data on the performance of shading devices [12]. A favorable comparison of

ASHWAT predictions and measured data has been reported by Kotey *et al.* [13].

One of the main features of ASHWAT is a generic thermal-resistance network – a system that allows heat transfer between any pair of nodes, not just adjacent nodes. This feature offers the possibility of calculating of the U-value and SHGC for a CFS exposed to any combination of indoor/outdoor temperatures (dry bulb and mean radiant), and any level/direction of incident solar flux (beam and/or diffuse).

The presence of a shading layer in a CFS influences the way in which solar radiation interacts with each of the individual layers, with the CFS as a whole, and with the building. Similarly, a shading layer adds significant complexity to the mechanisms of heat transfer, and two additional details must be considered. First, many shading layers include open areas so they allow direct transmission of radiation, solar or longwave. Examples include venetian blinds, any drapery fabric with an open weave or roller-blind material with an array of holes. Second, in the case of an indoor shading attachment, air usually flows through and around the shading layer. The common element between these two cases is that heat transfer can take place directly between two nodes that are not "adjacent" to each other. In the corresponding thermal network these additional heat transfer paths appear as resistors that bypass or "jump over" one or more intermediate layers. Figure 1 shows a shading attachment on the indoor side of a glazing system and the indoor portion of the thermal network. As can be seen from this three-resistor network, each of the three temperature nodes is in thermal communication with the other two nodes; each node has some influence on heat transfer at the other two.

The network shown in Figure 1 offers the opportunity to characterize the shading attachment more realistically, as well as the possibility of generating accurate solar-thermal performance results for the CFS. Moreover, the utilization of this three-resistor network leads to advantages in time-step building energy simulation [12,14].

The ASHWAT models were originally supplemented with an estimate of the three convection coefficients of the thermal network shown in Figure 1 as a function of glass-shade spacing. See Figure 2. The curves of Figure 2 were generated based largely on known limiting cases [10]. The glass-to-shade heat transfer is approximated to be purely diffusive. Hence, the corresponding heat transfer coefficient, $h_{gs}$, is set equal to the conductance k/b. Moreover, convective heat transfer at the indoor-facing side of the shading layer (surface 6) is assumed to be independent of the thermal interaction between the shading layer and the glass (surfaces 5 and 4 respectively). The shade-to-air convection coefficient ($h_{sa}$) is the combination of a constant component at the run-off value corresponding to surface 6 and a spacing-dependent component at surface 5. Therefore there is a constant offset of $h_{in}$ between the $h_{ga}$ and $h_{sa}$ curves. See Appendix C of reference [10] for more details on the derivation of the curves shown in Figure 2.

Although no difficulty has been reported regarding the application of the ASHWAT three-resistor network, the estimates of the convection coefficients do not enjoy the same fundamental grounding as the other components of ASHWAT [15]. In 2015, a new technique was proposed [15] for a more accurate evaluation of the three convective heat transfer coefficients associated with an indoor shading attachment. The new technique was applied to obtain the convection coefficients of a sample case with an indoor-mounted roller blind. It was shown that while ASHWAT gives a good estimate of the heat transfer coefficients and accurately predicts the general trends, the match is not exact. There is room for potential improvement of the model using the predictions of the new technique. For example, the ASHWAT model overestimates the glass-to-shade heat transfer coefficient for intermediate glass-shade spacings, while underestimating the effect of spacing on the variation of convection coefficients. However, it is not clear whether the reported discrepancies in the convection coefficients currently used in ASHWAT and the values predicted by a newly developed technique will strongly affect the overall performance of the models.

Wright [15] studied the sensitivity of the solar heat gain coefficient of windows without attachments with respect to various window design parameters and operating conditions. It was shown that SHGC is insensitive to the heat transfer models, including the evaluation of the convection coefficients. The most pronounced sensitivity was shown to be to the solar optical models, specifically the evaluation of the solar radiation directly transmitted to the indoor space and absorbed at the glazing layers. But no similar study on complex fenestration systems has been reported. Specifically, the sensitivity of the "indices of merit", *i.e.* U-value and SHGC, of complex fenestration systems to the indoor convection coefficient has not been quantified. In the present paper, the sensitivity of SHGC and U-value of a variety of complex fenestration systems to the indoor-side convection coefficient is examined for design summer and winter conditions using the window analysis software VISION5 [16,17].

## METHODOLOGY

The window analysis software VISION5, developed at the Advanced Glazing System Lab of the University of Waterloo [18], was used to assess the sensitivity of U-value and SHGC to the indoor convection coefficient for a number of CFS configurations under summer and winter conditions.

In VISION5, a fenestration system is defined by its layers (glazing, roller blind, venetian blind, drape or insect screen), the solar and thermal properties of the layers (emissivity, solar-optical properties, *etc*.) and the spacing between the layers. In the case of venetian blinds and drapes some details on the geometry of the attachment, *e.g.* slat size, slat angle or pleating ratio, are also needed. A built-in library of several commercial glazing layers and a number of typical shading devices and insect screens is available in the software. The between-layer conditions, *e.g.* the fill gas or the type of ventilation between glazing and shading layers, can also be specified. Loads are specified in terms of the total insolation and its beam-diffuse split; the solar azimuth and elevation angles; outdoor and indoor mean-radiant and dry-bulb temperatures; and outdoor and indoor convection coefficients.

In VISION5, rather than specifying the individual convection coefficients ($h_{ga}$, $h_{gs}$ and $h_{sa}$ in Figures 1 and 2), convection coefficients are specified by $h_{in}$, the asymptotic value of the glass-to-air convection coefficient, $h_{ga}$, corresponding to large b (see Figure 2). To assess the sensitivity of SHGC and U-value to the indoor convection coefficient, $h_{in}$, SHGC and U-value of each configuration were first calculated for ASHRAE design weather conditions, including $h_{in}$ values that correspond to summer or winter conditions, and free or forced convection at the glazing. Next, $h_{in}$ was slightly changed and the new SHGC and U were calculated. The difference between the new and original values divided by the change introduced in $h_{in}$ gives the sensitivity factor. Since the relation between SHGC or U and $h_{in}$ is not linear, the size of the perturbation introduced in $h_{in}$ is important. Ideally, an infinitesimally small $\Delta h_{in}$ would be introduced to evaluate the *local* sensitivities as derivatives of SHGC and U with respect to $h_{in}$, $\partial(SHGC)/\partial h_{in}$ and $\partial U/\partial h_{in}$. However, the accuracy of the calculations performed by VISION imposes a lower limit on the size of $\Delta h_{in}$. In other words, $\Delta h_{in}$ must be large enough so the resulting change in SHGC (or U-value) would be detectable within the resolution of the results reported by the software. A number of $\Delta h_{in}$ values were tested and a value of $\Delta h_{in}$=0.5 W/m$^2$K was chosen.

Complex fenestration systems comprised of typical single- and double-glazing windows, and eight different attachments were examined under ASHRAE summer and winter design conditions. The single-glazing window is a 3mm layer of plain glass ($\varepsilon$=0.84). The double-glazing system is comprised of two 3mm layers of glass; with a spacing of 12.7 mm (0.5 inch), filled with pure argon; and with a low-e coating ($\varepsilon$=0.102) on the outdoor-facing surface of the indoor-side glazing layer (surface 3). Table 1 gives a summary of the attachments examined in this study. All the attachments are mounted 100 mm (~4 inch) from the window – the spacing usually recommended to avoid condensation – on the indoor side.

In Table 2 the weather conditions used to represent winter and summer are summarized. These conditions are in accordance with the ASHRAE standard design conditions [12], except for the solar elevation angle which is set to $\beta$=45°. Insolation is 100% beam and the window solar azimuth angle is 0. Low ($h_{in}$=3.4-5 W/m$^2$K) and high ($h_{in}$=20 W/m$^2$K) convection coefficients were used at the indoor side to represent free and forced convection near the window, respectively.

Note that according to the ASHRAE design conditions the mean-radiant temperature is assumed equal to the air temperature, $T_m$=$T_a$. Although this is a standard assumption, it may not be the case in certain situations, *e.g.* with clear-sky radiation on the outdoor side or radiant heating on the indoor side. To accommodate this, different values can be assigned to $T_m$ and $T_a$ in VISION.

## RESULTS

In Tables 3 and 4, SHGC, U-value, and their sensitivity factors to $h_{in}$ are listed for the complex fenestration systems examined. The designations listed in Table 1, followed by a number indicating the number of glazing layers, are used to identify the various configurations. R2-1, for example, corresponds to a single-glazing CFS with the R2 attachment.

From a design point of view, only the summer SHGC is important for the calculation of the cooling load, while the winter U-value is important for calculating cold-weather heating loads. Since the subject of this paper is window attachments, and especially the shading devices, more attention has been to the summer conditions and hence SHGC. Nevertheless, for the sake of completeness, SHGC, U-value and sensitivity factors are reported here under both summer and winter conditions. Note that results indicate very small variation in SHGC between summer and winter design conditions, which is in agreement with the results of an earlier study of windows with no attachments [16]. Note that the absorbed radiation at the glazing, and hence SHGC, depends on the solar-optical properties of the CFS layers, the beam-diffuse split of the solar radiation, and the arrangement of the thermal resistors in the CFS.

The presence of an attachment can decrease SHGC notably. This decrease is much more pronounced for the single-glazing systems (up to 60%), but still notable for some of the double-glazing systems (up to ~20%). Nevertheless, SHGC is almost not sensitive at all to the indoor convection coefficient. The SHGC-$h_{in}$ sensitivity factor does not exceed 0.04 $m^2K/W$, *i.e.* a change of 1 $W/m^2K$ in $h_{in}$ causes a maximum change of 0.04 in the corresponding SHGC. In relative terms, a 10% error in the calculation of $h_{in}$ leads to a maximum error of 3% in the calculation of SHGC. Under summer conditions, the highest relative sensitivities were observed for R2-2 and V2-1.

The insensitivity of SHGC to $h_{in}$ can be explained by considering the thermal-resistor network of a complex fenestration system. A portion of this network, centred on a layer at temperature $T_i$, is shown in Figure 3. With $T_i=T_g$, this network corresponds to the indoor-facing glazing layer. The solar radiation transferred into the indoor space as heat gain, characterized by SHGC, is a function of the radiation absorbed at the innermost glazing layer ($q_g$ in Figure 1) which is determined by solar optics and the resistances attached to either side of the node representing this layer. In a multi-glazing system, the convective resistances connecting the indoor-side glazing to the indoor space are a small part of the network of resistances attached to the glazing. It is, therefore, not surprising that changing $h_{in}$ does not affect SHGC significantly. The observed insensitivity is in agreement with the notion that the solar radiation absorbed at the indoor-side glazing is transferred to the indoor ambient, *i.e.* turned into heat gain, mainly through radiative heat transfer. Although it was expected [10] that SHGC of a single-glazing system might be more sensitive to $h_{in}$, the results show no appreciable difference between the SHGC-$h_{in}$ sensitivity factors of single- and double-glazing systems.

The presence of an attachment at b=100 mm does not change the U-value of a fenestration system considerably. The largest change in the U-value of the double-glazing configurations was ~2.5% for the low-$h_{in}$ winter condition, regardless of the type of the attachment. Compared to the double-glazing configurations, the U-value of the single-glazing configurations is relatively more sensitive to the presence of an attachment. The presence of an attachment decreases the U-value of all the examined single-glazing configurations in the winter, with a maximum decrease of ~9.5%, observed when drapes were added to the single-glazing system. Calculations show that the U-value is insensitive to the indoor-side convection coefficient. The results suggest that a 10% error in $h_{in}$ causes errors less than 4% in the U-value. Noting that the U-value is not function of temperature, the U-$h_{in}$ sensitivity factor (absolute or relative) is, as expected, not notably influenced by the type of the attachment.

The effects of two additional factors, the solar elevation angle, β, and the glass-shade spacing, b, were also studied for the R2-2 configuration and under the low-$h_{in}$ summer condition. Only a summary of the results is presented here. Calculations show that although SHGC varies notably with β, the SHGC-$h_{in}$ sensitivity factor of R2-2 with the shade mounted at b=100 mm is not a function of the solar elevation angle (0<β<90°). For a solar elevation angle of β=45°, SHGC slightly increases when the glass-shade spacing is reduced from 100 mm (~4 inch) to 12.7 mm (0.5 inch). Note that according to Figure 2, by changing b, the ratio between the convection coefficients of the network shown in Figure 1 is changed. More specifically, when b increases; the glass-shade heat transfer, dominated by diffusion through the air between the two layers, is weakened; while glass-to-air and shade-to-air heat transfer are both enhanced. The results show, however, that the SHGC-$h_{in}$ sensitivity factor is independent of b in the range 12.7 mm<b<100 mm.

## CONCLUSIONS

The sensitivity of the solar heat gain coefficient and U-value of a number of complex fenestration systems to the indoor convection coefficient was examined using the window analysis software VISION5. ASHRAE design weather conditions were used. Eighteen configurations were examined under four different combinations of weather conditions and free or forced convection at the glazing.

Results show that the presence of an attachment mounted at a large spacing (100 mm) from the glass can significantly influence SHGC, but not the U-value, of a fenestration system. Nevertheless, both SHGC and the U-value show very small sensitivity to the indoor convection coefficient.

A previous study had indicated the possibility for improving the current estimates of the indoor convection coefficients in the ASHWAT window analysis models by using a new computational technique. However, the results of the present study confirm the utility and reliability of the approximate convection coefficients currently used in ASHWAT. The insensitivity of SHGC and U-value to the indoor convection coefficient suggests that improved convection coefficients will not greatly contribute to the overall accuracy of the window-analysis and building-energy models.


## ACKNOWLEDGEMENTS

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Table 1 – Summary of configurations examined

| **Attachment** | | **Specifications** |
|---|---|---|
| Not attachment | B | N/A |
| Roller blind | R1 | Black, 14% open |
| Roller blind | R2 | White, 14% open |
| Venetian blind | V1 | Dark, Aluminum, 1" slats at 45° clockwise from vertical |
| Venetian blind | V2 | Bright, Aluminum, 1" slats at 45° clockwise from vertical |
| Drape | D1 | Open, Dark, 100% pleating ratio |
| Drape | D2 | Open, Bright, 100% pleating ratio |
| Insect screen | I1 | 0.12mm diameter, 0.43mm spacing |
| Insect screen | I2 | 0.15mm diameter, 1.05mm spacing |

Table 2 – Summary of weather conditions

| | | **Winter** | **Summer** |
|---|---|---|---|
| **Insolation** [W/m$^2$] | Outdoor | 0 | 783 |
| | Indoor | 0 | 0 |
| **Temperature** [°C] ($T_m$=$T_a$) | Outdoor | -17.8 | 35.0 |
| | Indoor | 21.1 | 24.0 |
| **Convection coefficient** [W/m$^2$K] | Outdoor | 25.67 | 21.00 |
| | Indoor (natural) | 3.41 | 5.00 |
| | Indoor (forced) | 20.00 | 20.00 |

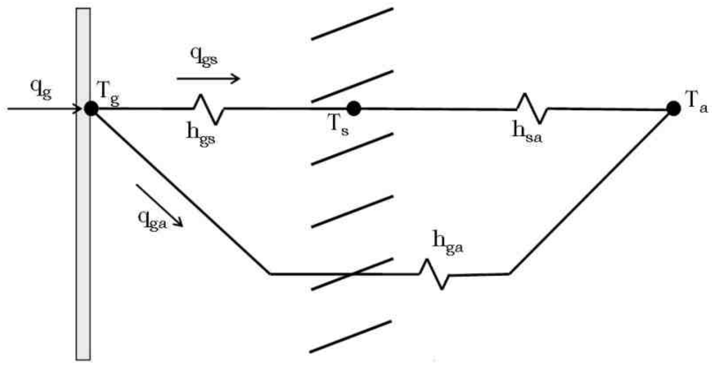


Figure 1 – Thermal network of the indoor side of a complex fenestration system [15]
(g: glass, s: shade, a: indoor air)

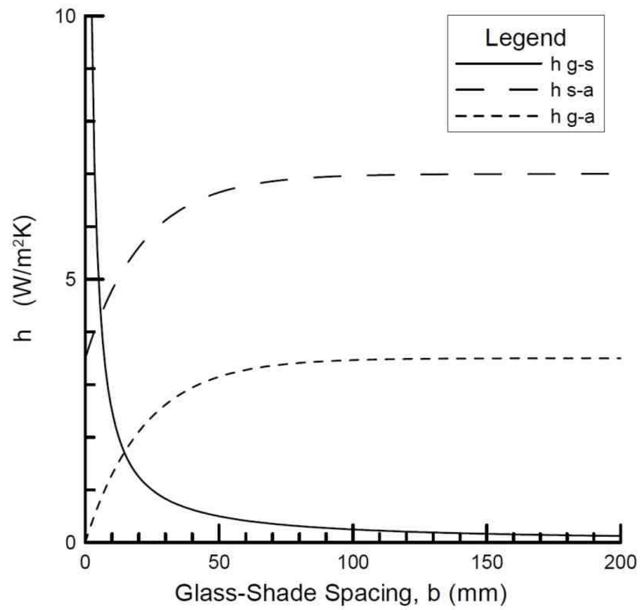


Figure 2 – Convection coefficients of the indoor side of a complex fenestration system, $h_{in}$=3.5 W/$m^2$K [10]

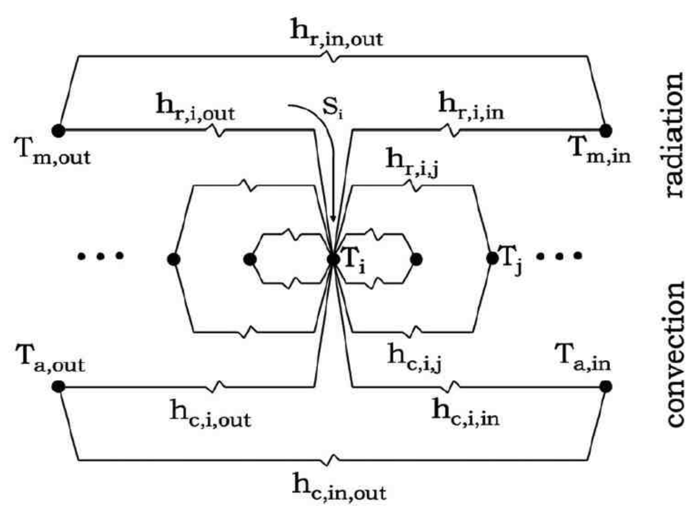


Figure 3 – Thermal network of a multi-layer system [9]

Table 3 – Indices of merit and sensitivity factors, single-glazing configurations

| Model | Index of Merit/ Sensitivity Factor | Summer | | Winter | |
|---|---|---|---|---|---|
| | | h=5W/$m^2$K | h=20 W/$m^2$K | h=3.41 W/$m^2$K | h=20 W/$m^2$K |
| **B-1** | SHGC [-] | 0.83 | 0.85 | 0.82 | 0.85 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.00 | 0.00 | 0.00 | 0.00 |
| | U [W/$m^2$K] | 7.37 | 12.89 | 5.99 | 13.28 |
| | ΔU/Δ$h_{in}$ [-] | 0.00 | 0.26 | 0.64 | 0.30 |
| **R1-1** | SHGC [-] | 0.68 | 0.80 | 0.67 | 0.80 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.02 | 0.00 | 0.02 | 0.00 |
| | U [W/$m^2$K] | 7.17 | 12.85 | 5.46 | 13.16 |
| | ΔU/Δ$h_{in}$ [-] | 0.56 | 0.26 | 0.72 | 0.30 |
| **R2-1** | SHGC [-] | 0.36 | 0.41 | 0.35 | 0.41 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.00 | 0.00 | 0.00 | 0.00 |
| | U [W/$m^2$K] | 6.97 | 12.81 | 5.46 | 13.16 |
| | ΔU/Δ$h_{in}$ [-] | 0.58 | 0.26 | 0.72 | 0.30 |
| **V1-1** | SHGC [-] | 0.65 | 0.76 | 0.63 | 0.76 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.02 | 0.00 | 0.04 | 0.00 |
| | U [W/$m^2$K] | 7.24 | 12.86 | 5.55 | 13.18 |
| | ΔU/Δ$h_{in}$ [-] | 0.54 | 0.24 | 0.72 | 0.30 |
| **V2-1** | SHGC [-] | 0.34 | 0.40 | 0.33 | 0.40 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.02 | 0.00 | 0.00 | 0.00 |
| | U [W/$m^2$K] | 7.08 | 12.83 | 5.55 | 13.18 |
| | ΔU/Δ$h_{in}$ [-] | 0.56 | 0.26 | 0.72 | 0.30 |
| **D1-1** | SHGC [-] | 0.70 | 0.78 | 0.68 | 0.78 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.00 | 0.02 | 0.02 | 0.00 |
| | U [W/$m^2$K] | 7.06 | 12.80 | 5.43 | 13.13 |
| | ΔU/Δ$h_{in}$ [-] | 0.56 | 0.26 | 0.72 | 0.30 |
| **D2-1** | SHGC [-] | 0.55 | 0.60 | 0.54 | 0.59 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.00 | 0.00 | 0.00 | 0.00 |
| | U [W/$m^2$K] | 6.93 | 12.77 | 5.43 | 13.13 |
| | ΔU/Δ$h_{in}$ [-] | 0.56 | 0.26 | 0.72 | 0.30 |
| **I1-1** | SHGC [-] | 0.68 | 0.72 | 0.66 | 0.72 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.00 | 0.00 | 0.02 | 0.00 |
| | U [W/$m^2$K] | 6.87 | 12.62 | 5.43 | 12.98 |
| | ΔU/Δ$h_{in}$ [-] | 0.54 | 0.26 | 0.68 | 0.32 |
| **I2-1** | SHGC [-] | 0.80 | 0.84 | 0.78 | 0.84 |
| | Δ(SHGC)/Δ$h_{in}$ [$m^2$K /W] | 0.00 | 0.00 | 0.02 | 0.00 |
| | U [W/$m^2$K] | 7.46 | 12.91 | 5.99 | 13.27 |
| | ΔU/Δ$h_{in}$ [-] | 0.50 | 0.26 | 0.64 | 0.30 |

Table 4 – Indices of merit and sensitivity factors, double-glazing configurations

| Model | Index of Merit/ Sensitivity Factor | Summer | | Winter | |
|---|---|---|---|---|---|
| | | h=5 $W/m^2K$ | h=20 $W/m^2K$ | h=3.41 $W/m^2K$ | h=20 $W/m^2K$ |
| **B-2** | SHGC [-] | 0.45 | 0.55 | 0.44 | 0.56 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.00 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.81 | 4.12 | 1.95 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.22 | 0.04 | 0.26 | 0.02 |
| **R1-2** | SHGC [-] | 0.44 | 0.55 | 0.44 | 0.56 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.00 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.86 | 4.13 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.20 | 0.04 | 0.24 | 0.02 |
| **R2-2** | SHGC [-] | 0.35 | 0.48 | 0.35 | 0.49 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.00 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.89 | 4.16 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.20 | 0.04 | 0.24 | 0.02 |
| **V1-2** | SHGC [-] | 0.43 | 0.54 | 0.43 | 0.55 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.00 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.87 | 4.13 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.20 | 0.04 | 0.24 | 0.02 |
| **V2-2** | SHGC [-] | 0.36 | 0.48 | 0.35 | 0.49 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.02 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.89 | 4.16 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.20 | 0.04 | 0.24 | 0.02 |
| **D1-2** | SHGC [-] | 0.44 | 0.55 | 0.43 | 0.55 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.00 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.86 | 4.13 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.20 | 0.04 | 0.22 | 0.02 |
| **D2-2** | SHGC [-] | 0.40 | 0.51 | 0.39 | 0.52 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.02 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.87 | 4.15 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.22 | 0.02 | 0.22 | 0.02 |
| **I1-2** | SHGC [-] | 0.42 | 0.53 | 0.42 | 0.54 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.02 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.86 | 4.14 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.22 | 0.02 | 0.24 | 0.02 |
| **I2-2** | SHGC [-] | 0.45 | 0.55 | 0.44 | 0.56 |
| | $\Delta(SHGC)/\Delta h_{in}$ [$m^2K$ /W] | 0.02 | 0.00 | 0.02 | 0.00 |
| | U [$W/m^2K$] | 2.86 | 4.13 | 2.00 | 3.49 |
| | $\Delta U/\Delta h_{in}$ [-] | 0.20 | 0.02 | 0.24 | 0.02 |

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