Air Pollution and Daylight Availability in the Urban Area: Dynamic Simulation in an Open-plan Office in London

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Abstract

The deposition of air pollutants on glazing can significantly affect the daylight transmittance of building fenestration systems in urban areas. This study presents a simulation analysis of the impact of air pollution and glazing visual transmittance on indoor daylight availability in an open-plan office in London. First, the direct links between glazing visual transmittance and daylighting conditions were developed and assessed. Second, several simple algorithms were established to estimate the loss of daylight availability due to the pollutant deposition at the external surface of vertical glazing. Finally, some conclusions and design strategies to support façade strategies at the early design stage of an urban building project were developed.

Introduction

In large cities the deposition of air-borne pollutants on to building surfaces can notably affect daylight availability in buildings. For glazing elements, the impact of air pollution deposition on daylight transmittance is commonly quantified in terms of the application of a glazing dirt correction factor (BS, 2008). For accurate daylight design in a polluted urban area it is important to have appropriate, site-relevant values for the glazing dirt correction factor. Between 1999 and 2003 several field surveys were implemented in the UK and Singapore (Tregenza et al. 1999; Sharples et al. 2001; Ullah et al. 2003) to measure the drop in glazing daylight transmittance due to pollutant depositions in urban buildings. For the British surveys, Tregenza et al. (1999) observed an average transmittance reduction of 4-8% for commercial buildings in clean environments, whilst Sharples et al. (2001) found that the loss in diffuse transmittance for a vertical window did not usually exceed 10%. These findings can be used in architectural daylighting calculations for regions environmentally similar to the temperate maritime climate of the UK. Another investigation, in the high-density city of Singapore, which has a tropical humid climate, found a total transmittance reduction ranging from 9% to 36% for vertical and horizontal widows (Ullah et al. 2003). In general, Tregenza et al. (1999) concluded that the glazing dirt correction factor is related to the particulates in the external atmosphere, precipitation and building form. Two studies (Mastekbayeva and Kumar, 2000; Ullah et al. 2003) further emphasized the fact that external atmospheric pollutants should be first considered when evaluating the loss of glazing daylight transmittance.

However, the dirt correction factor mentioned above was generally measured via a simple approach (e.g. lux meter), which did not take into account the nature and composition of pollutants in the urban atmosphere (Ullah et al. 2003). The glazing soiling mechanism was therefore studied. The glass soiling means ‘a visual nuisance resulting from the darkening of exposed surfaces by the deposition of atmospheric particles’ (Watt and Hamilton, 2003). An earlier study (Lanting, 1986) pointed out the particulate element carbon (EC) is the main soiling source at the glazing surface in cities. A global soiling model of modern glazing was developed in Paris city under a simple exposure condition (sheltered from rain) (Lombardo et al. 2005). It has been found that four soiling parameters vary in a logical trend with an increasing exposure time. Based on the measured data from six European cities, Favez et.al (2006) built new models to predict the soiling impact on optical properties of architectural glazing in terms of two typical pollutants: EC and ions (soluble inorganic particle). These studies would give an opportunity to quantify the dirt correction factor in a more accurate approach.

It can be concluded from the literature that there have been only a few studies focusing on a direct link between the situation of air pollution / glazing dirt deposition and the final reduction of daylight availability in buildings. In addition, some simple design strategies could be required to support a practical daylight design application that takes in to consideration the negative impact of environmental urban air pollutions.

This article presents daylighting simulation in an open-plan office building, and has two aims: (i) to investigate a link between the vertical glazing transmittance and indoor daylight availability and (ii) to build algorithms to estimate the reduction of daylight availability according to typical pollutants in European urban areas. The achieved results could benefit the development of guidelines for façade design at an early stage.

Building Model and Simulation

Location, office model, and glazing sizes

A multi-story office building in the urban area of London was simulated in this study (Figure 1). This

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location has a typical temperate maritime climate. The office had an open-plan working space (L×W×H: 21.6×10×3m) and vertical side windows in just one façade. Two glazing sizes were studied: one with a large glazing area to wall area ratio (GWR) of 60% and another with a small GWR of 30%. The total visual transmittance (VT) value of the glazing used in the modelling was decreased from 0.85 to 0.3 in 0.05 step intervals to simulate a range of transmittance changes due to air pollution. It was assumed that the glazing was directly exposed to the urban air (i.e. no obstructions, no sheltering effects from recesses or shading elements). The reflectances of the office room surface are: 0.8 (ceiling), 0.6 (wall) and 0.3 (floor).

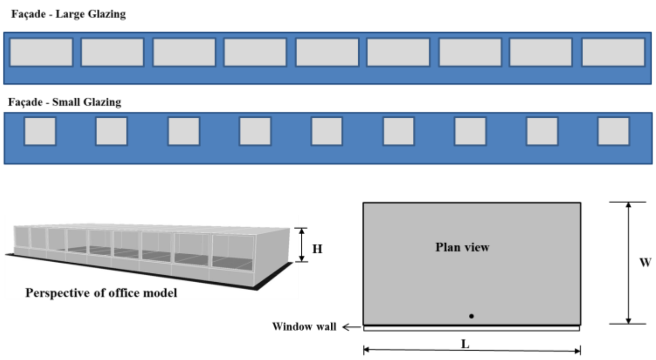

Figure 1: The office model and glazing sizes.

Daylighting simulation

As a climate-based daylight modelling tool (Mardaljevic, 2006), DAYSIM (Reinhart and Herkel, 2000) was adopted in this study to assess the daylight availability. Four various daylight metrics were used: Average Daylight Factor (ADF); Daylight Autonomy (DA); continuous Daylight Autonomy (DAcon), and Useful Daylight Illuminance (UDI) (Reinhart et al. 2006). Average Daylight Factor is a conventional metric that is primarily used under CIE overcast sky conditions, and which can display basic daylight availability. As a dynamic metric under various sky conditions, Daylight Autonomy is an indicator of whether the daylight illuminance meets the required working illuminance. Continuous Daylight Autonomy data include not only the daylight illuminance above a standard level, but also partial credit of each time step when the daylight illuminance lies below the required illuminance level. A minimum illuminance of 500 lux at the working plane was chosen for the office building modelled in this study. The Useful Daylight Illuminance (UDI) metric can also be used to evaluate daylight availability under various climates. Three UDI types are defined according to the daylight illuminance ranges: 0-100 lux (too dark), 100-2000 lux (useful light), and over 2000 lux (too bright).

The calculation position in the office modelling was at a horizontal working plane height of 0.8m above the floor. A calculation grid with 880 points was evenly distributed across the plane. In this study, an average value of all the calculation positions was derived to represent the daylight availability of the office. For each office model (large or small GWR), the simulated average value of ADF, DA and UDI associated with the varying glazing transmittance were used to produce algorithms.

Glass Soiling Model

The glass soiling model has been studied over a 15 year period (Lombardo et al. 2005). From measurements in six European cities (Athens, Kracow, London, Prague, Montelibretti and Troyes) two equations were developed to estimate the air pollutant impact on glass optical properties (light absorption and light scatter) (Favez et al. 2006):

$$X = 0.16EC/(EC + 15) \quad (1)$$

$$Y = 0.28ions/(ions + 64) \quad (2)$$

where X is the light absorption (%); EC is particulate elemental carbon amounts (μgC/cm^2) at the external glazing surface; Y is the diffuse visual transmittance and *ions* is the soluble inorganic particle amounts (μg/cm2) at the external glazing surface. Two curves (Figure 2 and 3) were plotted for Equations (1) & (2) to express the variations of light absorption and diffuse transmittance due to pollutant depositions respectively.

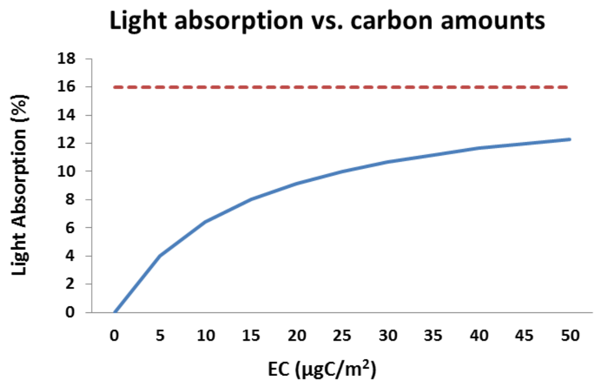

Figure 2: The impact of particulate elemental carbon amounts of glazing surface on the light absorption.

Figure 2 shows how the increasing EC amounts will clearly increase the light absorption (solid blue curve). However, the measurements of Favez et al. (2006) pointed out that a saturation of EC deposition can be found. This will result in a top limit of light absorption at around 16% (red dashed line).

Similarly, an increasing diffuse light transmittance occurs with the increase of ions amount (solid blue curve in Figure 3). The top limit of diffuse transmittance is around 20% (red dashed line), which is due to the saturation of ions deposition (Favez et al. 2006).

As mentioned in several studies (Lanting, 1986; Lombardo et al. 2005; Favez et al. 2006), EC deposition is the main factor that can substantially reduce the visual transmittance of glazing in urban buildings.

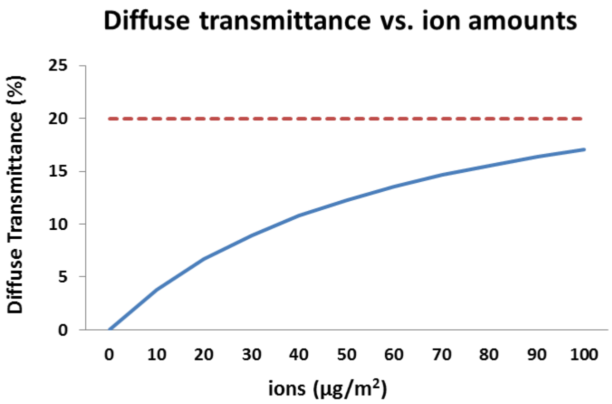

Figure 3: The impact of soluble inorganic particle (ion) amounts on the diffuse transmittance of glazing.

This soiling effect (Equation (1)) was generally found at the external glazing surface (Favez et al. 2006). According to the measurement (Favez et al. 2006), nevertheless, the ions' impact on the diffuse transmittance was just used for indicating the haze of glass (clearness of view), while no any findings relating to the total visual transmittance were reported.

In this study, therefore, only Equation (1) was adopted as the basic algorithm to establish the relationship between external air pollution and daylight availability.

Results and Discussions

This section includes three parts: relationships between glazing transmittance and daylight availability; algorithms to predict the loss of daylight availability in terms of one typical pollutant EC; and applications of these algorithms. All the regression equations were derived using IBM SPSS Statistics (version23). F-test and p-value were used in the regression of equations.

Glazing transmittance and daylight availability

First, the simulated results of the office with a large glazing size (GWR 60%) were analysed.

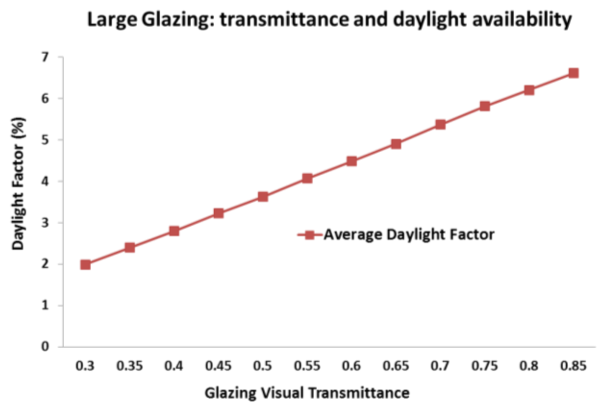

Figure 4: The relationship between glazing visual transmittance and average daylight factor (large glazing area).

Figure 4 indicates the impact of glazing visual transmittance on the average daylight factor (ADF) in the highly glazed office. With a GWR of 60%, a VT of 0.3 can ensure a good daylighting condition (ADF=2%). Increasing glazing VT will significantly increase the ADF. For example, taking the VT of 0.3 as a reference, a doubling of VT to 0.6 sees a relative ADF increase of 126%. A linear equation can be achieved through the regression to express the simple varying trend:

$$ADF = 8.48T - 0.583 \quad (R^2=0.999) \quad (3)$$

where ADF is average daylight factor (%) and T is glazing visual transmittance.

Figure 5 presents the variations of average daylight autonomy and continuous daylight autonomy with various glazing visual transmittances. In contrast to the linear variation of ADF, the two DA values vary in a polynomial trend. Apparently, the increasing VT would result in an increased DA or DAcon. It is normal that DAcon value is higher than DA value at each VT. However, the difference between DA and DAcon tends to decrease with an increasing VT. The absolute difference between DAcon and DA, on average, is around 16%. This is because daylight illuminances lower than 500 lux will be still included in the calculation of continuous DA with a discounted credit (Reinhart et al. 2006).

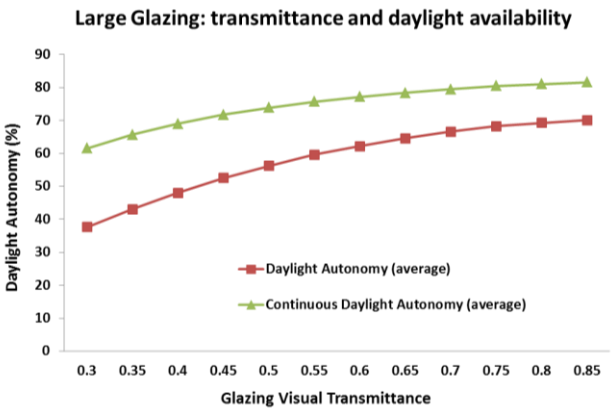

Figure 5: The relationship between glazing visual transmittance and average daylight autonomy (large glazing area).

Two equations can be regressed in terms of the two curves in Figure 5:

$$DA = 41.23T^3 - 165.20T^2 + 205.17T - 10.22, \quad (F\text{-test}, p<0.001) \quad (4)$$

$$DAcon = 88.31T^3 - 217.34T^2 + 192.10T + 21.17, \quad (F\text{-test}, p<0.001) \quad (5)$$

where DA and DAcon are daylight autonomy and continuous daylight autonomy respectively (%) and T is glazing visual transmittance.

In Figure 6, three average UDI values vary in three different trends, with the various glazing VT values in the open-plan office. When the glazing VT increases, both UDI (100-2000 lux) and UDI (<100 lux) tend to slightly decrease, while UDI (>2000 lux) slightly increases. Clearly, UDI (100-2000 lux) achieves the largest value for each VT. At VT = 0.45, UDI(<100 lux) and UDI(>2000 lux) have a similar value. UDI(<100 lux) has a lower value than UDI(>2000 lux) when VT<0.45, whilst an opposite trend can be found for VT>0.45. The average UDI values of the three types are around 15% (<100 lux), 64% (100-2000 lux) and 21% (>2000 lux). In an office with a large glazing area it would be normal to find the biggest occurrence of daylight illuminance is in the range of 100-2000 lux. Also, the large glazing size will bring in a relatively higher occurrence of daylight illuminance greater than 2000 lux). Thus, the 'dark' range (illuminance<100 lux) has the lowest occurrence. The lower glazing transmittance (<0.45) will give rise to lower daylight illuminances (<100 lux).

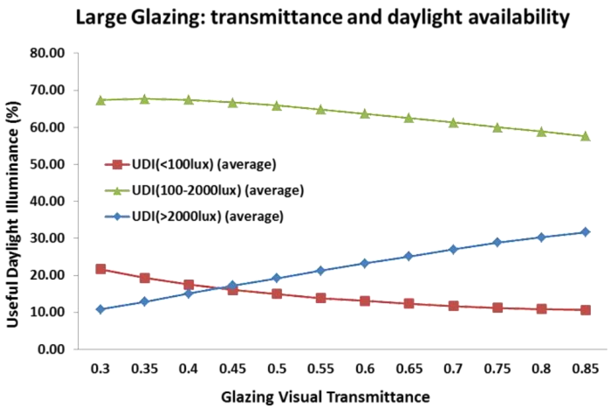

Figure 6: The relationship between glazing visual transmittance and average useful daylight illuminance (large glazing area).

Based on the UDI curves in Figure 6, three equations were regressed for the large glazing area as follows:

$$UDI(<100lux) = -46.59T^3 + 115.8T^2 - 103.51T + 43.49, \quad \textit{(F-test, p<0.001)} \quad (6)$$

$$UDI(100-2000lux) = 71.10T^3 - 144.92T^2 + 72.88T + 56.57, \quad \textit{(F-test, p<0.001)} \quad (7)$$

$$UDI(>2000lux) = -24T^3 + 27.99T^2 + 31.45T - 0.46, \quad \textit{(F-test, p<0.001)} \quad (8)$$

where UDI (<100 lux), UDI (100-2000 lux) and UDI (>2000 lux) are the occurrences of daylight illuminance in three different ranges (%); T is glazing visual transmittance.

In the second stage of the analysis the simulated results of the office with a small glazing area (GWR 30%) were considered. Similar to Figure 4, a linear relationship was found between glazing visual transmittance and average daylight factor, as can be seen in Figure 7 (small glazing GRW 30%). The linear trend was expressed by the following equation:

$$ADF = 3.97T - 0.308, \quad (R^2=0.999) \quad (9)$$

where ADF is average daylight factor (%) and T is glazing visual transmittance.

A larger VT will produce a bigger ADF. Taking the VT 0.3 as a reference, VT values of 0.6 and 0.8 have a relative ADF difference of 126% and 218% respectively. Compared with the large glazing area (Figure 4), the magnitude of the ADF increase of the small glazing area office is relatively smaller. Normally, to reduce the glazing size from a GWR of 60% to a GWR of 30% results in a 50% reduction of ADF value across the working plane.

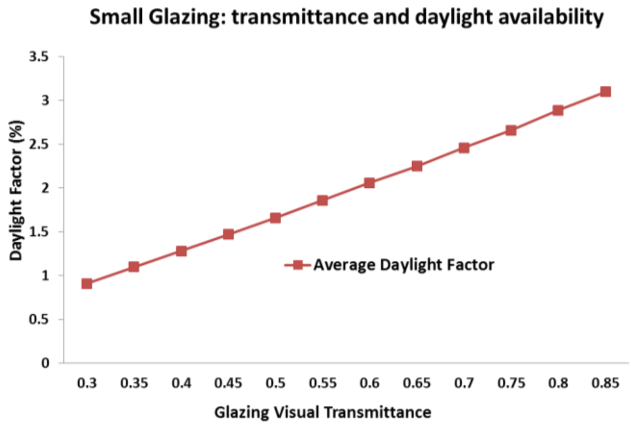

Figure 7: The relationship between glazing visual transmittance and average daylight factor (small glazing area).

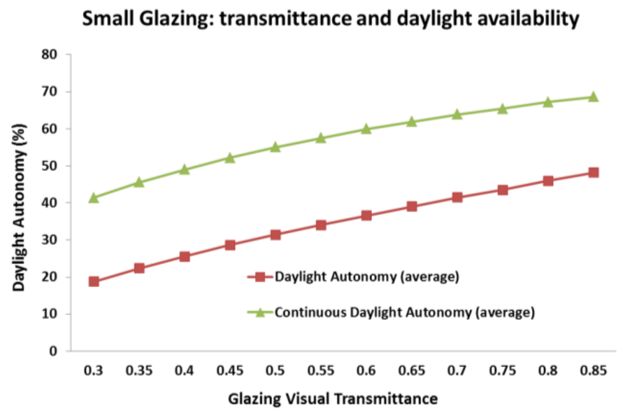

Figure 8: The relationship between glazing visual transmittance and average daylight autonomy (small glazing area).

Figure 8 illustrates the variation of average daylight autonomy and continuous daylight autonomy with various glazing visual transmittances. The increasing VT significantly increase the DA and DAcon. Unlike for the large glazing area (Figure 5), the small glazing area leads to two parallel curves of DA and DAcon. For each transmittance, the absolute difference between DAcon and DA is around 21%.Two equations were therefore regressed as follows:

$$DA = 37.09T^3 - 88.67T^2 + 115.81T - 8.98, \quad \textit{(F-test, p<0.001)} \quad (10)$$

$DAcon = 50.70T^3 - 136.9T^2 + 152.75T + 6.57,$ *(F-test, p<0.001)* (11)

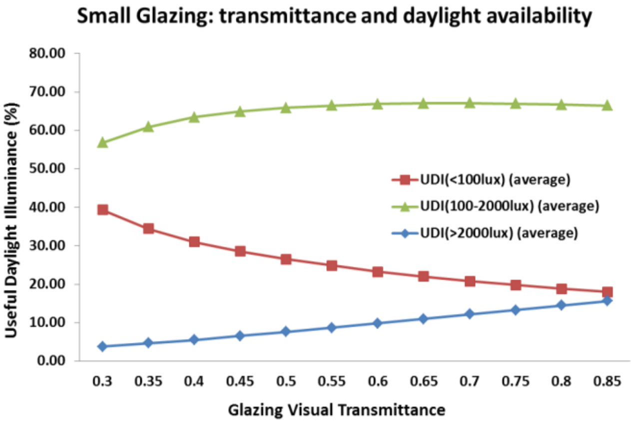

Figure 9: The relationship between glazing visual transmittance and average useful daylight illuminance (small glazing area).

In Figure 9 three average UDI values for the small-glazing office have different variations in terms of varying glazing transmittances. When VT<0.45, increasing glazing transmittance can still increase the UDI (100-2000 lux) values. However, if VT>0.45 then the increase of glazing transmittance will not significantly affect the UDI (100-2000 lux). Similar to the results for the large glazing area (Figure 6), a higher VT will give rise to a smaller UDI (<100 lux) and a larger UDI (>2000 lux). The difference between UDI(<100 lux) and UDI(>2000 lux) tends to become smaller with an increasing glazing transmittance. The average UDI values within the three ranges are 26% (<100 lux), 65% (100-2000 lux) and 9% (>2000 lux). Interestingly, it can be found that the large glazing (Figure 6) and the small glazing (Figure 9) achieve the same occurrence of useful daylight illuminance (100-2000 lux). In contrast to the large glazing area, the small glazing area office receives a larger UDI (<100 lux) and smaller UDI (>2000 lux) value. These results could be explained by the glazing size: the 30% GWR still meets the minimum requirements of window size in British Standards Regulation (BS, 2008), which could ensure a proper daylighting level (100-2000 lux) and less high level daylight illuminance (>2000 lux) in the office building.

In terms of the UDI curves in Figure 9, three equations were regressed as follows:

$UDI(<100lux) = -135.80T^3 + 294.69T^2 - 232.55T + 85.91,$ *(F-test, p<0.001)* (12)

$UDI(100-2000lux) = 151.63T^3 - 328.13T^2 + 232.75T + 12.78,$ *(F-test, p<0.001)* (13)

$UDI(>2000lux) = -16.61T^3 + 34.67T^2 - 0.74T + 1.37,$ *(F-test, p<0.001)* (14)

Pollutant particle and daylight availability

At the external glazing surface the light absorption (X) of the EC layer can be calculated using Equation (1). The light transmittance T_{EC} can be achieved from:

$$T_{EC} = 1 - X - R \quad (15)$$

where R is the reflectance of EC layer. According to the study by Favez et al. (2006), the amount of reflected light from the EC layer was insignificant (R≈0). Thus, the light transmittance T_{EC} is just decided by the light absorption:

$$T_{EC} = 1 - X \quad (16)$$

This could be used as a dynamic dirt correction factor for the window transmittance in urban buildings.

Based on equation (16) and equations (3 to14), several algorithms for assessing the negative impact of EC on daylight availability have therefore produced. For the large glazing area, the differences (Δ) of daylight availability between clean and polluted glazing are calculated by:

$$\Delta ADF = 8.48TX \quad (17)$$

$$\Delta DA = 41.23T^3A - 165.20T^2B + 205.17TC \quad (18)$$

$$\Delta DAcon = 88.31T^3A - 217.34T^2B + 192.10TC \quad (19)$$

$$\Delta UDI(<100lux) = -46.59T^3A + 115.8T^2B - 103.51TC \quad (20)$$

$$\Delta UDI(100-2000lux) = 71.10T^3A - 144.92T^2B + 72.88TC \quad (21)$$

$$\Delta UDI(>2000lux) = -24T^3A + 27.99T^2B + 31.45TC \quad (22).$$

For the small glazing area, the differences (Δ) of daylight availability between clean and polluted glazing are achieved using the following:

$$\Delta ADF = 3.97TX \quad (23)$$

$$\Delta DA = 37.09T^3A - 88.67T^2B + 115.81TC \quad (24)$$

$$\Delta DAcon = 50.70T^3A - 136.92T^2B + 152.75TC \quad (25)$$

$$\Delta UDI(<100lux) = -135.8T^3A + 294.69T^2B - 232.55TC \quad (26)$$

$$\Delta UDI(100-2000lux) = 151.63T^3A - 328.13T^2B + 232.75TC \quad (27)$$

$$\Delta UDI(>2000lux) = -16.61T^3A + 34.67T^2B - 0.74TC \quad (28)$$

In equations 17 to 28, T is the glazing visual transmittance; ΔADF, ΔDA, ΔDAcon, ΔUDI are the differences of average daylight factor, daylight autonomy, continuous daylight factor and useful daylight illuminance respectively (the value of clean glazing – the value of polluted glazing):

$$\Delta ADF = ADF(T) - ADF(T \times T_{EC}) = ADF(T) - ADF(T(1-X)) \quad (29)$$

$$\Delta \mathrm{DA} = DA(T) - DA(T \times T_{EC}) = DA(T) - DA(T(1 - X)) \quad (30)$$

$$\Delta \mathrm{UDI} = UDI(T) - UDI(T \times T_{EC}) = UDI(T) - UDI(T(1 - X)) \quad (31)$$

Thus, A, B and C can be defined as:

$$A = 1 - (1 - X)^3 \quad (32)$$

$$B = 1 - (1 - X)^2 \quad (33)$$

$$C = 1 - (1 - X) = X \quad (34)$$

In terms of these algorithms, the loss of daylight availability can be estimated for a specific glazing after measuring the situation of EC soiling.

Applications

This part presents the applications of the algorithms (equations 17-28). Typical glazing visual transmittances of 0.3, 0.5 and 0.8 were selected as representative of glazing systems with low, medium and high visual transmittance respectively. Only the ADF, DA and UDI(100-2000 lux) are discussed here.

In Figure 10, the relative reductions of average daylight factor (R_{ADF}) due to the EC depositions are given according to VT 0.3, 0.5 and 0.8. The following equation was used for the calculation of R_{ADF}:

$$R_{ADF} = \frac{\Delta ADF}{ADF} \times 100\%, \quad (35).$$

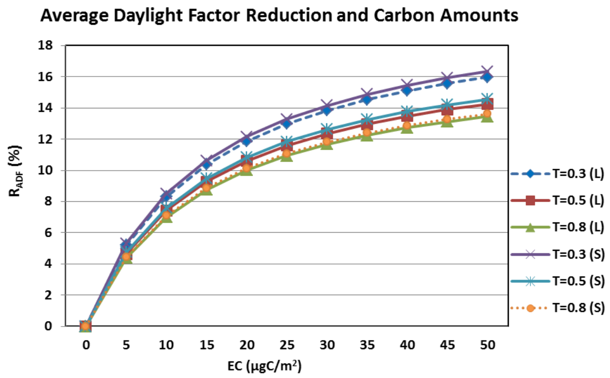

Figure 10: The relative reduction of ADF with the increasing elemental carbon amounts at external glazing surface with three typical visual transmittances (0.3, 0.5 and 0.8).

The ADF reductions vary in a polynomial trend; an increasing EC deposition would clearly reduce the ADF at the working plane, especially in a range of 0-10μgC/m². When EC deposition is low (<5μgC/m²), no clear differences of ADF reductions can be found between various glazing sizes and transmittances. However, the ADF reductions start to diverge at the value 5μgC/m² and the divergence tends to be larger with an increasing EC deposition. Generally, the glazing size does not substantially affect the relative reduction of ADF due to EC. The glazing transmittance is the main factor affecting the reduction. The lower the VT then the higher is the relative reduction of ADF. For locations dominated by cloudy sky, the indoor daylight availability is highly sensitive to the glazing dirt deposition. It is essential to clean the window surface of urban buildings on a frequent basis. If the EC deposition saturation level is assumed to be 30μgC/m² (Favez et al. 2006) then the maximum relative reduction of ADF would be less than 16%.

Figure 11 shows the relative reductions of daylight autonomy (R_{DA}) affected by the EC depositions according to glazing VT values of 0.3, 0.5 and 0.8. The R_{DA} values were calculated by the following equation:

$$R_{DA} = \frac{\Delta DA}{DA} \times 100\%, \quad (36)$$

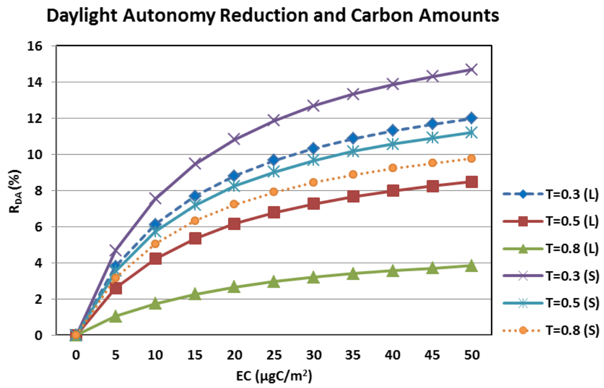

Figure 11: The relative reduction of DA with the increase of elemental carbon amounts of external glazing surface with three typical transmittances (0.3, 0.5 and 0.8).

The relative DA reductions increase with the increasing EC amount at the external glazing surface. Unlike the observations of ADF in Figure 10, both the glazing size and transmittance can have clear effects on the reduction. The large glazing with a VT of 0.8 sees the lowest DA reduction (any R_{DA}<5%), while the highest DA reduction can be found for the small glazing area with a VT of 0.3 (most R_{DA}>5%). Interestingly, the large glazing with a VT of 0.3 achieves a higher DA reduction than the small glazing with a VT of 0.5 and 0.8. This could indicate that the visual transmittance plays a more important role in reducing daylight autonomy than the glazing size. The average R_{DA} values of each curve are 10.3% (small, VT of 0.3); 8.38% (large, VT of 0.3); 7.84% (small, VT of 0.5); 6.85% (small, VT of 0.8); 5.88% (large, VT of 0.5) and 2.57% (large, VT of 0.8). Similarly, the maximum relative reduction of DA would be less than 14% if the EC deposition saturation level were assumed to be 30μgC/m² (Favez et al. 2006). It can be pointed out that a large glazing size combined with a higher visual glazing transmittance would ensure proper daylighting conditions even with the occurrence of heavy outdoor air pollution and without regular cleaning and maintenance.

Figure 12 displays the impact of increasing EC deposition at the external glazing surface on the relative reduction of useful daylight illuminance in a range of

100-2000 lux (R_{UDI}). Similarly, the R_{UDI} can be calculated by the equation:

$$R_{UDI} = \frac{\Delta UDI}{UDI} \times 100\%, \quad (37)$$

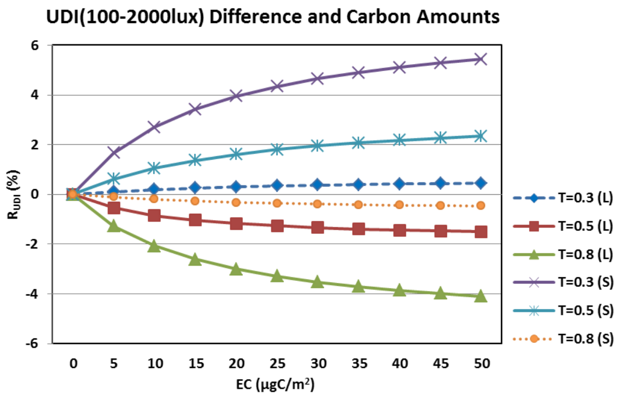

Figure 12: The relative difference of UDI(100-2000 lux) with the increase of elemental carbon amounts of external glazing surface with three typical transmittances (0.3, 0.5 and 0.8).

Apparently, the variations of relative reduction of UDI (100-2000 lux) can be divided into two groups in terms of negative/positive value of the R_{UDI}. With the $R_{UDI}>0$ three curves (small, VT of 0.3; small, VT of 0.5; large, VT of 0.3) show an increasing relative reduction with the increase of EC amount. This indicates that EC has a negative effect on the availability of useful daylight illuminance. The small glazing with a VT of 0.3 has the highest R_{UDI} values while the lowest R_{UDI} values are achieved by the large glazing with VT of 0.3. The R_{UDI} values of the small glazing with VT of 0.5 are in the middle. These results mean that the small glazing size area, combined with the low transmittance, are very sensitive to the pollutant deposition according to the availability of useful daylight illuminance. On the other hand, with an increasing EC deposition, a decreasing trend is found at the three curves when the $R_{UDI}<0$ (large, VT of 0.8; large, VT of 0.5; small, VT of 0.8). This expresses an opposite fact: EC deposition can positively affect the availability of useful daylight illuminance. In addition, the large glazing with a VT of 0.8 sees the lowest R_{UDI} values, which means the best positive influence on the availability of useful daylight illuminance. The highest R_{UDI} values are found for the small glazing with a VT of 0.8. In general, the top ranges of absolute R_{UDI} values for the curves are: 1% (large, VT of 0.3; small, VT of 0.8), 3% (small & large, VT of 0.5) and 6% (large, VT of 0.8; small, VT of 0.3). Except for the extreme cases (small glazing size and low transmittance; large glazing size and high transmittance), the EC deposition will not substantially affect the availability of useful daylight illuminance. According to the definition of UDI, the broad range of illuminance (100-2000 lux) could well explain the results. A frequent cleaning maintenance could be just required by the buildings with a small glazing area (GWR 30%).

According to the analysis and discussions above, obviously, different daylight metrics like ADF, DA and UDI will give rise to some divergences of the impact of pollution on final daylighting conditions in the office.

Conclusion

This study has presented a simulation analysis of daylight availability and air pollution in a typical open-plan office in an urban area of the UK. Some conclusions that can be drawn from this study include:

1). It could be necessary to implement a study of the direct link between the glazing transmittance and indoor daylight availability in the office buildings in order to simplify the design process at an early stage.

2) Several simple algorithms have been established to estimate the impact of glazing transmittance on the daylight availability at the working plane of office buildings. In addition, further algorithms to predict the reduction of the daylight availability due to one typical air pollutant (element carbon particulate) were developed. These algorithms could be used to support efficiently the façade design.

3). It would be essential to implement a dynamic analysis using CBDM (climate-based daylight modelling) in order to achieve a practical and comprehensive evaluation of daylighting performances in the open-plan office building, due to the fact that the conventional method of Average Daylight Factor might only provide a fundamental assessment without including locations and climates. However, it should be noted that various daylight metrics would result in the final evaluations with some divergences.

4) For the metric using Average Daylight Factor, the indoor daylight availability is substantially sensitive to the glazing visual transmittance, which receives a direct influence from the outdoor air pollution. However, the glazing size will not have a significant effect on the daylighting condition if a minimum GWR of 30% has been achieved.

5) According to the metric using daylight autonomy, both the glazing visual transmittance and size can have effects on the indoor daylight availability. However, the glazing transmittance should be the first factor to be considered in a daylighting design. A clear negative impact of air pollution could be just found for the glazing systems with medium/low visual transmittance. A large glazing combined with a high transmittance will possibly provide with a proper daylighting condition with the occurrence of outdoor air pollution.

6) According to the indoor daylight availability and the metric using useful daylight illuminance, the air pollution could be a positive factor for the glazing systems with a large size (e.g. 80% GWR) and high visual transmittance, or a negative factor if the glazing systems have a small size (e.g. 30% GWR) and a low visual transmittance.

Limitations and future work: these conclusions are obviously limited to a simple office model and one typical air-borne pollutant (EC) and a specific location and climate. The office models with various facade systems and orientations and under more complicated conditions of air pollution should be investigated to find the general findings of glazing dirt correction factor in daylit rooms. These issues will be studied in future work.

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