The Technical Merit of Double Facades for Office Buildings in Cool Humid Climates

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So-called double facades (DF) or ventilated facades, environmental second skins, etc are attracting great interest in European architectural circles as modern building enclosures. The DF label actually covers a wide range of different enclosure types. In most cases, a DF has three layers of glazing with ventilation and solar control devices between the outer two glazing layers, although some ventilate the space between the inner glazings. In most cases, the airflow through the glazing cavity is driven by natural buoyancy (hot air rises) aided by wind pressure differences, although some systems use small fans (often driven by photovoltaics). In hybrid systems, HVAC supply or exhaust air streams are directed through a glazing cavity before connecting with the outside.

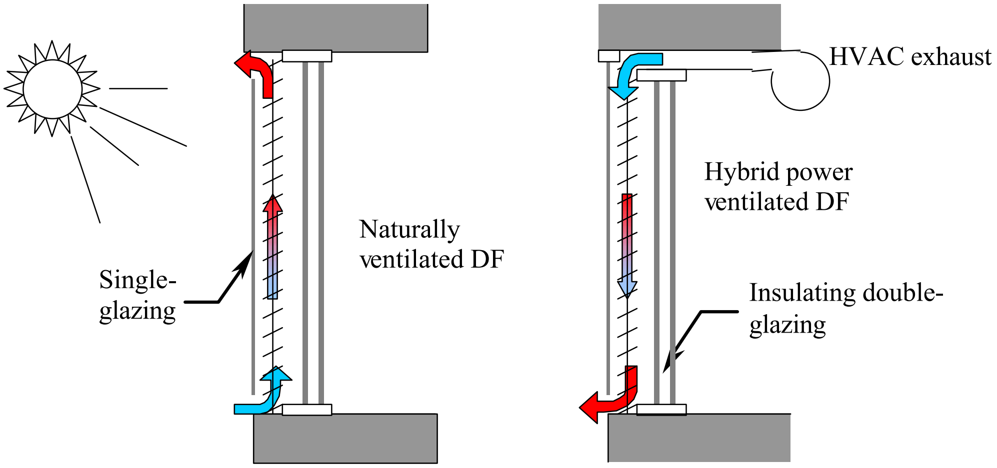
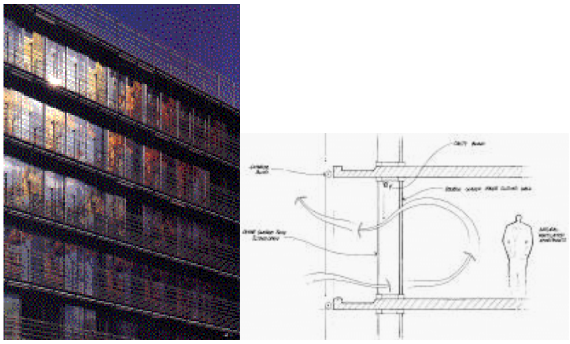


Figure 1: Two (of many) Generic Types of Double Facades

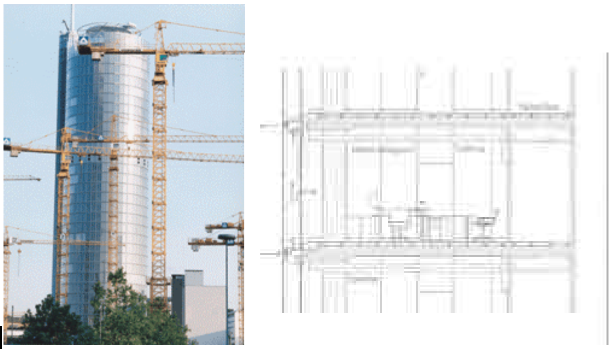
The ventilated cavity shown schematically in Figure 1 may be extended over the height of several stories, the whole height of the building, the height of a single storey, or some combination of the above. The most common solution is the single-storey height ventilation space. A single-storey space offers the advantages of separating fire, smoke, odour, and noise between floors as well as the construction simplicity (and economic advantages) of a repeating unit. Some built examples of double facades are shown below.

APARTMENT BLOCK. PARIS.

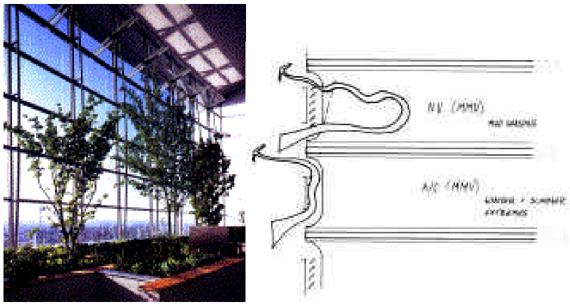


STADTTOR. DUSSELDORF.

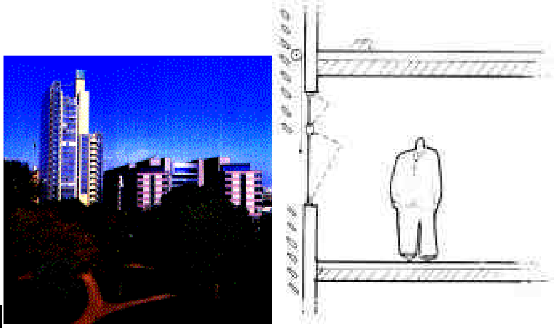
RWE AG MAIN OFFICE BUILDING. ESSEN



COMMERZBANK HQ. FRANKFURT



POTSDAMER PLATZ, BERLIN



The current interest in double facades in temperate climates (i.e., Continental Europe and the UK) appears to stem from several beliefs and desires. Double facades are believed to reduce cooling loads, allow for more or better natural ventilation, facilitate daylighting, increase noise control, and reduce heating energy consumption.

This paper aims to provide a critical review, at a general level, of the technical merit of each of these beliefs.

Cooling Load Reduction. Reducing cooling load can best be achieved, in approximate order of effectiveness, by using opaque wall elements, shading, and/or solar-control coatings. Many analyses of DFs begin with the assumption that close to 100% of the vertical enclosure must be transparent. This eliminates the possibility of using the most effective means of reducing cooling load. Shading can also be very powerful, but requires exterior shading elements to be truly effective. Reflective glazing is not seen as an acceptable means of reducing cooling loads since the reflected light energy can cause glare and overheating of adjoining buildings. Psychologically, reflective coatings create a sense of separation between the building and its surroundings when viewed from the exterior during the day. Perhaps most importantly, reflective glazing with a low solar heat gain coefficient (SHGC) does not admit as much natural light as clear glazing, with visible light transmittances of below 20% common for reflective windows. This lower light transmittance is not a problem in climates with bright sunshine all year round (e.g. Arizona, Miami) but for Continental Europe and Northern parts of North America, significant portions of the year are dull and overcast. A high natural light transmittance is desirable for psychological and daylighting reasons, and reflective glass usually cannot provide this characteristic.

Hence, the solution proposed by a DF is to use clear glass but to absorb most of the solar heat that passes through the outermost pane of glass on shading devices (some fraction of the energy is also reflected by the shades). If the cavity in which the shading device is placed were a sealed glazing unit, the heat absorbed by the shades would raise the temperature of the air space and this heat would then be partially transmitted into the building. A ventilated facade uses air flow – induced by wind pressures and thermal buoyancy – through the glazing space to remove this heat. For this reason DFs are also often called ventilated facades.

Shading devices of less than 300 mm projection that are fully retractable so as not to influence cleaning and to reduce snow/ice/wind loads, are both feasible and desired. The architectural design of these devices is of course critical. In some parts of the world, notably south-east Asia, large horizontal shading devices at the floor line are used that allow foot traffic for cleaning (this load is not a problem since the strength is controlled by wind and snow loads.)

Consider Figure 1, which compares the total percentage of glazing to the effective solar gain into the building (Solar Heat Gain Coefficient = SHGC) for three types of glazing. If a building has a large percentage of transparent glass, this glass must have a low SHGC to reduce solar loads. In fact, this is the reason most all-glass buildings in the past used dark body tints or reflective coatings. Unfortunately, the choice of body tints and reflective coatings reduces visible light transmission. Ideally, one would like to have low SHGC for those times and orientations that receive high solar radiation but maximize visibility and useful winter solar gains (very few winter solar gains are needed in office buildings however, so this is a relatively unimportant issue). Double-facades, by using ventilated movable solar shading devices behind glass are one way to achieve this ideal. Spectrally-selective glazing with fixed or movable exterior shading is another way to achieve the same goal. Similar low-solar gain performance can also be achieved by reducing the percentage of wall area that is glazed, and this has the advantage of reducing winter heat loss, glare and uneven daylighting as well. Reduced glazing area also almost always results in reduced construction and maintenance costs, and reduced embodied energy.

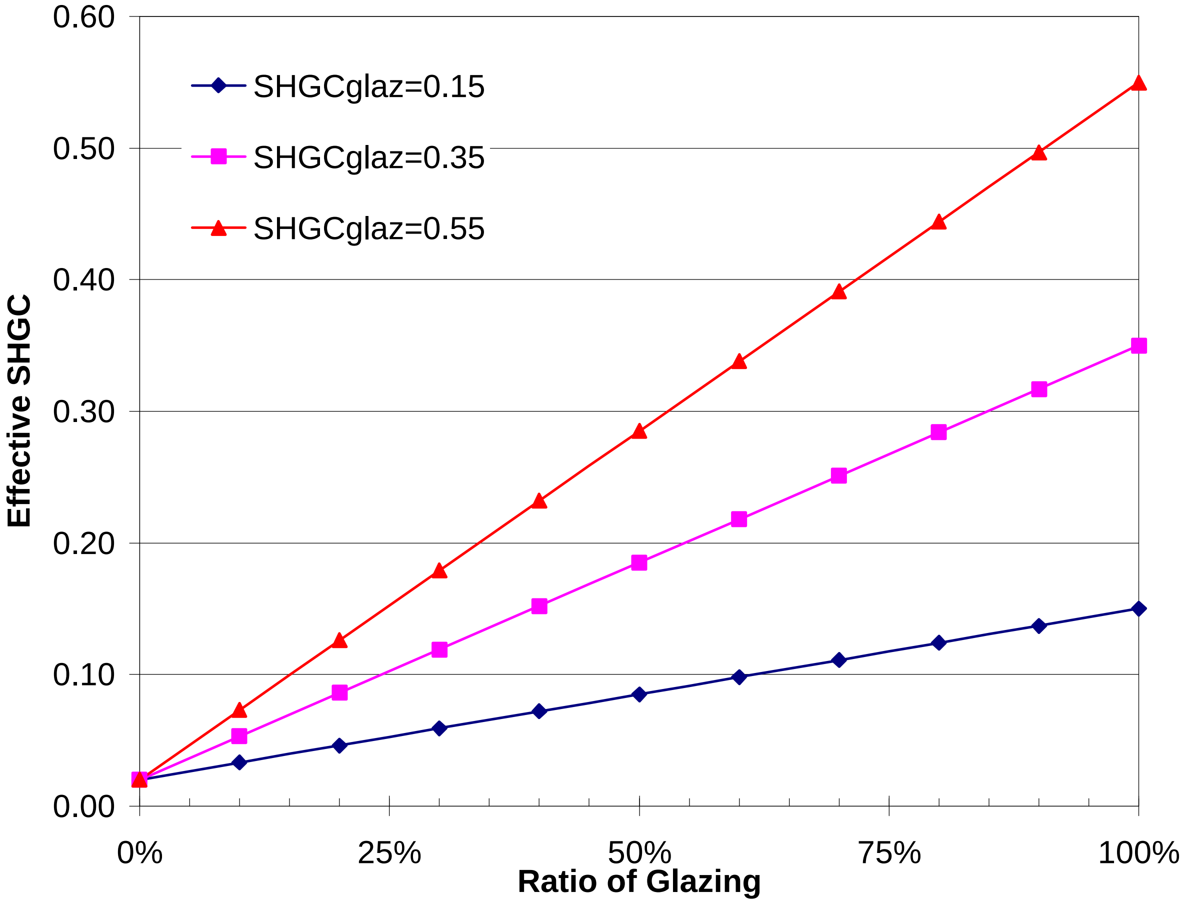


Figure 1: Effective SHGC as a Function of Glazing Area

Natural Ventilation. DFs have also often incorporated openings for natural ventilation. Issues of natural ventilation are not, of course, connected to the design of a double façade. While natural ventilation and DFs can be designed in an integrated manner, there is no compelling technical argument to do so. In fact, the differences in climates and comfort expectation between continental Europe and North-eastern North America are significant enough that natural ventilation is rarely of assistance in cooling deep-plan office buildings. Natural ventilation might be used in conjunction with artificial cooling by the careful design of certain building types and occupancies.

The space between the two layers of glazing in a DF does buffer wind gusts and thereby helps to control comfort and utility problems with the space inside. Natural ventilation air flow need not flow through windows however. In fact allowing ventilation flow through windows requires means to deal with the simultaneous entry of noise, dust, insects, rain and snow. Protected, operable, screened and sound baffled openings can, and have, been incorporated into buildings. It is also important to realize that many very tall buildings in the past, notably the Empire State Building, Chrysler Building, and the RCA building, used operable windows in conjunction with air conditioning systems without any serious difficulty.

Therefore, DFs are not required, and may even be a handicap (in that summer gains are high), for natural building ventilation.

Daylighting. Facades that use large expanses of clear glass obviously increase the amount of light entering a building. Daylighting can save energy (although only when combined with controls that turn artificial lights off) and is generally preferred by occupants.

Daylighting and DF are also not tightly connected issues. Most types of facades can (even should) be designed to provide an appropriate amount of daylighting. The amount of window area required to provide daylighting depends on a number of factors, but DFs are certainly not the only or best way to achieve excellent daylighting in commercial buildings. Properly placed windows (e.g., lightshelves and similar) have long been successfully used for daylighting.

Double facades have pros (they can allow lots of light in when it is dull and overcast) and cons (they allow too much light and glare in most of the time, and too much heat out during all winter nights). A façade with 40 or 50% of its area covered in high visual transmission glazing can usually provide plenty of daylight deep into a building. In some of the scenarios discussed below, it has been assumed that the floor and service distribution system is 0.6 m deep and that a parapet wall 0.9 m projects above the finished floor level. This leaves a 2.0 m high glazed band around a building with 3.5 storey heights. The extra daylighting and view provided by adding transparency to the 0.9 m parapet is negligible, unlike the additional cooling and heating loads imposed by a transparent skin.

Sound Control. The addition of a third pane of glass to a façade, along with asymmetrically sized air spaces results in reduced sound transmission relative to typical double-glazed sealed units. The sound transmission of sealed triple-glazed glazing units with asymmetrical airspace sizes is almost always superior to a DF, since there is no direct air connection of the exterior air cavity to the outside air. The DF can provide better sound control if the windows are the primary ventilation opening. Dedicated ventilation openings provide the best in sound performance.

Heating Load Reduction. Claims of the superior thermal resistance of DF systems are generally only true when the comparison is made to a standard double-glazed curtainwall. The thermal bridges caused by floor penetrations and outer pane glazing supports used in most DFs makes even this claim dubious. However, there are several curtainwall systems available in North America that use triple-glazing in thermally-broken curtainwalls. This type of system can have a heat loss coefficient (U-value) as low as 0.8 W/m^2 C (over R6) when used in conjunction with gas filling and low-E coatings. Other commercially available systems suspend thin plastic films between two sheets of glass, driving the U-value even lower, (R-values of nearly 10 are practical). Hence, there is off-the-shelf technology available that can reduce the thermal transmission well below that of a DF with much less cost and complexity.

Heating loads in an office building can be made to be relatively unimportant in cool and cold climates if the typically high levels of internal heat generation from the occupants and the extensive use of computers, copiers, printers, etc. is kept inside via an airtight and well insulated building enclosure. A properly designed quality curtainwall can often reduce or eliminate the need for perimeter heating, and thereby largely offset the capital cost penalty of highly insulating glazing units. Figure 2 shows how good quality curtainwalls (U=1.3 W/m^2 C) can practically eliminate heating requirements if the percentage of wall area is kept below 50-70%. This figure assumes that no heat is released by occupants and equipment, nor is any stored in thermal mass. If ¼ of the lighting is left on for safety reasons, the heat given off would be sufficient to maintain the interior temperature during –20 C weather, even with a 100% glazed façade, if a super-efficient curtainwall (e.g., U= 0.8 W/m^2 C, Visionwall™) were used. During occupancy, ventilation loads are the most significant, not conductive losses through a well-insulated façade, and hence heat recovery of the ventilation air is the most important energy saving strategy.

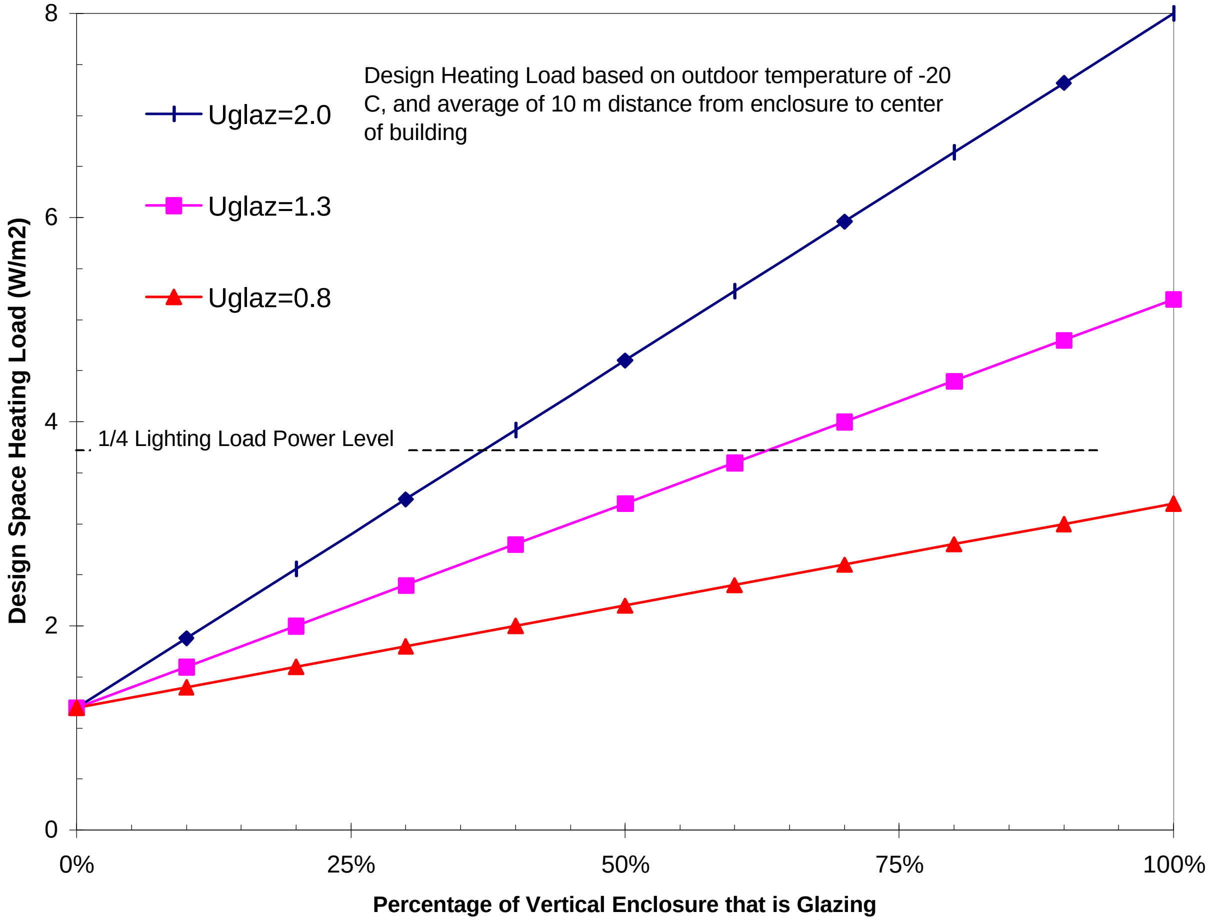


Figure 2: Space Heating Load Requirements a Function of Glazing U-value and Area

Heat and Cooling – A closer look. The claim that double facades are energy efficient is somewhat difficult to substantiate. Let us first compare the performance of various "best available" glazing technologies with the performance of a DF, and then consider other whole building design options with the DF option. Table 1 lists a broad range of generic glazing product types that might be chosen for a commercial or institutional building for which a DF is being considered. All of the options assume that the glazing is installed in a thermally broken metal curtainwall, with high performance spacers in the glazing.

When comparing the values in Table 1 the performance of a typical efficient opaque wall system should be considered – i.e., Solar Heat Gain Coefficient SHGC <0.02, U<0.35 W/m^2 C, R'$_w$>45 dB. Hence, no glazed system that is presently available can come close to the level of performance delivered by a simple and relatively inexpensive opaque wall system.

	SHGC[1]	**VT[2]**	**U[3]**	**Sound**
Opaque Wall	<0.02	0.0	<0.35	>45
Double SS (Spectrally Selective)	0.28 – 0.40	0.55 - 0.68	1.1-1.4	33-35
Double SS w/ exterior shades	0.05 - 0.10	0.55 - 0.68	1.1-1.4	33-35
Double w/ reflective coating	0.07 - 0.20	0.15 - 0.40	1.4-1.5	33-35
Triple SS Argon filled	0.25 - 0.35	0.52 - 0.62	0.8-1.1	38-45
DF vented outer w/ shades	0.10 - 0.30	0.65 - 0.75	1.0-1.5	35-40
DF exhaust vented w/shades	0.07 - 0.15	0.70 – 0.75	<0.7[4]	35-40

Table 1: Performance Characteristics of a Double Facades and Best Available Glass Curtainwalls

1. Solar Gain Heat Gain measured with best performance, shades at optimum angle for design conditions
2. Visual transmittance (VT) measured - without shades drawn or tilted.
3. Heat Loss Coefficient-measured for winter conditions with a gas fill in sealed units, no impact of shading devices.
4. Assumes that exhaust air would otherwise be vented directly outdoors. Heat recovery of the exhaust air will usually save much more energy than venting through a DF.

The SHGC for the Helicon DF, one of the better-designed DF for which performance values are available, is about 0.13, but only when the shades are closed to 70 degrees. As discussed above, a typical double-glazed unit with reflective coatings can achieve this level of solar control, but at the cost of much lower natural light transmission during all hours, not just when the sun is shining directly on the wall. The Helicon can modulate the visual transmittance and solar control of the facade on a continuous basis by controlling the shading device.

The use of clear (e.g., Visual Transmittance, VT >0.55), unshaded spectrally selective double-glazing would result in a SHGC much higher than a DF (e.g. typically about 0.35, but as low as 0.28) and hence a higher cooling load. However, the addition of light-coloured shading to the *exterior* of any clear double-glazed unit would allow for very low SHGC values, under 0.1 if required. The shading can of course be controlled (by the building control system or the occupant) to admit as much natural light as desired. Under design cooling conditions, the solar radiation striking a west-facing wall will often be well over 600 W/m^2 – only a small fraction of this light needs to be admitted to the interior to provide sufficient daylighting. The use of perforated horizontal or vertical shading elements will allow some view during hot sunny weather, the same conditions during which a DF must have the blinds closed. In fact, any shading device exposed on the exterior will be able to allow more light to pass through to the interior than an equivalent DF, since the heat generated by the absorbed solar energy is rejected to the exterior far more efficiently than in a DF. This is so because the absorbed heat is retained within the glazing cavity of a DF by radiation and convection despite ventilation.

A simple analysis of peak cooling loads for a Toronto office building is summarized in Table 2 below. This analysis considers an energy efficient office with the following characteristics:

- energy-efficient lighting 15 W/m^2 (not quite state-of-the-art),
- good or better quality (thermally broken) curtainwall,
- ventilation at 10 lps/person (20 cfm/person),
- occupant density of 1 person per 13 m^2 (140 sf) – equal to 10 W/m^2,
- 15 W/m^2 for plug loads such as computers and copiers.

		DG-clear air filled	**DG-SS (spectrally selective)**	**DF-1 based on Helicon data**	**DG-SS exterior shades**	**DG-SS w/glazed band lighting control**	**DG-SS punched windows + lighting control**	**DG-SS w/spandrel + inner shading + lighting control**	**TG-SS punched + inner shading + lighting control**
Interior Temp	C	25	25	25	25	25	25	25	25
Interior RH	%	50	50	50	50	50	50	50	50
Coincident Dewpoint	C	14.0							
Humidity Ratio	kg/kg	0.0099	Vapour Press	1590 Pa					
Enthalpy	kJ/kg	50	Sensible	25.2	Latent	25.3			
Ext Design Temp	C	30	30	30	30	30	30	30	30
Exterior RH	%	70							
Coincident Dewpoint	C	24.0							
Outdoor Humidity Ratio	kg/kg	0.019	Vapour Press	2981 Pa					
Enthalpy	kJ/kg	78	Sensible	30.2	Latent	48.2			
Solar Gain	W/m^2	700	700	700	700	700	700	700	700
Scenario #		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

		DG-clear air filled	**DG-SS** (spectrally selective)	**DF-1 based on Helicon data**	**DG-SS exterior shades**	**DG-SS w/glazed band lighting control**	**DG-SS punched windows + lighting control**	**DG-SS w/spandrel + inner shading + lighting control**	**TG-SS punched + inner shading + lighting control**
Floor to floor ht	m	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Bldg Depth to Core	m	8	8	8	8	8	8	8	8
Glazing ht (eff)	m	3.5	3.5	3.5	3.5	2	1.33	1.75 m	1.33
Glazing area (% of façade)		100%	100%	100%	100%	57%	38%	50%	38%
Glazing Area (% of lfoor)		44%	44%	44%	44%	25%	17%	22%	17%
SHGC (effective)	--	0.7	0.35	0.125	0.1	0.35	0.35	0.21	0.23
Curtainwall U-value	W/m2K	2	1.3	1.3	1.3	1.3	1.3	1.3	0.7
Opaque U-value	W/m2K	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Calc Solar load	W/m	1715	858	306	245	490	327	257	216
Calc Solar load	W/m^2	214 75%	107 61%	38 36%	31 31%	61 50%	41 40%	32 35%	27
Calc Conductive	W/m^2	5.22 2%	3.69 2%	3.69 3%	3.69 4%	2.75 2%	2.33 2%	2.59 3%	1.83
Plug Loads	W/m^2	15 5%	15 8%	15 14%	15 15%	15 12%	15 15%	15 16%	15
Lighting	W/m^2	15 5%	15 8%	15 14%	15 15%	7.5 6%	7.5 7%	7.5 8%	7.5
Occupants-Sensible	W/m^2	5.8 2%	5.8 3%	5.8 5%	5.8 6%	5.8 5%	5.8 6%	5.8 6%	5.8
Occupants-Latent	W/m^2	4.2 1%	4.2 2%	4.2 4%	4.2 4%	4.2 3%	4.2 4%	4.2 5%	4.2
Ventilation-Sensible	W/m^2	5 2%	5 3%	5 4%	5 5%	5 4%	5 5%	5 5%	5
Ventilation-Latent	W/m^2	21.2 7%	21.2 12%	21.2 20%	21.2 21%	21.2 17%	21.2 21%	21.2 23%	21.2
Total Load	**W/m^2**	**285**	**177**	**108**	**100**	**122**	**101**	**93**	**87**
Square ft per ton of AC	ft2/ton	132	213	349	376	308	371	405	432
Using 65% ERV		**269**	**160**	**91**	**83**	**106**	**85**	**76**	**70**

Table 2: Peak Cooling Load Analysis of Various Glazing Strategies for an Office Building

Peak cooling loads are typically generated in the climate of North-eastern North America by afternoon sun, which imposes a solar load of as much as 700 W/m^2 while it is 30 Celsius and 60%RH outside. Although thermal mass could play an important role in improving comfort and reducing peak loads, it has not been considered in the analysis since it would require a detailed analysis and would benefit (in a different way) all of the systems.

Several possible enclosure/service system scenarios are considered in the analysis:

1. A 100% double-glazed clear glass curtainwall. The waste of this solution can be seen by the peak load predicted -- high enough to require one ton of AC for every 132 sf in this zone! Many studies by the proponents of DFs use this type of building as their comparison, but *very few buildings are actually built this way* for obvious reasons. Solar control in the form of body tints and reflective coatings are generally employed for all-glass buildings, (typically at the expense of visual transmittance).
2. A fully-glazed curtainwall with the spectrally selective coatings can reduce the solar heat gain while providing excellent visible transmittance. This solution drops the solar load to about one-half of the total load, but it still requires 213 sf/ton AC. There is an increase in cost for glazing but a significant savings in plant (AC and duct) costs versus the previous scenario.
3. The double-façade specifications of the Helicon building in London have been used since this is one of the best documented projects the authors have been able to find. The predicted performance is very good -- about 350 sf/ton -- as expected given the quality design. Many DF are not as well designed as the Helicon. Note that a common AC design value for speculative office buildings (which have lower glazing areas and solar control glazing) in North America is 400 sf/ton.
4. The most obvious technical comparison to a DF would be a spectrally selective glazing in a curtainwall with exterior shading, preferably but not necessarily operable, like that in a DF. This enclosure would of course be predicted to out-perform a DF by the mere virtue that any heat absorbed by the shades is rejected directly to the exterior and not trapped by the outer pane of glass used in a DF. Hence this type of wall is predicted to result in a lower peak cooling load (376 sf/ton) than a DF.

The lighting loads (15 W/m^2) are reduced (by 50%) for all of the subsequent scenarios, since dimmable lights are often a cost-effective option that could be used in all of the systems (including the DF).

5. The Double-Glazed Spectrally Selective curtainwall could be transparent in a band only 2m high around the entire building. The glazing band solution significantly reduces the solar gain versus a completely clear wall by reducing the area of glazing. The performance is somewhat inferior (by about 10-15%) to a well-designed double-façade, but would be significantly less expensive to build (perhaps half as much), clean, and maintain. Its energy performance could exceed that of the DF considered by using an Enthalpy Recovery Ventilator for the exhaust air.
6. The concept of the previous scenario can be extended to punched windows. Even at the generous size of 2 m by 2m located at 3 m centers (e.g., 1 m wide columns between windows

and 1.5 m tall spandrels), the use of double-glazed spectrally selective glass with NO shading results in lower energy consumption than a DF. With an ERV, the loads could be reduced to about 30-35% below that of the top-quality DF building.

7. The glazed band concept of Scenario 5 can be improved by adding interior shading (likely venetian blinds). This would commonly be done of course. The performance is near the practical limit of what can be done to reduce cooling loads by demand control since the solar load has been reduced to 15% of the total load in this scenario.
8. Finally, triple-glazed *punched* windows will further reduce summer loads and can also practically eliminate winter heating requirements.

Several well-developed technologies, proven cost effective in some applications, have been included in the analysis of some of the scenarios. For example, in humid climates the high summer humidity generates a significant cooling load. An Enthalpy Recovery Ventilator can be used to reduce this cooling load penalty in the summer and the heating load requirement in the winter. The bottom line of Table 2 above shows the predicted impact of an ERV.

Ideally, the lighting system of the building, or at least the exterior 6 to 8 m, could be designed (and even operated) in connection with operable shading systems. This ensures that the maximum depth of natural daylighting is achieved and the lighting power reduced with dimmable ballasts. Such an approach maximizes natural lighting while minimizing cooling loads and allowing view to the outside. Automatically dimmable lights have been implemented in many buildings, like the local Green on the Grand building, Canada's first C2000 building, (Figure 3).

Figure 3: Green on the Grand – Canada’s Super-Efficient Low-Resource Use Office Building

Many DFs built to date have a ventilation space of at 0.4 to 0.6 m. A space of this size is needed to allow human access to the ventilation space to allow for cleaning. The cost of adding a large ventilated cavity in terms of both construction cost and lost buildable area are significant (the additional cleaning costs of a DF are not insignificant and are also worth considering). The cost of projecting the outer glass pane outward 0.5 m is also relatively high, although this cost could likely be reduced through clever value engineering.

Conclusions

DF's are merely one approach to overcoming the large energy consumption and comfort problems that are created by the use of excessive glazing areas of inferior performance. Other technically valid and less expensive solutions to solve the same problems have been posed above. The most environmentally sound and least expensive (construction and operating cost) solution avoids the problems that DFs are intended to solve by reducing glazing area and increasing the quality of the glazing product.

The Hyatt in Cincinnati – An all glass façade with occupants indicating their preference for solar control by drawing the interior shades

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