A Critical Review of the Use of Double Façades for Office Buildings in Cool Humid Climates

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SO-CALLED DOUBLE FAÇADES (DF) or ventilated façades, environmental second skins, etc have attracted great interest as modern building enclosures. Numerous examples have been built in Europe but only a few have been completed in North America. 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.

The ventilated cavity shown schematically in **Figure 1 (Page 50)** may be extended over the height of several stories, the whole height of the building, the height of a single story, or some combination of the above. The most common solution is the single-story height ventilation space. A single-story space offers the advantages of separating fire, smoke, odor and noise between floors as well as the construction simplicity (and economic advantages) of a repeating unit.

The current interest in double façades in temperate climates (i.e., Continental Europe and the UK) appears to stem from several beliefs and desires. Double façades 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. The scope of this work is for new commercial buildings that are entirely or mostly glazed in Canada and the Northern tier of the United States.

COOLING LOAD REDUCTION.

Reducing cooling loads can best be achieved, in approximate order of effectiveness, by using opaque wall elements, exterior shading, solar-control coatings on glazing, and interior shades. Many analyses of DFs begin with the assumption that close to 100 per cent of the vertical enclosure must be transparent. This eliminates the possibility of using the most effective and lowest cost means of reducing cooling load. Shading can also be very powerful, but requires exterior

BELOW AND RIGHT: Examples of all-glazed hi-rise building enclosures.

shading elements to be truly effective. Reflective glazing is often not seen as an acceptable means of reducing cooling loads since the reflected light can cause glare and overheating of adjoining buildings. Psychologically, reflective coatings also 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 per cent common for reflective windows. This lower light transmittance is not a problem in climates with bright sunshine all year (e.g. Arizona, Florida) 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 to allow light in, but to absorb and reflect most of the solar radiation that passes through the outermost pane of glass on shading devices. 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. Some ventilated façades 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 façades. However, shades with a DF do result in a higher temperature in the space, and exterior glazing slows the rejection of this heat significantly.

Shading devices of less than 12" (300 mm) projection that are fully retractable so as not to influence cleaning and to reduce snow/ice/wind loads are both feasible and desirable. 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 (Page 50)**, 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, the glazing system 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 coating—it is economically prohibitive (for all but big budget buildings) to use clear glass because of the high capital cost of the large cooling system required. 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 (note, however, that very few winter solar gains are needed in well insulated office buildings because of the large internal gains, so this is a relatively unimportant issue). Double-façades, 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, as well as reduced embodied energy.

The sizing of the plant to control the cooling load will be considered later in more depth. Note: this assumes a SHGC of 0.03 for an opaque wall.

DFs have also often incorporated openings for natural ventilation. Issues of natural ventilation are not, of course, tightly 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 their summer gains are high), for natural building ventilation.

DAYLIGHTING

Façades 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 can dim and turn artificial lights off) and is generally preferred by occupants.

Daylighting and DF are also not tightly connected issues. Most types of façades 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., light shelves and similar) have long been successfully used for daylighting.

Double façades have advantages (they can allow lots of light in when it is dull and overcast) and disadvantages (they allow too much light and glare in most of the time, and too much heat out during all cold nights). A façade with 40 or 50 per cent of its area covered in high visual transmission glazing can usually provide plenty of daylight deep into a building. In general, high glazing ratios (over 50 per cent) provide no beneficial daylighting and require special measures to avoid glare and visual discomfort, especially in modern offices that contain computer screens.

In some of the scenarios discussed below, it has been assumed that the floor and service distribution system is 2'10" (0.85 m) deep and that a wall projects 3' (0.9 m) above the finished floor level. This leaves a 6'6" (2.0 m) high glazed band around a building with 12'4" (3.75 m) story heights. The extra daylighting and view provided by adding transparency to this 3' (0.9 m) parapet is negligible, whereas the additional cooling and heating loads and glare problems imposed by a transparent skin are significant.

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, recommended above, provide the best in sound performance, and airtight triple or quadruple glazed punched windows also provide excellent sound control.

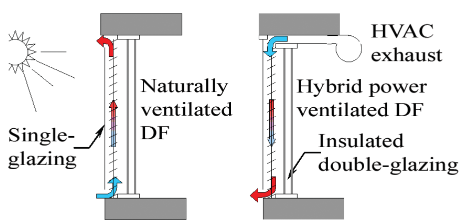

Figure 1 – Two (of many) Generic Types of Double Façades.

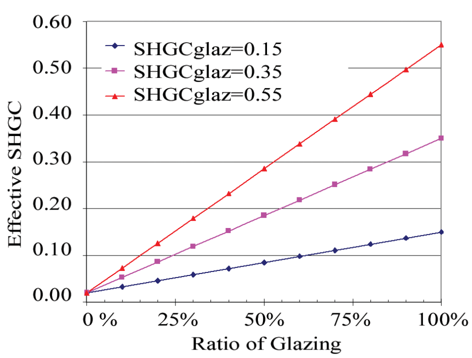

Figure 2 – Effective SHGC as a Function of Glazing Area and Glazing SHGC Natural Ventilation.

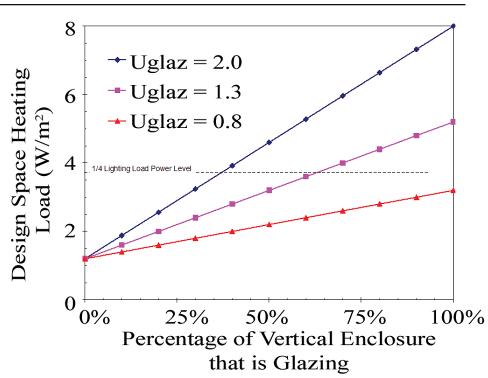

Figure 3 – A closer look at Space Heating Load Requirements as a Function of Glazing U-value and Area Heating and Cooling. Design Heating Load based on outdoor temperature of -4F (-20C) and an average of 32.8 ft (10 m) distance from enclosure to center of building.

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/m²C (over R6, e.g., Visionwall™ or Kawneer 7550) 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 overall 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 should 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. are kept inside by an airtight and well-insulated building enclosure. A properly designed quality curtainwall can often reduce and usually eliminate the need for perimeter heating, and thereby largely offset the capital cost penalty of highly insulating glazing units. Figure 3 shows how very good quality curtainwalls (U=1.3 W/m²C or 0.30 Btu/ft²F) can almost eliminate heating requirements if the percentage of wall area is kept below 50-70 per cent. In practical terms, heating the minimum level of ventilation air is all that is required for heating in such a building. Unfortunately, most curtainwalls in common use have much higher heat flow, greater than 0.35 Btu/ft²F (U=2 W/m²) and in many cases, 0.5 Btu/ft²F (U=2 W/m²)!

This figure assumes that no heat is released by occupants and equipment, nor is any stored in thermal mass. If one quarter of the lighting is left on for safety reasons, the heat given off would be sufficient to maintain the interior temperature during a cold -4F (-20C) night, even with a 100 per cent glazed façade, if a carefully designed high performance curtainwall (e.g., U<0.8 W/m²C or 0.15 Btu/ft²F), 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 an important energy saving strategy.

The claim that double façades are energy efficient is somewhat difficult to substantiate. We conducted a simple peak load analysis of one zone of an office building to compare the performance of different façades, and assess the capital cost implication for cooling plant.

Almost all technical comparisons in the literature use standard double-glazing as the benchmark. This is outdated technology that is inappropriate for a quality building and is actually uneconomical on a first-cost basis in many parts of the world. Any building design concerned with energy consumption and occupant comfort should use low -E, argon-filled double-glazed units with super spacers in properly thermally broken frames as a minimum baseline. 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/m²C, 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.

The SHGC for the Helicon DF in London (designed by Sheppard Robson), 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 façades on a continuous basis by controlling the shading device.

The use of clear (e.g., Visual Transmittance, VT >0.50), 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-colored 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 very high—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 solar energy absorbed by the shade is rejected to the exterior far more efficiently than in a DF. This is so because some of the absorbed heat is retained within the glazing cavity of a DF despite ventilation.

A simple analysis of peak cooling loads for a Toronto, Canada office building is summarized in **Table 2 (Page 53)** below. We considered a single perimeter zone of offices, with a 12.3 ft (3.75 m) floor to floor height and a depth of 26 ft (8 m) to the core zones. The peak load analysis considers an energy-efficient office with the following characteristics:

- Energy-efficient lighting 0.9 W/ft^2 (10 W/m^2);
- Very high quality (1.4 W/m^2C) or exceptional (0.8 W/m^2C) curtainwall;
- High ventilation rates at 10 lps/person (20 cfm/person);
- Occupant density of 1 person per 140 sf (13 m^2);
- 10 W/m^2 for plug loads such as computers and copiers; and
- Spectrally selective glass with a SHGC= 0.35 and VT>0.55.

Peak cooling loads are typically generated in the climate of North-eastern North America by afternoon sun. In this case we chose a solar load of 700 W/m^2 at outdoor conditions of 86F (30C) and 60 per cent RH and indoor conditions of 75F (24C) and 60 per cent RH. 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 slightly different way) all of the systems.

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

A 100 per cent 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 cooling for every 133 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).

A 100 per cent glass curtainwall with spectrally selective coatings to 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 226 sf/ton cooling. There is an increase in cost for glazing but a significant savings in plant (chiller, fans and ducts) costs versus the previous scenario.

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 average—about 405 sf/ton—as expected given the quality design. Many DF are not as well designed as the Helicon. Note that a common cooling capacity design value for speculative office buildings (which have lower glazing areas and solar control glazing) in North America is 400 sf/ton.

The most sensible technical comparison to a DF would be 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 expected 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 (444 sf/ton) than a DF. The capital costs would likely be less than a DF, but the capital and maintenance costs of exterior blinds are still high.

The lighting loads are reduced (by 25 per cent, to 75 W/m^2) for all of the subsequent scenarios, since daylight-dimmed lights are usually a cost-effective option that would likely be used for all high-performance systems (including the DF).

The Double-Glazed Spectrally Selective curtainwall (Scenario 4) could be limited to a transparent band 2m (6 ft 7") high around the entire floor. 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 (at 344 sf/ton) 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 reach that of the DF considered by using an Enthalpy Recovery Ventilator for the ventilation air or by reducing the band height a further 10 per cent to 20 per cent.

The concept of the previous scenario can be extended to punched windows. Even at the generous size of 2 m by 2 m (6'7" by 6'7") located at 3 m (9'10") centers (e.g., 1 m or 3'3" wide columns between windows and 1.5 m or 4'11" 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 25 per cent below that of the top-quality DF building. This solution would be cost competitive with a mid-range all-curtainwall building.

The glazed band concept of Scenario 5 can be improved by adding interior shading (likely Venetian blinds) and reducing the glazing band to 6' (1.75 m). This would commonly be done of course, but the blinds considered here would have very high reflectivity and some small amount of perforation for daylighting and view. The performance is near the practical limit of what can be done to reduce cooling loads by demand control but the solar load still contributes 40 per cent of the total peak load in this scenario.

Finally, triple-glazed *punched* windows will further reduce summer loads and can also practically eliminate winter heating requirements. This scenario will also be affordable relative to the DF and exterior shaded scenarios. This scenario still provides generous views and daylighting, while allowing for improved control of glare, thermal comfort, and a cooling load of as low as 600 sf/ton with an ERV.

Several well-developed technologies, proven cost effective in many applications, have been included in the analysis of some of the scenarios. For example, in humid climates the high summer humidity and high occupant density generates a significant latent cooling load. An Enthalpy (or Total Energy) Recovery Ventilator can be used to reduce this cooling load penalty in the summer and the humidification/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 20 to 25 ft (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.

The combination of high performance features assumed in Scenario 8: triple glazed solar control glazing, high thermal resistance enclosure, daylighting design with control, and ERV demand controlled ventilation have been incorporated in some buildings, such as the Green on the Grand (Canada's first C2000 building) near the University of Waterloo, **(Figure 3)**. Enermodal designed the mechanical system of this building, completed 10 years ago, which consumed less than 40 kBtu/ft^2 (125 kWhe/m^2) in 2005.

Many DFs built to date have a ventilation space of at 18" to 2 ft (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 costs 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 also not insignificant and worth considering). The cost of projecting the outer glass pane outward 1.64 ft (0.5 m) is also relatively high, although this cost could likely be reduced through clever value engineering.

TABLE 1: PERFORMANCE CHARACTERISTICS OF A DOUBLE FAÇADES AND BEST AVAILABLE GLASS

	SHGC[1]	VT[2]	U[3] (W/m²C)	Sound (dB)
Opaque Wall	<0.02	0.0	<0.35	>45
Double SS (Spectrally Selective)	0.28 - 0.40	0.55 - 0.68	1.2-1.5	30-35
Double SS w/ exterior shades	0.05 - 0.10	0.55 - 0.68	1.2-1.5	30-35
Double w/ reflective coating	0.07 - 0.20	0.15 - 0.40	1.4-1.6	30-35
Triple SS Argon filled	0.25 - 0.35	0.52 - 0.62	0.8-1.2	35-45
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]	35-42

Design Heating Load based on outdoor temperature of -4F (-20C) and an average of 32.8 ft (10 m) distance from enclosure to center of building.

Solar Gain Heat Gain measured with best performance, shades at optimum angle for design conditions.

Visual transmittance (VT) measured—without shades drawn or tilted.

Heat Loss Coefficient-measured for winter conditions with a gas fill in sealed units, no impact of shading devices.

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.

CONCLUSIONS

This general review suggests to these authors that 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 proposed above. At this stage of research and experience, it appears that the most environmentally sound and least expensive (construction and operating cost) solution for new buildings avoids the problems that DFs are intended to solve by reducing glazing area and increasing the quality of the glazing product. The only cost of the proposed approach is the loss of an all-transparent-glass aesthetic. There are no technical disadvantages.

The application of DF technology to special use buildings, and retrofit of buildings may generate different conclusions. There are some cases where DF technology may result in energy savings relative to other available approaches.

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TABLE 2: PEAK COOLING LOAD ANALYSIS OF VARIOUS GLAZING STRATEGIES FOR AN OFFICE BUILDING

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
Glazing ht (eff)	m	3.75	3.75	3.75	3.75	2	1.33	1.75 m	1.33
Glazing area (% of façade)		100%	100%	100%	100%	53%	36%	47%	36%
Glazing area (% of floor)		47%	47%	47%	47%	25%	17%	22%	17%
SHGC (effective)	—	0.70	0.35	0.125	0.1	0.35	0.35	0.21	0.231
Curtainwall U-value	W/m²K	2	1.4	1.4	1.4	1.4	1.4	1.4	0.8
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	1838	919	328	263	490	327	257	216
Calc Solar load	W/m²	230 (81%)	115 (69%)	41 (44%)	33 (39%)	61 (56%)	41 (46%)	32 (40%)	27 (36%)
Calc Conductive	W/m²	6.58 (2%)	4.89 (3%)	4.89 (6%)	4.89 (6%)	3.45 (3%)	2.90 (3%)	3.24 (4%)	2.30 (3%)
Plug Loads	W/m²	10 (4%)	10 (6%)	10 (11%)	10 (12%)	10 (9%)	10 (11%)	10 (12%)	10 (14%)
Lighting	W/m²	10 (4%)	10 (6%)	10 (11%)	10 (12%)	7.5 (7%)	7.5 (8%)	7.5 (9%)	7.5 (10%)
Occupants-Sensible	W/m²	5.8 (2%)	5.8 (3%)	5.8 (6%)	5.8 (7%)	5.8 (5%)	5.8 (7%)	5.8 (7%)	5.8 (8%)
Occupants-Latent	W/m²	4.2 (1%)	4.2 (3%)	4.2 (5%)	4.2 (5%)	4.2 (4%)	4.2 (5%)	4.2 (5%)	4.2 (6%)
Ventilation-Sensible	W/m²	5.6 (2%)	5.6 (3%)	5.6 (6%)	5.6 (7%)	5.6 (5%)	5.6 (6%)	5.6 (7%)	5.6 (8%)
Ventilation-Latent	W/m²	11.6 (4%)	11.6 (7%)	11.6 (12%)	11.6 (14%)	11.6 (11%)	11.6 (13%)	11.6 (14%)	11.6 (16%)
Total Load	**W/m²**	**283**	**167**	**93**	**85**	**109**	**88**	**80**	**74**
Square ft per ton of AC	Ft²/ton	133	226	405	444	344	426	470	510
Using 65% ERV	W/m²	272	156	82	74	98	77	69	63
	Ft²/ton	138	242	460	511	384	488	547	600