

HVAC Strategies for Well-Insulated Airtight Buildings

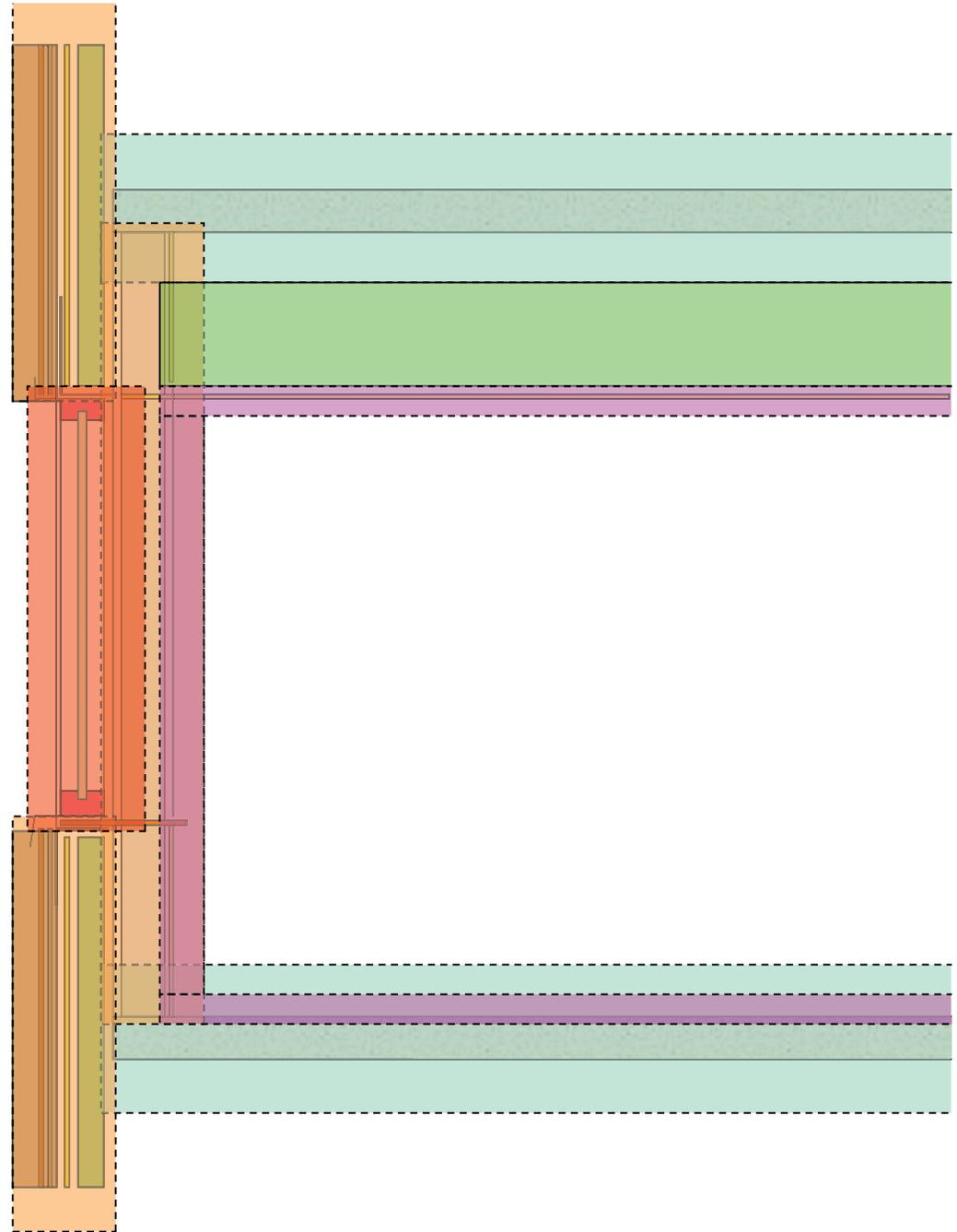
TM29:2002

CIBSE, Department of Trade and Industry: DTI

Construction Integration

Subcontractors

- Superstructure
- Exterior Envelope Erector
- Windows
- Carpenters
- HVAC, power and data systems
- Interior finish



Design and Construction

Haughey, D.

The Right Way for Industrial Buildings,

Architects Journal, June 1993.

Braham, D., Barnard N.,
Jaunzens, D.,

Thermal mass in office buildings, Part 1 An introduction, Part 2 Design Criteria,

BRE Digest 454, Garston:
Building Research
Establishment, 2001.

HVAC Strategies for Well-
Insulated Airtight Buildings

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and Industry: DTI

- **Insulation:** insulation must be installed as a continuous layer to be effective as calculated. It has been estimated that gaps in insulation account for 6% of overall envelope area in commercial buildings. This discontinuity can amount to 33% additional heat loss. Thermal bridges and impossible insulating details are systemic problems of the building industry.
- **Thermal capacity:** by storing excess heat in winter and absorbing heat gains in summer, to be rejected using free-cooling techniques during the night.
- **Airtightness:** Very large amounts of energy is lost through air leakage. In addition to the energy loss, air leakage is also the primary source of water condensation in the exterior envelope assembly, leading to durability problems. Measurements have shown that air leakage can typically move 100 times more moisture into an envelope assembly than would occur by diffusion alone. Also, air leakage can contribute to problems of indoor air quality (IAQ) from the unfiltered air. Finally, air leakage contributes to uneven temperatures within the building and can lead to complaints of draughts and difficulties in achieving uniform indoor temperatures.
- **Envelope Details to serve above:** Details that address the coordination of the trades and the specific areas most often cited as problems points should be carefully considered by the architect and then followed up by the contractor. The following are suggestions to achieve these goals:
 1. Inclusion of air locks at entries
 2. During Design Development (Detail Design) the line of barrier materials, air and water, should be completely traced by the design team. Any discontinuities should be addressed.
 3. Quality assurance: At completion, both air leakage testing and thermographic imaging may be undertaken to assure the owner of a well-built wall.

Masonry Walls

- **Insulation:**
 - thermal bridging occurs primarily at door and window interfaces. Continuous sealant and proprietary cavity closures (as part of window and door assembly) are necessary here.
- **Thermal capacity:**
 - As a result of the non-structural nature of much of masonry construction, its use as a thermal capacity material is limited.
- **Airtightness:**
 - Inner wythe usually serves as air barrier, although gypsum board or finish plaster may also serve such a function. (Problems above dropped ceilings when finish is not continuous).
 - Continuous mortar beds and end joints standard.
- **Envelope Details to serve above:**
 - Pre-formed insulated lintels should be used over window and door openings in cavity masonry construction.
 - Cavity closures should be incorporated whenever the cavity is interrupted.

Curtain walls and lightweight cladding

- **Insulation:**
 - Especially between premanufactured assemblies such as mullion curtainwall systems and surrounding building fabric.
- **Thermal capacity:**
 - No significant use as a thermal capacity medium (lightweight nature makes its temperature swing quite rapid). However, PCMs may change this.
- **Airtightness:**
 - Due to differential movement between the lightweight cladding and the adjacent materials, need to insure continuity of a membrane material (most commonly EPDM (ethylene-propylene-diene-terpolymer)).
- **Envelope Details to serve above:**
 - Sealant details and continuity of membranes critical.

Windows

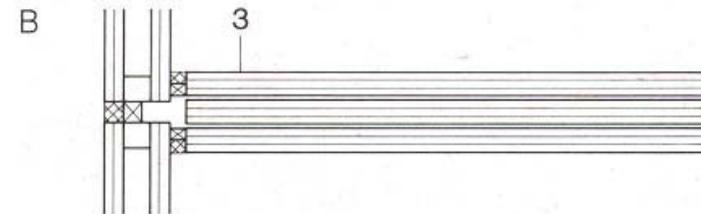
Muneer, T. Abodahab, N.,

Weir, G. Kubie, J.

Windows in Buildings, Thermal, Acoustic, Visual and Solar Performance

Architectural Press, Oxford, UK
2000.

- **4-7% of developed nation energy consumption is due to heat losses from domestic glazings alone.**
- **In EC countries, at least one-quarter of the domestic heating bill is due to the thermal energy loss through glazings because they are the weakest thermal component in the exterior envelope.**
- **Recently, higher levels of insulation, lower infiltration rates and larger areas of glazed aperture are required in the design of buildings.**
- **Use of double-glazed windows most common method of providing a reasonable level of thermal resistance.**
- **However, the edge-seal creates a thermal bridge between internal and external environments.**



Windows

3 insulated glazing

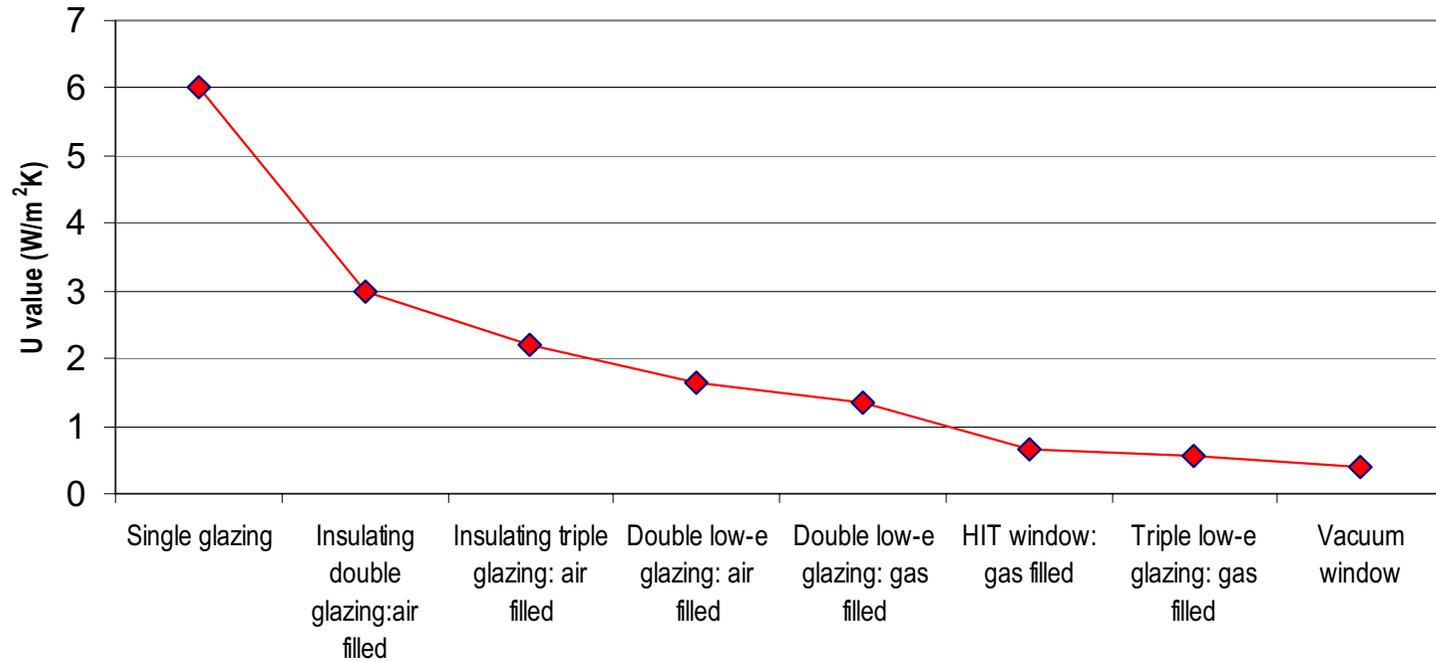
5 Sealant

7 Pressure gasket

- Heat is lost (transferred) through
conduction
convection
radiation
- All types of heat loss combined into one parameter
defined as the U-value (W/m^2K)
- The lower the U-value, the better is the thermal
insulation.

Windows

U-values of various glazing systems



Glazing system	Center-glass U-value (W/m ² K)
Double glazing, air filled	2.78
Double glazing, low-e, air filled	1.99
Double glazing, low-e, argon-filled	1.70
Triple glazing, air filled	1.76
Triple glazing, low-e, air filled	1.36
Triple glazing, low-e, argon-filled	1.19
Quadruple glazing, low-e, krypton filled	0.62

Windows

Daylight

- 1 Double glazing
- 4 Window frame
- 6 Seal
- 7 Setting block fixing/seal
- 9 Bridge setting block
- 10 Thermal break

- **Artificial lighting accounts for up to 5% of total primary energy consumption**
- **Office buildings may consume up to 50% of their total energy consumption in the form of artificial lighting**
- **Daylight transmissivity of a double-glazed window with 4 mm thick float glass is 80%.**
- **One coating of low-e material, transmissivity becomes 75%. U-value is reduced by about half**
- **In the UK, the annual solar energy incidence on buildings is 1614 TWh as compared to 1504TWh for the country's entire oil production**

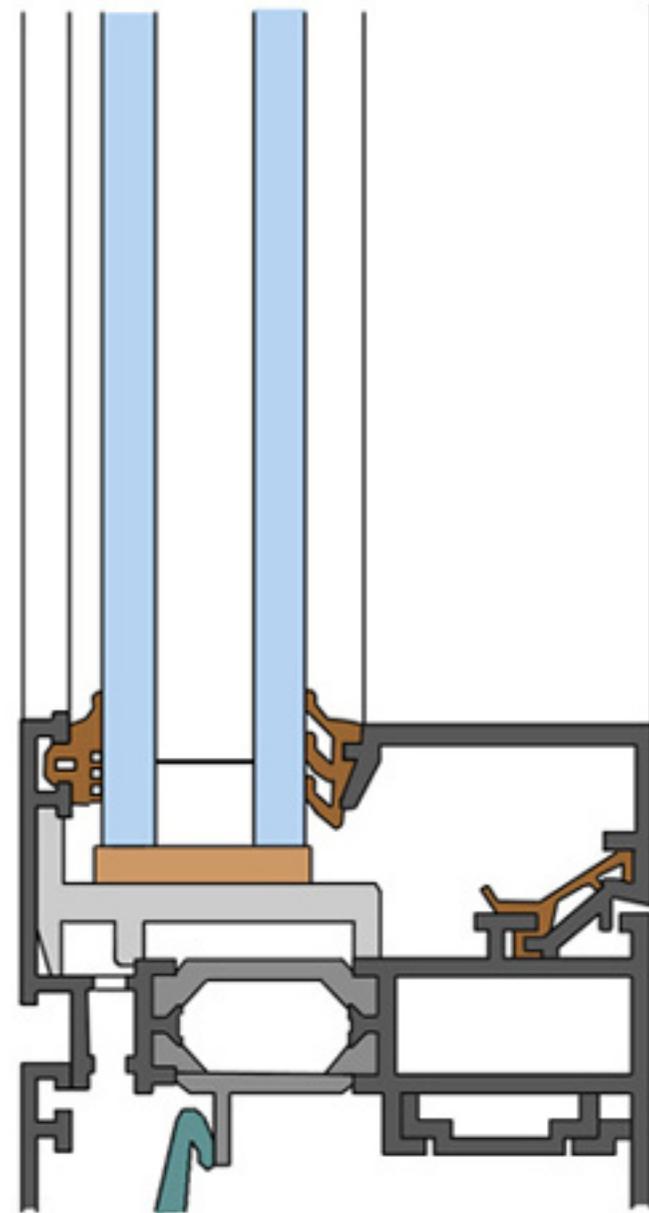


Image by MIT OCW.

Windows

Acoustics

- Contributors to a window's sound insulation potential are its:
 1. Mass
 2. Air-tightness
 3. The gap width of the window cavity
 4. Acoustical isolation of the absorbent material around the edges of the air space
- Each doubling of glass thickness, sound insulation is increased by about 4dB
- Good performance corresponds to providing sound insulation of over 40 dB
- A good air gap (for acoustics) has a width of at least 150mm
- Best thermal air gap is around 20mm
- Therefore, optimization is required

Windows

Technology

Superinsulating windows incorporate some of the following:

- Low-e coatings
- Inert infill gases
- Insulating edge spacers
- Low conductive frames

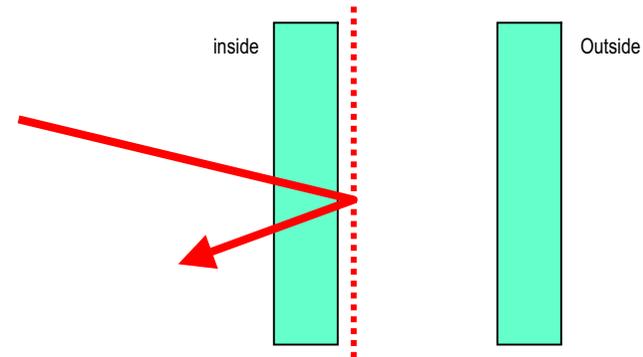
Super-insulated windows provide the following:

- Improvements in comfort from elimination of cold downdraughts and radiation exchange
- Better noise-attenuation performance
- Increase in total light admission without increasing overall energy losses
- In tropical and temperate zones, a reduction of overheating reducing overall indoor cooling loads
- Reduction of condensation problems at building edge
- Greater visual opportunities for the designer

Thermal Properties

Greatest advances

- Low-e coating: suppresses radiative heat flow.
substantially transparent to visible light and reflective of long-wave infrared radiation



- Heavier gases: suppresses convection

Molecular masses

- Air: $M=28.96$
- Argon: $M=39.95$
- Krypton: $M=83.8$
- Xenon: $M=131.3$

Windows

Technology

Wavelength selective coatings:

Low-e

- **Low-emissivity (low-e) coatings are low absorptive coatings used to suppress radiation exchange**
(Low-e: emmissivity = 0.12-0.2 compared w/
uncoated: emmissivity = 0.88)
- **Metal coatings less than 10 nm thick and partial visibility and solar transperence**
- **Preferred metals are silver (most common), gold, and copper**

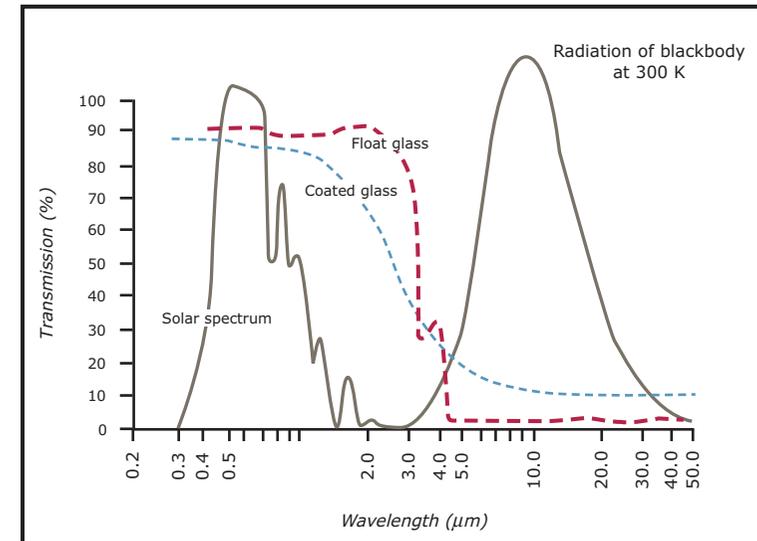


Image by MIT OCW.

Windows

Coating Technology

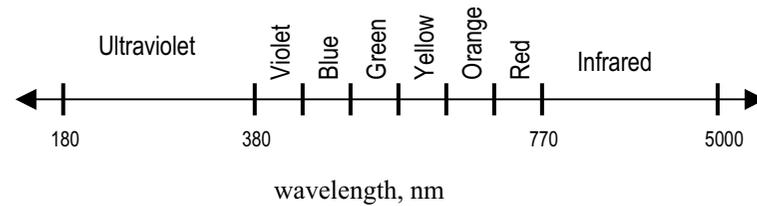
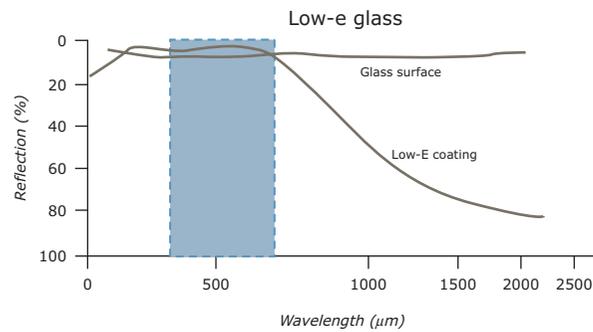
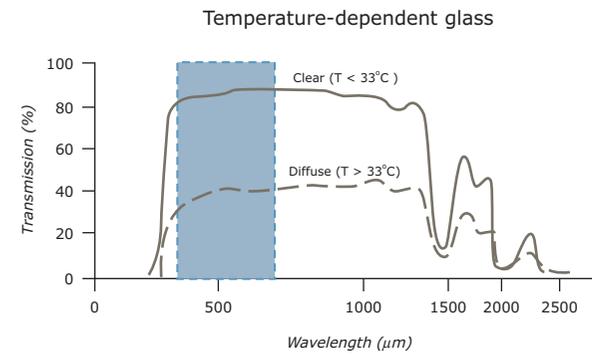
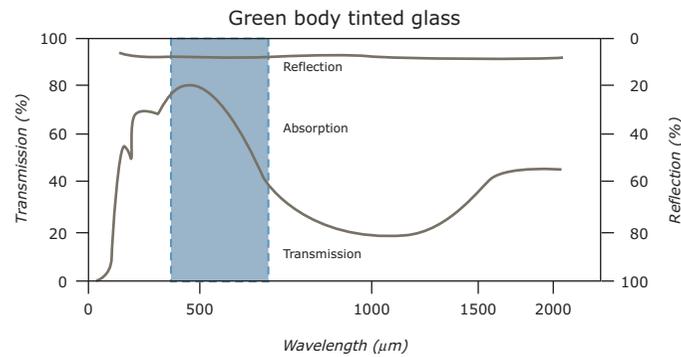
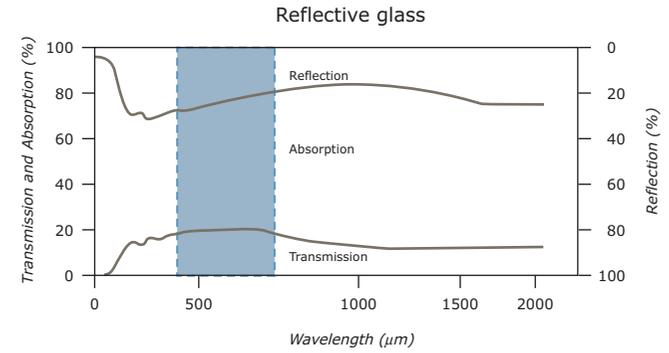
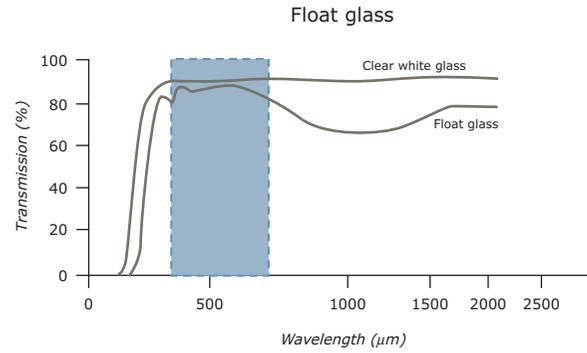


Image by MIT OCW.

Windows

Technology

Wavelength selective coatings:

Spectral-splitting

- Used to divide solar spectrum into different broadband regions.

Holographically coated glazings

- Can be tuned to reflect any waveband in the solar spectrum while allowing 75-80% transmittance in the visible and assists with photovoltaic applications

Windows

Compagno, Andrea

*Intelligent Glass Facades,
Material, Practice, Design*

Birkhauser, 1999.

Insulation Technology

Aerogel windows

- **Aerogel: microporous silicate foam material which reduces thermal transmission**
with slight vacuum and 2cm layer,
 $U=0.37 \text{ W/m}^2\text{K}$

Xerogel

- **Similar to aerogel but a little less effective**

Geometric media

- **Capillary and honeycomb types, made of polycarbonate, acrylic and others**

Windows

Vacuum Windows

- Evacuation of the space between panes, in combination with low-e coating
- Eliminates cavity gas convection and much of the radiant heat transfer
- Conduction through spacers becomes primary mode of heat transfer

Issues

- Seals must maintain vacuum
- Special attention must be given to the frame
- Temperature difference between inside and outside panes results in thermal exp/contr that could stress the assembly
- Spacers are necessary in the glass cavity to avoid inward collapse of glass

Still under proof-of-concept testing

Windows

Glazing: construction types

2 Types

1. Frame system

2. Suspended point fixing

- 1 Double glazing
- 4 Window frame
- 6 Seal
- 7 Setting block fixing/seal
- 9 Bridge setting block
- 10 Thermal break

Thermal Properties

Edge of glass and frame thermal analysis

Total rate of heat transfer through fenestration can be calculated knowing the separate heat transfer contributions of:

1. Center-glass
2. Edge seal
3. Frame

Critical to good performing frames is the edge seal (spacer)

Edge seals are made of the following materials:

- Aluminum
- Steel
- Metal spacer with thermal break
- Fiberglass/plastic
- Butyl
- Foam

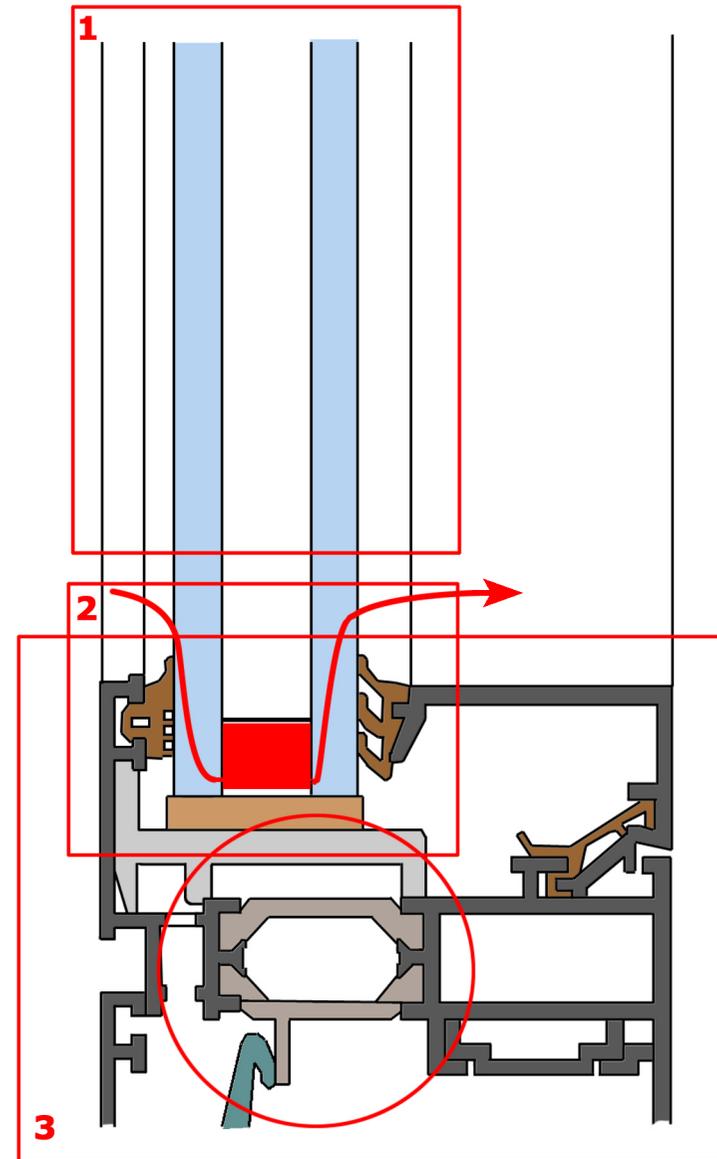


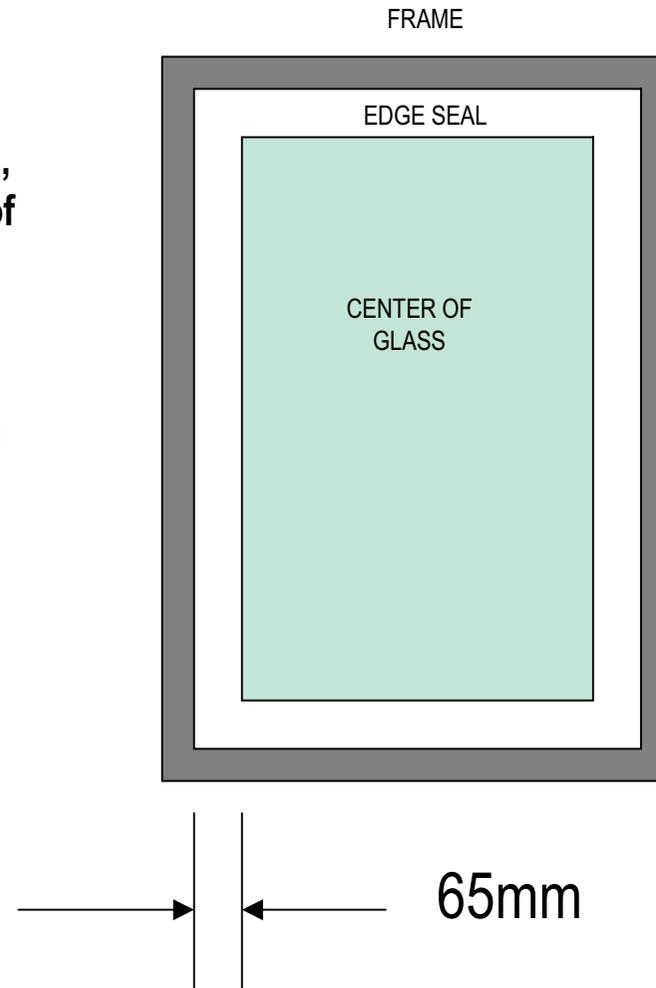
Image by MIT OCW.

Thermal Properties

Spacers in multipane units greatly increase conductive heat transfer between the contacted inner and outer glazing.

This phenomenon, called cold-bridging, degrades the thermal performance of the glazing unit locally.

Conductive region of edge seal is limited to a 65mm wide band around the perimeter of the glazing unit.



Thermal Properties

From ASHRAE Handbook of Fundamentals

Calculation of overall U-Value of fenestration using area-weighted U-values

$$U_o = \left(UA_{cg} + U_{eg} A_{eg} + U_f A_f \right) / A_{pf}$$

A_{cg} = projected area of glazing, m²

A_{eg} = projected area of edge – seal, m²

A_f = projected area of frame, m²

A_{pf} = projected area of the entire fenestration, m²

U = center of glass U – value, W/m²K

U_{eg} = edge of glass U – value, W/m²K

U_f = frame U – value, W/m²K

U_o = overall U – value, W/m²K

Thermal Properties

Frame

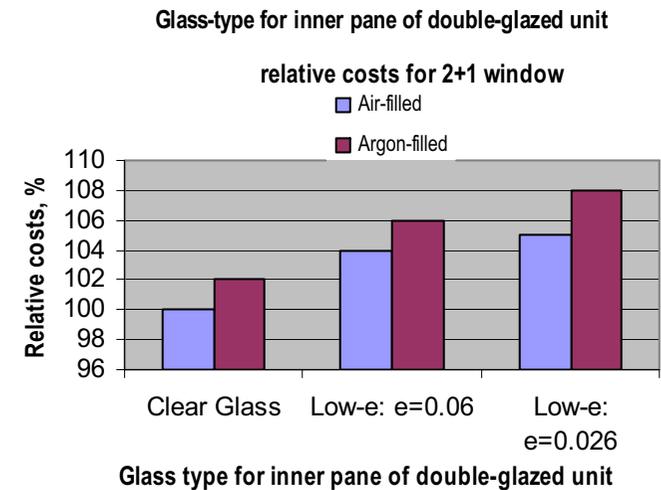
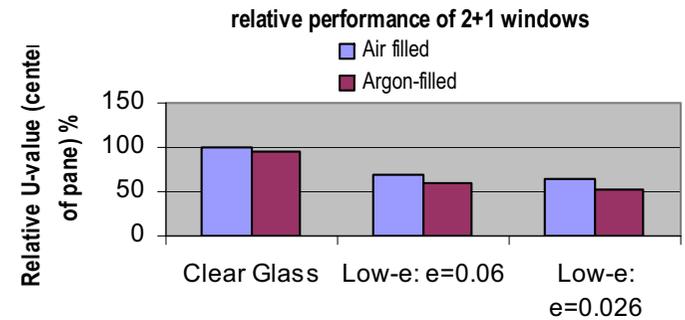
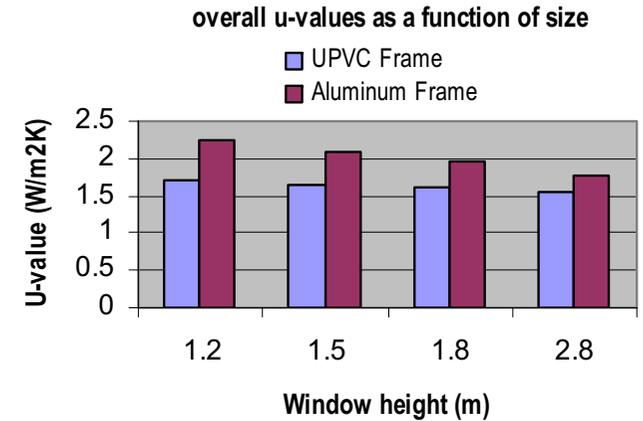
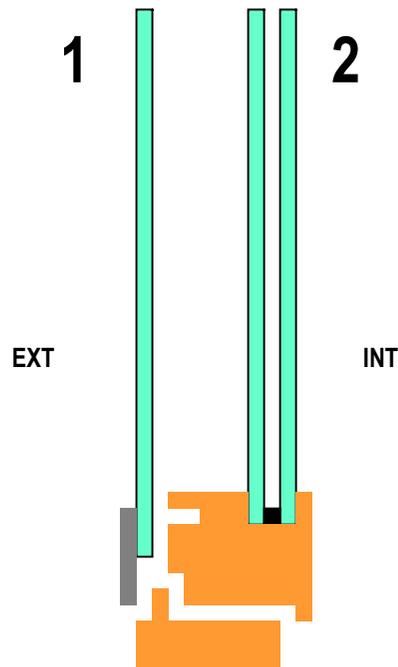
Typical frame U-values for conventional windows

Frame material	Spacer type	Frame type/number of panes					
		Operable			Fixed		
		Single	Double	Triple	Single	Double	Triple
Aluminum	Aluminum	12.4	12.4	12.4	10.1	10.1	10.1
Aluminum w/ thermal break	Aluminum insulated	5.4	5.4	5.4	6.6	6.6	6.6
			4.9	4.9		5.2	5.2
Aluminum clad wood, reinforced vinyl	Aluminum insulated	3.9	3.6	3.3	3.2	3.0	2.8
			3.2	2.7		2.6	2.3
Wood, vinyl	Aluminum insulated	3.1	2.9	2.7	2.9	2.8	2.7
			2.6	2.2		2.4	2.1
Fiberglass	Aluminum insulated	2.7	2.5	2.3	2.6	2.3	2.0
			2.2	1.8		2.1	1.6

Window Systems

Windows with 1.5-2.0 U-values (W/m²K) and shading coefficients of 0.2-0.3 are preferable for providing the envelope with the required performance to use passive servicing of the building.

1. U-values are greatly influenced by the frame technology.
2. 2+1 Window



Glass and Window Systems

American Architectural
Manufacturers Association,
AAMA

Conclusions

Primary Issues with high performance windows:

- Inability of maintenance personnel to properly service, maintain and repair components.
- Interface between frame and rough-opening not properly sealed.
- Need to write into spec a training session for maintenance personnel.

Sources of Water

Trechsel, Heinz R.

*Moisture Analysis and
Condensation in Building
Envelopes,*

ASTM Stock No.: MNL40

ASTM, West Conshohocken,
PA, 2000.

When moisture enters the envelope environment:

- 1. Durability may be compromised through material degradation.**
- 2. Organisms may spawn (fungus and various molds) causing IAQ issues.**

Indoor

- People
- Commercial and Institutional
- Residential
- Bathrooms
- Residential kitchens
- Construction Moisture

Outdoor

- 1. Rainwater**
- 2. Groundwater**
- 3. Humid air**

Trechsel, Heinz R.

*Moisture Analysis and
Condensation in Building
Envelopes,*

ASTM Stock No.: MNL40

ASTM, West Conshohocken,
PA, 2000.

Sources of Water

Terminology

- **Absolute humidity:** ratio of the mass of water vapor to the total volume of the air sample.
- **Humidity ratio:** ratio of mass of water vapor to the mass of dry air contained in the sample.
- **Specific humidity:** ratio of the mass of water vapor to the total mass of the dry air.
- **Relative humidity:** the ratio, at a specific temperature, of the moisture content of the air sample if it were at saturation, and the actual moisture content of the air sample. Given as a percentage.
- **Water vapor pressure:** the partial pressure exerted by the vapor at a given temperature.
- **Water vapor permeance (permeance coefficient):** the time rate of water vapor transmission through unit area of flat product induced by unit water vapor pressure difference between its surfaces.
- **Water vapor permeability:** the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit water vapor difference between its two surfaces.
- **Water vapor resistance and resistivity:** the reciprocals of permeance and permeability.
- **Hygrothermal material:** a material that will absorb moisture.

In principal, any transport process is brought about by a driving force or a potential. Gas diffusion and liquid transport as a consequence of capillary forces are considered here.

Vapor permeability

Trechsel, Heinz R.

*Moisture Analysis and
Condensation in Building
Envelopes,*

ASTM Stock No.: MNL40

ASTM, West Conshohocken,
PA, 2000.

Vapor transport through material

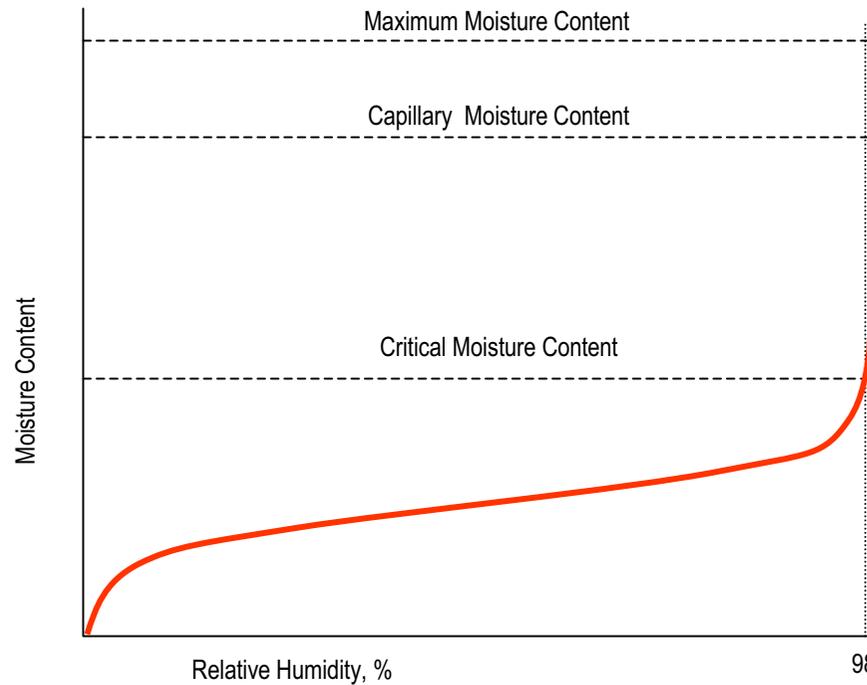
$$m_v = -\delta_p \cdot \text{grad } p_v$$

m_v = density of vapor flow rate or vapor flux, $\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$

δ_p = vapor permeability of material, $\text{kg} \cdot \text{m}^{-1} \cdot \text{Pa}^{-1} \cdot \text{s}^{-1}$

p_v = vapor concentration, $\text{kg} \cdot \text{m}^{-3}$

Sorption Isotherm of a porous building material



See ASTM Standard E96,
*Test Methods for Water Vapor
Transmission of Materials*

Also see:

Hens, H., "Heat, Air and
Moisture Transfer in Insulated
Envelope Parts," Final Report,
Vol. 1, Task 1: *Modelling*,
International Energy Agency
Annexd 24, Laboratorium
Bouwfysica, K. U.-Leuven,
Belgium, 1996, p.90.

Kumaran, M.K., "Heat, Air and
Moisture Transfer in Insulated
Envelope Parts," Final Report,
Vol. 3, Task 3: *Material
Properties*, International
Energy Agency Annexd 24,
Laboratorium Bouwfysica, K.
U.-Leuven, Belgium, 1996,
p.135.

Vapor Resistance Factor

Open porosity

$$\mu = \frac{1}{\Psi_0}$$

μ = vapor resistance factor, unit : dimensionless

Ψ_0 = open porosity, $m^3 \cdot m^{-3}$

...if pores are nonuniform and directed
randomly, then

$$\mu = \frac{\Psi_\tau}{\Psi_0}$$

Ψ_τ = tortuosity factor

Heat conduction

$$\lambda = \frac{Q \cdot l}{(A \cdot \Delta T)}$$

Q = heat flow rate across an Area A ,

l = thickness of test specimen, and

ΔT = hot surface temp. - cold surface temp.

Water Vapor Permeability/Permeance

$$\delta_p = \frac{J_v \cdot l}{(A \cdot \Delta p)}$$

J_v = water vapor flow rate across an Area A ,

l = thickness of test specimen

Δp = difference in water vapor pressure across the specimen surfaces

Failure Criteria

Failure: termination of the ability of an item to perform a specified function.

Two modes of failure:

1. Condensation and repeated wetting of assembly materials
2. Mold and fungal growth

For molds to form, an ambient relative humidity of 75-80% is necessary. However, areas within an exterior envelope that trap moisture may reach these levels while the ambient humidity is lower.

Critical humidity (RH%) level for mold growth and decay failure on different materials.

Material	Mold growth	Decay
Pine sapwood	>80-95	>95
Pine Heartwood	>80-95	>95
Particle board	>80-95	>90
Gypsum board	>80-95	>95
Fiber board	>80-95	>95
Wallpapers	>75-95	>90
Putties	>90-95	
Different coatings	>75-95	
Concrete	>95-98	

Achieving Fabric Performance

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TM29:2002

CIBSE, Department of Trade and Industry: DTI

pp. 14-20

Three essential principles require greatest attention:

- 1. The global (overall), and localized, thermal resistance of the assembly.**
- 2. The global (overall), and localized air in/exfiltration of the assembly – *closely linked to water infiltration.***
- 3. Careful consideration of solar radiation control and daylighting opportunities.**

Double Skin Facades: DSFs

Definition:

Exterior envelope system composed of three layers, one of which is a ventilated cavity

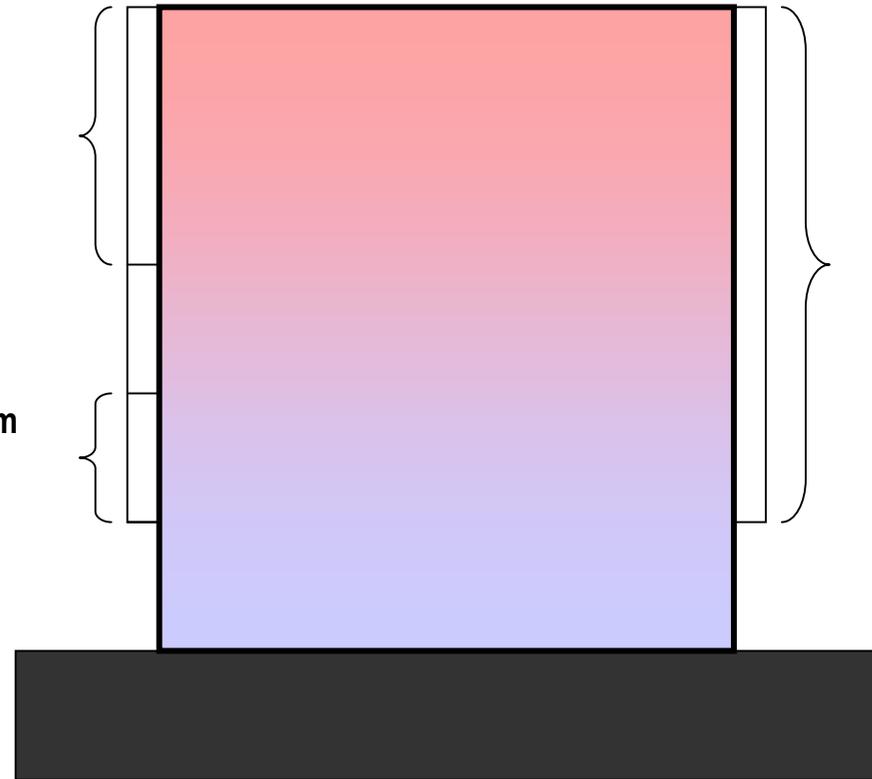
1. External
2. Ventilated Cavity
3. Internal Screen

Screens are:

- Primarily glass
- Single or double insulated units
- Spaced between 200mm – 1400mm

Ventilated cavity:

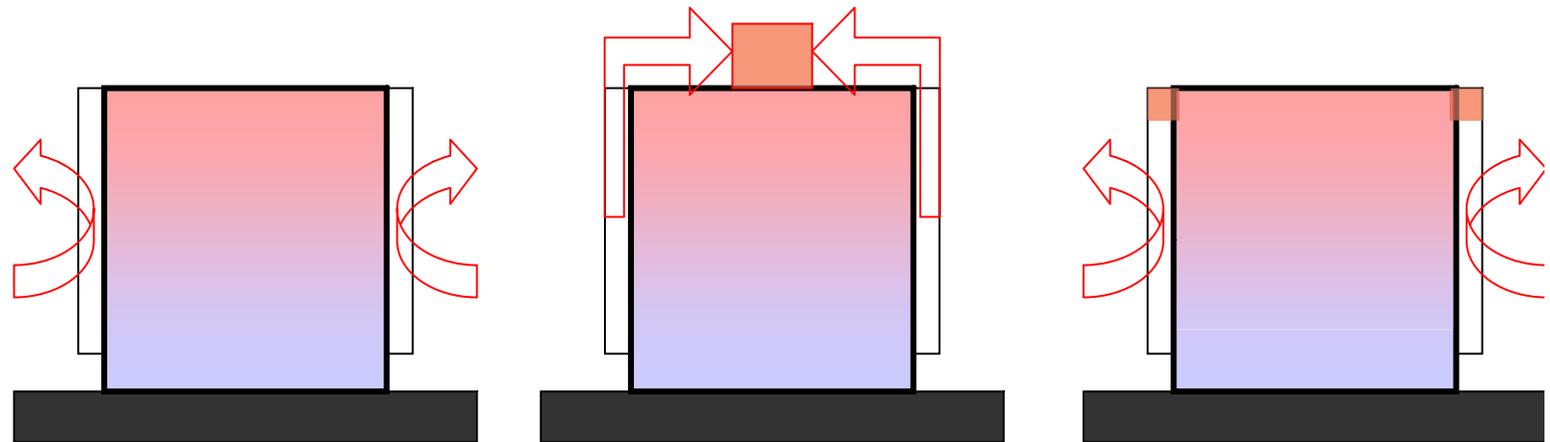
- Often contains solar shading element
- Accessible from the inside for maintenance



Double Skin Facades: DSFs

Three types (from buildingenvelopes.org)

1. Naturally ventilated wall (air curtain, dependent on stack effect alone)
summer: ventilated to the outside
winter: closed for higher thermal resistance
2. Active wall (linked into mechanical air distribution, good for cold climates)
summer: heat is removed mechanically
winter: heat is centrally recovered
3. Interactive wall (mechanically driven cavity air, good for hot climates/high cooling loads)
summer: heat is removed mechanically
winter: with little solar gain, ventilation is minimized, boosting thermal resistance



DSFs

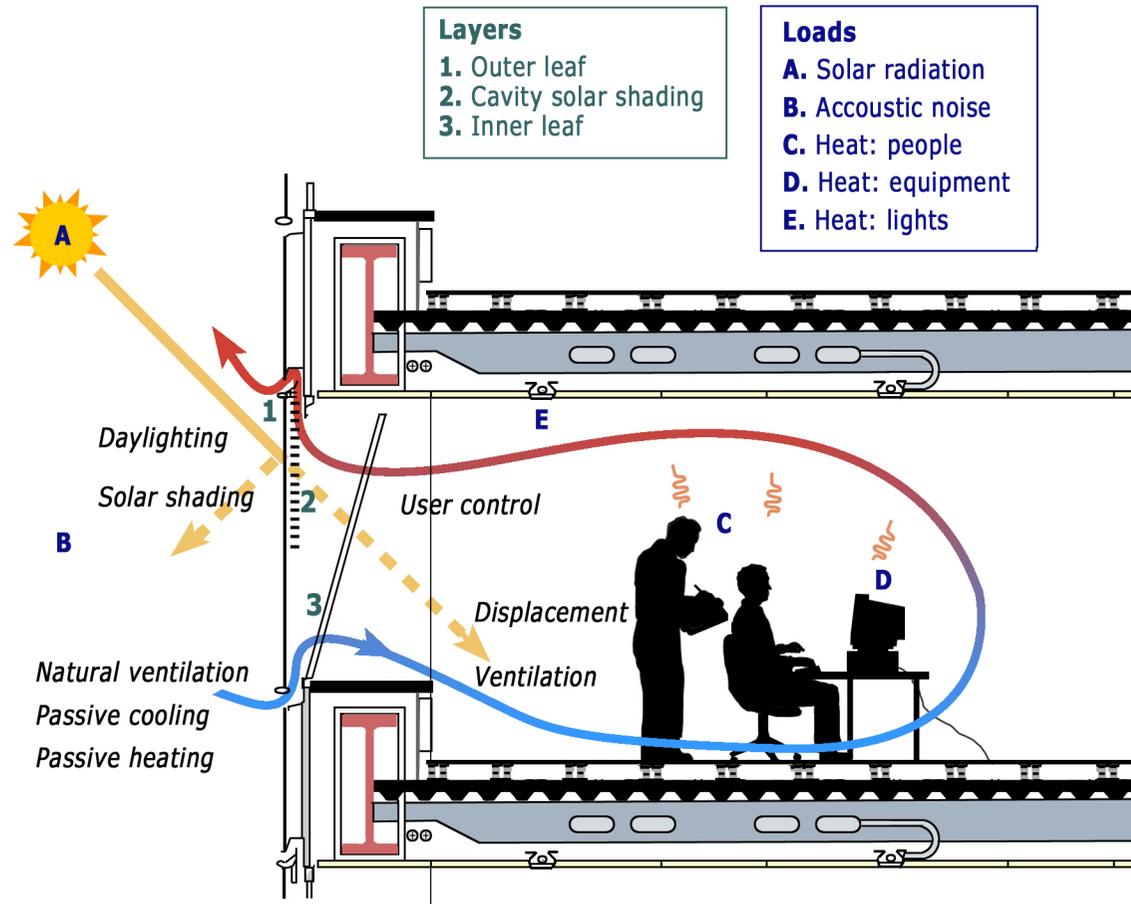


Image by MIT OCW.

DSFs: Principles

Service people, not space

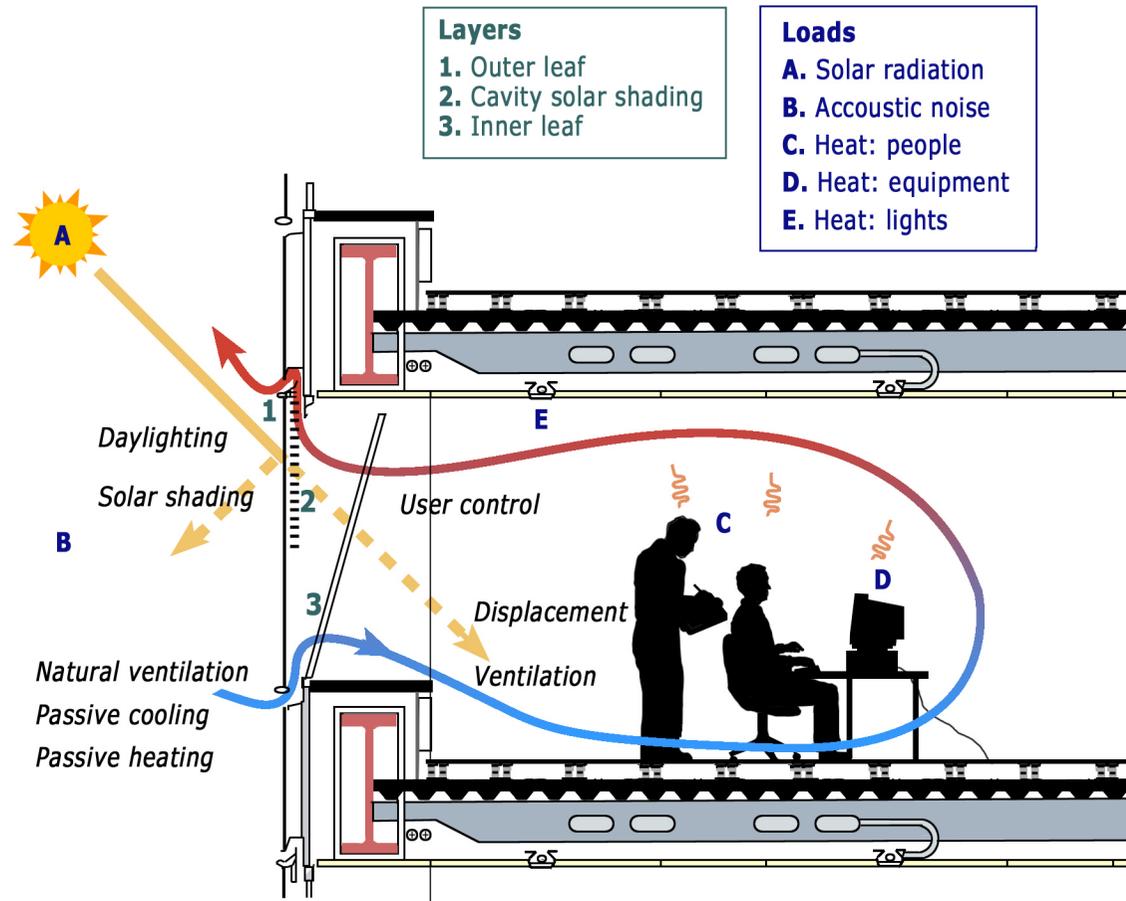
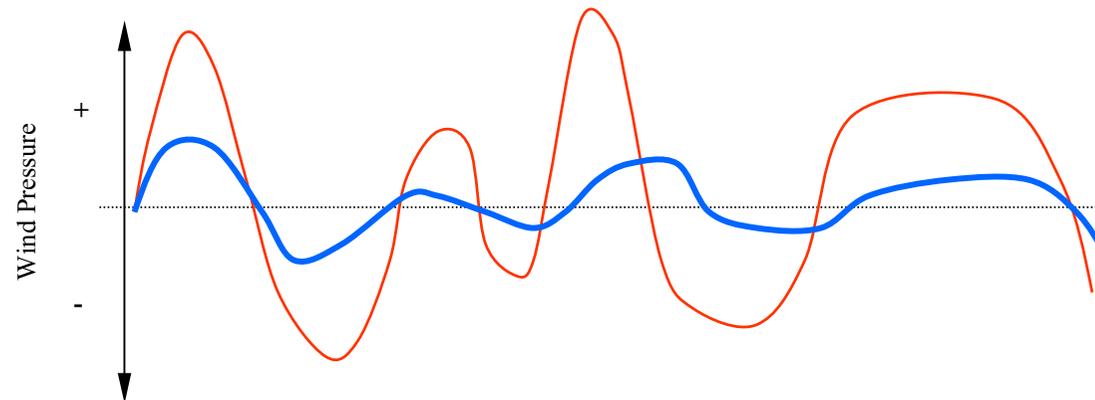


Image by MIT OCW.

DSFs

Goal of assembly

1. Reduce impact of solar radiation on building climate and control
2. Increase thermal resistance of exterior envelope from third leaf layer and through heat removal from convection within the cavity and diminished heat transfer owing to the increased temperature of the cavity air
3. Provide controlled daylighting
4. Provide a good acoustic barrier
5. Provide greater occupant control of microclimate especially as a means of opening windows even in a high rise building
6. Reduce load needed to be serviced by HVAC equipment. There is the potential to eliminate equipment entirely, including ductwork, however for the most part this has been very difficult to achieve realistically (issues of real estate value).
7. Reduce wind pressure on weather envelope



Ventilation Strategies for DSFs

Arons, Daniel M. M.

Properties and Applications of Double-Skin Building Facades,

Master of Science in Building Technology, MIT June 2000.

Compagno, Andrea

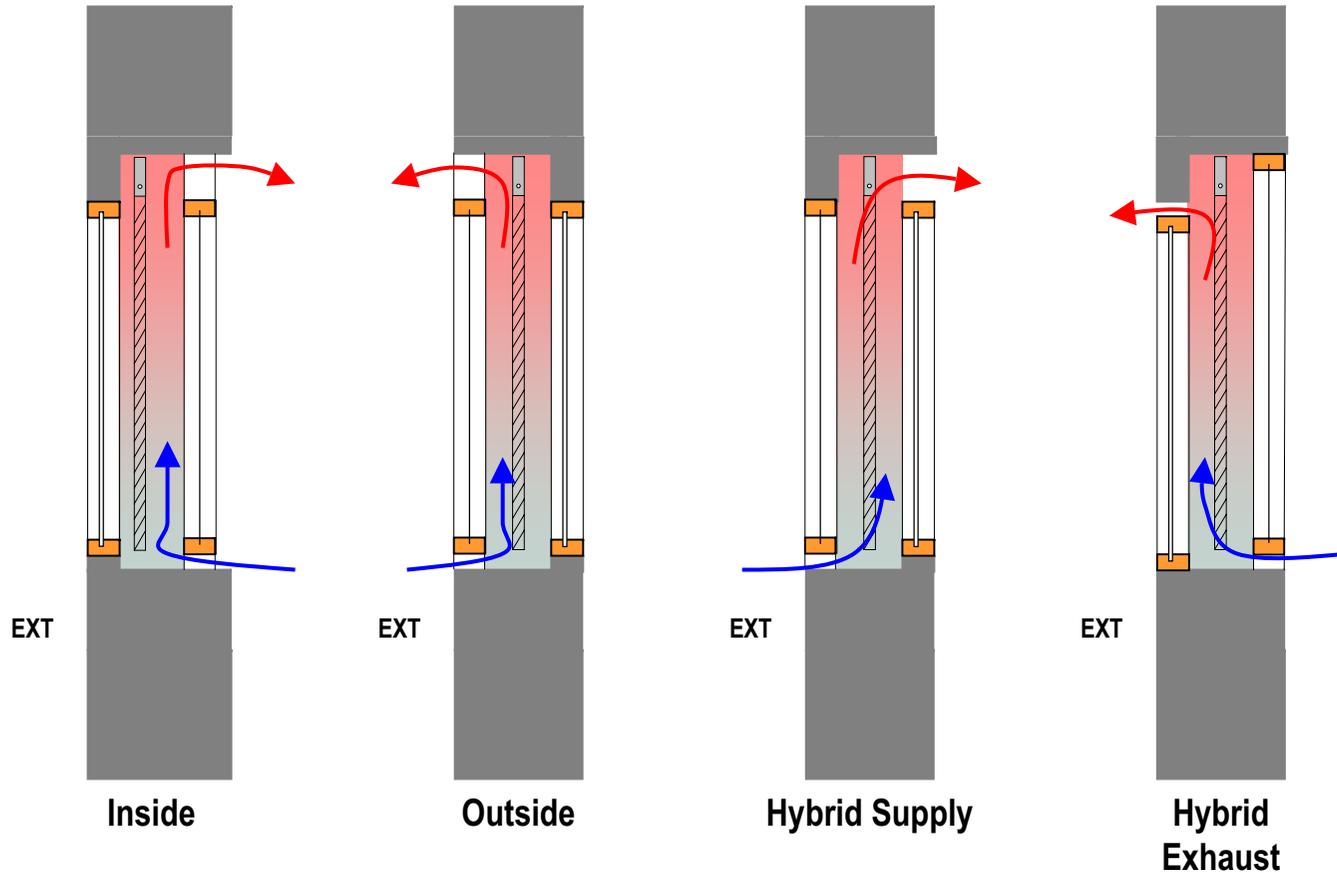
Intelligent Glass Facades

Birkhauser Publishers, Berlin, 1999.

Melet, E.

Sustainable Architecture: Towards a Diverse Built Environment,

NAI Publishers, 1999.



Types of Construction

Oesterle, Lieb, Lutz, Heusler
Double-Skin Facades,
Integrated Planning,
Prestel Verlag, Munich, 2001.

1. **Box Windows: “punched window type”**
2. **Shaft-Box façade: a particular type of “box” window, multi-story.**
3. **Corridor façade: continuous cavity throughout the length (or parts) of the façade.**
4. **Multi-story façade: multiple-bay, multi-story cavities.**

Oesterle, Lieb, Lutz, Heusler

*Double-Skin Facades,
Integrated Planning,*

Prestel Verlag, Munich, 2001.

Mockup Needs

1. Module intersection and construction sequence issues
2. Testing (difficult without larger volume of building)
3. Aesthetic approval

Cost \$50,000 - \$100,000

DSFs

New Parliamentary Building,
Westminster, London
Michael Hopkins and Partners, 2001.

Library
University of Technology, Delft
Mecanoo Architects, 1998.

"Briarcliff House"
Farmborough, England
Arup Associates, 1984.

Business Promotion Center,
Duisberg, Germany
Foster and Partners, 1993.

- Active Wall example
- Mechanically ventilated cavity façade
- Windows: external insulating unit of clear laminated glass, argon filled and internal float glass with a low-e coating and internally a single pane of toughened glass.
- Solar shading integrated into 75 mm cavity
- Supply air from back of room at the floor, return air at height of light shelf ensuring good cross ventilation
- air is drawn up through vertical ducts and heat is recovered
- Target: a reduction of energy consumption by 2/3
- No BMS data available yet.

- External glazing of insulated glass and low-e coating. Internal glazing designed as a sliding door and gives access to the cavity for cleaning
- Ventilated cavity is 14cm wide
- Air from room enters at floor level and is mechanically ventilated through cavity
- DSF increases the thermal resistance of the wall during the winter months and allows for the management of solar gain during the summer

- Early example of DSF
- DSF with heat recovery system
- DSF does two things:
Protects occupants from aircraft noise and gives greater solar shading control.
- Outer pane is 10mm heat absorbing glass pane, placed 120 cm in front of the actual building skin
- Winter: warmed air is directed to a heat exchanger at roof
- Summer: air is brought to roof and exhausted

- External pane is 12mm single glazing situated 20 cm in front of full-height insulating glass façade. Pilkington Planar fittings used to secure glass
- Internal argon-filled insulated glazing layer consists of storey-high side hung windows with thermally broken aluminum profiles, inside 6mm float glass outside 8mm laminated glass with low-e coating
- air distribution from slits at the bottom of the window frame spreading fresh air into a "puddle" along the floor and using displacement ventilation
- Chilled ceilings are used as well as a 60cm strip of perimeter heating

- Since opening, overheating at the top floors has been a complaint. Reason is the continuous vertical cavity concentrates hot air toward the top floors.

DSFs

Victoria Life Insurance Buildings,
Cologne

T. Van den Valentyn and A. Tillmann, 1996.

-Outer glazed skin consists of 2.7m wide and 1.13 high laminated glass (6 + 8mm glass panes) which is fixed to the transoms of the façade frames via pressure caps recessed in the glass

-Inner skin consists of a premanufactured storey-high frame elements of aluminum and low-e coated glass

-The cavity is 0.7m wide

-The wall does not ventilate the interior space because of the surrounding fumes from traffic. It's primary function is as a noise buffer from that traffic.

-Fully air-conditioned building

Office Building,
Halensee, Berlin, Germany

Leon/Wohlhage, 1996.

-Functions like a story-high solar collector

-Constructed directly on a busy highway

-Cavities are one story tall and separated by a bent concrete parapet

-Outer layer is completely closed yielding a very good noise buffer. The cavity is 0.85m wide.

-Winter: cavity remains closed and serves as a thermal buffer

-Summer: the inner layer remains closed and the cavity is ventilated

-During the swing seasons, the occupants can open the inner layer and bring in fresh air as desired

- To reduce cooling loads during the summer the concrete structure is cooled at night and used as thermal storage

Headquarters
Gotz, Webler + Geissler, Architect.

-DSF used in conjunction with a central atrium to regulate the thermal resistance and the cooling load for the building

- Also air is mechanically circulated horizontally from one side of the building to the other to take advantage of solar gain

RWE Essen Tower
C. Ingerhoeven, 1999.

Tower 34m in diameter
130 m high

-High thermal resistance of façade led to minimization of cooling loads.

-DSF allows for windows to be opened through the use of a wind pressure buffer at the base of the windows at each floor.

-Exposed concrete used for thermal mass.

-- Cooling supplied by hydronic radiant panels in ceiling.

-- Heating supplied by hydronic fin tube at perimeter windows by the floor.

-- Naturally ventilated 70% of the time.

--Cost 3x typical curtainwall

DSFs

Current Issues

- 1. Very little real building behavior data. Claims of energy consumption savings of 30% have NOT been verified.**
- 2. US office standards call for deeper perimeter office depths (15-20m typical) than in Europe (7m) making cross ventilation difficult.**
- 3. US humidity levels, especially in the East, Midwest and South may make the use of natural ventilation through DSFs difficult. Also a potential problem with chilled ceilings.**
- 4. Cost premium of the wall can be in excess of 200-300% of a typical insulated curtainwall. With realistic payback periods of 20 or so years, the capital costs are currently prohibitive for large scale use. Even in Europe, these technologies require substantial subsidies.**
- 5. Usually better, less expensive ways exist to reduce energy consumption.**
- 6. Difficult to shift load to account for large swings in populations. For example theater audiences.**
- 7. Systems call for heightened control monitoring and careful adjustments made within an integrated strategy. Training of building personnel critical.**
- 8. Anecdotal evidence that Americans in the workplace have a tighter comfort zone than many Europeans.**

5

New Materials

Materials

Glass

Insulation

Phase change materials

Textiles

New Materials

Glass and Window Assemblies

- **Electrochromic windows:**

Movement of ions from electrode through electrochromic layer darkens the assembly. Reversing the voltage lightens the assembly.

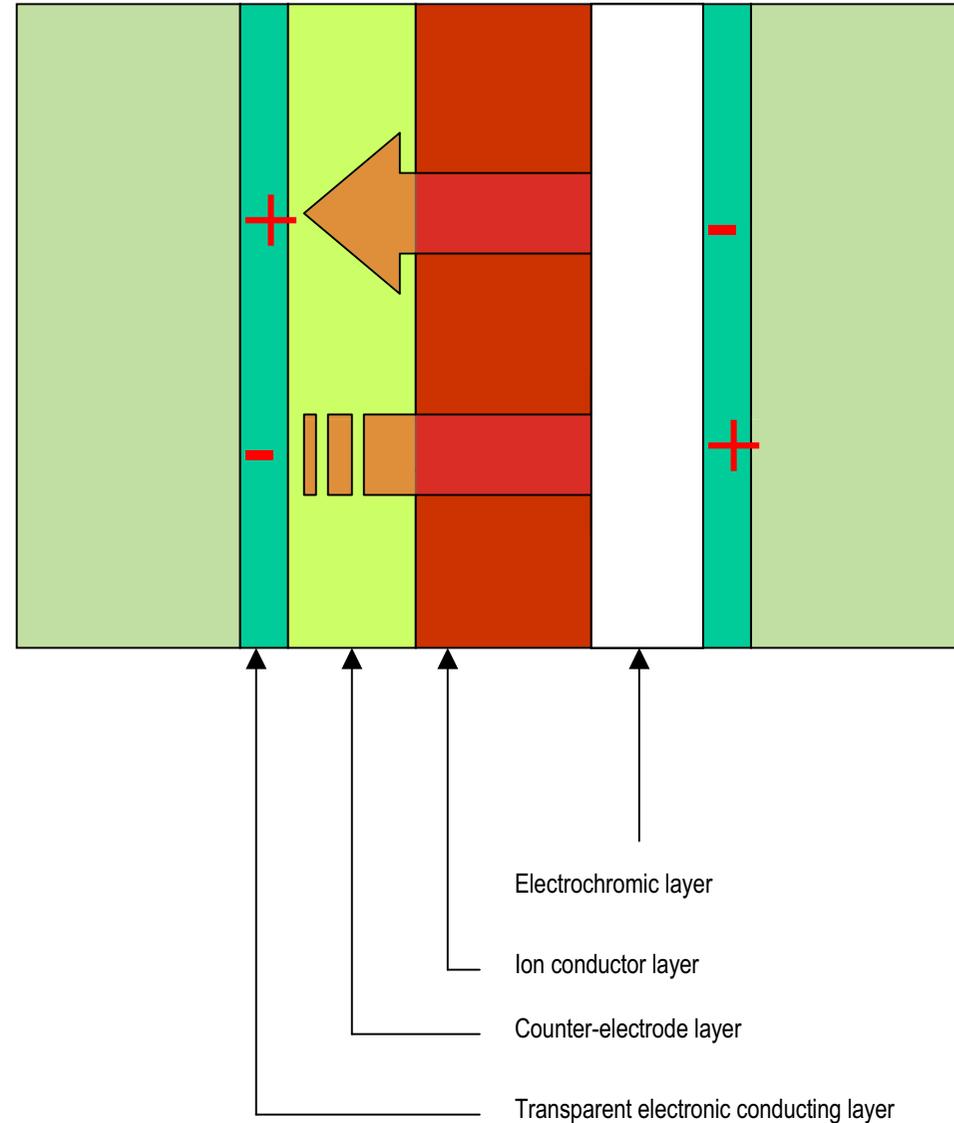
- **Liquid crystal windows:**

primarily used for interior privacy control

- **Thermochromic windows:** gel-based coatings are most promising – a product now on the market is cloud-gel, a thin plastic film that can be incorporated into a window assembly.

- **Photochromic windows:**

photochromic windows reduce glare from sun but do not control heat gain. A photochromic window may darken most in winter than in summer because of the incidence angle.



New Materials

Insulation-Translucent

Aerogel

First discovered in 1931 by Steven Kistler, physicist. Later produced for elementary particle detectors. Present forms include silica and carbon.

Silica aerogel:

R-20 /inch
(in 90% vacuum)
1/2" x 1 ft.sq. = \$900

Carbon aerogel:

R-38 /inch
(in 90% vacuum)

Prices seen to drop with increased demand.

Dynamic Insulation (Pore ventilation)

Gaia Research

Dynamic Insulation Guidance Note, Department of the Environment, Transportation and the Regions, Edinburgh, Scotland, 2000.

Thomas Herzog, Aerogel Exterior Envelope System

New Materials

Phase change materials

liquid



solid

- A: solid to liquid = endothermic
- B: liquid to solid = exothermic
- 1: diurnal temperature differential
- 2: dampened interior temperature differential

