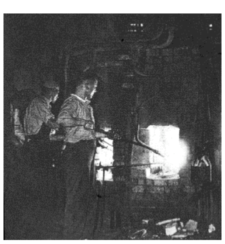
Glass in History
Glass Types

As old as the Pharoh

- Unlike any of the refined construction materials, steel entering general use by 1850, concrete by 1830, glass is over 5,000 years old.
- As a product of a labor intensive process, glass didn't become cheap or plentiful in buildings until the early 1800's (that industrial revolution thing again)

Blown Glass

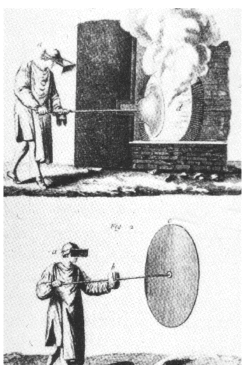


- Historically, glass made from sand, soda ash, lime, alumina, and potassium oxide was heated in a furnace or kiln to a consistency of heavy molasses.
- The glass blower would insert a tube (punty?) into the vessel containing the glass and dip out a grapefruit sized mass

Blown Glass

- The glass blower would then blow into the tube while slowly spinning it to keep the glass from dripping off the tube.
- The glass could be gently shaped with tongs, even blown inside of wooden forms to elaborate shapes.

Disc Glass



- The earliest glass for windows came from discs of glass made by rapidly spinning the rod to flatten out the glass.
- Some older Virginia homes (up to 1935!) still have disc glass in their windows. It can be recognized by the bulls eye mark made where the rod was connected to the glass

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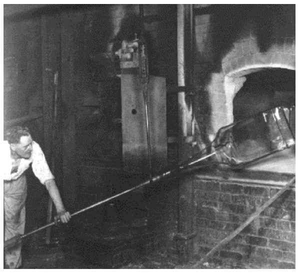
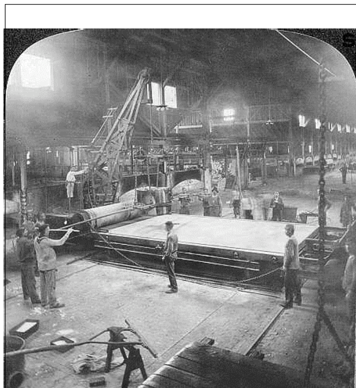


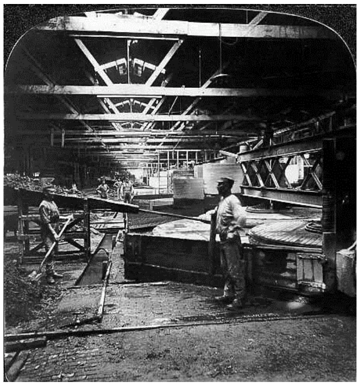
Cylinder Glass

- Another process for glass involved blowing a cylinder of glass, cutting the ends off while hot, flattening the tube into a sheet, and cutting flat glass panes from the sheet.

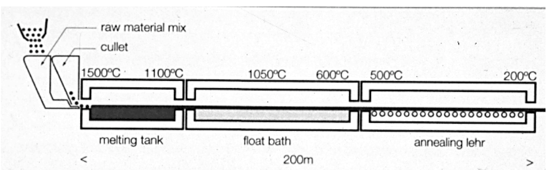
Casting plate

- To make the very large sheets of glass demanded by the emerging steel frame construction, the glass industry developed large casting plates (steel) upon which the molten glass was spread and allowed to cool.
- This made for a rather lumpy cast glass, not at all precise or transparent enough for the emerging storefront.
- An additional series of steps polishing the glass using multiple grades of abrasives brought the glass to the precise transparent finish we now know as plate glass.





Floating Glass



- Pilkington glass co made a huge breakthrough in the process of making glass in the late 1940's (patented 1952). They developed a process of casting molten glass on top of a bath of molten metal (tin) The glass floats on the tin and leaves a perfect surface finish on both sides…no polishing required!
- This greatly reduced the cost of glass…just in time for the modern skyscraper to emerge.

Raining Glass

The John Hancock Insurance tower in Boston had an initial curtain wall framing design which greatly minimized the appearance of mullions by using clips attached to the reflective coating to hold the glass to the building.

The coating delaminated, the glass fell, and it became the tallest plywood structure in the world!

Now there are mullions

Thin and flexible

Part of the cause of the glass failure was that the tower moved more than expected due to wind forces on the wide face.

One retrofit which has been successful was the addition of a tuned mass damper to the top of the building to help counteract the sway.

A super cooled liquid

- Glass never becomes a solid.
- It is characterized as "An inorganic product of fusion which is cooled to a rigid state without crystallizing"[1]

1. Intelligent Glass Facades, by Andrea Compagno

Clear Glass

- Glass is not completely clear… typically it transmits only 85% of incident light.
- This is partly due to reflections, partly to the iron (the stuff that makes glass green when seen from the edge)
- If high transmission levels are needed, like for solar panels, a low iron glass transmitting 95% of incident light is available

Frank Israel glass stack

Glass Types & 05 costs

- Common types
  - Annealed 1/4" clear $12.15 s.f
  - . 1/4" tinted $12.10 s.f.
  - Laminated 1/4" clear $18.20 s.f.
    - Projectile resisting 1 3/16" clear $106.00 s.f.
  - Heat Strengthened
  - Fully Tempered 1/4" clear $13.45 s.f.
  - Mirror coating 1/4" pyrolitic $18.30 s.f.
  - Spandrel glass 1/4" opaque $20.50 s.f.
  - Add for low-e 15%

More types and costs

- 1/2" insulating clear $16.25 s.f.
- , tinted $19.25 s.f.
- 1" insulating clear $24.00 s.f.
- , tinted $27.00 s.f.
- , tempered $30.50 s.f.
- , clear, mylar film $28.50 s.f.
- , tinted, mylar film $30.00 s.f.
-

A few more

- Full vision, glass mullions 10-20'high $68.00 s.f.
- Alum tube frame with insul glass $55.00 s.f.
  - Highest quality $132.00 s.f.

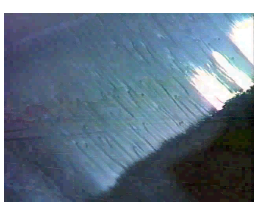
Low stress is bad

- As a super cooled liquid, glass is particularly sensitive to stresses in its surface film…like a soap bubble is.
- Glass cooled slowly forms very low internal stresses. It's called *Annealed* glass. When broken, the low internal stresses form long *shards* of sharp glass, not so good for whoever is nearby!
- Annealed glass is also not very strong. Strength is developed by adding thickness.
- Annealed glass is made from 3/32" thick for picture framing, through more common 1/4" or 1/2" to 1" thick for special orders

Adding layers

- Glass can be strengthened by increasing the thickness, but this also increases the thickness of the shards made when it breaks.
- *Laminated* glass assembles layers of glass with a *PVB* (polyvinyl butryal) *Interlayer* between each layer. The layers are assembled under heat and pressure to make a pretty permanent sandwich of glass which is .6 times stronger than annealed glass!
- The real plus here is that when the glass breaks, it tends to stick to the interlayer, not in your skin!
- A side bonus…laminated glass reduces sound transmission from outside sources for a much quieter interior!
- You can tell if its laminated by the "thunk" sound made when tapping it.

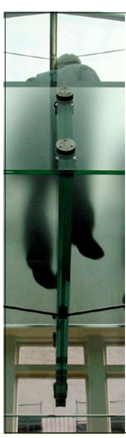
Laminated Glass

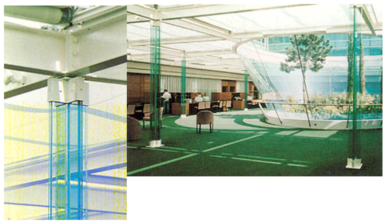


- Can be layered for projectile resistance. (bullet resistant)
- Provides better acoustic isolation from exterior noise
- Keeps shards attached to interlayer for safety.
- Remains in window frame longer after breaking, good secondary envelope

- PVB butacite interlayer for vertical
- ionoplast interlayer for horizontal

- Apple Store Soho, NY, Peter Bohlin arch.





Laminated qualities

- Any kind of glass can be laminated,
  - Laminating annealed glass holds shards in place when broken
  - Laminating Fully Tempered glass holds the kernals in place in overhead glazing
  - Laminating is also the process used for liquid crystal, photochromic, and electrochromic glazing.

Some stress is better

- *Heat Strengthened* glass uses a process of re-heating annealed glass and cooling it quicker to develop some stress in the surfaces of the pane.
- Heat strengthened glass is commonly used as exterior glazing for taller buildings. The additional stresses in its surfaces make it up to 2 times stronger than Annealed glass of the same thickness!

High stress is good

- Glass cooled quickly forms very high internal stresses it's called *Tempered* glass. When broken, the high internal stresses form small round-ish *kernals* that don't cut as easily as the shards from annealed glass.
- These high stresses also build a lot of strength into the glass. Fully Tempered glass is considered 4 times stronger than annealed glass for impact and thermal loads.
- But any edge prep, cutting, or drilling MUST be done before the glass is tempered. Any attempt to cut it in the field and it explodes into many tiny kernels.
- Fully Tempered glass "rings" when you thunk it.

Strength summary

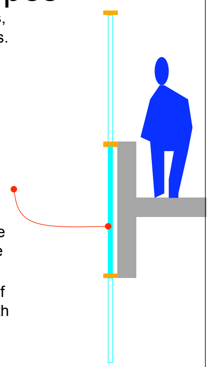
- AN = Annealed glass, makes shards, low strength
- LG = Laminated glass, layers with PVB liner, shards stick to liner
  - .6 x stronger than AN
- HS = Heat strengthened glass, partially tempered
  - 2 x stronger than AN
- FT = Fully tempered, reheat, rapidly cool to make high internal stresses
  - 4 x stronger than AN

Where to use

- AN out of impact zones, in low rise constructions for windows having sills over 24" above the floor.
- LG impact zones being door and sidelight glazing, and as exterior glazing for reduction of noise transmission. Considered a safety glazing due to PVB interlayer
- HS Strength zones, higher wind loading areas.
- FT impact zones, being door and sidelight glazing and for floor to ceiling glass interior or exterior. Combine with LG for use in overhead skylight glazing (keep those kernels out of your dinner!) Considered a safety glazing.

Other glass types

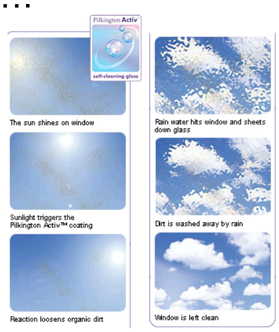
- *Wire* glass - used in some fire rated doors, usually limited in area and frame by codes. Wire embedded in molten glass tends to keep glass in the frame longer under fire loads.
- *Spandrel* glass - a glass panel with an opaque coating used to cover the space between the sill of a floor above and the head of a floor below.
- Glass block - two glass faces with a vacuum sealed between, laid up by a mason. Not automatically approved as fire rated…varies with manufacturer and code agency.
- Fire rated glass - an assembly made up of two layers of fully tempered (FT) glass with semi-transparent gels between. On exposure to extreme heat, the gels turn into an insulation (opaque)



Other glass….

- Self Cleaning glass - glass with a coating on the exterior face that stimulates a catalytic process with UV to break down the bond between organic dirt compounds and the glass, making it easier to wash off in the rain.
- A hydrophilic (water-rejecting) coating deposited by a pyrolitic (hard coat) process
- "Activ" by Pilkington

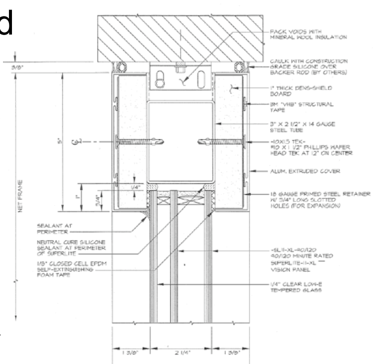
- http://www.pilkington.com/international+products/activ/usa/english/how+it+works/default.htm



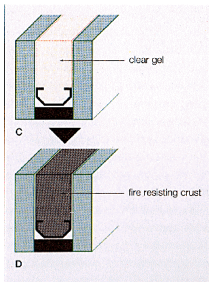
Fire rated glazing

- Fire code treats it as a "transparent wall" meets 2 hour ratings, UL labeled
- 2 1/4" glass assembly
- 5" sightline steel frame around struct. Steel tube
- 5" frame thickness
- "GPX" by Safti systems

- http://www.safti.com/framing_SLII-XL120.html



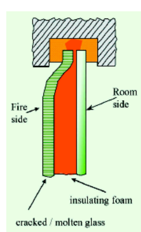
Fire rated glazing



- Unlike glass block or glass brick which attempt to use glass mass as an insulator against fire, this glazing places a clear polymeric gel between two heat strengthened panes of glass.
- The gel is 75% water and inorganic salts. The fire converts the gel into a crust which forms and insulation while the water evaporates, absorbing much of the fire's heat.
- By the time the pane on the fire side shatters, the insulating crust is strong enough to maintain the integrity of the panel.
- An 18mm cavity filled with gel gives 30 min resistance, a 28mm cavity gives 60 minutes, and two cavities in a triple glazed unit can give 90 minutes of protection.

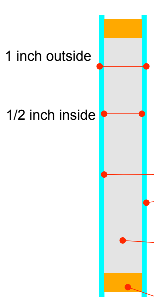
Other glass….

- Fire rated glass - an assembly made up of layers of fully tempered (FT) glass with three to five transparent intumescent interlayers between and held in a steel frame. On exposure to extreme heat, the gels turn into an insulation (opaque) that is a foam glass, holding the tempered panels together, blocking heat and gases from passage through the glass assembly for up to 120 minutes.



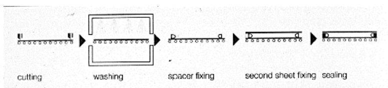
- Pilkington Pyrostop

Insulation



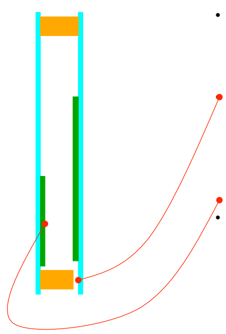
- While single panes of glass were a big improvement over an open window for keeping heat in and cold out (and vice versa in hot climates) It still isn't what a person would think of as insulation.
- The industry standard approach to reducing heat loss began in the late 1960's.
  - Two panes of glass were assembled with seals between them
  - a vacuum drawn between the panes, and the IG unit (Insulating Glass) unit was born!

Double the market!



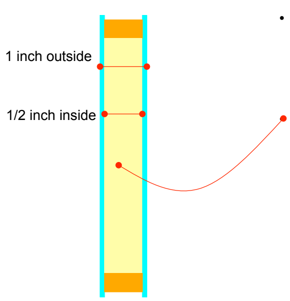
- It took an extra assembly process to make the insulating glass, but with two panes now making up one lite, the industry was selling twice as much glass per building!

Good Ideas don't always work the first time



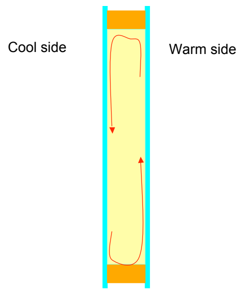
- These windows dramatically improved the thermal resistance of windows
- But didn't last long. Premature failures of the edge seal meant a loss of vacuum, and an intrusion of outside air & moisture.
- This made a perfect terrarium for growing molds between the panes...

New Seals & Gas



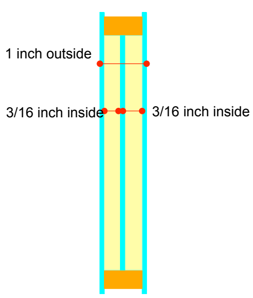
- The industry quickly develop longer lasting edge seals and replaced the vacuum with a fill of inert gas
- Nitrogen or Argon are common gases used to fill the void between the two panes

convection



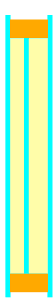
- One of the primary sources of heat transfer in the double pane IG unit was convective flow.
- As one pane was heated in the sun, or cooled from the AC, the gas adjacent to that pane would heat up and rise, or cool down and fall
- This convective loop would bring warm gas to the cool pane and cool gas to the warm pane causing ***heat exchange*** (either loss or gain)

If two are good...



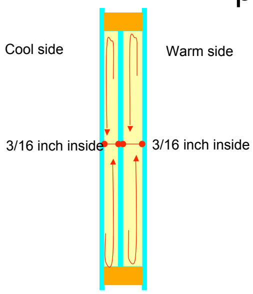
- The double pane IG unit quickly moved toward being an industry standard for commercial glazing in the early 1970's
- The Oil Embargo and resulting oil shortage of the early 1970's spurred the development of many energy - conserving materials and products.
- For the IG unit, this meant adding a third glass pane between the two outside panes

Three must be better



- This became known as the triple glazed IG unit
- The thinking behind the third pane was sound. In a double glazed unit, the air space would scrub heat from one side of the glazing and lose it to the other in the convective loop.
- The third glass pane between the two outside panes made two separate chambers, so the convective loop couldn't transfer heat directly from one side to the other

Convection… and the third pane



- With the third pane, two convective loops have to develop in a much narrower space, where friction plays a greater role in slowing down the loop.
- The inner pane would have to heat up or cool down to transfer heat through conduction in the inner pane from one cavity to the other.
- It worked, sort of, but the performance gains didn't really outweigh the extra cost and weight of the triple glazed unit and so it mostly disappeared from the market….

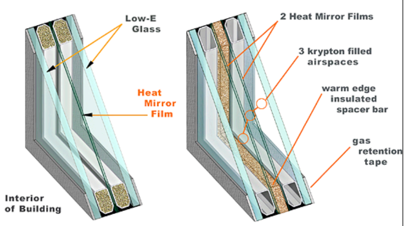
Single glazing R=.9

Double glazing R=2
(1/2 space)

Double glazing R=2.77
(1/2 argon filled space)

Triple glazing R=3.44
(1/2 argon filled space)

Double glazing with suspended film R=6.67
(1/2 argon filled space)



R=8.3 R=12.5

http://www.southwall.com/products/heatmirror.html

Coats for all seasons!

- To improve thermal performance, the industry shifted to a focus on cutting down heat gain through the glass.
- This made a lot of sense as most of the IG market was concentrated in the office building type, where even in Fargo, North Dakota, office buildings had to be cooled all year… even when it was -40° F!

Tints and Coats

- Technically, there were two development paths to reduce heat gain glass tints and applied coatings.
- Tints were made by adding different minerals to the molten glass. Bronze, Green, and Gray tints were common and could be formulated to reduce transmission of available light (and at the time it was thought heat) by 80%

Shiny coats

- The coatings of the early 1970's were literally a layer of metal applied to the glass in a vacuum deposition process called sputtering (Magnetron Deposition) which kept the thickness of the coating just a few atoms thick. This made for a fragile coating, (called soft coat) which is easily scratched.
- The other popular coating method was pyrolytic deposition (Chemical Vapor Deposition) which fuses the coating of metallic oxide to the glass before it cools giving the coating a higher degree of abrasion resistance.

Not fussy about selection

- These coatings are considered non-selective because they do not discriminate between wavelengths of light and wavelengths of heat…they reflect pretty much all wavelengths.

Hey…it's dark in here!

- As in many cases where an innovation is developed discretely by one subsystem supplier, the impact of tinted / coated glass rippled through the industry.

- The sequence was roughly
  - Sunlight brings heat into the building
  - Since office bldgs have many people and heat producers in them, the suns heat is not welcome
  - Tint the glass to stop the sunlight…and sun heat
  - Add artificial lighting to replace the daylight lost in tinting
  - Add more cooling to compensate for the heat produced by the lights!
- Full circle, with more A/C needed as the result!

Getting choosy

- Towards the end of the 1980's it was possible to apply coatings which were selective about what parts of the spectrum to reflect, and what parts to transmit.

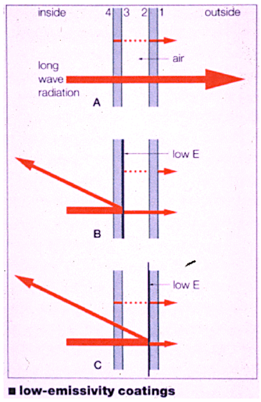
- The biggest breakthrough in selective coatings was the Low -E coating. (low emissivity)

- The low e coating selects short wave infrared (the heat carrying part of the spectrum) to reflect away from the window. Cutting the transmitted heat gain significantly.

Radiation…and hot upholstery

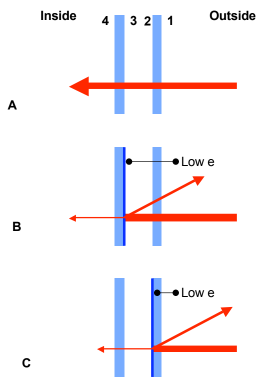
- Why is my car interior hotter than outside temperatures?

- Most glass allows short wave infra-red wavelengths through. These short wave IR wavelengths heat up the dash, upholstery, especially the steering wheel and seat belt clips (according to the materials ability to conduct and store heat)
- These hot materials in turn radiate long wave infra-red. So more short wave heats up more material which radiates more long wave IR….a heat buildup cycle!



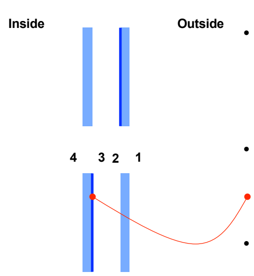
Low 'E'..reducing heat loss

- A. Most glazing allows long wave IR to pass freely through…Heat Loss.
- B. Low E on the inside pane (surface #3) reflects back into the space, reducing heat loss.
- C. Low E on the inside of the outside pane (surface 2) allows for heating up of the window cavity…and subsequent heat loss



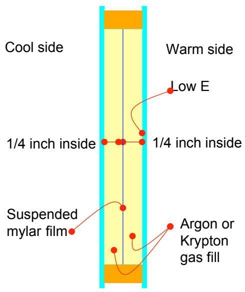
Low 'E'..reducing heat gain

- A. Most glazing allows short wave IR to pass freely through…Heat Gain.
- B. Low E on the inside pane (surface #3) reflects Short wave IR back outside, reducing heat gain but allows for heating up of the window cavity…and subsequent conductive heat gain
- C. Low E on the inside of the outside pane (surface 2) reflects short wave IR back outside and prevents heating up of the window cavity…reducing conductive heat gain



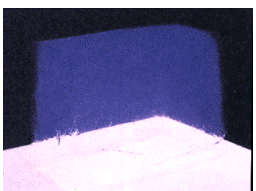
- Low E coatings are usually placed on the inside surface of either pane of an insulating glass unit.
- This protects the softcoat application from abrasion during cleaning processes.
- Surface #3 is preferred as it faces the still air of the cavity.

High performance insulating

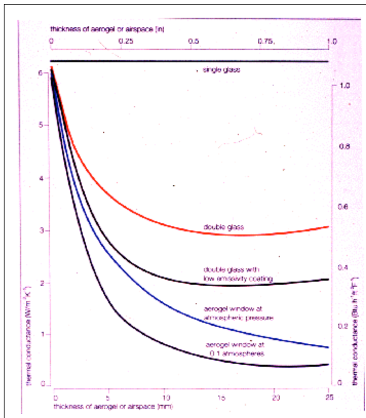


- Current technology in glazing combines low "e", suspended films (like triple glazing but with mylar) and heavy inert gases to raise thermal performance from an R value of 2 to almost R 13!

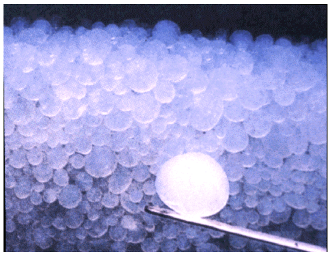
Next Generation



- High capacity energy absorbers will revolutionize glazing in the next 20 years.
- AeroGel, an insulation so light it floats to the ground slowly when dropped can sustain surface temperatures of 1000 degrees on top, and remain under 90 degrees at the bottom of a 3 inch thickness!



- Single glazing conductance (high) 1.25 (R .8)
- Double glazing .6 (R1.66)
- Double glazed with Low "E" .4 (R2.5)
- Aerogel window .1(R10)

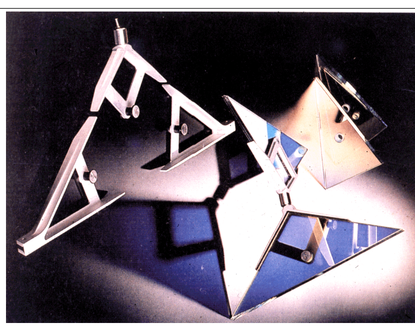


Future Glass

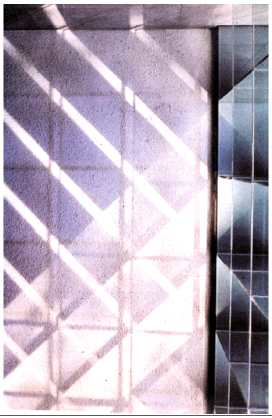
- A German company is experimenting with aero gel capsules between two panes of glass.
- At this point the aero gel is lightly translucent, not fully transparent.
- Between aero gels and selective coatings, windows may soon be as good as walls thermally.

Other coatings

- To increase transmission values
  - 3M polyester film used to increase transmission of incident light from 89% to 94%.
    - Works by reducing surface reflections
    - Cuts Ultra Violet transmission down to 2%
    - If mounted in the cavity in an IG unit, can act as a convective barrier.
- To select colors for reflections and shadows.
  - Dichroic coatings are specifically tuned to certain wavelengths of the spectrum.
  - Primarily used for making “cold” (reflect light but not heat) or “hot” (reflect light and heat) mirrors for laboratory work, these coatings have transformed the work of James Carpenter.



- Dichroic coatings on glass samples.



James Carpenter

- The glass grid inside the window has dichroic coating on the horizontals and verticals in varying densities.
- This allows for a reflection of the full spectrum (white) and a shadow from the variable density coating (blue)

Beyond static coatings

- Glass treatments that are changeable are on the horizon.
- Electrochromic glazing reacts to electrical current to change from transparent, to opaque, with the possibility of dot patterns in between.
- Photochromic glazing reacts to changes in intensity of light by darkening. The darkening is not even at this point and photochromics are usually reserved for use as shading devices, not windows themselves
- Thermochromic glazing responds to changes in heat by darkening. This gel, sandwiched between panes can change transmission values from 20 - 92%! Like photochromics, the change is blotchy, and use is limited to shading devices.