Architectural Conservation Technologies

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ABSTRACT

The traditional focus for achieving improved energy efficiency in commercial buildings is on engineering design and equipment selection. Most new construction programs offered by utilities in North America over the past two decades paid incentives for higher efficiency equipment and to a limited extent for better engineering design. Recent research in Ontario has indicated that architects consider "energy efficiency" something best left to engineers.[1] In 1987, Ontario Hydro, a Canadian electric utility, commissioned a study of the ways in which architecture could affect energy efficiency in commercial buildings. In 1997, a Canadian gas utility, Union Gas, revisited this subject and published a report cataloguing the architectural options to improve energy efficiency and providing case studies, including photographs of design options used in advanced buildings around the world.

Union Gas is working from the premise that optimum energy efficiency in buildings can only be achieved through an integrated design process which includes architects and engineers working as a design team. This newly published report has been designed to increase the interest and attention of architects with respect to energy efficiency in order to encourage their participation in such integrated design teams.

This paper summarizes the results of the research which was done for this report, illustrates the energy savings potential from selected options as well as combinations of options and catalogues a broad range of architectural design features that can improve energy efficiency.

Introduction

In 1987, Ontario Hydro commissioned a review of architectural options for electricity conservation as input to its conservation potential studies for demand side management. Its commercial DSM program which followed, *Savings by Design*, was a performance based incentive program which paid first $300 per kW and then $500 per kW for more efficient buildings. Few of the measures paid for under the program, however, were of an architectural nature. Almost all of the measures were equipment related. While that program was marketed to the design community as a whole, there was little awareness or involvement on the part of architects who, readily admitted that they left the issue of energy efficiency to their engineering colleagues.

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[1] Montross, Craig, and Fraser, Marion, 1998. "Building Design for a Sustainable Future." *In Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, Washington, D.C.: American Council for an Energy Efficiency Economy.

Aware of this market disconnect, the DSM department at Union Gas has sought to increase the involvement of architects in energy efficiency. It held a Charrette[2] to look at the market barriers and it commissioned this study, which has been published in a format designed to appeal to the sensibilities of the architectural community. The report puts the issue of energy efficiency into a broader design context including consideration of land use planning, urban design, transportation as well as buildings.

Methodology

Line Architect Inc., the firm commissioned by Union Gas to complete the study used primary and secondary research to identify architectural design options which are either emerging or have been used successfully in advanced buildings. Primary research included site visits in Europe and Ontario. The design options listed below were identified. A summary description of each is included in the Appendix. Some of the options and combinations of options were simulated using DOE 2.1e. Case studies were documented for 10 advanced buildings.

- landscaping
- displacement ventilation
- nocturnal ventilative cooling
- light shelves
- atria
- high performance glazing
- earth-to air heat exchange
- trombe walls (solar walls)
- building orientation
- thermal chimneys
- radiant cooling
- light shafts
- holography
- super-windows
- double envelope
- natural ventilation
- evaporative cooling
- daylighting
- skylights
- transparent insulation
- earth sheltering
- rock storage

Research Findings

Construction costs were generally higher per square foot for the European buildings than is typical in Ontario. The extra costs are a result of higher quality building envelopes. Some offset results from the deletion of the mechanical building cooling system in favor of natural ventilation. To achieve a building design which permits reasonable comfort without mechanical air conditioning requires high quality building materials and systems for the building envelope (e.g. high efficiency glass, high levels of insulation, open office layouts, operable shading devices, computerized building systems controls) and a dedicated effort to reduce installed lighting loads.

The same thorough design approach has been applied to high rise buildings by using a double envelope to avoid problems with excessive stack effect and wind pressure. Use of operable windows in a high rise building, however, requires the perimeter offices be sealed from the core and from vertical shafts, that door jambs be double gasketted throughout the core, and elevator lobbies vestibuled from the perimeter office spaces.

[2] Ibid.

Over the last five years or so, Germany has taken a major step forward with respect to energy conservation in buildings. "Green" environmental issues in Germany are a common thread in public thinking and influence many decisions in the way of life. E.g., municipal space is devoted to bicycle paths as an alternative method of transportation to automobiles. This has resulted in government initiatives, both legislation and subsidies to encourage conservation. As well, funding has been provided by private sources, including the electrical utility. For these reasons, seven of the 10 case studies included in the report are from Germany.

Building	**Location**
Wilkhahn Factory	Bad Munder, Germany
German Foundation for the Environment	Osnabruck, Germany
RWE Headquarters	Essen, Germany
Rheinelbe Science Park	Gelsenkirchen, Germany
Commerzbank Headquarters	Frankfurt, Germany
Design Offices of Josef Gartner & Co.	Gundelfingen, Germany
YMCA Environmental Learning Centre	Paradise Lake, Ontario
Green On the Grand	Kitchener, Ontario
International School	Lyon. France
Swisscom Telecommunication	Lausanne, Switzerland

Line Architect Inc. observed the following trends in advanced buildings in Germany:

- Recycling of used materials is practiced and consideration of "embodied" energy of materials is given in choice of materials for insulation, concrete finishes, carpeting, even to installation of recycled concrete material in Osnabruck.
- Natural gas is fuel of choice for heating for a cleaner environment at lower cost.
- Common heating system is gas-fired boilers with perimeter radiation units and convectors.
- There is acceptance by building occupants of a wider range of temperature and humidity for summer cooling that is accepted in North America.
- Natural ventilation is preferred to closed and sealed building envelopes.
- Mechanical air conditioning is installed only when necessary either for manufacturing or for rooms with high heat gains, e.g., cafeterias, computer equipment rooms.
- Large perimeter manually operable windows are common for natural ventilation.
- To offset the unwanted solar gain resulting from larger window areas, external shading devices are used; Some are automatically controlled; others are manually controlled.
- To offset the thermal loss of large window surfaces, better quality glazing units have been used: triple panes, inert gas filled cavities, multiple low emissivity coatings.
- Glazing materials with high transmittance of visible light are chosen for better daylighting.
- Open interiors layouts are used to permit daylighting to enter farther into the core of the building.
- Glazed transoms are used in interior walls of perimeter rooms to increase natural lighting to inside spaces. Large skylights are used for similar purposes.
- Tenants are required to take a proactive role in maintaining their own comfort during the cooling season by manually adjusting, opening and closing the operable window sections.
- Automatic interlock devices are used to shut off heating when the windows are open.
- Computerized building automation systems are used to monitor the status of the zone controls and room conditions.

- Daylighting is used to limit heat gain from internal loads such as lights and permit effective use of natural ventilation.
- High efficiency light sources are used throughout - e.g. less than one and one-half watts per square foot.
- Stand-alone and grid-connected photo voltaic systems are incorporated into the buildings as rooftop installations or integrated with sunshades or facades.

Simulation of the Design Options

Computer simulations were done to measure energy efficiency and energy cost savings which might be available from the most frequent strategies currently in use The program used was DOE 2.1e[3]. The method of simulation was to use a building representative of the type of energy efficient four-story office building that has been commonly built in Ontario over the last decade as a base case. Its features were as follows:

Height and Size:	four stories, 130 ft x 260 ft x 12 ft floor to floor.
Windows:	insulated glazed units, 4.8 ft high, continuous four sides of building;
Luminous Efficacy:	0.84;
Thermal Resistance:	R-2.
Insulation:	R14 walls, R12 roof.
Building mass:	4 in. concrete on steel pan floor; metal deck roof; 10.3 psf curtain wall.
Illumination:	2 watts psf
Mechanical:	temperature range 72F to 75F @ 50% RH.; two variable air volume systems: perimeter – cooling plus gas-fired HW heating; core - cooling plus heat only to top floor; 100% free-cooling in heating season only

Building equipment included both a gas-fired hot-water heating plant with boiler and pumps, and a cooling plant with cooling tower, pumps and electrically driven chiller. Both plants are necessary in Ontario for the building to meet marketplace expectations for space cooling within Ontario Building Code recommendation of ASHRAE 90.1 standard.

Each strategy or technology was then added to the base case individually as well as in combinations and energy usage and costs were compared against the base case. The simulations were done using a simplified model in order to isolate the specific option being analyzed. For example, daylighting is based on a 4.8 ft high window plus automatic lighting controls. The daylight penetration would increase with larger windows and the addition of light shelves. An elongated building-form to avoid deep internal spaces that cannot be served readily by daylighting would also affect energy savings.

[3] DOE 2.1e does not readily permit analysis of natural ventilation cooling for commercial building air-handling systems.

Table 1. Design Options

#	Option	Description
P1	External Shading	Fixed continuous 3.45 ft projecting horizontal shade at window head to east, west and south faces.
P2	Daylighting	Daylighting contribution from 20 ft perimeter only. Three-stage lighting control: off/50% on/100% on, 70 fc lighting level at desktop.
P3	Insulation & Superwindows	R20 insulation to all walls and roof. 40% of wall area with windows; Window thermal resistance R5
P4	Insulation & Superwindows	R30 insulation to all walls and roof. 40% of wall area with windows; Window thermal resistance R5
P5	Double Envelope	Double skin wall, 4 ft separation, to east, west and north faces, with insulated glazed units to exterior skin. South face: sun space 30 ft deep x 170 ft long with movable shades on the interior side of the outer wall; double skin wall where sun space stops. Double skin and sunspace vented to perimeter rooms; forced-air exhaust to exterior
P6	Earth Sheltered Walls	12in. concrete; 3 walls completely sheltered. Roof exposed. South wall: top 2 floors with 7.8 ft high windows; bottom 2 floors completely sheltered
P7	Sunspace/Atrium	Sunspace 30 ft x 170 ft x full height on south face only, with movable interior shades. Forced-air exhaust ventilation to exterior; vented to perimeter rooms
P8	Heavy Thermal Mass	12in. masonry walls (139.4 psf of wall area excluding windows); 10in. concrete roof (126.2 psf); 10in. concrete floors (117 psf)
C4	German Combination	Windows: triple-glazed insulating units 6.0 ft high, continuous four sides; luminous efficacy 1.32; thermal resistance R-5. Operable external shading. Daylighting: yes. Insulation:R-30 walls and roof. Building Mass:8in. masonry walls; 10in. concrete roof; 10 in. concrete floors. Illumination: 1.5 watts psf. Mechanical System: Temperature range 72F to 80F @ 50% RH

Results

Table 2 illustrates the energy consumption and costs for each of the simulated design options as well as shows the energy and costs savings over the base building. The results shown are for the Toronto region. The report includes the results for Windsor and Thunder Bay as well.

Table 2. Comparison Of Annual Energy Consumption And Energy Costs

Toronto Region[4]

		Total Energy Consumption (ekWh)	Energy Savings	Annual Energy Cost[5]	Cost Savings
BA	Base Building[6]	3,963,460	0.0%	$184,443	0.0%
P1	External Shade Building	3,777,432	4.7%	$178,177	3.4%
P2	Daylighting Building	3,785,787	4.5%	$175,183	5.0%
P3	R20 Insulation & Superwindows	3,474,982	12.3%	$175,626	4.8%
P4	R30 Insulation & Superwindows	3,393,519	14.4%	$173,910	5.7%
P6	Earth Sheltered Building	2,959,485	25.3%	$159,425	13.6%
P7	Sunspace/Atrium Building	3,677,290	7.2%	$178,132	3.4%
P8	Heavy Thermal Mass Building	3,602,971	9.1%	$175,563	4.8%
C1	Combination 1 : (2+4+8)	2,851,410	28.1%	$146,647	20.5%
C2	Combination 2 : (2+4+6)	2,937,861	25.9%	$156,965	14.9%
C3	Combination 3 : (4+7+8)	2,861,109	27.8%	$162,564	11.9%
C4	Combination 4 : G	2,851,039	28.1%	$138,308	25.0%
BA5	Double Envelope Base Building	3,816,580	0.0%	$183,845	0.0%
P5	Double Envelope Building	3,241,387	15.1%	$171,852	6.5%

- Individual technology efficiencies are not cumulative nor does the addition of a technology always improve efficiency of a combination. Each situation must be analyzed in turn.
- For the base case building, the total energy consumption was greatest in Thunder Bay region followed by Toronto region and then by Windsor region. However, the cost of energy consumed was in reverse order with Thunder Bay being the least expensive.
- For single technology, Earth Sheltering produced the best saving in total energy consumption and energy cost for all three meteorological regions.
- For Toronto, the largest total energy saving of 28.1% and greatest cost saving of 25.0% were both offered by the "German" combination.
- For Windsor, the largest total energy saving of 33.3% and greatest cost saving of 27.8% were both offered by the "German" combination.

[4]Cost of energy based on 1997 rates for electricity and natural gas.

[5] The energy consumption and costs are for the combined total of electrical and natural gas.

[6] The average annual costs of energy for the base building are $0.0852/kWh electricity and $0.1699/m3 natural gas which include demand and consumption charges.

- For Thunder Bay, the largest total energy saving of 28.7% was offered by the combination of daylighting, R30 insulation with superwindows, and earth sheltering. However, the greatest cost saving of 23.3% was offered by the combination of external shading, daylighting, R30 insulation, triple glazing/low-e, heavy thermal mass, and temperature range 72F-80F @ 50% RH ("German" combination).

Conclusion

Design options for improving energy efficiency are not always high tech solutions. Some of the common sense options are reminiscent of approaches that were commonly used before the notion of creating an artificial environment became a technical possibility and then an accepted norm.

Appendix - Catalogue of Architectural Options for Energy Efficiency

Landscaping: Deciduous trees are effective for solar shading in the summer and permit desirable solar penetration when the leaves have fallen in winter. Deciduous forests can also have a moderating effect on climate by absorbing and reflecting as much as 90 percent of the incoming solar radiation and lowering air temperature due to evaporative cooling.

Building Orientation. The building site, positioning and orientation of the building are significant for energy conservation strategies such as daylighting, solar gain and natural ventilation. Orientation of the building to avoid sightline blockage by surrounding obstructions or shadows cast by them will help maximize available daylight. Solar gain in summer, particularly through large windows, can raise a building's interior temperature well above the exterior daytime temperature. South-facing windows can be shaded easily but not so for east and west-windows, consequently the highest indoor temperatures will result from closed windows facing east and west.

Natural Ventilation. In North America refrigerated air-conditioning has become the norm for office buildings. This requirement was partly responsible for the sealed building envelope which, in turn, contributed to the "sick building syndrome". Occupants now are more and more asking for more fresh air and openable windows. In countries such as Britain and Germany, assisted ventilation and cooling is becoming more acceptable or in some cases, preferable, to mechanically refrigerated ventilation. Natural ventilation can replace or supplement forced-air systems and avoid or reduce energy use required to operate such systems. Natural ventilation enables building occupants to influence their microclimate and thereby enhance their sense of well being. Not only will natural ventilation improve indoor air quality, it can provide cooling, all by passive means. In order to reach its maximum potential, natural or passive ventilation must rely upon a balance of many building components and aspects such as orientation to sun and wind; geometrical configuration; window size, location and details; and interior layout.

Displacement Ventilation The principle of displacement ventilation is based on fresh cool air introduced at low velocity at or near floor level becoming warmed by occupant and equipment-generated heat and rising. The air gradually mixes and becomes tempered as it rises and collects against the ceiling where the stale air is exhausted. The standard North American technique is to introduce fresh air through ceiling diffusers at relatively high velocity. This fresh air is intended to mix fully throughout the space and then be exhausted either at the ceiling or floor. The advantages of displacement ventilation over standard techniques is that it provides a more selective way of removing stale air and pollutants from their source than does a full mixing of fresh air throughout the space. Less air mixing is involved therefore less fresh air is needed and less energy is used to run the HVAC system. Tempering the air in winter time will alleviate the discomfort to occupants' feet that might otherwise be caused by cool air.

Thermal Chimneys. Thermal chimneys function on the same principle as stack effect: cool outside air displaces warm inside air, creating an upward movement of air within the chimney by thermo siphoning. In the mid 1990's a number of buildings were built in Great Britain which articulated thermal chimneys as a design feature (Queen's Building at DeMontfort University, Ionica Building). In one building (Lloyd's Register of Shipping Headquarters) a curved roof rises toward the thermal chimneys to accelerate air movements which create aerodynamic suction and enhance the stack effect.

Evaporative Cooling. This strategy is most practical in arid regions and is dependent on availability of water. It is comparable to a forest grove which cools the ambient air by transpiration. Cooling is achieved by absorption of heat during the change of state from water to vapor. Evaporative cooling using roof ponds will limit usage to single story buildings or the top floor of multistory buildings. Passive cooling also can occur with soil covered construction. The soil provides insulation against solar gain and provides cooling by evaporation of soil moisture.

Nocturnal Ventilative Cooling. Nocturnal ventilation cooling relies upon thermal mass to act as a heat exchange medium. Cool night air is forced, either by fans or nocturnal wind, over the thermal mass which becomes cooled when it transfers its stored heat from daytime to the night air. This strategy is often used in combination with other strategies and works best when the ambient daytime and nighttime temperatures have a big difference such as 30 C. daytime to 20 C. or lower, nighttime. Nocturnal ventilation cooling may not be completely effective and must be supplemented by other means of cooling. When using nocturnal ventilation the desire is to keep the building mass cool as long as possible during the daytime.

Radiant Cooling. Dew formation on grass is caused by radiative heat loss to the night sky and is a demonstration of the effect of radiant cooling. Radiant cooling which relies on clear night skies for cooling the building roof mass also has been successfully used. Heat is transferred from the high-mass roof to the sky by infrared radiation and to a lesser degree by convection. During the daytime the roof must be insulated from direct solar gain and hot ambient air so that only the building interior heat is absorbed. "Skytherm" is a commercially available system of radiant cooling involving a flat structural steel deck with water-filled plastic bags and movable insulating panels over it.

Daylighting. Artificial lighting is a major energy user, particularly in an office building. Fortunately, daylighting can replace or supplement artificial lighting for a major part of the daytime and thereby dramatically reduce electricity consumption. Additional savings result from the lower cooling load made possible by the reduction in heat-producing light fixtures. The cooling component is obvious when consideration is given to the inefficiency of incandescent lights or even fluorescent lights with high-efficiency electronic ballasts. From 60% to 90% of a lighting system's electrical energy is converted to heat.

Light Shelves. Horizontal surfaces adjacent to windows will reflect daylight onto the interior ceiling surface. Light colored or polished top surfaces on the shelves will increase the amount of reflected light and adjustable shelves can ensure maximum penetration depth if the adjustment is coordinated with the sun's altitude. Light shelves may be positioned on the exterior or interior side of the window and the depth of penetration can be calculated based on the simple equation: angle of incidence equals angle of reflection. An added benefit of a light shelf is that it also functions as a sunshade. Exterior adjustable louvres can serve as sunshade, sunscreen or light shelf as required.

Light Shafts. Light shafts, when used primarily to enhance daylight penetration into interior spaces, are limited by the economics of the shaft space used. For that reason light shafts are used mostly in low buildings unless combined with either passive or active solar collector and distribution systems which will permit effective use of narrow floor openings. For the renovation of Thresher Square building in Minneapolis, Minnesota, a passive solar optic reflector on the roof directed daylight into a long narrow clerestory window that beamed the light down, via a second reflector inside a tall narrow light shaft, to reach all six floors.

Skylights. Skylights are overhead apertures which can provide daylight to positions deep within a building that cannot be effectively served by windows in perimeter walls. Skylights may be in the simple form of a flat glazing over an opening in a flat or sloped roof or the more complex form of vertical or sloped glazing, generally combined with reflecting surfaces as with 'sawtooth' skylights common to industrial buildings. Flat skylights have a major disadvantage because solar transmission peaks in the summer, increasing cooling loads, and is at a minimum in the winter, exactly the opposite of what is needed for good annual energy performance. Protruding skylights such as bubble or pyramid types will intercept some additional low altitude sun if the glazing is of the diffusing type. Lighting, geometry, color and surface textures are important considerations in determining the proportion of visible light striking the skylight that actually enters the interior space.

Atria: Atria originated as open central courts but now are commonly roofed over with transparent glazing. They are also placed along the side of buildings or used as a connection between two or more separate buildings. In addition to allowing more daylight into building interiors atria can act either as a solar collector or a thermal buffer depending on its position relative to the sun and building and can be used for natural ventilation.

Holography. Holographic film incorporated as a window component can increase daylight penetration. Sunlight striking the film can be diverted from its normal course and redirected to the ceiling where it will provide a large area of diffuse full-spectrum light. Holographic glazing is also capable of redirecting sunlight from varying azimuths, e.g. morning and afternoon sunlight, onto a desired surface. Similar angle-selective glazing include patterned glass, lamellae, laser-cut panels and oriented microstructures.

Transparent Insulation. In addition to its thermal insulating characteristics, transparent insulation allows passage of daylight in translucent form. There are four typical structures of transparent insulation. Two of these: laminated and foam structures experience heavy light transmission losses from multiple reflections and are therefore less than ideal for daylighting purposes. Honeycomb and homogeneous structures are the most promising for combining daylighting with insulation in large apertures. The honeycomb structured insulation panels resemble bundled minute thin-walled glass tubes set at right angles to the surface of the panel. Since the walls of the tubes are parallel to the main direction of incident light, an enhanced daylight penetration is indicated. An example of homogeneous structured insulation is aerogel, a microporous solid fabricated from silicon oxides.

High Performance Glazing. High performance glazing utilized in windows and skylights not only permit the penetration of daylight but improve the ability of an opening of controlling thermal transfer by heat loss and heat gain with minimal reduction of visible solar light. High performance glazing controls heat loss by means of low-emissivity (low-e) coatings and inert gases sealed in the spaces between multilayers of glass or plastic film which boost their thermal resistance above the R-2 of standard insulating glass. Low-e coatings help control radiation, inert gas helps control convection within the spaces and advanced edge design can help control condition.

Super-Windows. Super-windows are high performance glazing set in frames of minimal thermal conductance, typically achieving a thermal resistance from R-4 to R-6 for the entire window assembly, not just at the center of the glazing. When switchable glazings are utilized as a component, the term "smart windows" is also used to describe super-windows that seemingly adjust on their own to varying thermal and lighting conditions. Prototype super-windows now can gather more thermal energy than they lose over a 24-hour period even in winter time. These windows can outperform an R-19 insulated opaque wall even on the north side. It is a realistic expectation for the future that cooling-dominated structures such as office buildings will be clad with glass curtain walls that reduce the energy loss to such a low level that perimeter heating will no longer be necessary.

Earth Sheltering. Earth sheltering utilizes the insulation effectiveness of soil. The effectiveness will vary depending upon the compaction or density, type and moisture content. Earth sheltering can take the form of earth berms against exterior walls, roof sod and totally buried structure. Of relevance to the last form is the fact that below about 26 feet the temperature of the surrounding earth remains stable at 50 degrees Fahrenheit.

Earth-to Air Heat Exchange: Air flow through earth cooling pipes has been tried experimentally in both residential and commercial buildings. Heat is transferred to the earth by conduction. Practicality of this cooling technique for energy conservation is not yet proven. In a house in Florida a 24-inch corrugated galvanized steel culvert was installed as a closed loop earth-tube heat exchanger with an in-line centrifugal blower used to move the air. Because of the high humidity prevalent in Florida, condensation and bacterial growth was of concern. It was found that heat transfer was most effective in the first 50-diameter length of pipe and with 20%

soil saturation. In Suwon, Korea, at the Daewoo Institute of Construction Technology, a 100-metre long buried pipe was used to draw air from a forest grove and empty into a south-facing atrium.

Double Envelope: Double envelopes refers to exterior walls with an inner and outer glazed skin. The amount of separation and extent of compartmentalization of space between the skins will affect both the resistance to heat conduction and heat convection within the cavity. The type of glazing will affect heat radiation primarily. Although double envelope strategy has been employed since the early 1980's in buildings such as Occidental Chemical Centre in Niagara Falls, N.Y. and Enerplex North in Princeton, NJ it wasn't until the late 1990's that double envelope was used in high-rise office towers such as Commerzbank in Frankfurt and RWE in Essen, Germany. Double envelopes can utilize solar heat gain in winter as well as reduce the cooling load in summer. This is possible partly by reducing solar radiation and partly by natural ventilation due to chimney or stack effect between inner and outer skins. Control of solar radiation is achieved by adjustable louvers within the cavity between the two skins. An additional advantage offered by the double envelope is elimination of infiltration and exfiltration by control of air pressure differences between the cavity space and building interior space. Dependent on the height of the compartments within the cavity, double envelopes offer the opportunity of natural ventilation for high-rise buildings. However, care must be given to isolate naturally ventilated spaces from elevator shafts and similar strong stack-effect contributors.

Trombe Walls (Solar Walls). Trombe walls rely upon solar energy as their source of heat. The heat storage element or collector is a heavy masonry wall, usually a component of the building's structure. Sunlight in the form of short wavelength radiation passes through a transparent shield, such as glass, and is converted to infrared heat energy and absorbed by the heavy masonry wall. By conduction and convection the air in the space between the collector and transparent shield becomes heated and may be ducted to the interior building space when needed. An insulation curtain or blanket is lowered at night, to reduce heat loss through the transparent shield. Low emissivity film or transparent insulation would be effective in place of the night insulation curtain.

Rock Storage. Rocks placed in buried chambers or under concrete slabs on grade have been used as thermal storage media in an air-tight and waterproof containment. An alternative approach is to use heavy-walled concrete pipe for thermal storage. In all cases air is forced through the storage element by fans and heat is transferred to the rock or pipe walls. When unconditioned air is passed through it will absorb heat and in turn will heat the building interior space. The opposite effect, that is cooling instead of heating storage can be achieved by passing cool air over the rock or pipe. The rock or pipe will transfer its stored heat to warm the cool air and, in its resultant cooled state, the rock or pipe will absorb heat from warm unconditioned air when cooling of such air is wanted. Moisture condensation and odor generation in the rock bed must be considered and avoided.

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