A Study Of The Transwall System As A Multi-Use Architectural Element

by

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Chapter I

INTRODUCTION

1.1 PREMISE

The Transwall system, proposed and developed by Fuchs, McClelland and their colleagues, combines some characteristics of the direct gain and thermal storage wall systems.[1] It fulfills the function of a passive heating device as well as an architectural element - the window. The significance of the transwall system, in the author's opinion, lies in its expression of technologies in an architectural way. Passive solar systems designed for human comfort should not be limited in the narrow term of thermal comfort. They should also be an integral part of architecture in terms of aesthetic, spatial, emotional, and functional senses. Along this direction, the author sees several opportunities to expand the uses of the transwall by modifying it into a multi-use architectural element.

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[1] Fuchs, R. and McClelland, J. F., "Passive Solar Heating Of Building Using A Transwall Structure". Solar Energy 23, 1979, pp.123-128.

1.2 OBJECTIVES AND JUSTIFICATION

Solar heating and cooling systems, virtually ignored in the recent past because of economic infeasibility, are becoming increasingly attractive as fossil fuels costs continue to rise. Although the current initial investment of passive solar heating and cooling systems is generally high, increased technological advances and mass production of solar equipment should alleviate numerous economic problems in the foreseeable future.

At present, solar designers are much too concerned about the cost effectiveness and performance of solar products. Thermal comfort (a physical and psychological sensation determined by body senses and perception of environmental temperature)[2] is an element of human comfort which is even more important than a low utility bill. Currently, most solar systems are designed as functional elements (like plumbing) rather than as architectural elements. They can be designed so that they not only fulfills physical function, but also enriches the living environment psychologically as windows and fireplaces do.

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[2] Howell, W., "The Psychological Consequences of Energy Conservation". Department of Psychology, Rice University, Houston, Texas.

Sara Balcomb, Vice-Chairman of New Mexico Solar Energy Association, has pointed out that a very much neglected aspect of solar design is aesthetics. Too many solar homes have been designed to function well, with little, or at best, secondary thought to appearance (either exterior or interior) or to the living functions of the homes as opposed to the heating functions.[3] Interview research conducted by Solar Energy Research Institute also confirms that the passive solar residential user does experience drawbacks which are directly related to the interior design aspects of the space : the lack of aesthetic appeal, glare control, textile deterioration, the poor livability of the interior environment, etc.[4] A solar house is still a home which should be a joy to live in : comfort, convenience, economy, aesthetic, and a developing sense of being in tune with our natural surroundings are important. As Paul Davis, associate professor of English at the University of New Mexico, wrote, "To know once again the feel of the earth's changes, the rotation from season to season, from day into night and night into day. To know the luxury of December sun, to learn again the spiraling lines of light scribed by the sun

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[3] Balcomb, S., "The Solar Consumer - Living In A Glass House". Proceedings of the Second National Passive Solar Conference, Philadelphia, Pa., March 16-18, 1978, Vol.3, pp.778-780.

[4] Ibid.

shifting position through the stages of the year. To feel the chill in a naked night sky in July, the warmth in a February snow."[5]

From the marketing point of view, cost is only one determinant of consumer behavior. Consumer behavior is actually quite complicated and can not be measured solely by monetary units. For example, when buying a house, besides comparing the prices, other factors like surrounding environment, convenience of location, security, availability of amenities, future development, associated free services, etc. are brought into consideration. The same consumer attitude would very likely apply to the marketing of passive solar systems. Therefore in addition to the cost and performance one should be aware of the impacts of other factors like comfort, aesthetics, flexibility, multi-use, etc. on the marketability of the system. The cost of the modified transwall system is undoubtedly higher than the original one. However, the additional features of the modified system help to diffenentiate it from the original version as well as other passive systems, and thus would create a market of its own.

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[5] Davis, P., "To Air Is Human : Some Humanistic Principles In The Design Of Thermosiphon Air Heaters". Passive Solar Heating and Cooling Conf. and Workshop Proceedings, Albuquerque, New Mexico, May 18-19, p.45.

The author has made a survey of the monthly average daily temperature of 81 cities in North America based on the information in Mazria's The Passive Solar Energy Book.[6] The result shows that 63 of them have a monthly average daily temperatures between 63 F and 77 F for more than three months of a year. This means that more than 77% of the cities surveyed require no or very little cooling or heating for at least 25% of a year. What can a passive solar system do for us during this three month period? A multi-use passive system which provides services to its user all the year around would be desirable to maximize utility.

1.3 SCOPE OF STUDY

Some of the author's ideas in this thesis are based on the concepts and findings of other passive systems while others are ideas of his own. Owing to time and financial constraints, it is difficult for the author to put his ideas on trial and measure their workability in reality. Therefore, in this thesis, the author has no intention of presenting detailed information about performance efficiency, applicability and reliability which would certainly require further experimentation and field testings. Mathematical illustrations concerning conceptual applications of ideas

[6] Mazria, E. M., The Passive solar Energy Book. Emmaus, Pa., 1979, Appendix G, pp.386-397.

will be based on simple equations provided by Weller and Youle in their book: Thermal Energy Conservation - Building and Services Design. Assumptions are provided to simplify calculation. In the sub-section concerning the modified transwall as a cooling device, the author will only illustrate how the system helps to stop outdoor heat, the major heat source in summer, from entering the interior. The scope of this study is limited to the preliminary and exploratory stage with the primary purpose being to arouse awareness of multi-use passive solar systems and of the need of human comfort.

In this thesis, the author will review the concepts of current passive solar systems and those of the transwall system. The ideas of the modified transwall are then presented which suggest that a transwall could be used :

1. as an adjustable thermal mass;
2. as a cooling device;
3. as an interior design element;
4. as a component of convertible greenhouse and living space;
5. as a shading device.

Conceptual applications of ideas and design guidelines will follow. Finally, the potential problems and limitations as well as the potential benefits of the modified transwall system will be discussed.

Chapter II

REVIEW OF PASSIVE SOLAR CONCEPTS

The definition of a passive solar system is a heating or cooling system in which thermal energy flows by natural means. In a purely passive system, there are no pumps, fans or other mechanical devices used to transport thermal energy from where it is collected to where it is needed.

The integrated nature of passive solar systems permits the design of a variety of collector concepts. The imagination of the designer and builder is the only limiting factor. Passive systems can be as simple as a window or greenhouse. Passive solar energy systems may be grouped into three generic types: direct gain, indirect gain and isolated gain systems. Currently the most widely used passive systems which have some influences on the ideas of the modified transwall are direct gain, thermal storage walls, thermal storage roofs and attached sunspaces. These systems can be applied in a wide variety of building applications as separate or combined systems.

2.1 DIRECT GAIN

In a direct gain system, as shown in fig.1, solar radiation shines through windows directly into a living space. One simply has an expanse of glazing, usually double-pane glass, facing south. Nearly all of the solar radiation entering the room is immediately converted to heat.[7] Thermal mass for storing excess solar heat is most effective when located in direct exposure to the sunlight (as in a concrete floor). To reduce heat loss and, therefore, to increase overall thermal performance, insulation may be applied at night to the glazing, either inside or outside. This is a sort of live-in solar collector. The characteristic sun angles result in a good situation since the south face is exposed to a maximum amount of solar energy in the cold winter months when the sun angles are low and a minimum amount of solar energy in the summer when the sun angles are high. So the basic seasonal characteristic or control of heat gain is automatic.

Glazing is a relatively inexpensive form of solar collector and is widely available and thoroughly tested.[8] It serves multiple functions, allowing solar radiation to enter

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[7] U. S. Department of Energy. Volume 1: Passive Solar Design Handbook - Passive Solar Design Concepts, Washington, D.C., 1980,p.A-14.

[8] D.O.E., Passive Solar Design Concepts, p.A-24.

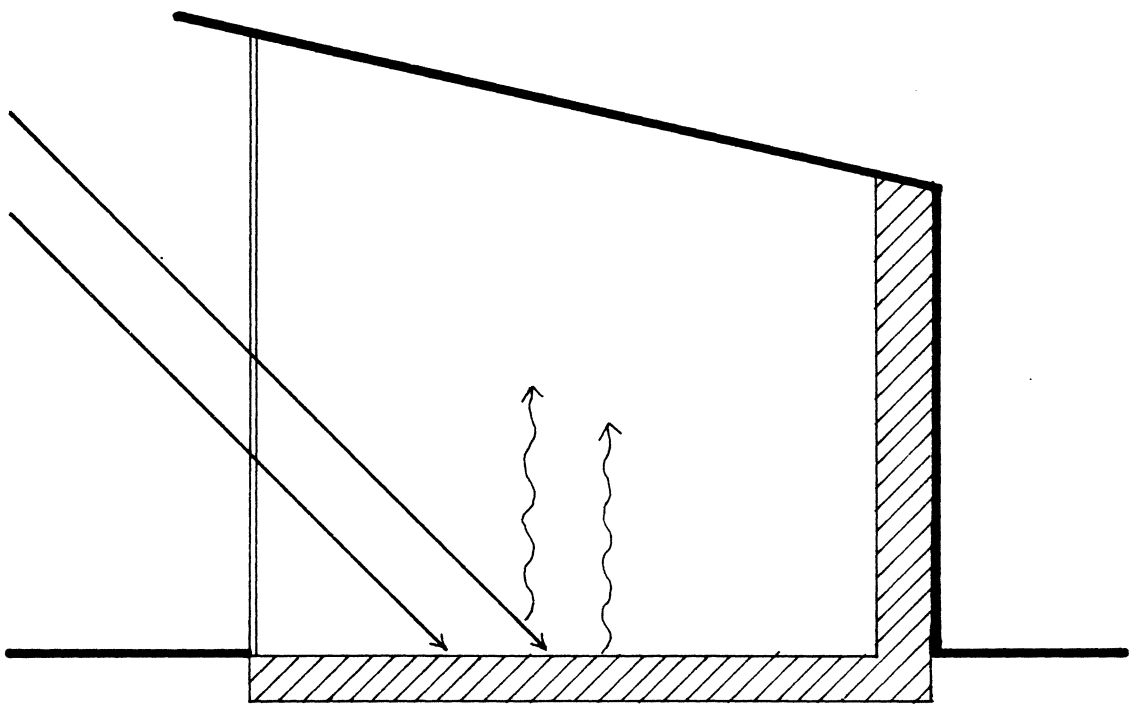

Fig.I Direct Gain

the building while also admitting natural lighting and providing visual access to the outside. Direct gain is the simplest solar energy system to conceptualize and can be the easiest to build. In many instances it is achieved by simply relocating windows.

However, the large glazing expanses of this system can result in too much glare during the day and loss of privacy and heat at night. Ultraviolet radiation in the sunlight will degrade fabrics and photographs. Also, large amounts of thermal mass, which is expensive, are required to achieve significant energy savings.[9] Even though direct gain has the worst overall performance compared to transwall system and thermal storage walls,[10] however, the author sees that direct gain has its own merit in the way that it has a higher performance in space heating.[11] If its higher rate of heat gain is utilized while its higher rate of heat loss at night could be reduced, it would become an efficient passive solar system. This idea will be employed to modify the existing transwall system.

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[9] D.O.E., Passive Solar Design Concepts, p.A-25.

[10] Fuchs, R. and McClelland, J. F., "Passive Solar Heating Of Buildings Using A Transwall Structure". Solar Energy Journal, Vol.23, 1979, p.126.

[11] Mazria, E. M., p.222.

2.2 THERMAL STORAGE WALLS

A "thermal storage wall" passive system (or indirect gain) is located between a glazing wall and the space to be heated, as shown in fig.2. The heat reaches the room by conduction through the storage wall or by air circulation through vents at the top and bottom of the wall. At present there are two general types of thermal storage walls. On employs heavy masonry material approximately one foot thick. The outside surface of the wall painted a dark color, is heated as the sun irradiates it. The masonry concept is frequently called the "Trombe wall". The second general type of thermal storage wall employs water instead of masonry materials. Water absorbs the heat, and heat radiates directly to the room. Although both the masonry and the water wall concepts provide solar flux absorption, storage, and distribution, the masonry wall experiences greater temperature variations because the thermal energy is transferred into and out of the wall by conduction, and not by convection as in the water wall. A water wall has the ability to absorb heat quickly enough to keep the surface temperature relatively cool during the daytime, while a masonry wall (which transfers heat to its interior slowly can reach surface temperature of 130 deg.F.[12] The masonry, therefore, re-

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[12] Mazria, E. M., p.170.

quires greater mass than the water wall because of the difference in specific heat capacity of the two materials.

Generally speaking, thermal storage walls do not have problems with glare and ultraviolet degradation of fabrics. Temperature swings are lower than those of direct gain systems.[13] The time delay between the absorption of radiant energy by the surface and the delivery of the resulting heat to the space provides warmth in the evening when most residences need it. However, this system requires two south walls, a glazed wall and a mass wall. Massive walls which occupy valuable space within the building are costly and are not generally used in modern residential construction. Insulation is also required at night in cold climates to reduce heat loss to the outside from the warm wall through the glazing.[14]

Direct gain systems (double glazing) can transfer two times as much solar energy for space heating as the thermal storage wall. This space heating ratio will be used by the author to make the transwall more adjustable to changing seasons.

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[13] D.O.E., Passive Solar Design Concepts, p.A-27.

[14] Ibid.

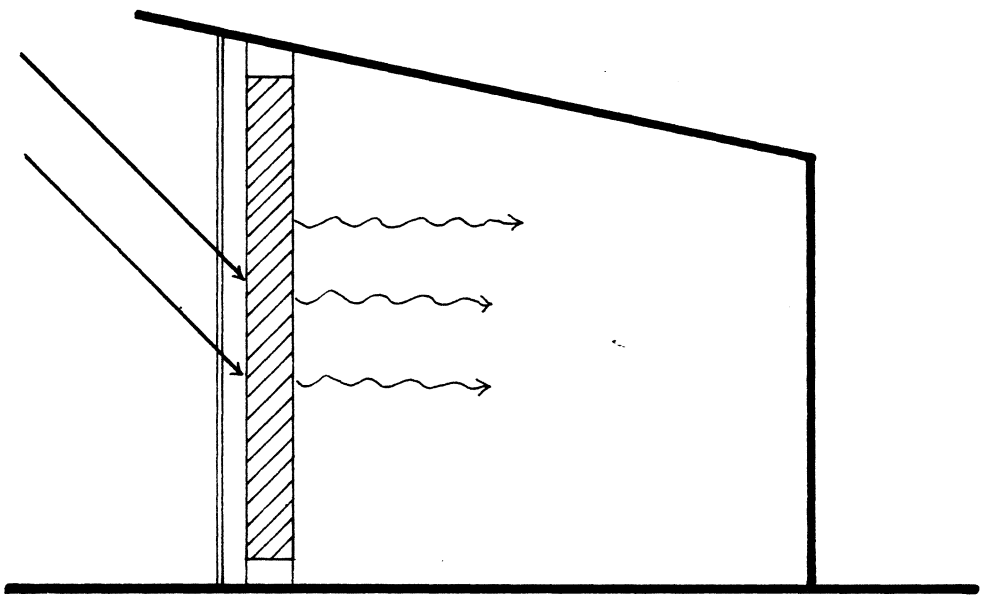

Fig.2 Thermal Storage Wall

2.3 THERMAL STORAGE ROOFS

Another type of passive system is the roof pond in which the thermal storage is in the ceiling of the house, rather than in the south wall, as shown in fig.3. The thermal storage takes the form of large clear vinyl bags filled with water. The water bags are usually placed inside a black water-proof liner on an uninsulated metal roof deck. In this case, movable insulation is required because the sun angles are altogether wrong. The sun provides abundant input in the summer and not very much in winter. However, by using movable insulation, a good cooling system can be obtained by utilizing night-time re-radiation. There are other variation on the system, mostly in the form of different types of water containers, insulating systems, and roof pitches.[15]

Compared with many passive systems, the heating and cooling effects of the thermal storage roofs are more uniformly distributed throughout the building. This system can eliminate glare and degradation problems. However, the heavy weight of thermal mass above the ceiling might be psychologically unacceptable and structural support for the heavy mass can be costly.[16]

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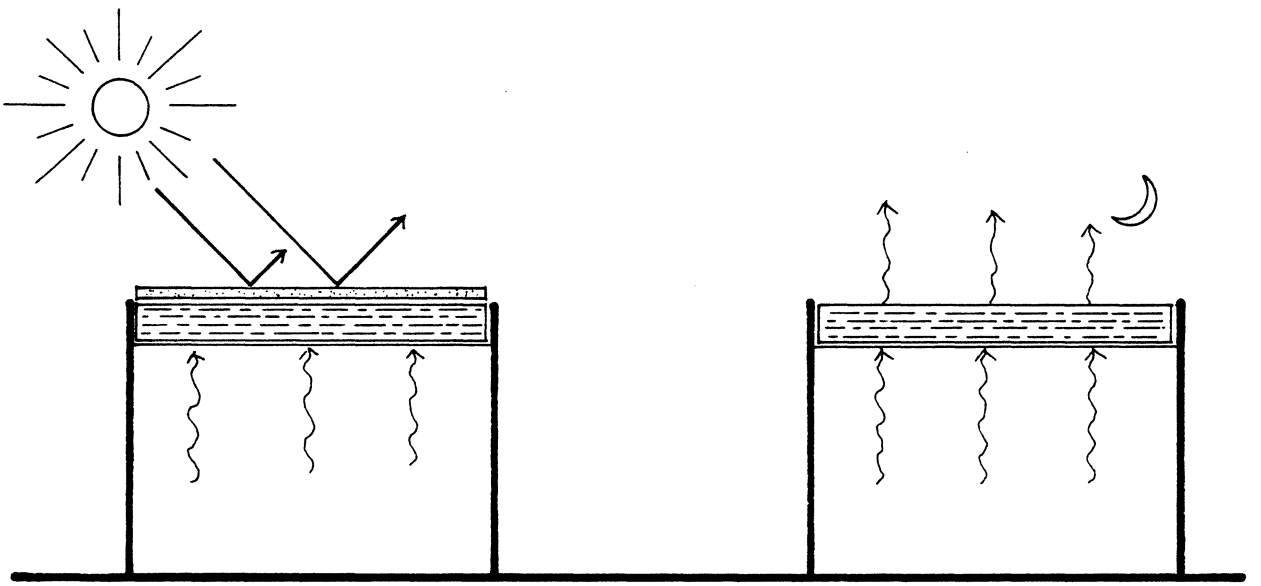
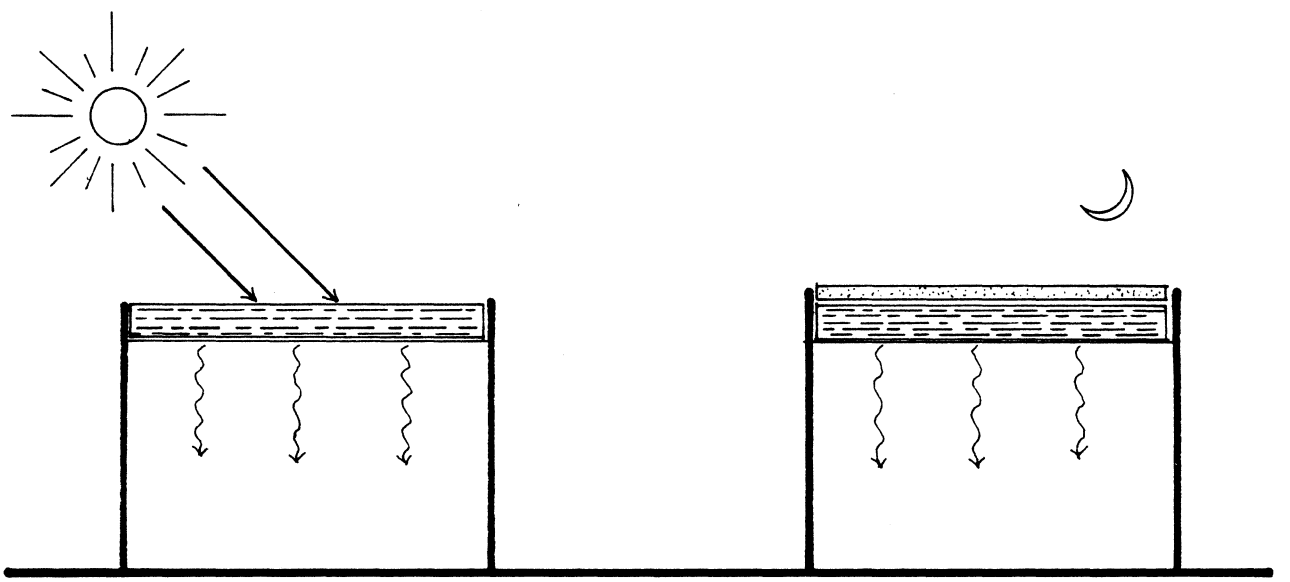
[15] D.O.E., Passive Solar Design Concepts, p.A-21,22.

[16] D.O.E., Passive Solar Design Concepts, p.A-28.



Summer



Winter

Fig.3 Thermal Storage Roofs - Summer and Winter Operation

A transwall system could be regarded as a thermal storage roof in a vertical position without movable insulation. Its large surface area serves as a planar source for both heating and cooling.

2.4 ATTACHED SUNSPACES

Attached sunspace system, which is a mix of the direct gain and thermal storage wall concepts, usually takes the form of a greenhouse or sunroom attached to the south side of a building, as shown in fig.4. One method is to have the sunspace and the living space share an uninsulated common wall which is a high density thermal storage wall usually of masonry or water. The thermal storage wall absorbs the solar radiation and transfers it as heat to both the sunspace and the living space at night. Another way is to vent the sunspace directly into the adjacent living space. The third method is to combine direct venting of the sunspace with the use of a common thermal storage wall. This combination yields a system which is really a vented thermal storage wall system with a greatly oversized air space between the glazing wall and the absorbing storage wall. By this expansion of the air space, it can now be utilized for a variety of purposes, most commonly the raising of plants.

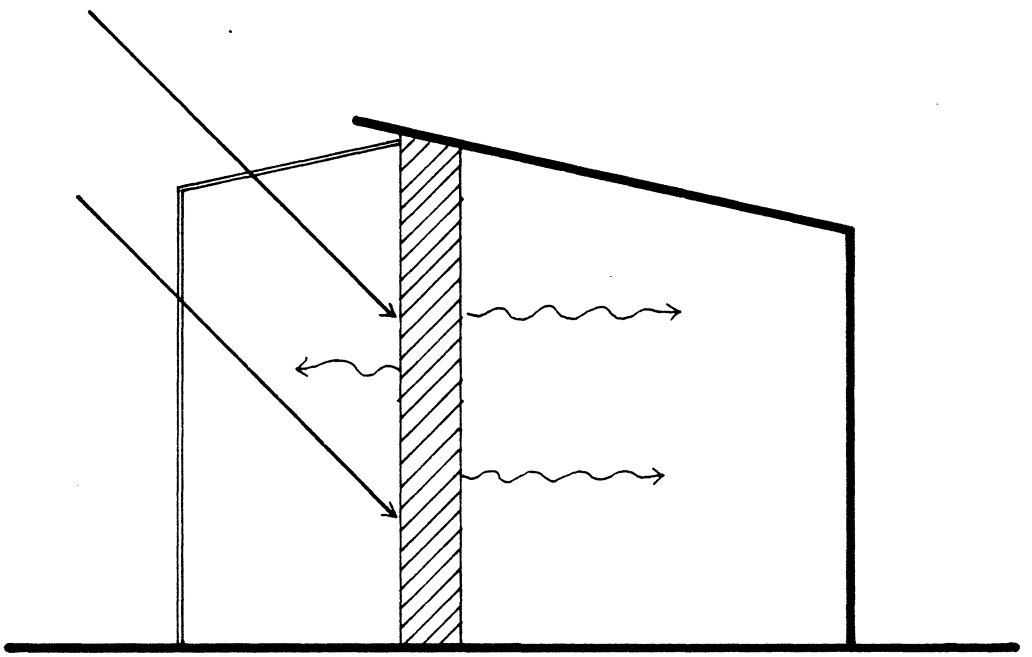


Fig.4 Solar Greenhouse

With attached sunspace, temperature swings in adjacent living spaces are small. This system also reduces heat loss from living spaces by acting as buffer zones. It provides space for growing food and other plants and thus helps bring people closer to nature. However, the performance of sunspaces is difficult to predict since thermal performance varies from one design to another.[17]

The major components of a sunspace are a direct gain exterior glazing wall and a common thermal storage wall between the sunspace and the adjacent room. One of the author's ideas is to make the exterior transwall adjustable so that it could act as a direct gain or as a thermal storage wall to satisfy the requirements of the space, depending on whether it is intended to be a sunspace (greenhouse) or a living space.

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[17] D.O.E., Passive Solar Design Concepts, p.A-29.

Chapter III

THE SCIENCE AND TECHNOLOGY OF TRANSWALL

3.1 INTRODUCTION TO TRANSWALL SYSTEM

The "Transwall" system, proposed and developed by Fuchs and McClelland, has a hybrid character, as illustrated in fig.5, which utilizes the advantages of the two current primary passive heating approaches, the Trombe thermal storage wall and the direct gain system, while minimizing their disadvantages.[18] It is a modular, water-based thermal storage wall placed adjacent to a south facing window. Each glass module that forms the wall assembly absorbs a large fraction of incident sunlight and stores the resultant heat in water contained in the module. The system allows light transmission similar to that of tinted glazing, thus retaining the window functions of exterior visions and daylighting. These features and the reduced weight and space requirements (according to Fuchs and McClelland, by factors of approximately 4 and 2, respectively) of transwall are advantages relative to concrete Trombe wall systems. Transwall attentuates sunlight intensity entering interiors and provides thermal sto-

[18] Fuchs, R. and McClelland, J. F., "A Preliminary Study of Passive Solar Heating Performance and Visual Clarity for a Transwall Structure". Proc. 3rd National Passive Solar Conf., San Jose, California, Jan.11-13, 1979, pp.107-113.

rage. Therefore it reduces glare, photodegradation, overheating, and low mean temperature problems associated with direct gain systems. The transwall system can also be expected to have better performance than most direct gain system in terms of both solar heating fraction and damping of temperature swings.[19]

3.2 TRANSWALL DESIGN AND OPERATION CONCEPT

According to Fuchs and McClelland's design, a transwall module, as shown in fig.6(a)-(f), is envisioned as a panel having two components. These include the module walls which form a containment volume, and a partially absorbing plate where solar energy is thermalized.[20]

The walls of the module consist of two large area transparent acrylic plates that are held parallel, approximately 6-1/4 ins. apart, by a frame. The frame forms a closed volume between the plates and provides structural support when the modules are assembled into a wall. Module specifications were developed through computer simulation and consultation to the following dimensions : 52 in. wide, 23 in. high, and 7 in. thick. Fabricated of acrylic plastic 3/8

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[19] Ibid., p.111

[20] Fuchs, R. and McClelland, J. F., "Passive Solar Heating of Building Using a Transwall Structure". Solar Energy Journal, Vol.23, 1979, p.126.

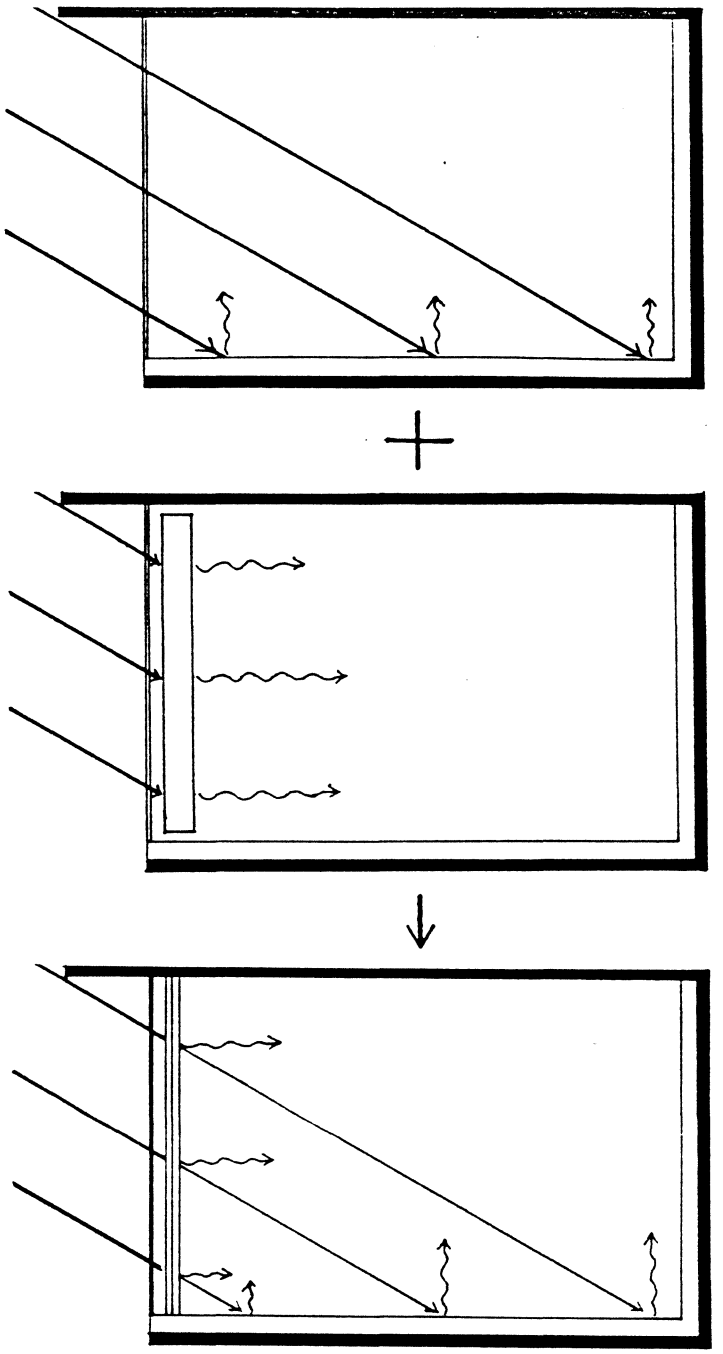

Fig.5 The transwall system incorporates aspects of both direct gain and Trombe wall systems for passive solar heating of interiors. The schematics show solar radiation entering the interior through double glazing and converting to thermal energy as denoted by the wavy lines.

Fig.6a Transwall Modules and Aluminum Support are designed for compatibility with economical mass production methods。 (McClelland, J. F., Passive Solar Journal, Vol.I, No.I, Jan. I982, p.58.)

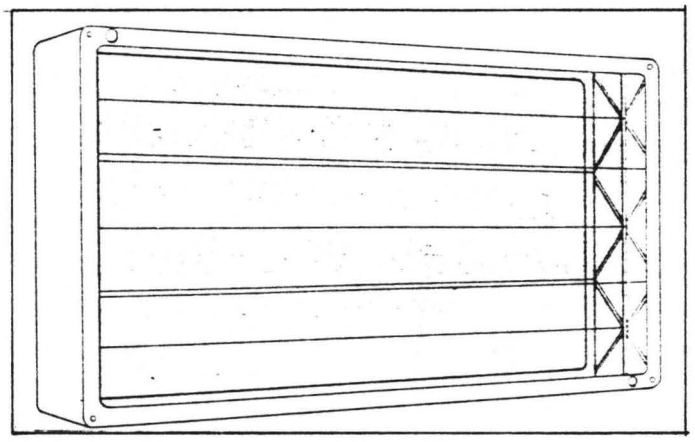

Fig.6(b) Schematic of a Transwall module showing the module containment frame, and semiabsorbing plate.

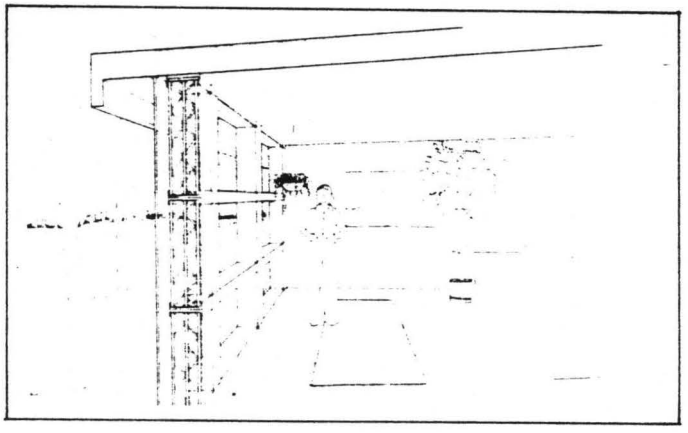

Fig.6(c) Illustration showing a Transwall system installed in a building interior with double glazing between the exterior and the transwall.

Fig.6(b) - 6(f) : Refer to Fuchs and McClelland, "A Preliminary Study of Passive Solar Heating Performance and Visual Clarity for a Transwall Structure", Proc. 3rd National Passive Solar Conference, San Jose, Calif., Jan.II-I3, I979, pp.I07-II3.

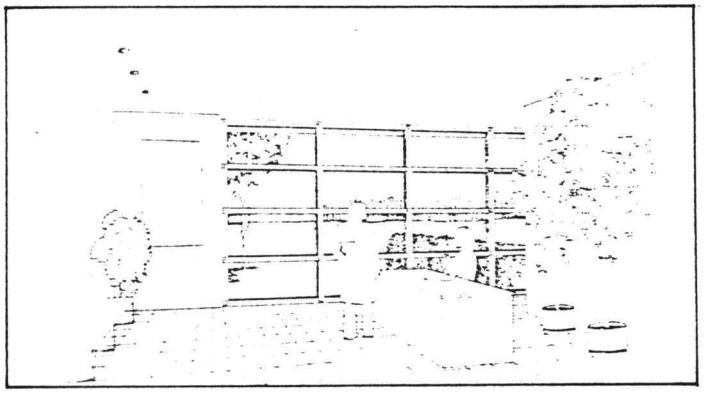

Fig.6(d)

Illustration showing a Transwall system installed in an interior.

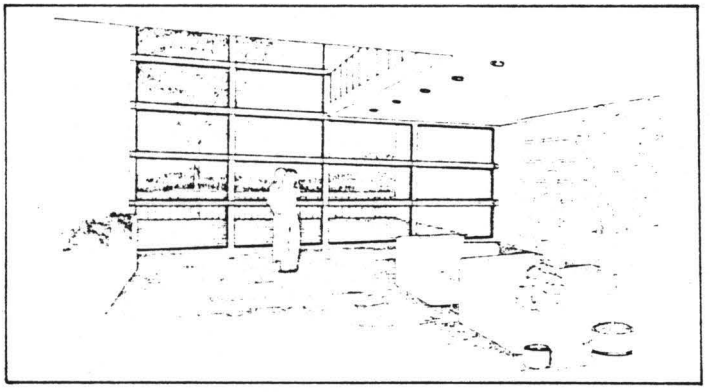

Fig.6(e)

Illustration showing a Transwall system installed in a multi-level interior.

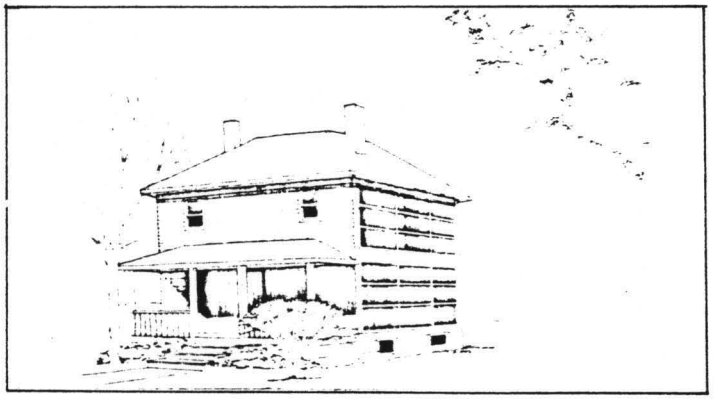

Fig.6(f)

Illustration of a Transwall system retrofitted in an older house.

in. thick, the modules require that three vertial rib braces be cemented inside each plate to prevent bowing under hydrostatic pressure. An absorber plate, located halfway between the two face plates, is supported by pairs of vertical strips cemented to each end plate. An aluminum retainer lid caps each module to prevent movement in the face plates due to hydorstatic pressure and to reduce water evaporation and contamination. Water mass contained within each module is approximately 238 lb. An additive inhibits biological growth inside the modules. This is a standard aquarium construction technique and has provided reliable leak free containment without additional structural reinforcement.[21]

Fig.7 shows a vertical cross-section schematic of a transwall design. In a 6 in. thick transwall, the liquid provides a heat capacity per unit area of 32.4 Btu/sq.ft. deg.F (660 KJ/sq.m. deg.C) which is equivalent to a 13 in. thick concrete wall.[22] Convective heat transfer in the transwall lowers its thermal performance efficiency but can be reduced by a combination of baffles and a gelling agent which increases the viscosity of the water-based thermal medium while still permitting visual transmission. Since

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[21] McClelland, J. F., "New Prototype of Transwall Tested". Passive Solar Journal, Vol.1, No.1, Jan. 1982, p.58.

[22] Fuchs et al., Proc. 3rd National Passive Solar Conf., p.108.

the results reported indicated that a transwall system would perform well even with convection occuring, the use of baffles and gelling agent are considered to be an optional feature.[23]

As reported by Fuchs and McClelland, sunlight incident on the transwall experiences a small initial reflection loss (typically 4%) at the air-to-glass interface before entering the transwall structure. The near infrared portion of the incident solar energy passing through the front plate is absorbed in the first inch or so of water. Approximately 65% of the incident sunlight reaches the partially absorbing plate, where it is variably absorbed, depending on the plate's transmissibility, and, in this case, about 50% of the solar energy is deposited as heat at the center of the storage medium. The remaining visible portion of solar energy (approximately 13% of the incident light) passes through the rear plate of the transwall to the building interior to provide additional solar heating via direct gain.[24] This light also provides interior lighting and a view of the exterior. The solar energy absorbed in the module is thermalized, thus raising the module temperature. Part of this thermalized energy is then slowly transmitted

[23] Fuchs and McClelland, Solar Energy 23, p.123.

[24] Fuchs and McClelland, Proc. 3rd National Passive Solar Conf., p.109.

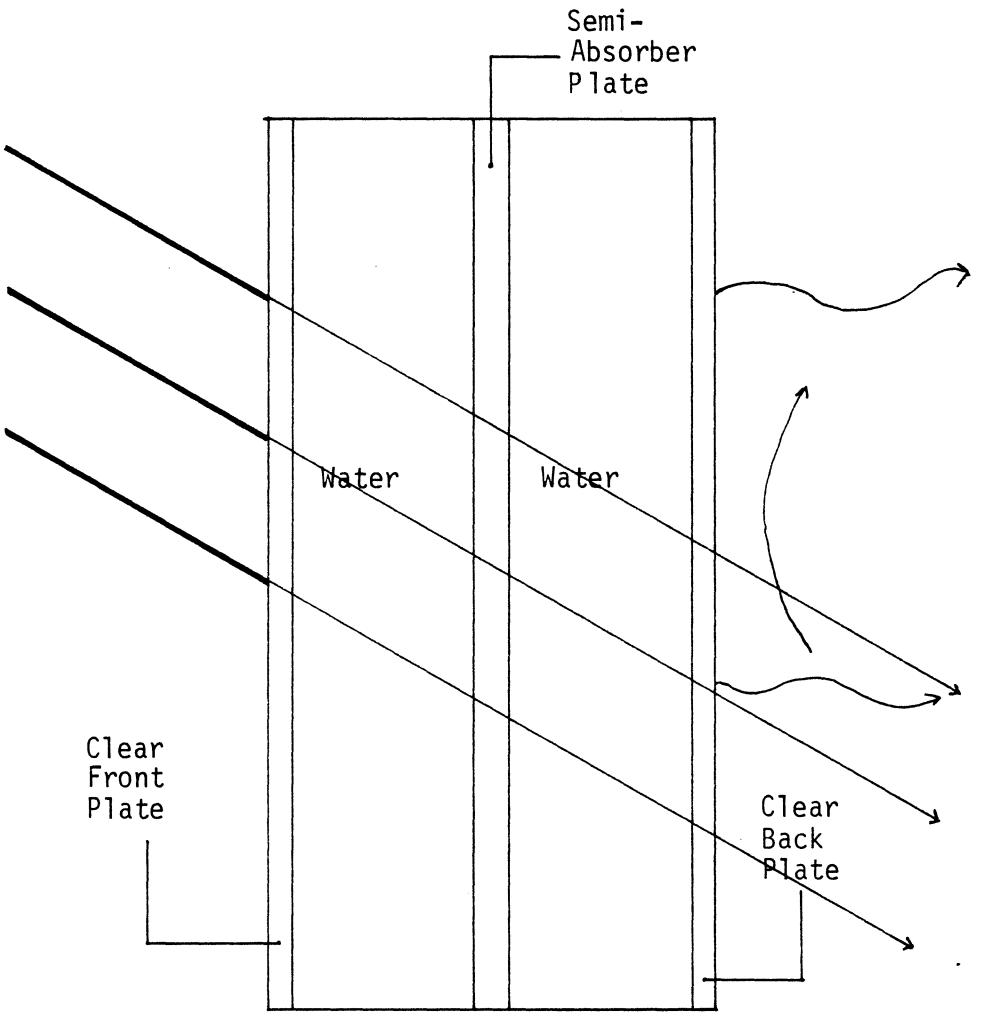

Fig.7 Schematic Cross-Section of the Transwall System, Illustrating Transfer of Solar Energy.

to the room via radiation, conduction and convection and from the rear plate.

From an architectural point of view, transwall overcomes the disadvantages of both Trombe wall and direct gain systems, since it admits light to the room and allows occupants to see through the window with minimum glare, photodegradation, and overheating problems. According to Fuchs and McClelland, the most important difference between the transwall and the conventional thermal storage wall in terms of thermal performance is that in transwall most of the solar energy is absorbed at the center of the wall, not at the front surface facing the windows.[25]

3.3 THERMAL PERFORMANCE

Appendix A summarizes the performance results for the quenched transwall (a combination of baffles and a gelling agent which increase the viscosity of the water based thermal storage medium), unquenched transwall, concrete thermal storage wall with and without air circulation, and direct gain systems. It is evident that the performance of the quenched transwall can be superior to that of the other systems. The unquenched transwall does not perform as well as the quenched transwall but it is approximately as good as

[25] McClelland, J. F., "New Prototype of Transwall Tested". Passive Solar Journal, Vol.1, No.1, Jan. 1982, p.58.

the best competing system, the concrete wall with air circulation.

The transwall is potentially superior because of the relatively low heat loss from the window. During the solar heating period, the front surface of a concrete wall rises to a high temperature (as high as 111 deg.F or 44 deg.C), and this results in a large flow of heat through the window. However, the front surface of the transwall does not overheat at any time (the maximum temperature is 77 deg.F or 25 deg.C) because the solar input is deposited in the interior of the wall. This results in a low heat loss through the window. In the direct gain system there is a relatively large and constant heat flow rate through the window.[26]

The initial testing of transwall investigating its potential impact on a building's cooling load and comfort during the summer months compared to a direct gain system has also been conducted by McClelland and others. The pricipal purpose of their work was to determine if there was an adverse summer impact from the transwall, which is designed as a heating system. According to the results, the average air temperature swing in the transwall room of 7.56 deg.F was 8.26 deg.F less than that of the direct gain room showing that the water is functional as thermal storage in summer-

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[26] Fuchs and McClelland, Proc. 3rd National Passive Solar Conf., p.111.

time. The results also indicated that the temperature of water in transwall cycled through an average daily range of 14.94 deg.F. The average maximium temperature of the transwall room was 79.5 deg.F and the average minimium temperature was 72 deg.F compared to a 86.4 deg.F average maximium and a 70 deg.F average minimium for the direct gain room. If the cooling thermostat was set at 78 deg.F, then the transwall room would have required auxiliary cooling for only 14% of the test period contrasted with 31% for the direct gain room. The transwall test room had an average maximum mean radiant temperature of 80.4 deg.F which is 8.5 deg.F lower than that of the direct gain room.[27] These results suggest that transwall will not adversely affect the cooling load of a building and, with proper management, may be an asset. In ddition to this, the transwall equipped room felt more comfortable during the day with its greatly reduced glare and lower radiant temperature compared to the direct gain room. The only disadvantage noted was that the transwall equipped room did not cool as much in the evening. In part this is due to the test situation which required the sealing of the rooms so that cooler night air could not be used to flush the rooms. It was also found that the addi-

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[27] McClelland, J. F. et al., "Recent Developments in the Transwall System". Proc. 6th National Passive Solar Conf., Portland, Oregon, Sept.8-12, 1981, p.181.

tion of a heat mirror coating on the outer side of the inner pane of glass reduced the auxiliary energy required by 50%. Heat mirror produced a higher predicted performance improvement than R6 movable night insulation.[28]

3.4 POTENTIAL ADVANTAGES OF TRANSWALL

The transwall has all the advantages of a conventional water wall. It is a particularly good application for heat mirror because most of the energy absorbed by the coating would go into storage. The transwall has other advantages associated with architectural, installation, and commercialization considerations. The system requires less space and load bearing capacity than concrete base thermal storage. Water density is 62.4 lb/cu.ft. compared to 140 lb/cu.ft. for concrete, and the thermal capacity of water is 62.4 Btu/cu.ft./deg.F while that of concrete is 38 Btu/cu.ft./deg.F.[29] It may be possible to enhance this aspect through the use of phase change components in the thermal storage medium.[30] The window retains its function in admitting light and providing a view to the outside, but during times when sunlight is directly incident on the window, the

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[28] Ibid., p.182

[29] D.O.E., Passive Solar Design Concepts, p.AP-25.

[30] Fuchs and McClelland, Proc. 3rd National Passive Solar Conf., p.111.

level of illumination in the room is not uncomfortably high (only 13% of the incident sunlight reaches the interior). These aspects allow the transwall to be readily integrated into a variety of interiors. The modular design provides ease of installation, especially in the case of retrofits. Transwall is also attractive from a commercialization point of view because it allows the primary component of a passive system to be manufactured, promoted by advertising, and marketed through a distribution network of dealers.[31] This is an important consideration in advancing the utilization of passive solar energy.

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[31] Ibid., p.112.

Chapter IV

MODIFICATIONS OF TRANSWALL FOR MULTI-USE PURPOSE

4.1 MODIFICATIONS OF TRANSWALL

The transwall system was developed as a solution to some of the problems associated with basic passive solar heating systems. It utilizes the concepts of direct gain and indirect gain systems and achieves a higher level of efficiency and integration than most other thermal storage systems currently designed, as indicated in Appendix A.

The idea of the modified transwall is to expand the use of the original transwall as a multi-use architectural element. There is no intention to improve the performance efficiency of the original design. However, the author feels it is desirable to make it more adjustable to our climates which change all the year around, from day to night, from spring to winter. Moreover, thermal comfort is quite subjective. Its criteria changes as a function of one's mood and indoor activities. The origin of the concepts of the modified transwall is to make it adjustable such that it can be put into use the way one considers optimum at any particular time so as to provide better thermal and human comfort.

Water is a very inexpensive substance in North America. Compared with concrete, common brick, magnesium brick, and adobe, water has the lowest density, and conductivity and the highest specific heat almost five times the others. It is approximately three times more efficient than masonry for thermal storage per unit volume. Another unnoticed advantage of water as thermal storage mass is that its volume can be added or withdrawn very easily and inexpensively. In the case of transwall, water mass in the modules can be changed by adjusting water level of the modules.

At present, transwall resembles a series of water-filled, aquarium-like, glass containers supported atop each other by aluminum frames. The module dimensions have been mentioned in the previous chapter. The author's idea is to join each individual module in the same row by a pipe under the bottom plate. Each module has its own control of water inlet and drainage from the pipe. If the control of a particular module is closed, it becomes independent from other modules in terms of water flow, inward or outward. If the controls of all the modules in the same row are opened or closed at the same time, they would act like one module. One end of the pipe is connected to the water main and the drainage. With this modification, water volume in each module becomes adjustable by simply turning on the water main or the drain con-

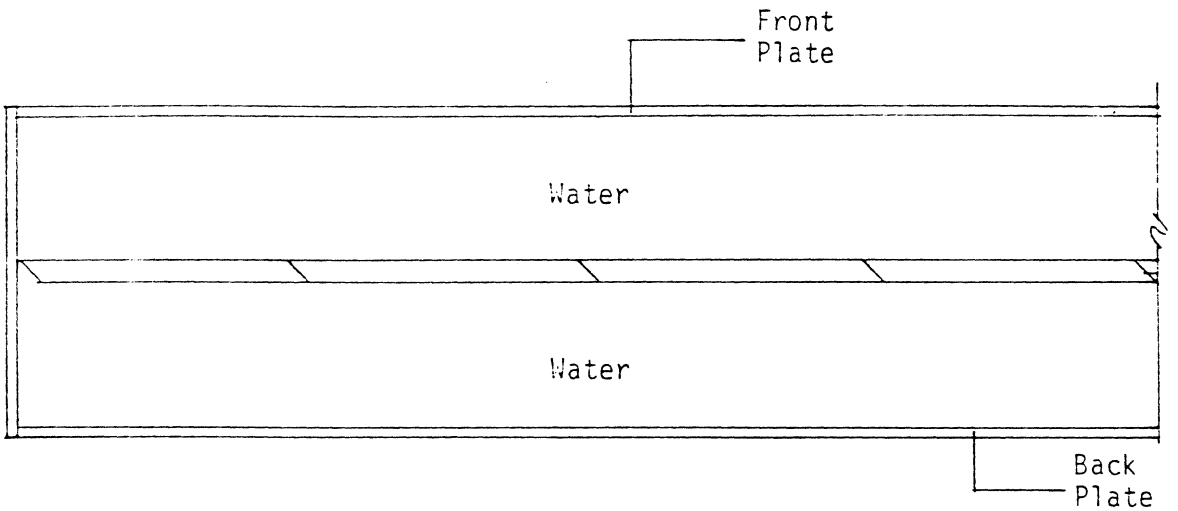
trol. Another modification is to break the absorbing plate of each module into several smaller pieces, the width and number of which is determined by the internal thickness and width of the module, respectively. The idea is to have as few pieces as possible and, at the same time, be able to turn them around inside the module, as shown in fig.8. For example, with module internal dimensions of 52 in. wide, 23 in. high, and 6-3/4 in. thick, in order to be able to turn the absorbing plate around, the width of each divided absorber plate should be smaller than 6-3/4 in. In this case, their width should be 6-1/2 in. so as to allow them to turn easily without touching the outer or inner plates of the module. With this width, the original absorber plate would be divided into 8 pieces. They would now act like movable vertical louvers. For design simplicity, all absorber plates of modules in the same row are under one control and therefore must be turned at the same time and in the same direction through a manual device. A reflective coating is applied to one surface of the now divided absorber plates. During warm summer days, by positioning the reflective surface of the absorber plates to face out, more direct sunlight will be reflected outdoors, thus less energy will be absorbed by the module and enter the room via direct gain. During cold winter days, the reflective surface will be

turned to face inside; then the energy absorbing ability of the module will then be the same as the original transwall. By turning the absorbing plates parallel to the direct sunlight and draining off the water mass of the module, the modified transwall would act more or less as a direct gain system rather than as a thermal storage mass.

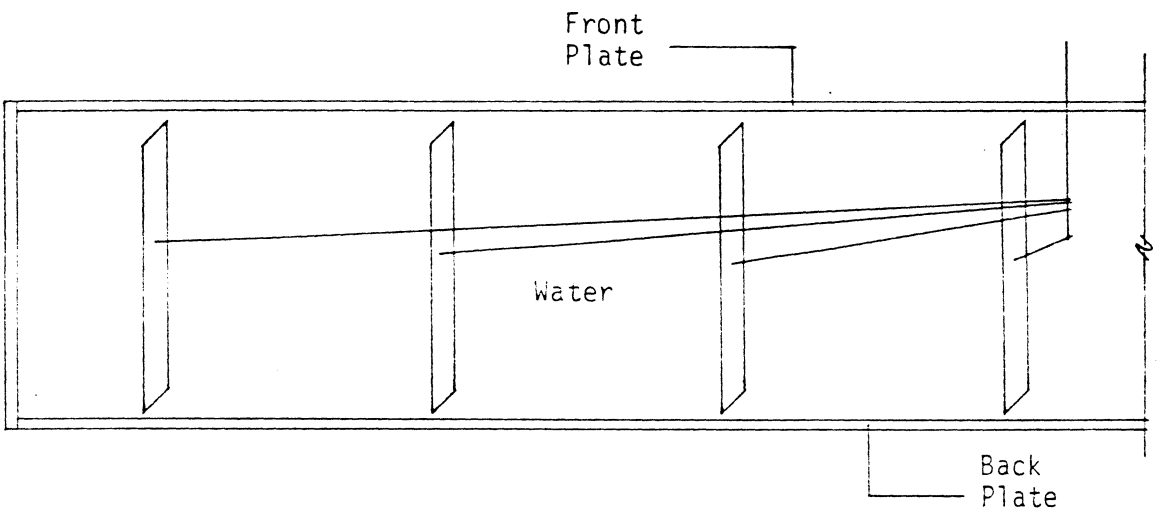
4.2 TRANSWALL AS AN ADJUSTABLE THERMAL MASS

Currently, passive solar systems are all designed with fixed rather than with adjustable thermal storage. Therefore, it would be expensive or troublesome to have them redesigned, once they are installed. Professional passive system designers are all looking for optimum solutions for their designs. However, it is easy to understand that there is no one single optimum solution which can satisfy our changing climatic requirements. The criteria of these optimum solutions is to minimize back up heating and cooling loads and, at the same time, avoid overheating the building based on an annual average. Resident's situation would be much improved if passive systems were able to provide different optimum solutions in response to different climatic changes.

When a thermal storage wall is properly sized, the temperature in a space will remain comfortable throughout much



Absorber Plates in Closed Position



Absorber Plates in Open Position

Fig.8 Schematic Module Plan with Turnable Absorber Plates

of the winter without any additional heating source. However, if a thermal storage wall is oversized, then more heat is transmitted through the wall than is needed, resulting in a space that is uncomfortably warm or overheated. The space would also become uncomfortably warm if outdoor temperature becomes unexpectedly high. Of course, heat can be vented from a warm space to reduce interior temperatures. This would reduce the system's efficiency by disposing of valuable heat in winter. If a wall is undersized, then there will not be enough heat transmitted through the wall, and supplementary heating will be required to keep the space warm.[32] This problem is even more serious when outdoor temperature drops to unexpectedly low. The correct size of a thermal storage wall will always change with climate and space heating or cooling requirements, which are usually a function of indoor activities.

According to Mazria, about 60% to 70% of the solar energy incident on the south-facing glazing of a direct gain system will be utilized for space heating. A thermal storage wall system will transfer about 30% to 45% of the energy incident on the collector into a space. These percentages are largely determined by reflective and absorptive radiation losses through the glazing.[33] The above information suggests that

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[32] Mazria, E. M., p.153.

there exists a ratio of approximately 1 to 2 between direct gain and thermal storage wall. This means that each 1 square foot of collector area (glazing) in a direct gain system supplies approximately the same quantity of heat to a space as 2 square feet of thermal storage wall does. Mazria also recommends that, as a general rule, to provide heat storage for one or two cloudy days, increase the collector area of either a direct gain or indirect gain systems by 10% to 20%.[34] It is quite clear at this point that an adjustable, interchangeable direct/indirect gain system would be better to fit our changeable climates, and the modified transwall is introduced for this purpose. Since the level of water in the modified version is now adjustable, this means that the volume of the thermal mass can also be adjustable. When all the modules are filled with water, the transwall will act as a thermal storage mass only. If the water level is lowered, for example, by 1 foot, and if the clear transwall height is 7 feet, and its width is 10 feet, then instead of having a thermal wall of area 70 square feet, we would have a direct gain system of 10 square feet (1' x 10') and a thermal storage wall 60 square feet (6' x 10'). By employing the ratio of 1 to 2 between the two systems, it

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[33] Mazria, E. M., p.222.

[34] Mazria, E. M., p.226.

would not be difficult to figure out a combination of the two systems to suit the requirement of any particular day. However, in this case, even though the absorber plates at the center of the modules can be opened, the outer and inner plates of the modules will definitely allow less solar energy to reach the interior than conventional direct gain systems. Therefore, instead of having a ratio of 1 to 2 as mentioned by Mazria, it now becomes X : Y. As long as this relationship exists, an adjustable thermal storage mass could work well as a function of climatic changes or indoor activity requirements.

4.3 TRANSWALL AS A SHADING DEVICE

The idea discussed here is not to deal with the heat gain problem through the transwall during warm summer days but to find a means of reducing direct summer glare and at the same time allowing maximum daylighting load and thus internal heat gain. The original transwall only helps to reduce glare by admitting approximately 13% of the solar energy incident on the south-facing glazing regardless of where the sun is. Problem of direct solar heat gain will not be dealt with in this section.

Large solar windows, which are the primary source of direct sunlight in a space, may result in troublesome glare,

create uncomfortably warm and bright conditions for people occupying the space and discolor certain fabrics. According to Mazria, the effectiveness of any shading device depends upon how well it shades the glass in summer without shading it in winter.[35] However, if it is only for the purpose of reducing glare, the effectiveness of any shading device depends upon how well it shades the portion of the glazing where there is direct sunlight without shading the portion where there is no direct sunlight.

The most effective method for shading south-facing glass in summer is with an overhang, which only blocks direct sunlight striking south-facing glazing while allowing natural lighting into interior and an exterior view. This shading device is simply a solid horizontal projection located at the top exterior of a window. The optimum projection of the overhang from the face of the building is dependent upon window height, latitude and climate. However, a fixed overhang is not necessary the best solution for shading south-facing glass since climatic seasons do not correspond to the sun's movement across the sky.[36] A fixed exterior shading device will provide the same shading on September 21 when direct sunlight is unpleasant, and on March 21 when it is

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[35] Mazria, E. M., p.250.

[36] Mazria, E. M., p.254.

welcomed by most people. This happens because the sun's path across the sky is the same on those days. Another disadvantage of such an optimum projection is that one cannot have any direct sunlight in his/her room in a particular day even though he/she would like to have some on some occasions. Adjustable overhangs provide a potentially better solution. They can be regulated seasonally, for example, to partially shade a window in September and then adjusted to admit full sunlight in March. However, these devices may be more expensive to build due to additional hardware. They are also sometimes difficult to design and maintain.[37]

Shading devices, such as roller shades, venetian blinds, drapes and panels, offer ease of operation and maintenance. However, they often eliminate, or severely limit, a view of the outside. Since these shading devices are adjusted either vertically from up to down, or horizontally, they are unable to offer an optimum solution in providing maximum daylight and minimum glare or comfortable direct sunlight. According to the author, in order to shade direct glare and at the same time provide maximum daylighting, shading devices should be able to shade a window by rising up from below rather than hanging down from above, as shown in fig.9. Drapes and panels are often in a position of either closed

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[37] Mazria, E. M., p.254.

or open, therefore they are undesirable in terms of maximum daylighting and outdoor view and minimum glare.

Transwall with adjustable water level can best fit the above requirements, since water always rises from below. Moreover, transwall area filled with water still allows 13% of solar energy, which can also be used for lighting purposes, to enter the space via direct gain.

4.4 TRANSWALL AS A COOLING DEVICE

There are essentially two elements in every passive solar building, south-facing glazing for heat gain and thermal mass for heat storage. These elements, when properly designed, have the potential to provide both heating and cooling in climates with cool or cold winters and warm summers. All solar heating systems are based on storing solar energy within material for a period of time. This is accomplished by heating a material which will store the heat until it is needed. Cooling systems, on the other hand, do exactly the opposite. A substance is cooled, or heat is taken out, and kept that way so it can absorb heat at a latter time. Heating and cooling a space is essentially based on the same concept. According to Mazria, the idea is to keep a temperature difference between the substance and the surrounding

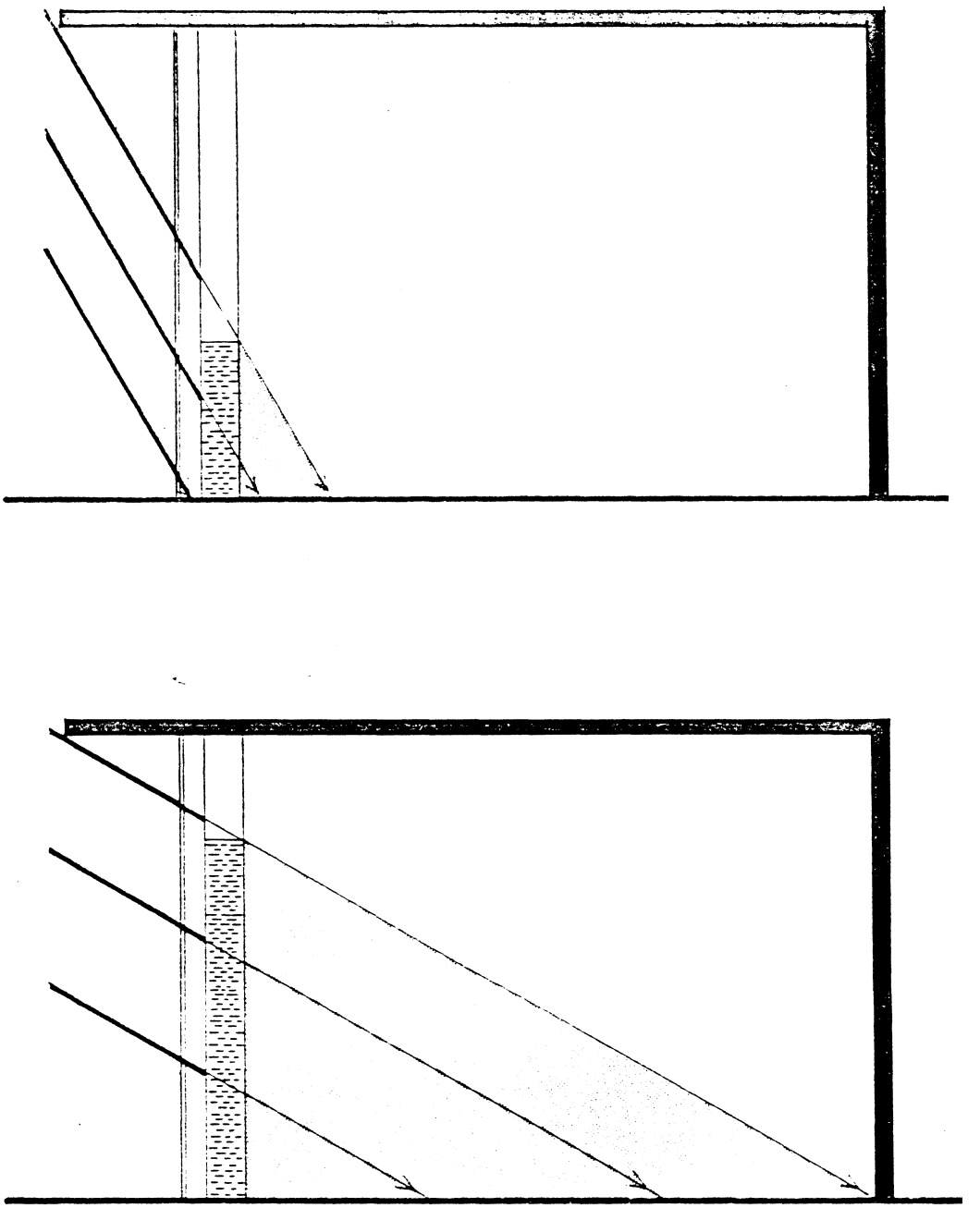

Fig.9 Schematic Diagram of Transwall as Shading Device - Minimizing Glare and Maximizing Daylighting by Adjusting Water Level of Transwall Module.

temperature.[38]

According to Weller and Youle,[39] heat is transferred from a surface to the surroundings or from the surroundings to a surface by convection and radiation processes.

Convection - In this process, heat always moves from warm to cool. The greater the temperature difference between two substances, the more heat will be transferred. As a warm fluid (liquid or air) comes in contact with a cool surface, the warmer molecules transfer some of their heat to the cool surface, become heavier and sink.[40] For example, warm air in contact with a cold glass window induces a downdraft of cool air at the floor near the window.

Radiation - All materials are constantly radiating thermal energy in all directions because of the continual vibrational movement of molecules (measured as temperature) at their surface.[41] In Weller and Youle's book : Thermal Energy Conservation - Building and Services Design, it has been established that all objects emit thermal radiation, the quantity depending on their temperatures. If a warm object is surrounded by a set of cold walls, then there will be ove-

[38] Mazria, E. M., p.26.

[39] Weller and Youle, Thermal Energy Conservation - Building and Services design. Essex, England, 1981, pp.27,28.

[40] Mazria, E. M., p.21.

[41] Ibid.

rall loss of radiation from the object as it is emitting more than it is receiving, and its temperature will drop. Thus when a person (a warm object) is standing in a room with cold walls there is a net radiation loss from the person to the walls.

In the simplest analysis, heat gains through the building fabric are those created instantaneously by direct solar radiation through glazing.[42] This direct radiation falls onto objects and surfaces in a room, causing them to heat up and re-emit heat by radiation and convection. The problems of heat gain and resulting high temperatures in building are best approached by controlling the gains at the source rather than dealing with them when the problem has affected other spaces in the building. The operation of the transwall as a cooling device is somewhat like a roof pond but without movable insulation. In order to fulfill this function, the transwall has to be kept cool or below room temperature so as to provide a cool mass to absorb heat through convection and radiation processes just mentioned. Exterior transwall will absorb heat energy from both outdoors and indoors while interior transwall will only absorb heat energy inside the building. During warm summer days, the water temperature of the transwall will continue to rise as outdoor heat is ab-

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[42] Weller and Youle, p.106.

sorbed through radiation and convection processes. When the transwall temperature rises up to a certain point which is close to or above the indoor temperature, the rate of energy absorption of the transwall will become slow or even negative, in which case, instead of absorbing indoor heat, it will radiate heat back to indoors. Therefore, more heat will be transferred when the temperature difference between the substances is greater, it is always necessary to keep the transwall temperature lower than indoor temperature in order to be efficient as a cooling device. In the cooling mode, the reflective coating surfaces of the absorber plates in the transwall modules should be turned to face out so that more solar energy will be reflected back outdoors rather than absorbed by the absorber plates. This helps to reduce heat gain of the transwall and the interior as well via direct gain, and thus slow down the temperature rise of the transwall. When the transwall temperature is eventually close or equal to that of the interior, the warm water mass of the transwall should be drained. This water can then be stored for domestic hot water use or some other purposes. The modules would then be refilled with cool water from the water main (50 to 55 deg.F in Blacksburg) and the process repeats.

4.5 TRANSWALL AS COMPONENT OF CONVERTIBLE GREENHOUSE/LIVING SPACE

The greatest disadvantage of direct gain systems perhaps, is that there is potential for wide temperature swings indoors. Fortunately, some spaces in buildings can easily tolerate wider-than-normal temperature fluctuations, and extra effort to moderate them may be unnecessary. Examples of such spaces include greenhouse, atriums, sun-porches, and garages. Although in some sense these are still direct gain systems, the term "attached sunspace" designates spaces that fluctuate widely in temperature because of the direct gain of the sun. At virtually all times of the day, the attached sunspace has an indoor temperature higher than outdoor temperature. Such higher temperatures tend to moderate the heat loss from the building. With the sunspace both supplying solar heat and reducing heat loss by acting as a buffer zone, that portion of the building adjacent to the sunspace sees a milder outdoor climate.[43]

Passive designers are increasingly realizing the advantages of embedding the sunspace into the building. By so wrapping the building around the sunspace, some of the advantages (extracted from D.O.E., Passive Solar Design Concepts, pp.C5-210,211) are:-

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[43] D.O.E., Passive Solar Design Concepts, pp.C5-204,205.

1. Heat loss from both the sunspace and building is significantly reduced.
2. Heat is easily transferred directly from the sunspace to a large portion of the building adjoining it.
3. Large amounts of natural lighting can penetrate deep within a building that might otherwise rely entirely on artificial light. Heat loss through the glass into the sunspace is negligible.
4. The sunspace is easily heated by building through the large amount of wall surface common to both.
5. The building itself can be more compact, while the wall area that it has in common with sunspace can provide a feeling of large exterior surface area.
6. Building costs are somewhat reduced compared to sunspaces attached to the south side of buildings. For example, the common walls between the sunspace and the building are less costly than those exposed to the outdoors. In addition, their foundations do not need protection from frost and, therefore, do not need to be as deep. The compact building design results in less perimeter foundation work and less total exterior area.
7. In such a location, the sunspace is more likely to be incorporated as part of an expanded living space.

A greenhouse or sunspace is essentially a partly direct gain and partly indirectly gain system. Since a greenhouse is directly heated by sunlight, it functions as a direct gain system. However, the space adjacent to the greenhouse receive its heat from the mass wall. Basically, sunlight is absorbed by the back wall in the greenhouse, converted to heat, and a portion of this heat is then transferred to the building. In this sense, the greenhouse (embedded or attached) is simply an expanded thermal storage wall system, only instead of the glass face being a few inches in front of the wall, it is now a few feet, or wide enough to grow plants.

The original transwall system is basically a combination of direct gain and indirect gain systems rather than a partly direct gain and partly indirect gain system like a greenhouse. However, upon modification, the transwall can act both as a partly direct and partly indirect gain system or as a variable combination of the two, since a modified transwall can now become a direct gain system if its water content is allowed to be drained. The interior transwall filled with water is equivalent to the common thermal storage wall of a sunspace. Therefore, whenever an embedded greenhouse or sunspace is desirable or required, the exterior transwall can be changed from a thermal storage wall into

a direct gain system by removing its water content and turning its absorber platesto an open position parallel to the direction of sunlight. The interiro transwall acts similarly to the back wall of the greenhouse. When a regular living space is desired or required, the exterior transwall can be changed to a thermal storage wall by refilling the modules with water and turning all absorber plates to a closed position.

4.6 TRANSWALL AS AN INTERIOR DESIGN ELEMENT

The increasing emphasis on refinement of passive solar systems has brought recognition to interior design as an integral part of passive solar architecture. Interior design can be used as a fine-tuning tool, minimizing many of the problems associated with passive solar energy use in residential buildings. A complementary working relationship between the building design and the interior can create a comfortable living environment. Since the average person spends 75% of his or her time indoors,[44] a livable house is very important. In addition, treatment of interior space in solar model homes may be a prime factor in determining sales success.

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[44] Mills, M., Indoor Air Pollution : Recommendations To The Congress, Solar Energy Research Institute, Golden, Co., 1980.

The advantage of the transwall system as an interior design element is that it provides flexibility and choices for its residents. Each person may have different color tastes and interior design requirements for one's home; even for the same person, these requirements change depending on one's age, mood, personality, etc. and also on the changes of external factors like climate, season, current trends, etc.

Colors play an important role in our living environment. Research dealing with relationships between color and behavior is complex.[45] The effects of color on behavior can vary depending on the nature of the three different color dimensions - brightness, hue and saturation; the context in which they are perceived; and the quality of the light illuminating the colors.[46] Color affects perception of not only the warmth of a room but also such qualities as its spaciousness, complexity, characteristics, social status, etc. Moreover, color has psychological impacts on the thermal perception of a space, e.g. green, blue, etc. are regarded as cool colors while red, orange, brown, etc. are regarded as warm.

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[45] Heimstra, N. W. and McFarling, L. H., Environmental Psychology. Belmont, California : Wadsworth Inc., 1974, pp.30,31.

[46] Ibid.

Transwall used as an interior thermal storage as well as partitions can provide a lot of variety for interior design purpose. For use as a visually removable interior partition or as a wall with changeable colors, the transwall will be connected to various drums containing different liquids of the resident's favorite colors rather than to the water main as described in previous chapter. A pumping device will be employed to pump the colored liquids in and out of the transwall whenever the user feels like it. With this modification, the user is not only able to choose the wall colors but can also visually change the volume of the space by filling some of the interior transwall with color liquids and some with water or nothing. And also, by applying different colored liquids to the exterior and/or interior transwalls, one can control the privacy level of one's room. This helps to eliminate one of the disadvantages of a glass house.

Besides using the transwall as an interior thermal mass and as a changeable color wall, the user can choose to use one or several or all modules of the transwall as aquariums for raising tropical fish or growing aquatic plants. These activities also help to enrich and temper the interior living environment. An interior transwall could be used as an interior design element as well as a partition between two

spaces while allowing some visual connection between the rooms so that spaciousness and privacy can be achieved at the same time.

Chapter V

CONCEPTUAL APPLICATIONS OF IDEAS AND DESIGN GUIDELINES

The applications of the ideas of the modified transwall are basically divided into two categories : one is thermally oriented and the other is architecturally oriented.

5.1 THERMALLY ORIENTED APPLICATIONS AND GUIDELINES

5.1.1 Transwall as Adjustable Thermal Mass

The author recommends that the exterior transwall area should be designed according to the average winter outdoor temperature (Jan. or Dec., whichever is the most severe). Even though transwall can help to alleviate overheating problems, it is economically unsound to design the transwall area based on the minimum daily temperature since auxiliary equipment still has to be installed to meet the heating requirements of unexpected climatic conditions. Therefore, what can be saved is just those energy which is required in a few unexpressed cold days. Moreover, a larger transwall would reduce its effectiveness in alleviating overheating problems and thus some of the warm water mass might have to be drained and then refilled with cool water to keep down the transwall temperature. This undoubtedly would cause more trouble for the user.

Recapitulating what was pointed out in the previous chapter, direct gain will utilize approximately 60 to 75% of the energy incident on the south facing glazing for space heating while a thermal storage wall system will transfer about 30 to 45% of the energy incident on the collector into space. According to Mazria, the above information suggests that a ratio of 1 (direct gain) to 2 (thermal storage wall) exists between the systems. The same information can also be found by comparing the recommended ratios of glass to floor area between direct gain and masonry wall systems as depicted in the solar energy class notes by Prof. Schubert of Virginia Polytechnic Institute and State University. They are based on data taken from The Passive Solar Energy Book by Mazria, Rodale Press, Emmanus, Pennsylvania, 1979. The ratios provided are designed to maintain average interior temperatures in a well insulated house (heat loss of 8 Btu/day/F/sq.ft.) between 68 and 70 deg.F. on clear winter days. This means that 1 square foot of collector area (glazing) in a direct gain system supplies roughly the same quantity of heat to a space as 2 square feet of thermal storage wall. According to this ratio then, 50 square feet of direct glazing will produce roughly the same amount of solar heating as the combination of 25 square feet of direct gain glazing and 50 square feet of thermal storage wall, or if

only thermal storage wall is employed, then 100 square feet of which will be required.

However, a transwall with no water and absorber plates in open position is not thermally equivalent to the direct gain system. Since the space between two absorber plates is approximately equal to the internal thickness of the transwall, solar input with incident angles equal to or greater than 45 deg. would have difficulty in reaching the interior; in this case, only 47% of the solar input could get into the space through the empty transwall module.[47] The other 53% will be aborbed by the absorber plates. When the incident angles become smaller than 45 deg., a fraction of the direct solar input could reach the interior as it does in other direct gain systems while a portion of it is still blocked by the absorber plates. only at noon could the empty transwall act like a direct gain system with almost 100% solar insolation reaching the interior. By using the sun chart at 36 deg. NL provided by Mazria's The Passive Solar Energy Book, p.317, the author has figured out that, on Dec. 21, if 100% of solar input could reach the interior through direct gain system (double-glazing), then 73% of solar insolation could reach the interior through the empty transwall modules (see

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[47] Fuchs and McClelland, "Passive Solar Heating Of Building Using A Transwall Structure", Solar Energy Journal, Vol.23, p.124.

Appendix B).

Moreover, transwall with water mass and absorber plates closed is not thermally equivalent to conventional thermal storage wall (concrete wall with air circulation). According to Fuchs and McClelland's article in Solar Energy journal, Vol.23, p.126, unquenched transwall is 97% (76/78) as efficient as conventional thermal storage wall. Therefore, instead of a ratio of 1 (direct gain) to 2 (thermal storage wall) as provided by Mazria concerning energy transferred for space heating,[48] the ratio of water-filled transwall to empty transwall, as worked out by the author is, 73% : (50% x 76/78), i.e., about 75% : 50% or 3 : 2.

5.1.1.1 Guidelines for Sizing of Transwall : Mazria Method

1. Determine latitude of location.
2. Intercept line representing average clear day exterior temperature. (Usually Jan. or Dec., use whichever is the most severe; based on graph depicted by Professor Schubert of V.P.I. & S.U., see Appendix C)
3. Use the ratios of glass to floor area for direct gain. (Based on graph depicted by Professor Schubert in Appendix C)

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[48] Mazria, E. M., p.222.

4. Intercept vertical axis giving the ratio of glass to floor area.
5. Divide the result by 0.73 to get the equivalent transwall size.

Case study : Consider a 50 by 30-ft residential structure with the long dimension on the East-West axis in Roanoke with average outdoor temperature of 37.4 deg.F in Dec. (based on the period from 1941-1970). The structure is assumed to have: a roof/ceiling component with an area of 1500 sq.ft. and a U value of 0.03 Btu/hr/F/sq.ft.; 8-ft. high walls and a U value of 0.06 Btu/hr/F/sq.ft.; the area of north, east and west walls is 15% double glazing; there is 40 sq.ft. of total door area located on the east and west walls; the doors have a U value of 0.36 Btu/hr/F/sq.ft.; the floor is 1500 sq.ft. and has a U value of 0.06 Btu/hr/F/sq.ft.; and there is assumed to be one air change per hour. The amount of additional heat needed due to infiltration per deg.F temperature difference may be determined by multiplying the number of air changes per hour by the volume of the structure times 0.018, which is the Btu required to raise one cubic foot of air one degree in one cubic foot of air one degree in one hour. The heat loss due to infiltration is determined to be: 12,000 cu.ft. x 1 air change/hr. x 0.018 Btu/F/cu.ft. = 216 Btu/hr/F.

The south-facing wall is a transwall system which consists of double glazing spaced 2 to 4 in. from the exterior face of a 6-1/2 in. thick transwall. The U value of the system is determined by taking the reciprocal of the total R value of the system:

Component	R value
Exterior Air Film	0.17
Double Glazing	1.45
Air Space	0.97
Transwall with Heat Mirror*	6.00
Interior Air Film	0.68
Total	9.27

$U = 1/R = 0.11$

*Refer to McClelland and others, "Recent Developments In The Transwall System". Proceedings Of The Sixth National Passive Solar Conference, Portland, Oregon : American Section Of The ISES, Inc., 1981, p.12.

The heat loss through the components of the structure is:

Component	U value Btu/hr/F/sq.ft.		Area sq.ft.		Heat Loss Btu/hr/F
Roof/Ceiling	0.03	x	1500	=	45
South Wall:					
Transwall	0.11	x	400	=	44
Opaque Walls	0.06	x	708	=	42
Windows	0.69	x	132	=	91
Doors	0.36	x	40	=	14
Floor	0.06	x	1500	=	90
Total					326

The total building heat loss is the sum of the heat loss through the building envelope components and the heat loss due to infiltration.

326 Btu/hr/F + 216 Btu/hr/F = 542 Btu/hr/F

The total daily building heat loss in Btu/day/F/sq.ft. of floor area, is determined by multiplying the hourly heat loss by 24 hours and then dividing by the floor area of the heated space.

(542 Btu/hr/F x 24 hr)/1500 sq.ft. of floor area

= 8.67 Btu/day/F/sq.ft. of floor area

Adjust For Deviation:

0.17 x 8.67/8 = 0.184

0.184 x 1500 sq.ft. of floor area

= 276 sq.ft.

Change to transwall area by multiplying 1/0.73

276 sq.ft. x 1/0.73 = 378 sq.ft.

5.1.1.2 Application Guidelines for Adjustable Thermal Mass

The purpose of these guidelines is to alleviate the over-heating problem. This is a continuation of the case study from above (section 5.1.1.1)

Steps:

1. Same as guidelines for sizing of transwall from (1) to (5).
2. Find out present outdoor temperature (say 45 deg.F).
3. Let x sq.ft. be the transwall area with no water mass, then (378 - x) sq.ft. be the transwall area with water and absorber plates closed.
4. Divide the water-filled transwall area by the width of transwall to get the height of water that has to be filled to avoid overheating problem.

Adjust For Deviation (outdoor temperature is now 45 deg.F)

0.12 x 8.67/8 = 0.13

0.13 x 1500 sq.ft. floor area = 195 sq.ft.

Change to transwall area by multiplying 1/0.73

195 sq.ft. x 1/0.73 = 267 sq.ft.

This means 267 sq.ft. of transwall with no water mass and absorber plates open will be enough when outdoor temperature is 45 deg.F.

Hence

$$3 \times 267 = 2 \times (378 - x) + 3x$$

$$801 = 756 - 2x + 3x$$

$$x = 45$$

Transwall area with no water = 45 sq.ft.

Transwall area with water = (378 - 45) sq.ft.

= 333 sq.ft.

Therefore, water level in the transwall should be filled up to 6-2/3 ft. (333/50) to avoid overheating the space.

5.1.2 Application Guidelines for Transwall as a Cooling Device

Example A: Transwall with no direct solar insolation. In the case study above the transwall area is found to be 378 sq.ft. The purpose here is to show how the transwall works as a cooling device during summer days. According to

Weller and Youle's Thermal Energy Conservation - Building and Services Design, pp.27-28, heat is transferred from a surface to the surroundings or from the surroundings to a surface by radiation and convection processes. The radiation transfer process is dependent on the surface absorptivity or emissivity and on the radiation temperature involved. The convection transfer process at a surface depends on the nature of the boundary layer of air which tends to be held by the surface giving the effect of a thin blanket. The factors involved are the air and surface temperature differences, the orientation of the surface and the local velocity of air.

Equations:

Radiation process $Qr = e(Hr)A(t1 - t2)$

Convection process $Qc = A(Hc)(t1 - t2)$

Where Qr = heat transfer by radiation

Qc = heat transfer by convection

e = emissivity of the surface

Hr = radiation coefficient

Hc = convection coefficient

A = area of surface

$t1 - t2$ = difference in temperature

The above equations are drawn from Weller and Youle's Thermal Energy Conservation - Building and Services Design, pp.5-21. Qr and Qc could be positive or negative. Positive number means that the object is losing heat, and a negative number means that the object is gaining heat from its surroundings. The convection coefficient, Hc, is a measure of the ease with which heat is transferred by convection, while the emissivity times the radiation coefficient, e(Hr), is a measure of the ease of radiation transfer.

Steps:

1. Establish designed summer indoor temperature, value of Hc, Hr and e, and initial transwall temperature.
2. Determine heat gain by radiation and convection processes from outdoors to the transwall.
3. If the transwall temperature rises higher than the designed indoor temperature, drain away the warm water mass and refill the transwall with cool ground water.
4. If the transwall temperature after sunset is still lower than the designed indoor temperature, no change of water mass occurs.
5. If maximum cooling effect is desirable, drain away all of the water mass and refill the transwall with cool ground water after sunset.

Assumptions:-

1. For rough estimation, average temperatures are used throughout and total heat gain or loss through the transwall is directly proportional to the time change.
2. Hc = 0.53 Btu/hr/sq.ft./F (refer to Weller and Youle, p.19)
3. Hr = 1 Btu/hr/sq.ft./F (refer to Weller and Youle, p.11)
4. e = 0.9 (absorptivity of glass)
5. Average outdoor temperature between 8 a.m. and 6 p.m. (10 hours) of certain day in July is 86 deg.F.
6. Initial transwall temperature is 60 deg.F. at 8 a.m.(ground water)
7. Solar insolation is completely shielded by overhang in July.
8. Designed summer indoor temperature is 75 deg.F.

Calculate:

Heat gain by radiation from outdoor to transwall

$$Qr = eA(Hr)(t1 - t2)$$

$$Qr/A = \{0.9 \times 1 \times (60 - 86)\} \text{ Btu/hr/sq.ft.}$$

$$= -23.4 \text{ Btu/hr/sq.ft.}$$

or a heat gain of 23.4 Btu/hr/sq.ft.

Heat gain by convection

$$Qc/A = (Hc)(t1 - t2)$$

$$= \{0.53 \times (60 - 86) \text{ Btu/hr/sq.ft.}$$

= -13.8 Btu/hr/sq.ft.

or a heat gain of 13.8 Btu/hr/sq.ft.

Total heat gain of transwall per sq.ft.

= (23.4 + 13.8) Btu/hr/sq.ft.

= 37.2 Btu/hr/sq.ft.

Water mass of transwall per sq.ft.

= 1/2 cu.ft. (6 ins. thick)

Thermal capacity of water

= 62.4 Btu/cu.ft./F

Therefore, thermal capacity per sq.ft. of transwall area

= 62.4 Btu/cu.ft./F x 1/2 cu.ft.

= 31.2 Btu/F

Since total heat gain is 37.2 Btu/hrsq.ft.

The rise in temperature of the transwall water

mass per hour = (37.2/31.2) deg.F

= 1.2 deg.F

Therefore, total rise of transwall temperature in

10 hours from 8 a.m. to 6 p.m. = 1.2 x 10 deg.F

= 12 deg.F

By 6 p.m. the transwall would have a temperature of 72 deg.F (60 + 12), which is still lower than the designed summer indoor temperature, 75 deg.F.

This simple example shows that the transwall is effective as a cooling device since it can, at least, stop outdoor heat from entering into interior spaces. It should also be noted that it is not required to drain away any water mass in order to keep the transwall temperature lower than the designed indoor temperature. In reality, the transwall would absorb heat from both outdoor and indoor through radiation and convection processes as long as its temperature is lower than its surrounding temperatures.

Example B - Transwall with some direct solar insolation

Steps:

1. Same as 1 in Example A.
2. Determine heat gain by radiation and convection processes on the part of the transwall which has direct solar insolation.
3. Determine heat gain by radiation and convection processes on the part of the transwall which has no direct solar insolation.
4. Drain away the water mass which rises above the designed indoor temperature and refill those empty modules with cool water. It is not necessary to drain a water mass with a temperature lower than the designed indoor temperature.

5. If maximum cooling effect is desirable, drain away all water mass and refill with cool water after sunset.

Assumptions:-

1. The overhang is designed so that the lower 1/5 of the transwall area has direct solar insolation on certain days in September.
2. Daily total solar insolation on the transwall through the vertical south-facing double glazing assuming ground reflectivity at 0.2 is 1102 btu/sq.ft. at 36 deg.N in September.
3. Absorptivity of the transwall is 52% of the solar insolation, as indicated in the previous chapter.
4. Average outdoor temperature from 8 a.m. to 6 p.m. is 80 deg.F.
5. Initial transwall temperature is 60 deg.F.
6. Total heat gain through transwall is directly proportional to time change.
7. Values of Hr, Hc and e are the same as in the previous example.

Calculation:

Heat gain for the upper 4/5 of the transwall
per sq.ft. due to outdoor heat
= {(0.9 + 0.53) x (80 - 60)} Btu/hr

= 28.6 Btu/hr

Total heat gain in 10 hours per sq.ft. of transwall

= 28.6 Btu x 10

= 286 Btu

For the upper 4/5 of the transwall

Total rise in temperature

= (286/31.2) deg.F

= 9.2 deg.F

Therefore, temperature of the upper 4/5 of the transwall at 6 p.m. is 69.2 deg.F

Total heat gain per sq.ft. for the lower 1/5 of the transwall

= (1102 x 52% + 286) Btu

= 859 Btu

Therefore, temperature of lower 1/5 of transwall at 6 p.m.

= (859/31.2) deg.F + 60 deg.F

= 87.5 deg.F

In order to be effective in stopping outdoor heat from being re-radiated into interior spaces, the temperature of the transwall water mass should be lower than the designed

indoor temperature, 75 deg.F, which is 15 deg.F above the initial transwall temperature. Since it is assumed that heat gain is directly proportional to time change, the time when the transwall temperature would rise to 75 deg.F is

8 a.m. + 10 x (15/27.5) hr = 8 a.m. + 5.5 hr

= 1:30 p.m.

The author suggests that the warm water mass of the lower 1/5 of the transwall should be drained and refilled with cool water before 1:30 p.m.

If the warm water mass is drained at 1:30 p.m. and refilled with cool water at 60 deg.F, the temperature of the lower 1/5 of the transwall at 6 p.m. would be 72.5 deg.F (60 + 12.5). Hence the average temperature of the entire transwall would be equal to 72.5 deg.F x 1/5 + 69.2 deg.F x 4/5 = 69.9 deg.F.

The case study in 5.1.1 and 5.1.2 indicates that 378 sq.ft. of exterior transwall which is designed according to the Mazria Method is workable (mathematically) in alleviating overheating problem in some unexpectedly warm winter days. On the other hand, it is also effective in stopping outdoor heat from entering into the interior space and at the same time provides a cooler surface to absorb some of the indoor heat.

5.1.3 Application Guidelines for the Absorber Plates

On winter mornings, if the weather is clear, turn the absorber plates of the transwall into an open position so that 66% of the incident solar insolation would reach the interior instead of the 13% which is admitted when the absorber plates are closed. Then the interior space would be heated up much sooner. When the interior temperature reaches 70 deg.F, turn the absorber plates back to a closed position, so that 52% more heat would be stored in the transwall water mass for night time heating while allowing 13% to reach the interior. This guideline is more important to families whose members are out to work or to school in the afternoon instead of in the morning and would not be back home until evening. This application helps to speed up space heating when people are at home and increase storage when people are out.

5.2 ARCHITECTURALLY ORIENTED APPLICATIONS AND GUIDELINES

5.2.1 As a Component of Convertible Greenhouse and Living Space

Planning of interior circulation should be done carefully. Avoid making opening on the back wall of the convertible space, so as to maximize thermal mass. Access to this space is more appropriate from either the east or west side of the space. The author recommends that this space be used

as a family room. However, if more bedrooms are required, then convert the greenhouse into a large double room instead of a family room. In this case, a very dark liquid has to be used for the common interior transwall to provide the appropriate level of privacy.

5.2.2 As Partition with Changeable Colors

The author suggests the use of liquids of cool color like green, blue, etc. for the interior transwall partitions in summer time, and warm colors like red, orange, brown, etc. in winter. For activities like business meetings, study, work and exercise, cool colors are more suitable. Warm colors are more appropriate for social gatherings, parties, romantic affairs, etc. If the user wants the room to have a more spacious feeling, the use of cool colors is recommended. Warm colors tend to make people feel that a space is more compact. Since the above suggestions are rather subjective, even though they have been psychologically tested and well documented. The user should try various colors to see which one would make him/her feel more comfortable psychologically. Transwall with changeable colors is a particularly good application for interior partitions in restaurants, clubs, offices and residences where the requirements of visual connection and separation between spaces, interior

atmosphere, and level of privacy might be changed quite often. Transwall could be applied as interior partitions to most spaces, with the exceptions of washroom, mechanical and other service spaces. If visual connection between two rooms or a visually larger space is desirable, use clear water instead of a colored liquid for interior transwall partitions.

During heating period, the author suggests that the user should determine what color he/she would like to have for the interior transwall partitions in the morning so that enough heat could be stored for evening heating purpose. Avoid changing transwall colors in the evening or late afternoon in winter because of the heat loss.

5.2.3 As Inoperable Windows Facing East, West and North

Most current designs of solar house have very limited openings in the east, west and north walls. This may not be desirable architecturally since good views may be on any side of a building. The transwall system with a heat mirror coating would produce a higher performance than R6 movable insulation. Therefore, the author recommends that exterior transwall could be used on the east, west and north walls for the purposes of providing views and daylighting. Transwall on the west wall could also help to reduce heat gain in the late afternoon during summer days.

5.2.4 As a Shading Device

The author suggests that this application should be limited in off heating and cooling periods (approximately 25% of a year for most cities in the U.S. as mentioned previously) and should only be used for the purpose of minimizing glare and maximizing daylighting.

Chapter VI

DISCUSSIONS

6.1 POTENTIAL PROBLEMS AND LIMITATION OF THE MODIFIED TRANSWALL

In reality, the workability of the modified transwall may not be fully realized, or it may create some other problems which would not be found in other basic passive systems. For this reason, an exploration of the potential problems and the limitations of this modified version is necessary.

There are two sorts of potential problems and limitation associated with the modified transwall - one is technologically related and the other is environmentally related. The original transwall has two 0.8 in. diameter holes in its plates for water filling.[49] The holes for the modified transwall will be located in the bottom plates to facilitate the adjustment of water level. This change in water inlet position may require a better water-tight design to deal with potential leaking problem.

A conventional greenhouse or sunspace (embedded or attached) in northern climates (North America) is oriented on an east-west axis. The roof is transparent and tilted to

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[49] McClelland, J. F. et al., "Recent Developments In The transwall System". Proc. 6th National Passive Solar Conference, Portland, Oregon, Sept.8-12, 1981, p.179.

face south. The angle of the transparent roof is designed to permit optimum transmittance of solar radiation. Transwall used as a component of convertible greenhouse and living space may create structural and operational problems if it is installed behind the transparent tilted roof. Or, one can design a tilted opaque roof so that its slope is parallel to the optimum sun angles rather than perpendicular to them as in the conventional greenhouse. However, in this case, the height of the front glazing and the transwall will be greatly increased. This again causes structural and economic problems. If a flat roof is used, solar access to the interior thermal mass will be limited and would thus lead to lower performance than a conventional greenhouse. One probable solution is to employ adjustable outdoor reflectors to increase solar input on the exterior transwall, and at the same time, allow solar energy to reach further inside the room so as to increase solar heat gain of the commom back wall.

A changeable color wall is a deluxe option of the transwall system. The potential problem and limitation of this feature is to find the appropriate dyes or color liquids which have good thermal storage capacity compared to water. Moreover, if several different colored liquids are allowed to pump in and out of the transwall modules, even though at

different times, it is important that no droplets of the outgoing liquid would stick on the surface of the transwall and mix with the incoming liquid.

As a cooling device, a transwall may turn out to be a waste of water resources if warm water, which has to be drained away to keep the transwall cool, is not put to proper use. As indicated in Example B, Section 5.2 of Chapter 5, in order to maintain the transwall's effectiveness as a heat absorber; approximately 283 gallons of water have to be drained away in that particular day. This trade-off may not be worthwhile if this water is not reused, and thus may cause a water shortage problem in the long run.

The modified transwall is not a self-regulated system. It requires human attention in order to achieve the best predicted performance. These adjustments may cause inconvenience to the user. Also, negligence on the user's part would lower the performance of the system.

As far as living environment is concerned, even when it is not raining, water, in the form of vapour is always present in the atmosphere. Ventilation has generally been considered necessary if healthy conditions are to be maintained in occupied houses, although the amount of air necessary to ensure healthy conditions in relation to environment and use

has seldom been specified in health or building regulations. The modified transwall, like the original version, has no operable openings of its own, and thus poses potential ventilation problem for its user unless vents or openings are installed on other outside walls, e.g. east and west, to drain away the excess moisture trapped indoors.

6.2 POTENTIAL BENEFITS OF THE MODIFIED TRANSWALL

As the author has mentioned in the previous chapter, both direct and indirect gain systems have their own advantages and disadvantages. Most current designs of passive solar systems are either direct gain or indirect gain. None of them is perfect. However, a better system would result if we could combine the advantages of both systems into one so that it can function either as a direct or an indirect gain system, or as a combination of the two. The modified transwall as an adjustable thermal mass is undoubtedly adequate for our changing climates. Designers would be able to design a larger heat collector area while avoiding overheating problems. The adjustable water mass of the transwall requires technology rather than energy. It is foreseeable that a computer program can be developed to help user to determine the average daily water level (or water mass) of the transwall so as to provide daily optimum thermal comfort

for the residents rather than one optimum solution for the whole system life.

As a component of a convertible greenhouse and living space, a transwall could provide flexible response to the changing needs of an average American family. The average family size usually increase from a couple to four or five and then drops back to two after sons and/or daughters have established their own residences. More bedrooms or living spaces will be needed when children are still living with parents. A couple, on the average, needs fewer bedrooms in their home before they have any children, and when they are older. This may imply that they usually have less spare time when they need more bedrooms in the house. The modified transwall, therefore, allows its user to change the function of a space from a living space to a greenhouse or a sunspace and vice versa within a very short time, and basically with no extra cost, in response to the change of family life styles.

In architecture, we often discuss the richness of form, space, emotional expression, atmosphere, and personal taste. All of these are important elements in determining human comfort, which is so subjective and varied from person to person. The transwall as interior design element leaves the control of some of the above elements in the hands of the

users rather than the designers who may not even know who the user will be. "If thermal comfort were strictly physical, we could not do much to save energy." said Dr. William Howell of Rice University after conducting a three year field-study observing the psychological effects of energy conservation.[50] Thermal comfort can be supplemented by psychological effects of color, space, texture, lighting, view, etc. The modified version of the transwall is able to respond to most of the above psychological factors relating to human comfort.

6.3 CONCLUSIONS

From the research, concept development, and conceptual applications of the multi-function transwall system, it seems appropriate to make the following conclusions.

First, this modified system has the potential to perform well as a multi-use architectural element. At the present time, it is only a concept and not a physical reality. The actual performance of this modified system is untested and is therefore uncertain.

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[50] Howell, W., "The Psychology Consequences Of Energy Conservation", Department of Psychology, Rice University, Houston, Texas.

The second conclusion from this work is that more advanced reviews of physics and engineering science concerning heat transfer together with computer simulation should be implemented before the design of technical details is carried out. Further analysis, experimentation and field tests are necessary to determine whether it is technically, economically and architecturally desirable and practical to integrate any of the author's ideas into the next generation of transwall designs.

And finally, it should be stated that this thesis presents only a beginning. Much more work is needed if the modified transwall system is to play a major role in the built environment as a multi-function architectural element.

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Appendix A

COMPARISON OF HEAT FLOW AND SOLAR HEATING FRACTION

Comparison of heat flow (expressed in Btu/day) and solar Solar Heating Fraction (SHF) values for five passive systems'

System	Solar input	Window heat loss	Wall heat loss	Suppl. heat-ing	Suppl. cooling (venting)	SHF
Quenched Transwall	8631	5956	2845	446	256	88%
Unquenched Transwall	8631	6497	2808	892	218	76%
Conc. wall (no air circ.)	8631	7237	2646	1252	0	67%
Conc. wall (air circ.)	8631	6763	2684	816	0	78%
Direct gain	8631	7218	2912	1622	123	57%

Fuchs and McClelland, "Passive Solar Heating of Building Using a Transwall Structure". Solar Energy 23, 1979, p.126.

Appendix B

SPACE HEATING RATIO OF TRANSWALL

Estimation of space heating ratio between direct gain and empty transwall on Dec.21. On Dec.21'

The following points have been mentioned in previous chapters:

1. Space between absorber plates is equal to internal thickness of transwall.
2. 47% of solar input could reach interior if passing through absorber plates.
3. Solar input is same as direct gain if no absorber plate blocking its way.

Obtain incident angles by using Sun Chart at 36 deg. NL on Mazria's The Passive Solar Energy Book, p.317.

Time	incident angle deg.	Solar insolation Btu/sq.ft.
8 a.m. and 4 p.m.	53	84
9 a.m. and 3 p.m.	42	154
10 a.m. and 2 p.m.	30	198
11 a.m. and 1 p.m.	15.5	224
12 noon	0	232

Solar input with incident angles equal to or greater than 45 deg. will pass through the absorber plates before reaching the interior, i.e. 47% would reach the interior.

Solar input with incident angles smaller than 45 deg.(say x deg.) would have {(tan x)/1}% of the area with 47% of solar input and {1 - (tan x)/1}% of the area with 100% solar input (same as direct gain).

tan 42 deg. = 0.9

tan 30 deg. = 0.57

tan 15.5 deg. = 0.27

Amount of solar input through empty transwall (with no water mass and absorber plates in open position).

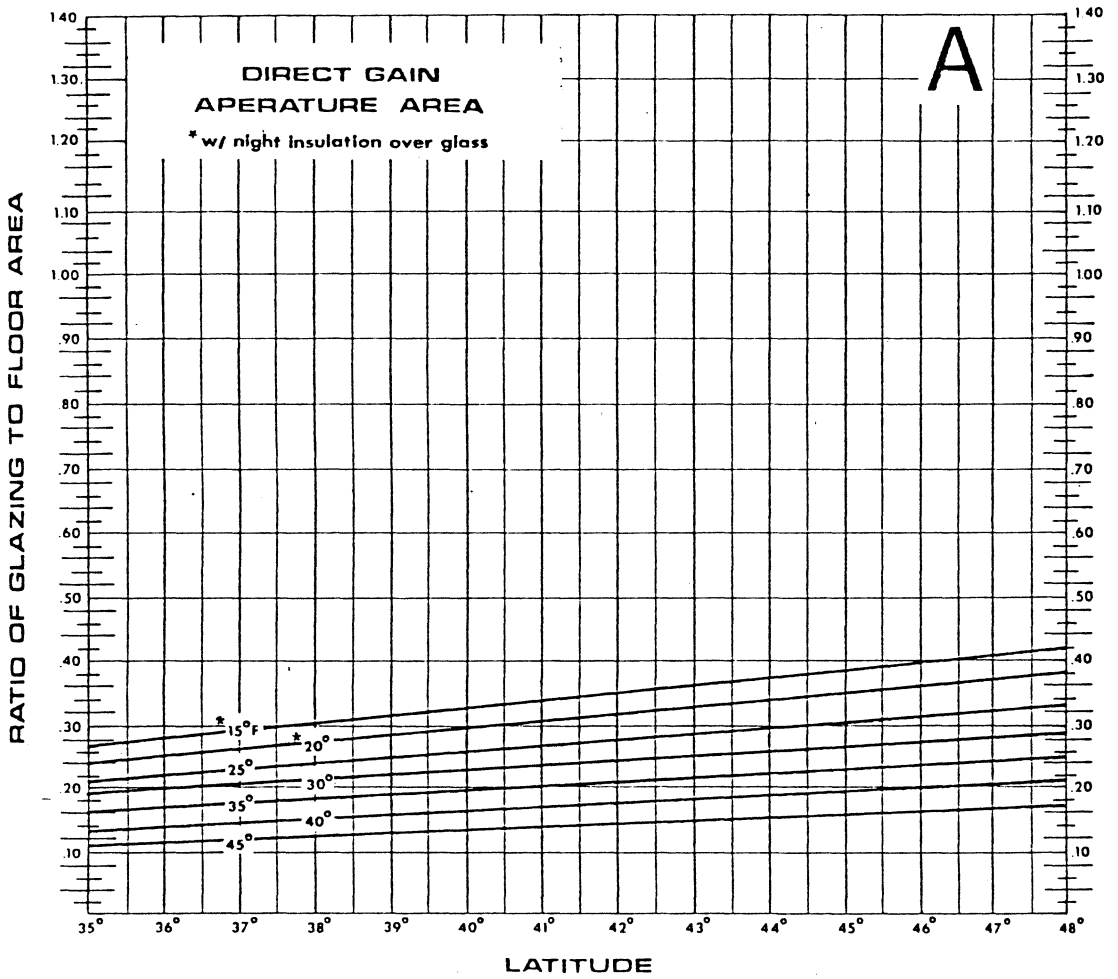
Time	Daily Solar Input (Sept.) Btu/sq.ft.	
8 a.m. and 4 p.m.	84 x 47% x 2	= 79
9 a.m. and 3 p.m.	(0.9 x 154 x 47% + 0.1 x 154) x 2	= 161
10 a.m. and 2 p.m.	(0.57 x 198 x 47% + 0.43 x 198) x 2	= 276
11 a.m. and 1 p.m.	(0.27 x 224 x 47% + 0.73 x 224) x 2	= 384
12 noon	232 x 100%	= 232
	Total	1132

Total of solar input on direct gain under the same condition is 1550 Btu/sq.ft. Therefore, ratio between the two systems on Dec. 21 is 1132 : 1550 or 0.73 : 1.

This means that transwall with no water mass and absorber plates open admits 73% of solar input which would otherwise be 100% admitted through direct gain system on Dec.21.

Appendix C

SIZING FOR DIRECT GAIN - MAZRIA METHOD



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A Study Of The Transwall System As A Multi-Use Architectural Element

by

Wing-Yuk Wong

(ABSTRACT)

The transwall system, proposed and developed by Fuchs and McClelland, fulfills the function of a passive solar heating device as well as an architectural element - the window. The significance of the transwall system, in the author's opinion, lies in its expression of technologies in an architectural way. Several directions for further development are suggested to modify the transwall system into a multi-function architectural element so as to maximize utility. These architectural uses are: (1) an adjustable thermal mass; (2) a passive cooling device; (3) an interior design element; (4) a component of a convertible greenhouse and living space; and (5) a shading device.