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ENERGY CONSERVATION

thru

OPTIMUM UTILIZATION OF SITE ENERGY SOURCES

for

ALL-SEASON THERMAL COMFORT

in

NEW RESIDENTIAL CONSTRUCTION

for

SINGLE-FAMILY ATTACHED (rowhouse/townhouse) DESIGNS

Assisted by

J. PETER HOLSMAN - Design Consultant

dated

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ENERGY CONSERVATION THRU OPTIMUM UTILIZATION OF ON-SITE
ENERGY SOURCES FOR ALL-SEASON THERMAL COMFORT
IN NEW RESIDENTIAL CONSTRUCTION FOR
SINGLE-FAMILY ATTACHED (ROWHOUSE/TOWNHOUSE) DESIGNS

Final Report

by

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ANALYSIS OF CURRENT APPROACHES TO RESIDENTIAL ENERGY CONSERVATION AND CONCLUSIONS REGARDING THE PURPOSE OF THIS STUDY

At the present time, there are several different approaches to national energy conservation in residential new construction. These include -- high-technology active solar equipment and systems, low-technology passive solar designs, the super-insulated and energy-efficient buildings, manual and automatic energy management controls, and occupant-operation techniques requiring life-style adaptation and user-education. However, each of these approaches is presently being pursued separately by its own special interest advocates. The result is the absence of the synergetic benefits of an integrated research program which includes all of these sub-programs. The results of a combined program could help to accelerate progress toward a passive solar energy efficient design system having the potential of becoming a new "standard construction" and therefore, making a significant impact on national energy conservation in the area of new residential construction.

1. High-technology active solar heating systems are too complex and too costly to gain wide acceptance by conventional builders, developers and owners. Used merely as add-ons to existing designs, they cannot justify their cost, not even with energy-efficient construction. (An exception to this is domestic solar hot water and swimming pool heating systems which are fast becoming economical and practical for many locations.) But used alone on standard designs, they cannot yet be justified for the mass market. Active-solar applications experience to date has laid the ground work for passive solar design, and we will use some basic active principles in our design

system including "remote storage for the protection of back losses" and "positive control and distribution for effective utilization."

2. Most low-technology passive solar systems must by nature be integrated into the enclosure design. Several approaches are still in the research, computer-modeling or prototype-testing stage and are not sufficiently understood or predictable for mass acceptance by the building industry or buying public. Most passive designs to date are limited to single-concept solutions which work well only in certain regions or only for certain occupants whose lifestyles are receptive to hands-on daily operation involvement in energy management. Also, many of these designs are not adaptable to the present market's demand for variety in size, shape, orientation and floor plan. One main obstacle to the development of a more marketable passive design has been the unwillingness of pioneering designers and builders to deviate from the purist idea that passive cannot depend on mechanical systems and controls without being branded "active."

We believe a passive solar design system must have a fully powered and automatically controlled energy-handling system for distribution and storage in order to be acceptable in many markets and locations. Another problem has been that many passive solar designs have included elements which serve only some passive function and though integrated into the design, they do not serve essential structural or enclosing functions and so they add unbearable costs. Our design will utilize existing elements of conventional construction for passive design functions, as well.

3. The so-called energy efficient designs which are the most well researched, well tested and broadly market adaptable of all energy conservation schemes to date are the most effective of these approaches, but they do not go far enough with insulation and tightness to render passive solar effective. On the other hand, the "super-insulated" designs go too far since their added payback is unreasonable, and if energy-of-manufacture is included, they are a step backwards. The major problem with the energy efficient designs is that they have been developed under some unnecessarily restrictive assumptions of building design, floor plan design and style, such as strictly minimum windows and maximum compactness, which have resulted in the incorrect impression that energy efficient design is unsuited to all segments of the mass market. We intend to show that very energy efficient features can be effectively

applied to broadly market acceptable building types and designs while still maintaining flexibility of plan, fenestration, exterior design and price. Our proposed scheme will fall somewhere between "energy-efficient" and "super-insulated" so that passive solar inputs will constitute the major portion of the energy needs for comfort.

4. Most current designs for residential construction use the relatively crude thermostat as the only product of our advanced controls technology to be used for energy management. This is because present systems have only dealt with one source of energy for comfort in our homes --- the central heating/cooling unit. Control systems and components are currently available off the shelf which can have a significant impact on energy conservation and multiple source utilization. Some are simple mechanical devices; others are solid-state or microprocessors. Our design will use more sophisticated but commonly available controls and control-systems concepts for controlling the various modes of collecting, conserving and storing several sources of heating and cooling energy for controlling distribution, and for synchronizing with daily and hourly changes in the outdoor environment.
5. Lifestyle adaptation for energy conservation is currently confined to manual night set-back, voluntary lowering of overall temperature levels to save costs (or by preference), closing drapes and blinds, and adding or removing layers of clothing (includes bed blankets), and the use of heat sheets or electric blankets. Some of these are not done for energy conservation because occupants are not aware of their effectiveness. Even more effective methods are available but have not been considered or accepted by the mass market because even the simple ones presently in use are not well understood or properly operated by most occupants. Most new thermostats have a separate manual fan switch which can be effectively used to redistribute existing solar gains from the sunny rooms on ordinary houses thus preventing overheating of those rooms while uniformly storing the heat in the surface masses of the whole house. This simple use of existing functions could save energy by using solar energy in existing houses but most people do not know enough to do it. This is primarily because detailed information on the operation of the system is never displayed in the unit thus depriving the occupant of the opportunity to learn how to operate his system to save money while still being comfortable. Our

design will provide for the optional manual operation of various elements of the enclosure and the system, the choice of various modes and ranges of operation for the automatic passive and auxiliary back-up systems, and will include the provision that full, detailed operating instructions for all aspects of the design be permanently displayed in appropriate locations on durable plaques including recommendations for use of clothing, bedding, window shades, blinds, exhaust fans, and other items.

What is needed now is a break from the purist approach which is overly theoretical, often regionally determined and usually custom or do-it-yourself designed and/or built. Our proposed design analysis undertakes the systemic approach and integrates the best and most cost effective technologies and techniques of each of these five separate areas of endeavor, along with some others, into a balanced design system which has as its goal the development of a design regime for optimum energy utilization and conservation in new residential construction that is both market-ready and market-acceptable. This could then provide the tools for making a significant reduction in energy consumption by the residential sector from now on!

SELECTION OF A PROPOSED STUDY PROGRAM AND GOALS

We have chosen the subject of "ENERGY CONSERVATION THROUGH OPTIMUM UTILIZATION OF ALL ENERGY SOURCES FOR THERMAL COMFORT IN NEW RESIDENTIAL MULTI-FAMILY CONSTRUCTION" for several reasons. The first of these is that as architects, we are most familiar with the total design of enclosures for comfort, and so, we are in a unique position to help effect a significant impact on energy conservation in this area. Secondly, since multi-family starts now exceed single family and since the row-house type to townhouses are the most common, universally acceptable and marketable form of multi-family, we have selected that as the one design type apt to have the greatest impact on total residential energy use. Specifically, we have picked the typical three-level, three bedroom, two story, garage under townhouse for a prototype because it is the most in demand, and it is the most economical version of those including garages. Therefore, it adapts to small or large projects, can be built by most builders and will adapt to many site locations and municipal zoning ordinances.

This study intends to produce a true hybrid design incorporating the best, most performance proven and cost effective products, materials, processes, technologies

and sub-systems which are "state-of-the-art" and "off-the-shelf" as of today. This includes all conventional building methods and materials which contribute to energy conservation.

Specifically, we are developing a design regime for a minimum cost, reliable-technology townhouse construction and operation system which, compared to present standard construction, --- 1) will have substantially reduced energy requirements, 2) provide adequate levels of comfort and control of comfort, 3) will be selective as to use of auxiliary energy sources, 4) will be somewhat self-sufficient in situations of interruption of fuel availability or utility cut-off, 5) can be built with readily available materials and components using conventional construction techniques and trade skills, 6) will not require unreasonable occupant participation for operation and 7) will utilize many materials and elements for the enclosure and its systems for dual functions, for energy collection, distribution, storage and conservation as well as the traditional purposes of structure, enclosure, privacy, ventilation, access safety and aesthetics.

PROTOTYPE DEVELOPMENT

We have taken an existing townhouse project, which was built to our plans, as the subject for redesign analysis in order to end up with a real "apples to apples" comparison of two alternative designs for the exact same criteria including site conditions, market, weather, etc., (one conventionally designed and constructed and one designed as passive solar energy efficient). This particular situation is typical of the whole problem of building industry acceptance because the design originally started out as passive solar but due to the fears and constraints of the client-builder, it ended up as a conventional three bedroom, three-level, garage-under townhouse of conventional design and construction with frame walls, concrete block party-fire walls and a not too unusual contemporary exterior design.

We have thoroughly reanalyzed every aspect of the plan, the construction, and the possible occupant living patterns, all in regard to energy conservation, utilization and distribution. We have specifically looked for opportunities to use elements for dual functions in order to minimize costs and complexities. In addition, we studied a wide variety of passive solar and energy efficient designs, prototypes

and test results of projects recently completed or in-work, which are relevant to this study. And, we have followed the development of products, materials and equipment related to energy efficiency and solar use. As a result of this analysis, we have assembled several lists of suggested features for inclusion in the final design including construction features, mechanical sub-systems, and operation regimes covering all aspects of the enclosures and its dynamic interaction with interior living patterns and exterior weather patterns. We are not^u in the process of interfacing these features and refining a design regime which will be flexible enough to adapt to most climates and markets in the nation but rigid enough to provide effective energy utilization and conservation. Some of our tentative conclusions are included at the end of this report.

PROTOTYPE ANALYSIS

To be effective and worthwhile, any enclosure system for human comfort must be energy efficient during all seasons of the year and not just the heating season. The goal must be to achieve comfort and conservation for all seasons! Nature is working with us toward that goal more than many realize. Colder winter days are usually clearer with more solar gain available for heating. Cloudy days in winter are usually warmer so that loss of solar gains is not as critical. Warm summer days indoors are often accompanied by cooler air outside which can be brought in for natural cooling if the humidity is right. Hot summer days are often followed by cooler nights when sensible cooling may be stored for use the next day. The general tendency for cooler nights is matched by our bodies' own drop in temperature for sleeping -- an advantage in both winter and summer. Winter winds are frequently from the north which is the most protected face of a passive design, and summer breezes are often from the south where operable direct-gain fenestration is located. And last, but most important, the angle of the sun during the coldest weather is at its lowest angle for maximum penetration, while in summer the angle is highest for maximum shading. An effective passive design must harmonize with and augment of all these relationships.

Since the diurnal cycle (days warmer -- nights cooler) is the most reliable and prevailing aspect of our environment, we conclude that a good passive system must effectively work with that cycle. Our system, therefore, will utilize that cycle during all seasons and will only use auxiliary or back-up systems and energies as second and third priorities in the control system hierarchy.

Another way nature is working with us through the physical principle of phase-change or change of state. This provides us with three basic opportunities for assistance. First, moving phase-change fluids make possible the air-conditioner and the heat pump. Secondly, control of the rate of air movement can control evaporative skin cooling. And third, new phase-change salts can store thermal energy effectively. Since these mechanisms can move and store heat more economically than it can be created by burning fuels, our design will use systems that utilize these principles for the main back-up or auxiliary function (second priority in the control system). Site consumed fossil fuel will be used for comfort heating only as the last resort back-up --- last on the control hierarchy.

For the purpose of this study, we have recognized seven distinct categories for analysis:

1. The Exterior Environment - Uncontrollable but exhibiting certain cycles and patterns of energy flow in regard to human habitations.

A. The Exterior Environment - We generally recognize two broad categories of comfort design in relation to the weather environment: summer when the problem is retardation of heat gains from outside and removal of heat gains once inside; and winter when the problem is opposite, the retardation of heat losses from inside and the admitting of heat gains from outside - plus the production of additional heat by auxiliary means. But, for the purposes of our analysis for energy-efficient passive solar design we broke these down into four basic but unique scenarios.

- a. Hot Weather - Ambient cooling by ventilation is not effective (except in very dry areas). Heat pump air conditioner required for cooling. Limited use of direct or stored night cooling can be effective in lower range (more so in cloudless southern areas. Requires auxiliary energy most of the time.
- b. Warm Weather - Ambient cooling can be effective most of the time (except in very humid areas). Direct and stored night cooling are very effective for one or two consecutive days. Very little auxiliary energy required.
- c. Cool Weather - Direct gain can supply all heating for day and all or most of night. Indirect gain to storage can provide any balance of heating

for night plus some or all heating for one or two consecutive cloudy days. Some auxiliary energy required depending on amount of sunny weather.

- c. Cold-freezing Weather - Direct gain can supply most or part of day heating with indirect gain supplying the balance with excess going to storage for night. Auxiliary heating energy required for part of most of night plus all or part of one or two consecutive cloudy days.

- 2. The Interior Environment - Controlled by man to be more uniform than outside but requiring careful management of energy balance for protection from the weather plus the addition of some auxiliary energy for added uniformity of comfort.

- A. The Interior Environment - Over the last 200 years our indoor environments have evolved from dominance by the patterns of outdoor weather to almost complete independence of outdoor temperatures and variations. Manual control has evolved to automatic control and adaptation to variable levels of comfort has evolved to constant and uniform levels of comfort. This happened with the help of advances in industrial and building technology and the availability of cheap fossil fuels. This process originally involved only heating but soon encompassed cooling as well. So, whereas amounts of clothing were varied to adapt to variations of indoor conditions, now there is a dependence upon the automatic uniformity of inside environments and people expect to be able to wear almost the same clothes indoors regardless of the season or the weather outside. And they expect the enclosures to automatically maintain that condition without any participation on their part.

Now energy costs are rising and availability is uncertain and so alternatives are being sought. Combined with an energy efficient enclosure, passive solar design can provide most of the comfort we really need, with little dependence on auxiliary energy sources for comfort, if we are willing to adapt to and participate in the comfort process.

The object of all of this is to keep the occupants comfortable, not the building comfortable! The comfort of the occupants depends on several

physical conditions which effect the balance of thermal gains and losses at the body which in turn determine comfort.

- a. Control of convection and conduction of heat from the body to the air mass of the room can be achieved with variations in clothing and bedding or with variations in the air temperature.
- b. Control of evaporation losses at the skin can be achieved with variations in relative humidity, the rate of air movement and also clothing.
- c. Control of the balance of infrared radiation to and from the body (and clothes) can be achieved by variations in the rate of re-radiation of the surrounding surfaces.

Since passive solar systems only work effectively at lower air temperatures than conventional heating and cooling systems, control of radiation and evaporation are the keys to the solution.

3. Conservation of Energy - The storing of free energy received from outside, the retardation of losses or gains, and the reclamation of energy used for other than comfort.
4. Natural Energy Utilization - Techniques for admitting and storing free natural energy.

Natural Energy Sources and Utilization - There are three sources of free, natural energy for comfort that come to any enclosure for habitation. They are at the enclosure whether we utilize them or waste them, available for enhancing our comfort without charge!

- A. Biological Energy - Our bodies are constantly burning fuel and for motive energy and constantly giving off waste heat to avoid overheating. It gives off latent heat by evaporation of moisture and sensible heat by radiation, convection and conduction. The more efficiently we trap it within the enclosure in winter and remove it in the summer, the less energy we have to buy.

- B. Geothermal Energy - The ground beneath the enclosure is a constant source of low temperature slow moving heat coming from tremendous mass and at a temperature slightly above half way between the extremes of our exterior environment. So it is a heat source in winter and a heat sink in summer. And since our comfort temperature is above it, it functions better.
- C. Solar Energy - Unlike biological and geothermal energy, solar energy at the point where we get it is not constant. It is only effectively in line of sight for one-fourth of the diurnal cycle off on region and then its intensity can be intermittent due to clouds. But managed effectively it can be the main source of heating energy for the enclosure and the breezes it causes plus the effect of its absence during night can be the main source of cooling.

Conservation measures can enhance the contribution of all three but geothermal and solar require specific orientation of specialized elements of the enclosure and its control and distribution systems. Geothermal energy is more or less self-storing in effect but it is constant so it does not matter. But solar requires radiation-transparent elements for collection, which are subject to net back-losses during three-fourths of the diurnal cycle and so storage for later use must be separated and protected from losses. This leads to what we call direct and indirect passive solar gains.

1. Direct gains come into living spaces through fenestration which is provided for daylighting, natural ventilation and view. Direct gains can be directly absorbed by surfaces or reflected to others for absorption and mass storage. This fenestration must be protected from back-loss.
2. Indirect gains come through glazing provided only for that purpose. Such gains are most effective if removed immediately for use or remote storage. Our passive design incorporates about 300 square feet of triple glazing for solar gain, half of this direct and half indirect for a total of about 20% of the livable floor area.

5. Auxiliary Energy Utilization - Sources and techniques for making up for the deficiencies of the passive and conservation effects.

Auxiliary Energy Sources - There are four sources of auxiliary energy available for consideration. Electricity is available almost everywhere. Gas and/or oil are available in many locations. Relative costs and availability vary from region to region to the extent that any one of them could be more or less costly than the others. But with the trend toward deregulation, all of them are moving toward parity of cost per heat value. But three facts stand out. First, only electricity can move three times as much heat as it can generate directly and second, only electricity can effectively cool on a small scale by moving heat the other way. Thirdly, only electricity can be generated directly by solar radiation. For purposes of our comfort system design auxiliary energy is considered in two ways. For the main auxiliary back-up system and the last resort auxiliary back-up system the heat pump/air-conditioner (air to air) is the most cost-effective and is universally applicable. However, maintenance costs can be high and the operating maintenance is reduced and the operating cost effectiveness is increased. For the last resort system, the best choice would be whatever fuel is being used for the domestic hot water system, which would be the cheapest locally available one. (If it has a solar booster, back-up is still required).

Furthermore, since the water heater is basically a boiler, our design uses circulator-pump operated "side-arm" with a finned coil located in the air handling section of the packaged heat pump in lieu of the standard resistance coils. This means that the most expensive energy is used in only one place and only for last-resort back-up.

For specific applications where extra heating is required such as in the bathroom where normal room comfort temperatures are not sufficient, electric radiant lamps or panels on manual controls will indirectly encourage conservation by encouraging low settings and setbacks. The electric blanket can also be used to the same end purpose.

6. Control and Distribution Systems - Devices and methods for operating various modes, such as, storage, collection of solar gains, circulation and storage of ambient cooling, sequences of control operations regarding auxiliary systems and coordination with changes in outdoor conditions.
7. Occupant Adaptation - Techniques for energy conservation and use which involve manual operation or manual setting of options on automatic systems plus the best use of shutters, shades, blinds, exhaust-recirculation devices, as well as clothing and bedding.

PRELIMINARY DESIGN FEATURES

Based on our research and analysis we have concluded that the following features can be effectively combined into a true hybrid passive-solar design which will be an optimum design for cost-effective energy conservation and utilization in new townhouse construction for the present mass market.

- A. Fenestration Systems - Two distinct fenestration systems are planned, one for north and one for south. The north openings will have more resistance to heat loss and more weather-stripping than south openings. This permits planning with north-facing rooms, which is necessary for cost-effective townhouse design compactness and for marketable floor plans. However, the north openings will be sized to minimum code requirements for light and ventilation whereas the south openings will be the maximum area required for direct solar gain. Both north and south will have vertically moveable insulation located within the opening to avoid interference with decorating and marketing, and to allow the use of low cost side seals. South openings will have solar control blinds for reflecting or controlling solar gains and are also located within the opening to avoid interference with decorating. Windows will be aluminum sliding units because they have the most reliable and durable weather-stripping and are the most economical type. Also, with thermal breaks now the industry standard, they perform as well as wood units.

1. North windows are two separate double-glazed, non-thermal-break aluminum window units mounted one inch apart for thermal break

providing quadruple glazing and quadruple weather-stripping.

2. South windows and sliding doors are double-glazed, thermal break aluminum units with integral storm(inside) providing triple glazing and quadruple weather-stripping.

Solar control blinds are conventional horizontal mini-blinds ordered with the top of the slats slivered or white and the bottoms black. When the reflecting side faces out, they reject solar gains in spring and fall when the louvered overhangs are only partly effective. When the reflecting side faces up, they reflect winter gains to the thermal-mass ceiling for short term re-radiation, without the problem of fading furnishings. When open downwards, they control the amount of direct gain to the floor. When closed with the black facing out, they become convective-collectors for direct gain when room darkening or privacy is needed.

- B. The Indirect Solar Gain and Indirect Passive Cooling System - The indirect solar-gain system consists of solar glazing which doubles as roofing, an air type collector which is integrated with the attic construction and a remote thermal storage mass.

1. The solar glazing low-cost u.v. stabilized triple-glazed fiberglass panels spanning from top to bottom of the attic and constituting all of the south facing roofing except overhangs. This glazing actually admits more solar radiation than triple glass.
2. The attic collector is ordinary gypsum board with conventional spray-on acoustical material and painted flat black. The texture will enhance heat transfer to the air. This attic is connected to the thermal mass storage. Also the optional solar domestic hot water collectors (drain-back type) will be mounted on the floor of the attic collector space thus requiring no additional glazing structures for that purpose.
3. The storage mass is the hollow concrete-block party-fire wall which is divided into two sections, one for downflow of air and one for upflow. The blocks are stack bond to form air passages. Some of the cells chases are filled with concrete for added mass, with more passages filled on the down-flow side than on the upflow side to

balance heat distribution in both sections. At the bottom and at the top are headers which connect the two sections. The bottom header is integral with the floor plenum and contains a bypass damper and a mixing damper connecting the storage loop to the main air circulation-distribution loop. This permits the use of stored heating or cooling energy. It also allows the storing of natural heating and cooling independently of space circulation and auxiliary energy use. The top header is integral with the attic plenum and contains a by-pass damper to allow connecting to, or separation from, the collector-attic. This permits solar collection and storage during the day and protection from storage back losses by thermosy-phoning at night. It also permits closing the solar attic off from the storage loop to prevent circulation losses during "unloading" of stored energy by the circulation system. Also, the block chases can be drained to the footing tiles at the ground floor level to dispose of any condensate generated during "unloading of the stored cooling."

4. The air handling system for indirect-gain consists of a blower coupled to a summer/winter sensor in the solar attic. On sunny winter days this circulates heated air from the collector-attic through the storage wall. During cool summer nights it circulates cool outside air through the storage wall. For this purpose the summer night mode of the sensor will be interlocked in parallel with the fresh air intake damper for attic cooling. (See J - Direct Passive Cooling Systems). (Note that this indirect passive cooling mode can utilize cool humid air as well as cool dry air since "loading" and "unloading" of the storage wall involved only sensible heat transfer to the living spaces. The controls for the indirect passive cooling modes will not allow direct ambient-air cooling of the living spaces whereas the controls for the indirect passive heating mode do allow such direct pass through if regional design adjustments warrant it. (See J-2 - Direct Passive Cooling System).

During sunny summer days it does not operate. At that time the attics are cooled by the separate ventilation system (See Item J below). (We are attempting to integrate the control and distribution systems for passive storage with those for cooling and ventilation to eliminate

some components - such as a blower and a damper - but have not accomplished this yet). Also, Photovoltaics would be preferred as a source of power and control for the storage system. Should the above mentioned integration prove infeasible, we will investigate its cost effectiveness for this design.

- C. The south wall shading system is a partially louvered continuous overhang system which is seasonally selective in shading the windows and walls below. Also it is set at an angle and the solid portion is planned for photovoltaic panels, which will operate the indirect-gain passive system. (Further study required) The louvers are integral with the overhang, are made of low-cost rough cedar boards. They are set at the angle of the winter solstice to permit insulation to strike the full area of the south wall and fenestration. However, the louvers are spaced so that as the angle of the sun approaches the summer solstice, shading increases as the need for solar energy decreases. Then just before the summer solstice shading is complete for maximum natural shading of windows and walls.
- D. The enclosure conservation package includes the windows mentioned above which are foam-caulked around the frames, plus an insulation system integrated with an infiltration and vapor barrier system. The amount of insulation would be varied for each region.
1. Walls consist of a conventional 2x4 stud bearing wall with R-11 batts, covered on the outside with a film vapor/infiltration barrier and then either one of the following: a) two and one-half inches of isocyanurate foam sheathing, R-20 total of, b) 2x4 furring with R-11 batts covered by one inch of isocyanurate from sheathing = R-8. Total R = 19. The total wall construction equals about R-35 either way.
 2. Roof insulation consists of nine inch batts in the roof rafters (R-30) plus six inch batts in the ceiling for a total of R-45 for the roof. The north slope of the roof is low enough to retain snow cover for additional insulating effect in northern regions and is roofed with aluminized asphalt to reflect the summer sun.
 3. Foundation insulation consists of two inches of styrofoam or urethane from top to frost line. At the basement wall this is on the outside.

At the garage door wall, it extends on the inside, up and over the top, and between the slab edge and the sill for a thermal break.

E. The vapor barrier and air-infiltration barrier consist of a single mylar film located within the insulation for optimum condensation control in both heating and cooling seasons. It is continuous through all floor assemblies and down to the foundation footing for maximum vapor and infiltration control. It is located on the outside of the structure, but it is still inside the dew point because the heavier insulation is beyond. This protects it from construction damage and penetration thus maintaining total integrity.

1. The added tightness of construction contributes very significantly to conservation efficiency by reducing wind filtration losses or gains, and to heating and cooling efficiency as well. By keeping out moisture on humid days, the latent heat load on the air conditioning is minimized. And by keeping in moisture in the winter, the efficiency of heating is increased by reduction of the evaporative-cooling effect of dry warm air moving across the body.
2. Further study has indicated the need for continuous and controlled ventilation to offset the effect of the extreme tightness of construction which has all but eliminated air infiltration and therefore ventilation as well. Since there is evidence that contaminants from construction materials as well as occupants may build up to undesirable or even harmful levels in such enclosures, minimum ventilation or "controlled infiltration" must be induced. Since this minimum quantity of ventilation is roughly one-half of the quantity of infiltration in a conventionally constructed enclosure, the net energy savings will still be significant and so the added "tightness" is still cost effective. (Also there is an added energy saving benefit of "controlled infiltration" when considered in conjunction with the increasing prevalence of work-day vacancy use patterns resulting from the current predominance of working couples as well as normal vacations etc. If the day-setback mode of the multi-setback clock thermostat is interlocked with the fresh air intake function mechanism, then no forced ventilation will occur when the home is vacant and

so there will be no infiltration load on the heating or cooling system during that period - typically nine hours a day or one third of the time! This can be done either by automatic switching from continuous fan to intermittent fan operation or by automatic operation of a fresh air damper). Our design includes a fresh air intake damper set at the minimum ASHRAE recommended ventilation rate of 0.5 air changes per hour or about 100 CFM. Connected to the return side of the air circulation system this will induce mild pressurization in the living spaces. Then that positive pressure will be relieved on the low cost version of the design (see J-1 Direct Passive Cooling Systems) through standard exhaust fan units which will act as relief vents even when not running. (These could be eliminated and be replaced with plain relief vents but a desirable degree of operating flexibility may be lost with regard to kitchen and bath exhaust needs). On the higher cost design for higher priced markets, which have centralized forced air ambient cooling systems (See J-2 Direct Passive Cooling Systems), the ventilation relief will be through a centrally ducted exhaust system leading from the kitchen and baths to the outside but interfacing, along the way, with the intake duct work thus providing for the optional air-to-air heat exchanger. Such heat exchangers are about 70% efficient and can be cost effective depending on the climate region. They will be more cost effective in regions where there are long and more severe heating and/or cooling seasons but in temperate climate regions they can not be cost effective since passive heating and cooling will already have substantially reduced the demand on off-site auxiliary energy. Furthermore, there are two types of such heat exchangers on the market. The first passes through humidity and would be used in cold climate regions where humidity generated inside the super-tight enclosure needs to be relieved in the relatively longer heating season there. The second type locks out humidity and would be used in hot humid climate regions where humidity outside the enclosure should be kept from entering and becoming a latent load on the cooling system. In hot dry climate regions where passive heating and cooling are both effective heat exchangers will not be cost effective.

THE PLENUM-SUPPLY SYSTEM

F. The floor plenum serves as the supply plenum for the circulation and

distribution of heating and cooling. The supply outlets are continuous slots in the floor construction which are covered by the flooring contractor with low cost grating or grill work. The return and supply risers are partition chases adjacent to the stair well. The volume of air per minute is increased slightly but the speed of the air is slower which reduces drafts and the room. This allows more heat transfer to the floor and ceiling construction creating more effective radiant comfort and also the resulting slower-moving air is cooler. This circulation system also serves to increase the storage rate of direct-gain heated air in the room surface masses by transferring to both sides simultaneously.

THE THERMAL-STORAGE PARTY-FIRE WALLS

- G. The party walls are of hollow concrete block and serve many functions. They are the thermal storage for indirect-gain solar heating and cooling. They are fire separation walls and are sound isolation walls. But most importantly, they are radiant comfort panels for heating and cooling. Both sides of the block are furred with 2x2's, insulated with 1½" batts in order to optimize storage time in regard to diurnal cycles and to minimize loss or gain rate to adjacent spaces - just enough to cause radiant effect, but not enough to cause overheating or condensation. (Note: All losses and gains from storage are to all the comfort spaces unique for remote storage! The rate of loss or gain can be fine tuned by varying the insulation to achieve the desired balance of radiation.

DIRECT GAIN MASS STORAGE

- H. Temperature Swing Attenuation is accomplished by increasing the mass within the enclosure. Our design has more than double the room mass of a conventionally built frame townhouse with an increase in cost of less than fifty percent. The walls and partitions are covered with two layers of 5/8 inch thick gypsum board as opposed to one ½" layer. The floors have 2½ - 3" of lightweight concrete fill or gypsym-based floor fill in lieu of sub-floor and sleepers. This mass absorbs excess direct solar gain and reflected solar gain thus minimizing the over-heating tendency of direct gain by storing energy for use later in the day. It works similarly for natural cooling too. The need for

auxiliary energy for heating and cooling is thus reduced by evening out the peak gains and losses of the diurnal cycle through the mechanism of short term mass storage. The effect is similar to the thermal-cycling mass attenuation effect of adobe wall structures of trombe walls except that this use of mass permits more glazing and also in this case the mass attenuation effect is indirectly coupled to the solar gain by means of the air circulation system.

THE RADIANT COMFORT SYSTEM

1. The combined effect of the radiant-storage party wall, the floor and ceiling plenum supply system and the increased room mass is to produce a forced-air radiant heating and cooling system. In this system, there is more area of radiant surface that is warmer than the air in the winter (and cooler than the air in the summer) than not. Therefore, heating comfort can be achieved at lower supply air temperatures because the radiant balance of the body is satisfied by the radiant panels. The reverse is true for warm weather comfort. The result of this effect is that comfort is maintained at more moderate temperatures and with less air movement which in turn, results in greater energy efficiency.

DIRECT PASSIVE COOLING SYSTEMS

- J. A choice of two natural ventilation cooling systems, both using ambient air, is provided to adapt the design to two market price levels. Both will reduce the use of auxiliary cooling and equipment.
 1. The low cost system consists of two modes. The power ventilation mode for whole-house cooling is dependent upon the manual opening of windows and doors and the manual operation of a switch that opens the exhaust damper at the stair well ceiling and turns on the fan. This switch is interlocked with the attic cooling exhaust fan which normally operates automatically from a sensor in the attic. When the manual switch is off, the attic sensor operates the attic cooling mode using the same fan and opens a fresh air intake damper into the attic plenum. The attic cooling mode can operate while the air conditioner is running but the manual ventilation mode cannot due to a lockout feature on the switch which prevents acc-

dental operation of both. This system would be installed in lieu of air conditioning in cold dry and probably cold-humid climates due to the shortness and mildness of those cooling seasons.

In temperate and especially in hot climate regions this system would be installed in addition to and operated alternately with air conditioning. In either case it will be very cost effective in saving energy.

2. The higher cost system includes an oversized air handling and air circulation system with a fresh air intake, a mixing damper, the substitution of a two speed blower (low for circulation and high for natural ventilation, an exhaust or relief ventilation, see E-2, and a temperature or enthalpy control for the damper depending on the region). This system will provide automatic natural cooling without opening windows, for the higher priced markets. This economizer cooling system, as an addition to an air conditioning system, will be more cost effective in temperate and especially hot climate regions where cooling costs are traditionally equal to or greater than heating costs (with a temperature stat in the drier areas and an enthalpy stat in the more humid areas). In cold dry climate regions, the economizer with a temperature stat can be cost effective as a substitute for air conditioning, whereas in cold humid areas an economizer would not be cost effective at all and air conditioning would be best used alone.

K. ENERGY RECLAMATION SYSTEMS

1. Gray waste water heat exchangers can be made or bought to preheat cold water supply for domestic hot water but it is not cost effective for residential applications, since temperatures are low at point of use due to mixing valves, separation of soil and waste piping would be required, most of the heat is lost to the living space both sensibly and latently where it provides a beneficial suppliment in winter and is easily exhausted in summer. We do not recommend this.
2. Waste heat from air conditioner compressors can be reclaimed to preheat domestic hot water supply and are readily available

from major manufacturers. We suggest they be considered only in climate regions where the cooling season costs are equal to or greater than the heating season costs. But we do not recommend this if solar domestic hot water system is included except maybe in extremely hot and humid climates where cooling systems are operated most of the time.

3. Waste heat reclamation from kitchen and bathroom exhaust has been covered under previous sections of this report.

AUXILIARY THERMAL ENERGY BACK-UP SYSTEMS

- L. When free natural energy sources and reclaimed energy sources are not enough to make up for the meager losses of the energy efficient enclosure, off-site purchased energy must be used for heating and cooling. There are three systems for this in our design, the main back-up system, the last-resort back-up system and the emergency back-up system. The main back-up source for heating and cooling is the packaged air-to-air heat pump (without resistance coils). In summer it is controlled so it only comes on when ambient cooling is not sufficient. In winter it only comes on if passive solar heating (direct, indirect or from storage) together with non-comfort thermal energy inputs is not sufficient. However, the outside temperature limit is set higher than usual so that the unit only runs in its most efficient operating range. When that limit is reached the last-resort back-up feature comes on, which is the side-arm hot water finned coil from the domestic water heater (or the solar domestic back-up heater) to the air handler, in place of the usual resistance heating coils. This is implemented by a small booster pump which is controlled by third priority of the thermostatic control. If the source of fuel for the last-resort back-up is interrupted then the emergency back-up system must be used which is the wood burning heat circulating fireplace. This unit has ducted outside combustion air and glass doors and can heat our very-well-insulated enclosure, not as evenly and not as automatically but sufficiently. It is connected to the return air of the circulation system (indirectly) so that during normal operation of both the output of the fireplace will reduce the demands on the other heat sources (a return air stat could be incorporated to assure that priority).

M. DISTRIBUTION SYSTEM AND MODES

The concrete block thermal-storage party-wall together with the solar attic collector constitutes a separately powered loop which can be closed off from the circulation-distribution loop in order to allow winter collection and storage of indirect solar gains for night use (or summer collection and storage of night cooling for day use) and to allow this simultaneously with main-back-up heating (or cooling). The reason for this is to force the heat pump (or air-conditioner) to operate during the winter day (or summer night) when ambient temperatures are less severe and the unit is therefore more efficient. While this is happening the passive system will be simultaneously collecting heating (or cooling) energy when it is also most efficient and storing it for later use when the heat pump (or air-conditioner) is less efficient, i.e. during the winter nights (or summer days)! This feature will optimize both solar availability and purchased energy since it stores solar gains (or cooling losses), even when they are not needed for the living spaces, on the probability that they will be needed during the other half of the diurnal cycle.

The provision of separate loops also enables the circulation and distribution loop to avoid back losses of purchased off-site energy out through the solar attic glazing. It also enables the prevention of the storing of purchased energy in the thermal-storage party walls at times when passive solar energy is available.

N. THE CONTROL SYSTEM

The control system is designed to operate all of the sub-systems of the enclosure either individually or in combination for optimum total energy efficiency of the whole system and the sub-systems. In addition to the controls mentioned previously a programmable multiple-setback thermostat is included to allow energy conservation options to be selected and varied by the occupants. This operates the passive systems and the main back-up system. Suggested operating regimes will be posted for reference and include: night setback to take advantage of the body's lower temperature tolerance during sleep, and day setback to take advantage of work-day vacancy. This thermostat also will have a switch labelled "passive only" which will lock out the main back-up

system and the last resort back-up so that the occupant has the option of going totally passive for heating or cooling to achieve optimum off-site energy conservation. He could then have the choice of adapting his living habits and clothing habits (including the use of comforters, electric blankets, night insulation, solar blinds, fireplace, sweaters, etc.) to whatever extent he chose. A second stat set just above freezing could override the "passive only" lockout to prevent plumbing from freezing. (The condo association might require a higher setting to protect party wall neighbors from excessive costs due to high losses (or gains) during long term vacancy of a unit).

0. OTHER THERMAL ENERGY SYSTEMS

1. Solar domestic hot water systems are the most commonplace and cost effective active solar systems available today. We suggest the flexible black rolled tubing mats for our domestic solar preheat system. Since they are relatively inexpensive to buy and install inexpensively on the floor of our solar attic, we have provided considerably more area of collector than is usual to compensate for the lower operating temperature. The system will use instantaneous heaters to boost the solar preheated water temperatures and will also serve as the last-resort back-up for heating as mentioned previously. If solar domestic preheat is not used, the instantaneous type heaters will still be used for domestic hot water, thus avoiding the operating, stand-by and distribution losses associated with conventional water heaters. These losses are easily recaptured in winter, but are wasted in summer and actually increase the load on cooling.
2. Lighting inputs are a benefit in winter and are easily removed with our passive cooling systems in summer. New low energy lighting is available but it is not market acceptable yet.

We have analyzed and continue to analyze our seven categories of thermal comfort energy in considerable detail and have concluded that even the limited scope of this study requires a quantity and complexity of analysis that tends to grossly exceed the resource limits of the Small Grants Program. To shorten the scope of the study to fit available resources would not do justice

to the subject since a systematic result requires a comprehensive approach. Nevertheless, many conclusions have been arrived at, some in more detail than others, and we believe that the main goal of the grant study has been achieved considering the limitations of the funding level and the scope and complexity of the subject.

To do proper justice to the subject, our preliminary conclusions will require additional detailed studies and extensive computations and either computer modeling or prototype testing..

In conclusion we must point out that the so called passive concepts utilized by this prototype design may not qualify for tax credits under the current law. We strongly urge that creative tax credit systems be devised and put into effect that would encourage passive, and more importantly hybrid passive-active designs, systems and components including even such things as some form of tax incentive for all south-facing glazing in excess of 25% of the total glazing, and for effective shading of summer sun on glazing and for achieving any solar savings fraction over an established energy budget for an enclosure, perhaps ties into the 90-75 standards in some way. To get our energy dependency down and our energy independence up we must do a better job of encouraging through tax incentives energy efficiency by any means that the mind of man can devise.

SECTION - TYPICAL

SECTION C-C

SECTION AA. TRU SUPPLY RETURN PENALTY

SECTION BB - THRU THERMAL STORAGE WALL