The Impact of and Potential for Energy Conservation Practices in Residential and Commercial Buildings in Texas

Governor's Energy Advisory Council
Contract S/D 8

Research Center
College of Architecture and Environmental Design
Texas A&M University

01
Acknowledgements

Texas A&M University

Principal Investigator
- Raymond D. Reed, Dean
  College of Architecture and Environmental Design

Project Investigators
- Duane Cote, Associate Professor
  Department of Environmental Design
- Claude D. Davis, Associate Professor
  Department of Urban and Regional Planning
- Richard Moore, Assistant Professor
  Department of Architecture
- Michael D. Murphy, Associate Professor
  Department of Landscape Architecture
- Walter H. Patterson, Assistant Professor
  Department of Building Construction
- F.J. Trost, Associate Professor
  Department of Building Construction

Project Coordinator
- Albert Pedulla, Coordinator
  Research Center

Research Assistants
- Doyle Borman
- James P. Singletary

Secretarial Services
- Patricia Bowman
- Linda Jamison

Governor's Office
- Harriet Hahn, Department of Planning Co-ordination
- William S. Duncan, Department of Planning Coordination
- Denzel Fischer, Department of Planning Co-ordination
- Milton L. Holloway, Office of Information Services

02
Abstract

1
Introduction

This study constitutes one of forty-one projects funded through the Governor's Energy Advisory Council. The purpose of these studies is to assist the State in determining energy related policy objectives to meet the needs of the State of Texas.

It is the specific purpose of this study to investigate the potential to conserve energy in the residential and commercial areas through the application of conservation oriented design practices and selected urban design and planning concepts.

2
Energy Profiles

Profiles of energy consumption in the residential and commercial areas are reviewed in the State of Texas. Charts reflecting end use statistics are indicated for comfort heating, hot water heating, cooking and comfort cooling for gas and electricity. Primary energy used to generate electricity for residential and commercial environments is documented.

3
Conservation in Architecture

3.1
General Design Considerations

3.1.1
Architectural

An understanding of the many variables associated with the design of the built environment and their relationship to energy consumption can contribute to effecting energy conservation practices. This section deals with energy uses in the built environment including life cycle considerations and design considerations such as shading, ventilation, insulation, lighting systems and the use of glass. The application of solar heating technology is also discussed.

3.1.2
Climatic

A broad spectrum of climatic conditions exists within the State of Texas. These can be reduced to essentially four varied climatic zones. Climatic influences obviously have significant impact on energy consumption. The design of residential buildings taking climatic considerations into effect can result in more efficient energy uses as well as an architecture that supports rather than negates climatic factors.

3.2
Residential Buildings

This section defines the elements of energy consumption in the residential sector for the State of Texas. Profiles of energy usage are presented by use category. Modeling of a typical dwelling unit of low and medium densities in different areas within the State is presented to reflect energy consumption variation due to geographic location. Potential energy savings resulting from the use of alternative design options to achieve conservation are also presented.

3.3
Commercial Buildings

The primary energy consuming use areas for the commercial sector are identified and analyzed in this report. Some of the problems associated with the deterrents to achieving conservation are presented and viable options to achieve conservation are discussed.

3.4
Modular Integrated Utility Systems (MIUS)

MIUS is a total energy system that recycles waste materials such as heat, water and biological waste materials that are generated in the built environment. These waste products are used to provide hot water, heating, comfort heating and to operate air conditioning systems. Such as recycling

system increases the efficiency of input energy and offers good potential for use in the residential and commercial sectors.

4
Conservation Potential from Implementing Planning Concepts

Various planning concepts related to urban forms have been proferred as having potential for achieving energy conservation. The effects of varying population densities, effecting mixed zoning uses, limiting the perimeters of cities and housing people close to their centers of activity are modeled to determine their energy conserving potential.

5
Political Ramifications

The potential adoption by governmental agencies of policies leading to energy conservation may have significant legal, political and economic effects. Some of these potential effects are discussed in general terms and suggestions as to areas for policy determination are offered.

6
Additional Research

As a result of this investigation a number of areas that require additional investigation were identified. This section presents a brief description of these areas.

03
Summary of Findings

- Public education is the appropriate beginning point for residential conservation efforts. An energy budget or energy use goal should be established. The budget would show expected monthly utility bills per square foot of residence so that the homeowner could establish his goals based on the size of his home and appliance mix. Monthly utility bills would then become a constant basis for evaluation and improvement.

- Beyond education, utility rates could be used as a stimulant for conservation. A surcharge for consumption above the anticipated monthly level appropriate to the dwelling would probably be effective.

- Energy consumption estimates should be provided to purchasers of new homes by builders. A standard basis of comparison is required, adaptable to degree day and cooling hour data. This would permit comparative shopping by home buyers seeking an energy efficient dwelling.

- Equipment and appliances that utilize electric resistance heating or gas cooling currently waste primary fuel. Equipment efficiencies in terms of primary fuel consumption should be provided by manufacturers.

- Off peak or demand charge residential rates should be established to encourage peak-reducing energy storage systems.

- Existing buildings vary widely in energy consumption for the same building type - example: banks reviewed varied 600%.

- Existing commercial buildings will require an individual building audit to determine possible conservation.

- Single story or low height buildings will respond to the addition of insulation more readily than high rise buildings.

- Added insulation provides a diminishing heat flow benefit - example: the first two inches of insulation may decrease heat flow by 75%, the second two inches by an additional 9 percent, and the third 2 inches by only 4 percent.

- High rise buildings are affected more by internal loads than external or transmission loads.

- Reduction of lighting requirements offer the greatest potential conservation in commercial buildings.

- Energy use in new construction should be controlled through establishment of energy budgets.

- The State Building Commission should adopt performance standards which can be applied to proposed new buildings to determine the budget for that building. Standards should not be construction codes but performance guidelines to allow the establishment of budgets only.

- The Modular Integrated Utility System (MIUS) concept should be encouraged in residential and commercial facilities.

- Wastefulness in the construction industry is an area that ultimately results in excess energy consumption. In addition to efficient use of construction materials significant savings may be achievable through factory prefabrication and modular construction techniques.

- Consideration should be given to life-cycle construction and operating costs as opposed to only short term costs.

- Building geometry can be a significant factor with respect to energy consumption and should be given serious consideration when designing buildings.

- The use of glass in buildings can have significant effect on energy consumption in buildings and should be used efficiently giving due consideration to orientation and placement.

- The use of shade and shading elements can assist in achieving thermal control.

- Principles of natural ventilation can be used to reduce the reliance upon mechanical environmental control systems.

- The use of insulation can contribute significantly to achieving energy conservation.

- Material assemblies used in the construction process should be designed so as to achieve effective insulation characteristics.

- Building orientation can contribute the effective utilization of solar heat gain in the winter to reduce the load on mechanical systems.

- The concept of solar heating systems offers great potential in reducing energy consumption for heating purposes. This area should be further explored.

- Lighting accounts for a significant level of heat gain in commercial buildings which contributes heavily to energy demand during the cooling cycle. Reduction in heat lighting levels can reduce heat gain significantly.

- Buildings that are designed to make advantageous use of climatic effects minimize the need for mechanical modification of the indoor environment.

- There are essentially four climatic zones (warm, temperate, hot-humid and hot-arid) that require varying environmental design criteria in the State of Texas.

- Optimum building form is considered that which loses the minimum amount of outgoing energy in winter and accepts the least amount of incoming energy in the summer.

- A square building is not optimum from an energy conservation viewpoint. An elongated building oriented on an east-west axis offers the most beneficial results with respect to energy consumption.

- Natural air flow for ventilation can be used advantageously in areas of relatively low humidity.

- Protection of buildings from undesirable winter winds through the use of wind breaks can reduce energy consumption levels.

- Consideration of the angle of the sun at different times of the year can assist in reducing energy consumption and should be considered in designing the built environment.

- Orientation of buildings to minimize thermal impact during the cooling season and maximize it during the heating season can assist in reducing energy consumption.

- The use of appropriate surface materials adjacent to the inhabited environment can have a considerable impact on the influence of thermal radiation on buildings.

- Modification of the inhabited environment to create comfortable conditions in high humid areas is very difficult. Modification of low humid areas is readily accomplished through the additions of moisture from pools, fountains and vegtative respiration.

- Air conditioning load can be divided into two distinct categories: internal load resulting from internal sources such as lights, people and equipment; external loads created by heat transmissions and solar gain as well as the tempering of outside air used for interior ventilation.

- Reflective or shaded glass greatly reduces heat gain from direct solar radiation.

- Energy for lighting represents the largest electrical input into commercial buildings.

- The reduction of energy use in existing and future buildings is not a technological problem but rather one of incomplete knowledge of the need to conserve energy as well as general indifference on the part of the user.

- Measures to reduce or eliminate unnecessary waste by retrofitting will be undertaken only if they result in cost benefits to the owner.

- While insulation can do a great deal to reduce energy usage there is an optimum point beyond which additional insulation has a diminishing effect in reducing heat flow.

- Reduction of lighting in existing commercial buildings offers the greatest potential for conservation.

- There is no code to provide guidelines for lighting in the State of Texas.

- Turning off a building's mechanical system during unoccupied hours could result in significant energy savings.

- Increasing thermostat settings in summer and reducing them in winter contribute to effecting energy conservation.

- Mechanical systems should be checked periodically to insure operation at maximum efficiency.

- Energy conscious design and efficient operation of buildings is one important facet of energy conservation.

- In order to provide guidelines for energy consumption in buildings, a set of procedures which can serve as a design manual should be developed.

- Consideration should be given to establishing energy budgets for each type building.

- The concept of the Modular Integrated Utility System (MIUS) should be encouraged in the construction of residential and commercial facilities.

- Community energy requirements are almost parallel with the community income indicating that consumption is based on what the community can afford and has little to do with energy needs.

- It is energetically less expensive to house people in higher densities than in lower densities. This would suggest that it is more economical to develop multifamily strategies for more efficient urban development.

- According to the communities studied within the context of this report, the most efficient density levels are between 6 and 10 people per acre.

- Studies should be made to determine the amount of land available for development within the existing perimeters of cities.

- Studies should be made of the economic effects of limiting the perimeter growth of cities.

- Existing codes should be reviewed to determine necessary changes.

- Cities should adopt limited growth policies.

- Home rule cities should extend land-use controls and building codes to their extra-territorial jurisdiction.

- Incorporation of Texas Cities should be made more difficult.

- Special districts should be made more difficult to establish.

- Constitutional tax limitations should be removed on cities and counties in Texas.

- County governments' legal ability should be strengthened to control land and establish codes in the unincorporated area of the county.

04
Table of Contents

1
Introduction

Energy consumption in the residential and commercial sectors of the built environment represents between 19 and 24 percent of the total energy consumed on the national level.[1] This accounts for 33 percent of the nation's primary energy expenditure.[2]

In the State of Texas it is estimated that the residential/commercial sectors consume approximately 16.3 percent of the State's total energy use.[3]

The recent energy shortage has made Americans aware of the need for energy conservation in all areas of our society. While conservation efforts alone cannot solve the national energy shortage, they can result in a reevaluation of energy use patterns that have prevailed in our energy consumptive society. Such a reevaluation should lead to an analysis of the policies and practices of the past as related to our limited supply of natural resources used to generate power.

It is the purpose of this report to present the findings of an investigative study into:

- the potential for energy conservation in the residential and commercial sectors in the State of Texas through the thoughtful application of architectural design that reduces energy waste and demand;
- the potential for energy conservation through the application of selected urban design and planning concepts.

While not a definitive study, it is hoped that the conclusions presented herein will be of assistance to the State of Texas in formulating energy related policy objectives.

1 Exploring Energy Choices, Preliminary Report, Energy Policy Project of The Ford Foundation, 1974.
2 Ibid.
3 Department of the Interior, Bureau of Mines, Division of Fossil Fuels, 1971 "Energy Facts Sheet for Texas".

2. Energy Profiles

An analysis of energy consumption patterns in the residential and commercial sectors of Texas is a prerequisite to any discussions of conservation opportunities. Although several national studies of consumption patterns have been made, no studies relative to Texas usage patterns were discovered in the literature search conducted as an initial part of this study. This study has attempted to establish those consumption patterns by surveying the major electric and natural gas utility companies serving the state. However, utilities have little firm data to support their estimates of the eventual use of their product. Consumption patterns presented here represents the combined estimates of the major utilities serving the state and is not supported by extensive research to scientifically determine what residential and commercial end use is being served by electricity and natural gas. Energy use for heating and air conditioning was confirmed by plotting monthly usage of both electricity and natural gas which clearly indicates the use of energy for those activities. These energy profiles were not prepared in an effort to quantify the volume of energy consumed in the residential and commercial use sectors. That quantification is to be determined by project S/D 2. Energy profiles presented in this study are provided to indicate what relative end use patterns for natural gas and electricity occur within the state.

Conservation opportunities will likely differ for the residential and commercial sectors. Therefore, it would be helpful to separate commercial and residential energy use. Surveying the utilities serving the state revealed variations in account classifications which prevent complete separation of residential and commercial energy use. Since there is little regulation of utilities on a state wide basis, no common customer classification or distribution reporting system exist within the state. Individual utility companies establish their own policy concerning classification of accounts. Many utilities classify a customer by volume of use rather than end use of product. As a result of that practice, most utilities classify master metered apartment buildings as a commercial customer rather than a residential customer. The same problem exists in the commercial sector. In many cases only the very large user of energy will be classified as an industrial customer. Therefore, small industrial operations may be buying energy on a commercial rate. These inconsistencies prevent accurate separation of energy use as reported by electric and natural gas utilities.

Natural gas utilities are required by law to report the quantity of natural gas distributed to the railroad commission annually. Electric utilities are not required to report their distribution to any state agencies. Most electric utilities operating in the state are intrastate companies and are not required to report their distribution to the Federal Power Commission. However, FPC reports indicate complete reporting of the major electric utilities. Therefore, FPC data was used for statewide monthly electric distribution profiles.

Electricity should not be considered a primary source of energy. Electricity is the result of some conversion process which converts primary energy into more useful electric energy. That conversion process results in energy losses in the form of low quality heat. About 98% of the electricity produced in the state is produced by converting fossil fuels (natural gas, coal, and oil) into electricity via a heat process. The remaining 2% is contributed by hydroelectric generation. Natural gas is the predominant heat fuel. Coal is now being used in one power plant to generate electricity for public distribution. Oil is generally used only as a stand-by alternate fuel when natural gas is not available. Therefore, electric generation should be considered as a more convenient form of energy available presently only through the conversion of fossil fuels. The quanity of heat required to generate a kilowatt of electricity varies with the efficiency of the generation system. For the convenience of establishing a common basis for both electricity and natural gas, a kilowatt of electrical energy will be considered to require 11,000 Btu of primary energy which includes conversion and transmission losses.

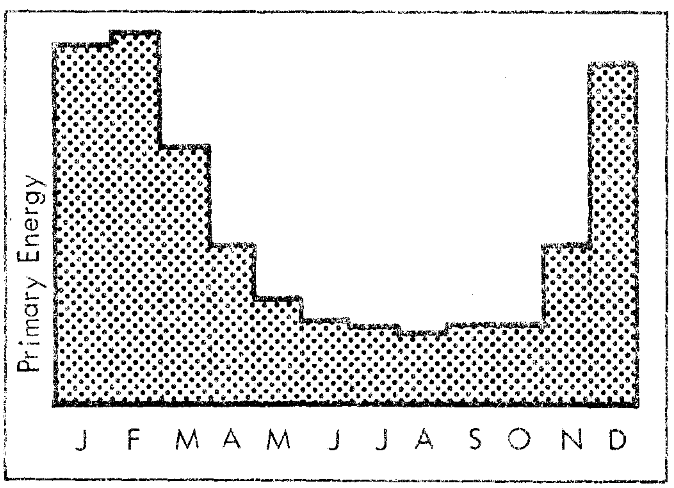
Natural Gas Usage

The following natural gas usage profiles were constructed to determine what end uses consume this primary source of energy in both the residential and commercial sectors of Texas. Identification of the source of consumption will indicate the activity required to accomplish conservation. Natural gas utility estimates of residential end uses are as follows:

Comfort Heating	55.9%
Hot Water Heating	27.2%
Cooking	9.0%
Comfort Cooling	2.9%
Other	5.0%
	100.0%

In an attempt to confirm these estimates, natural gas utilities were asked to provide a monthly breakdown of their residential distribution. A plot of monthly distribution illustrates the seasonal demand for natural gas and confirm that about 55 percent of the residential is for seasonal heating and 45 percent for other base load uses which occur consistantly throughout the year.

Residential Natural Gas



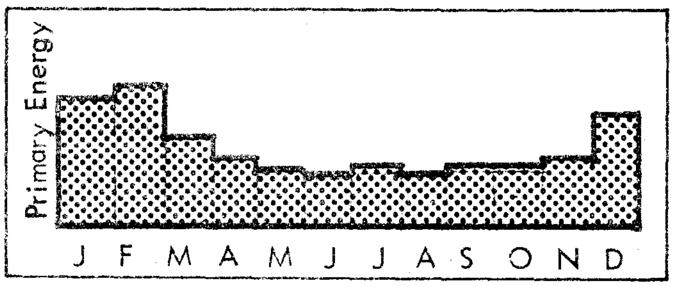
To conserve natural gas in the residential sector comfort heating and water heating would be important areas of use which could be effected by insulating those homes which are now poorly insulated, reducing heating thermostat settings, and reducing hot water consumption by more efficient use of hot water consuming appliances. These topics will be discussed in more detail in other sections of this study.

The commercial sector uses less than one half the quantity of gas consumed in the residential sector of the state. Utility estimates of commercial end uses are as follows:

Comfort Heating	28.6%
Hot Water Heating	33.2%
Cooking	16.9%
Comfort Cooling	10.6%
Other	10.7%
	100.0%

The monthly profile confirms the reduced percentage of natural gas for commercial heating.

Commercial Natural Gas



The reduced heating percentage is characteristic of the commercial building which has a high internal heat gain from lights, people, etc.

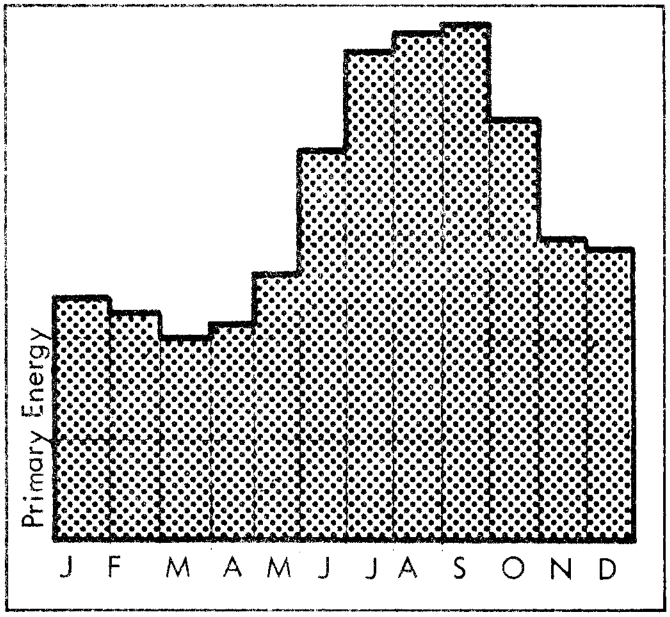
Electric Usage

Residential electric end use consumption was estimated to be as follows:

Lighting	20.1%
Comfort Cooling	32.9%
Comfort Heating	10.5%
Cooking	5.4%
Water Heating	5.4%
Other	25.7%
	100.0%

Monthly residential distribution profiles clearly indicate the seasonal effect of air conditioning.

Residential Electric



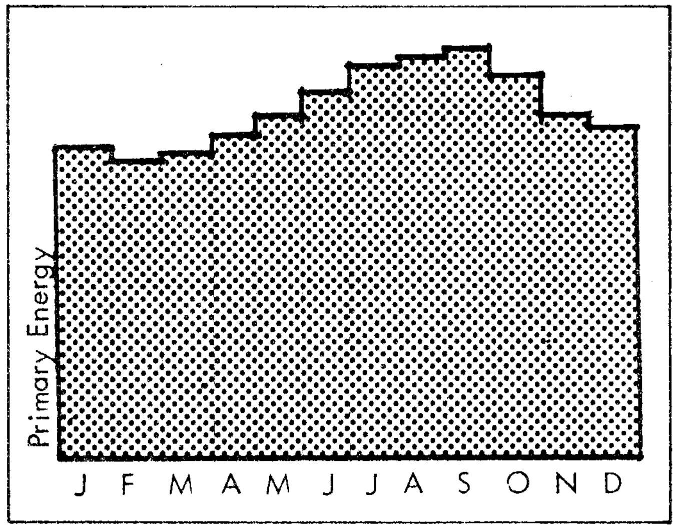
Separating the profile into base load and air conditioning load indicated about 30% of the total residential consumption is consumed in the 6 months between May and October for air conditioning. This tends to confirm utilities' estimates for comfort cooling purposes. Distribution of end use in the base load is difficult to confirm except by comparison to individual homes which may be considered typical. That comparison is made in a later section of this study.

Commercial use of electricity is estimated by electric utilities to be as follows:

Lighting	45.4%
Comfort Cooling	35.0%
Comfort Heating	5.5%
Cooking	2.9%
Water Heating	1.5%
Other	9.7%
	100.0%

The monthly distribution profile for commercial electric use indicates the internal nature of the thermal load on these buildings.

Commercial Electric

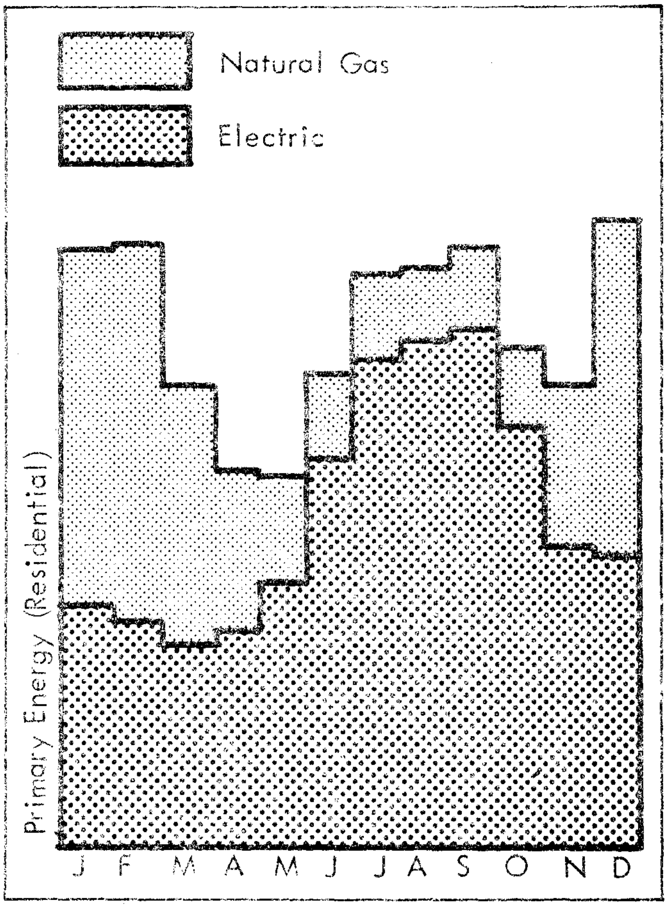


The slight increase of electric energy consumption in the summer months does not account for 35 percent of the total consumption. This suggests a year round use of air conditioning in most commercial buildings to overcome internal gains from lights, people, etc. That fact is even more obvious when you consider that much of the summer peak may actually be consumed in apartment building air conditioning which is reported as commercial load. Lighting and air conditioning present the major opportunities for conservation in commercial buildings.

Primary Energy Profile

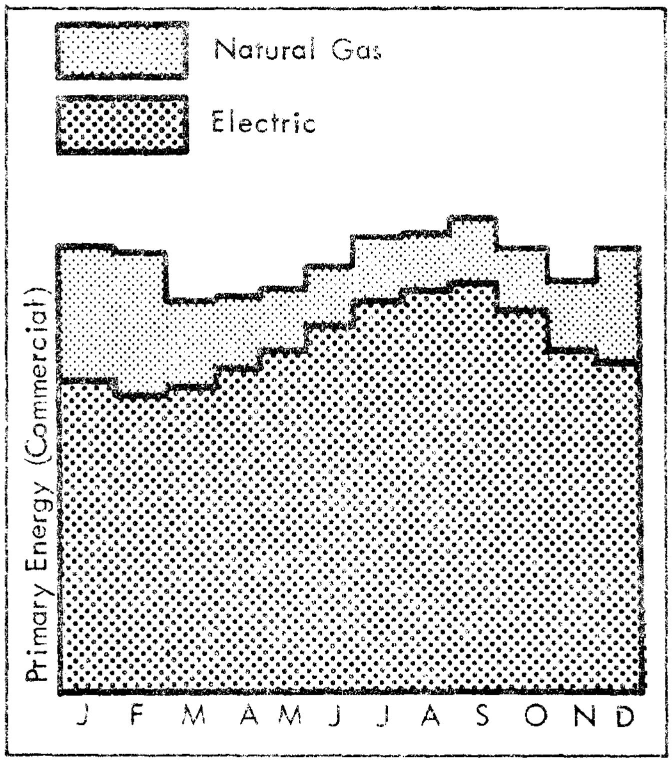
Primary energy used to generate electricity was combined with natural gas use to indicate the magnitude of consumption of both energy forms in the residential sector. The following monthly profiles indicate the percentage of primary energy which is required for electric generation and the percentage which is used directly in the residence or commercial building:

Residential Primary Energy



Combinations of primary energy required to produce commercial electric generation and natural gas used by the commercial sector is represented as follows:

Commercial Primary Energy



In the residential sector primary energy for electric generation is approximately 68 percent of the energy use. Natural gas used at the residence is the remaining 32% of the demand.

When electric and natural gas usage is combined to form total energy demand the following percenrages apply to the various end uses.

Heating	25.3%
Cooling	23.3%
Hot Water Heating	12.4%
Lighting	13.7%
Cooking	6.6%
Other	18.7%
	100.0%

Again, these percentages are not presented as absolute but are the best estimates made by surveying gas and electric utilities serving the state.

In the commercial sector primary energy for electric generation is approximately 80 percent of the energy use. Natural gas used in the commercial sector is the remaining 20 percent. When commercial end use of electricity and natural gas is combined the following distribution of total energy demand results:

Lighting	34.0%
Cooling	28.9%
Heating	11.3%
Hot Water Heating	9.4%
Cooking	6.4%
Other	10.0%
	100.0%

Lighting and air conditioning constitute about 63 percent of the total demand for energy in the commercial sector.

Conclusions

- Inconsistent recording procedures among utility companies in the State of Texas prevent an accurate separation of energy use as reported by electric and gas utilities.
- Electricity is not a primary source of energy but is the result of a conversion process which connects primary energy into electrical energy.
- Approximately 98% of the electricity produced in the state is produced by converting fossil fuels (natural gas, coal and oil) into electricity.
- Natural gas is the predominant fuel source for heating purposes in the state.
- In the residential sector approximately 55.9% of natural gas use in the state is attributed to comfort heating.
- The commercial sector uses approximately 28.6% of its total consumption for comfort heating and 33.2% for hot water heating.
- Residential electrical end use consumption data indicates that approximately 32.9% is utilized for comfort cooking and 20.1% is used for lighting.
- Approximately 30% of the total residential electrical consumption is consumed in the six month period between May and October for air conditioning purposes.
- Commercial use of electricity indicates a year round use of air conditioning in most commercial buildings to overcome internal gains from light, people and equipment.
- In the residential sector, primary energy for electric generation accounts for approximately 68% of the total energy use.
- The combined usage of electricity and natural gas indicates that approximately 25.3% is devoted to heating and 23.3% is devored to cooling.
- In the commercial sector primary energy for electric generation constitutes approximately 80% of total energy use.
- The combination of data for electricity and natural gas indicates an end use of approximately 34% of lighting and 28.9% for cooling.

References

1. Naman, I.A., Speech Before Texas Society of Architects Energy Conferences, Houston, Texas, April, 1974.
2. Ross and Barruzzini, "Lighting System Study, Public Building Service, March, 1974.
3. Slater, Richard and Norris, Deane, "Energy Conservation in Public Buildings", Rand Corporation Report #P-5093, October, 1973.
4. U.S. Department of Commerce, National Bureau of Standards, "Technical Options for Energy Conservation in Buildings", July, 1973.

3 Conservation in Architecture

3.1 General Design Considerations

3.1.1 Architectural Factors

> Again his dictum about houses...was a lesson in the art of building houses as they ought to be.
>
> He approached the problem thus: When one means to have the right sort of house, must he contrive to make it as pleasant to live in and as useful as can be?
>
> And this being admitted, Is it pleasant, he asked, to have it cool in summer and warm in winter?
>
> And when they agreed with this also, Now in houses with a south aspect, the sun's rays penetrate into the porticoes in winter, but in summer the path of the sun is right over our heads and above the roof, so that there is shade. If, then, this is the best arrangement, we should build the south side loftier to get the winter sun and the north side lower to keep out the cold winds. To put it shortly, the house in which the owner can find a pleasant retreat at all seasons and can store his belongings safely is presumably at once the pleasantest and the most beautiful.[1]

> Architecture more closely responsive to varying and specific needs will generate a more humane environment as well as one that uses energy more efficiently.[2]

Less affluent cultures, without fossil and nuclear fuels, house and shelter man's activities and possessions from the climate by designing with nature. In the desert, walls and roofs are built of thick earth to prevent the sun's heat from penetrating the interior until after sundown. At night the typically clear skies draw the heat out of the structure making the house comfortable for sleeping. Northern houses huddle together for mutual warmth. Fireplaces are made massive in cold climates to continue to radiate heat after the fire dies. In hot humid areas buildings are lightweight and open for natural cooling from thru ventilation. Their roofs are high and steep to permit convective cooling and efficient drainage. Cooling is achieved by careful orientation of openings to the prevailing summer breezes, as in the Texas "dogtrot" houses or by thoughtful siting on hillsides, lakeshores, etc. Summer kitchens keep canning and baking heat out of the house.

In mid-19th century, traditional American mobility and industrialization combined to produce balloon frame construction, a method which required minimum erection time and cost. Frame construction was and is in every corner of the land regardless of climate. The typical, universal, coast-to-coast, American house is of lightweight wood, one or two stories high, spaced row on row in keeping with the English country garden syndrome, oriented in strict conformance to the railroad surveyor's sense of order, alternately broiling and shivering in the absence of the trees that were sacrificed to build and heat it.

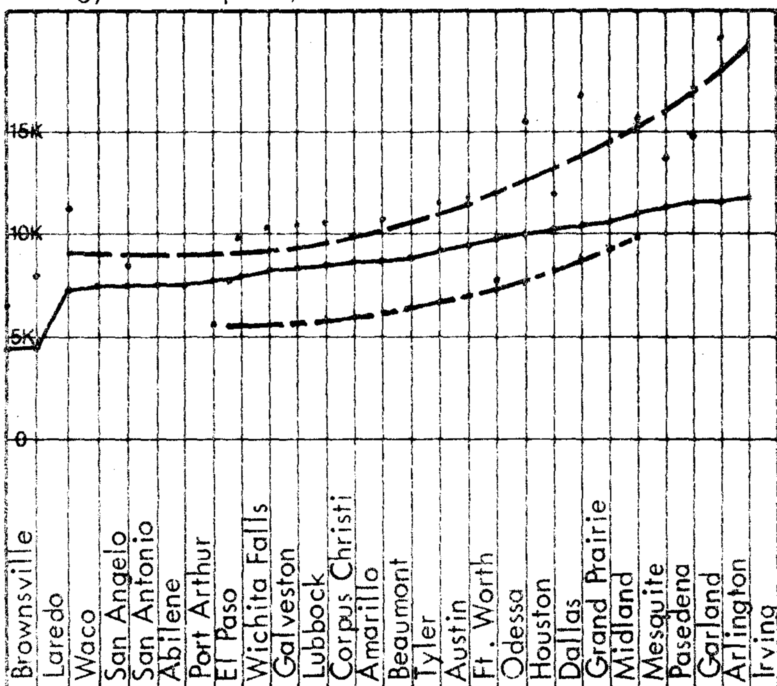
The discovery, unearthing and distribution of the country's fossil fuels made these houses livable. Benjamin Franklin's stove concept has been extended and enlarged to make fossil fuel burning furnaces now common to most American houses.

In recent years, the adjustment of the furnace thermostat is usually without any real thought to economic or energy consumption.

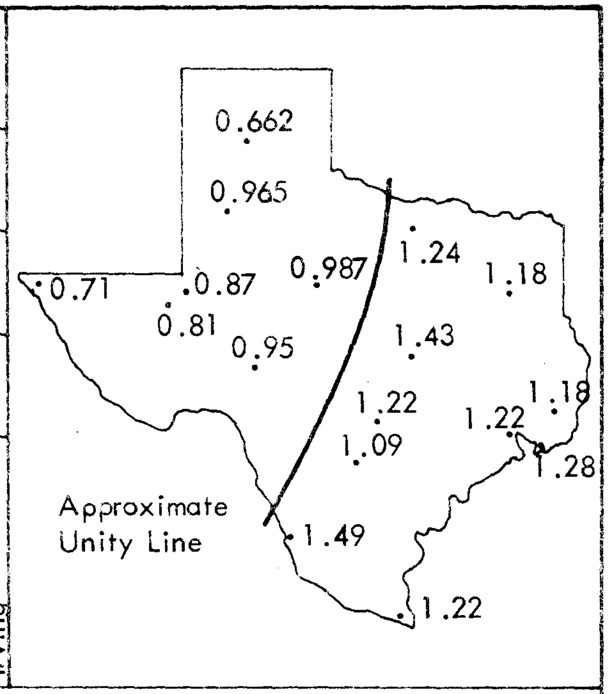
In the winter of 1973-74 the federal government asked householders to turn back their thermostats to 68 degrees. Many people simply refused to diminish the level of thermal luxury to meet what they suspect to be a synthetic energy crisis. The feeling was then, and continues now, that as long as we can afford fuel why not use it? This general attitude appears to be prevalent across Texas. The graph below shows the relationship between income and energy use in some two dozen typical Texas communities. It illustrates that energy use is not just directly proportional to income of the family but is rather an exponential function of that income.

Someone has suggested facetiously that all that is needed to reduce energy consumption is to reduce income; that a 1930's-style depression will solve the energy crisis. No one suggests that as a solution to the problem, but there are many proven ways to reduce energy consumption in buildings which lower energy consumption to acceptable levels until alternative solutions are found. This section will present some methods that have and may be used to control energy consumption in our buildings.

Energy Consumption/Annual Income



KWH - Annual Income

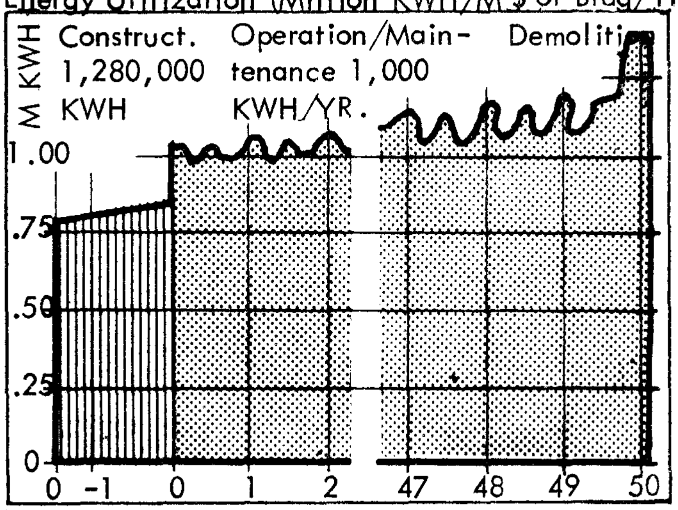


— — 1000 KWH consumed in cities east of "UNITY" line
—- - — 1000 KWH consumed in cities west of "UNITY" line
——— Annual Income - 1972[3]

Building Life

There are four broad areas of energy use in the life of a building: a) the production of materials used in construction, b) the assembly of materials into finished products, c) the maintenance and operation of the buildings and d) the ultimate demolition of these buildings. Each of these areas is influenced by the others and all are dependent on the design of the building.

Energy Utilization (Million KWH/M $ of Bldg/Yr



A typical example of waste in the production of construction materials is that of aluminum, the manufacture of which requires about five times more energy per pound than steel. The 4 million pounds of aluminum required for the skin of a new office building in Chicago could be replaced with about 5.75 million pounds of stainless steel. In energy terms, using aluminum would require 2.1 million kwh to process and assemble, about three times the 0.77 million kwh necessary for stainless steel. The difference would be about 1.3 million kwh on this building alone.

Another factor affecting wasteful use of materials in our structures is the employment in the design process, of excessive safety factors. Usually safety factors are provided for by building codes. If the codes were changed from specification-type codes to performance codes considerable savings might be effected. For example, codes could require testing of structural assemblies to determine their adequacy instead of specific sizes, shapes, etc.

Waste is a way of life in the construction industry. Estimators assume that a percentage of all materials on the job will be hauled to the refuse yard. The magnitude of waste is conditioned by a number of factors. If the materials and labor are reimbursable in the contractor's accounting, there is no incentive to reduce waste. Standardization of building products for modular coordination is minimal and is resisted by building products manufacturers as an unnecessary expense and by designers who feel that their creativity is being compromised when they employ standardized modular materials. Since job site power use is often random and indiscriminate significant energy savings can be achieved through factory prefabrication of standard building components. Construction costs and energy consumption may be reduced if the ultimate buyers of buildings insist that designers and builders maximize the use of standard materials.

Historically, the trade off where building operation and maintenance are concerned has been one of initial capital outlay versus ultimate operating costs with the usual developer opting for the lower first price in the expectation of passing along the long-term maintenance costs to the next owner. The servicing, cleaning, repair, painting - such expenses - were somewhere in the future and in any event energy was not a concern. If the windows lost or gained too much heat, if the structure leaked conditioned air at every joint, if the fans were inefficient - at least the debt service could be kept down to the point where the total package would be marketable when the initial depreciation and other tax write offs had been played out. To quote John F. Hartray of the architectural firm of Harry Weese and Associates:

> "The architects are building those terribly inefficient buildings because they are cheap. We have a system of economic incentives in this country that rewards shoddy construction."[4]

The final activity in the life of a building in which energy is used is the demolition of the building after it has fulfilled its usefulness. This is probably the least in terms of total energy use of the four but still considerable.

In the not too distant future the situation may arise where a life cycle energy cost analysis is at least as important as the life cycle financial cost analysis.

Observation[5]

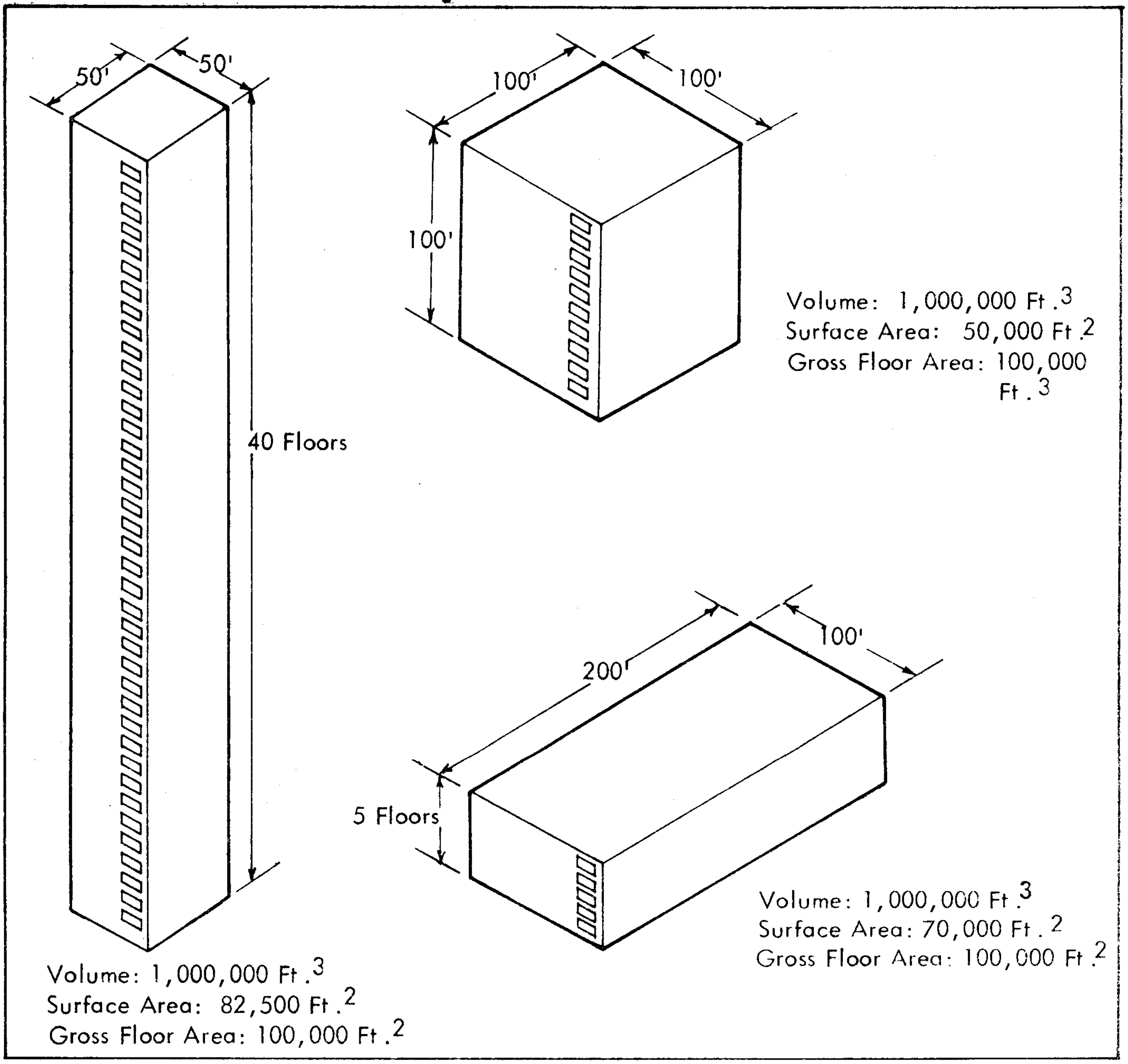
Of all the appliances, artifacts and objects made to serve our daily needs, a work of architecture is among the longest-lived--longer than appliances, vehicles or the machines for business and manufacture. Where an automobile may last from five to ten years and a television set even less, the life of a building may well be more than half a century and the infrastructure, the streets and utilities, last for hundreds of years. You can still go to Italy and travel on the Appian Way, a road that is 2,000 years old.

The importance of this, of course, is that the architectural decision--the openings in a building wall, the width of the building, the orientation--establishes a pattern of energy use that is carried forward for decades. If there is a change in taste, legislation or gasoline availability within ten years or less, requiring a shift from 400 to 100 horsepower cars, there can be a virtually complete replacement of the entire stock of automobiles. If, on the other hand, the same attitudes questioned the sealed glass building, they would continue as an important portion of our urban life.

Building Form

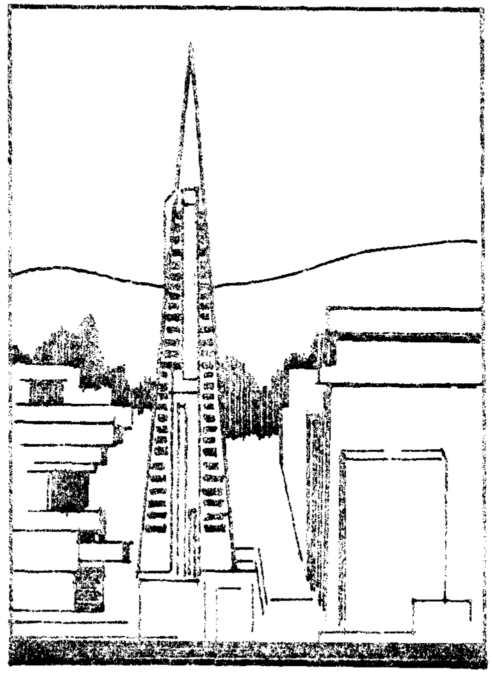
A sphere has the least surface area for a given volume. Hence, a spherical building would offer the most efficient shape to minimize heat transfer. Among the rectangular forms a cube would be the most efficient. Among buildings which sit with one of their principle surface on or in the ground the relationships change as is illustrated in the diagrams below.

Variation of Surface Area With Configuration[6]



Such comparisons assume that the heat transfer characteristics of the roof and the walls are identical, that any rectilinear conformation would be equally advantageous in terms of other energy use characteristics of the building, and that the microclimate surrounding the building's sides and roofs is identical. In fact, all of these factors are variables. Tall buildings require more support services. More of the building must be devoted to elevators, stairs, ducts, pipes, etc. Squat buildings may consume more energy if their interiors are darker due to the shortage of exterior wall windows for natural illumination. Air infiltration is a more prominent source of energy waste in tall buildings than in low ones.

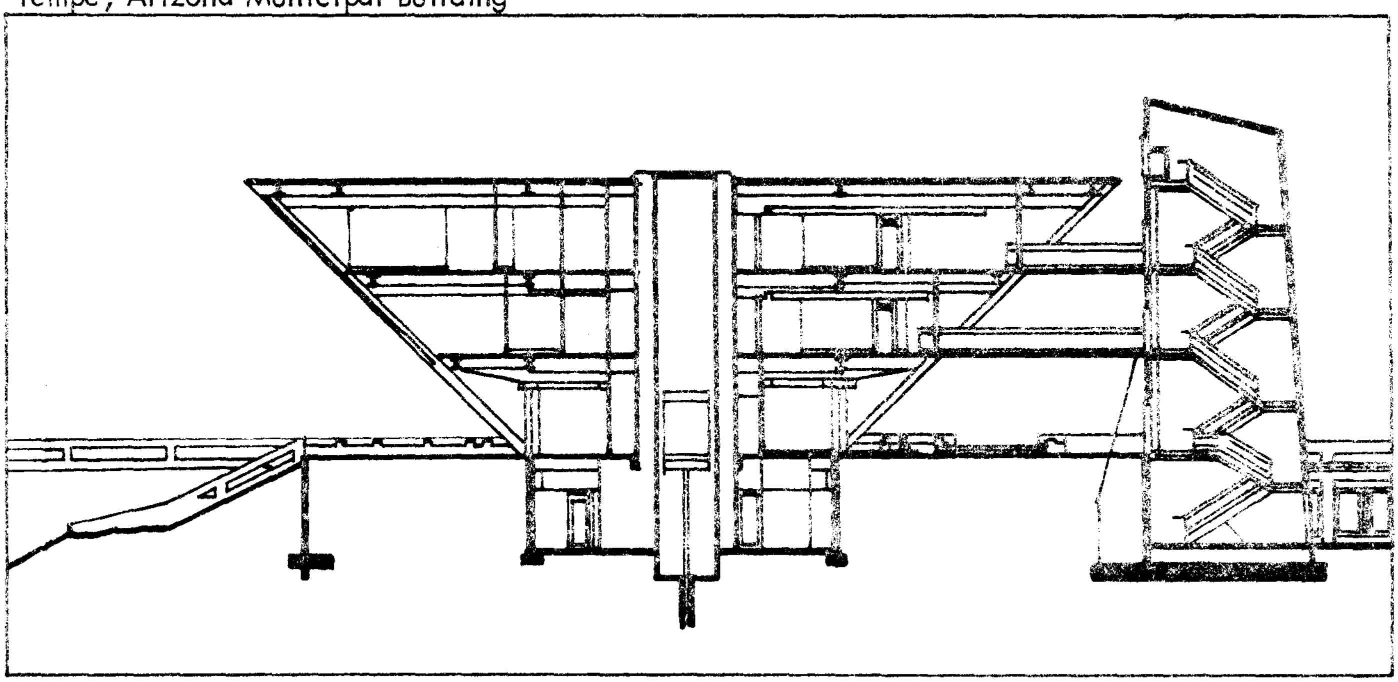
Trans America Corp. Building



An existing sky scraper which incorporates many energy saving ideas is the pyramid-shaped 48 story headquarters of Trans-America Corp. in San Francisco. It is estimated to use 29% less energy than a conventional design. Because of its shape it has more of the employees on the lower levels and therefore needs fewer elevators than the typical rectangular structure. This obviously results in a saving of electric power consumption.

Another pyramid-shaped structure uses just the opposite sort of form to achieve energy savings. The municipal office building in Tempe, Arizona is an inverted pyramid. The walls of the pyramid, sloped at 45°, allow the upper portion of the structure to shade the lower portions thus cutting direct solar heat gain, and attendant cooling costs. (For discussion of the effects of building form on heat gain and loss as related to the typical small house, see discussion under CLIMATE.)

Tempe, Arizona Municipal Building[7]



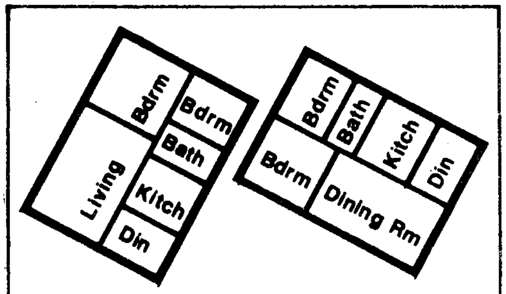
It should be noted that reducing the glass surface area does not cut available natural light proportionately. If the amount of glass planned for a building is reduced by one-third the natural illumination is reduced by only one-fourth. The result in a heated building would be proportionately more light and less heat loss.

As glass areas are reduced, placement becomes very important. In cold climates windows should be excluded from the north wall and concentrated on the south wall. Solar shaded glass on the south side can simulate diffuse northern light without the heat loss inherent in glazing on the north wall. In warm climates this pattern would be reversed, corridors, elevators and other utility and service functions could be placed along the windowless wall.

Refinements of building form can reduce energy requirements by taking advantage of the climate. For instance, in cold climates, buildings should be oriented away from the prevailing winds or have screens to avoid atmospheric leadage around doors, windows, etc.

Entry vestibules reduce energy waste by preventing the direct entry into the building of extremely hot or cold air.

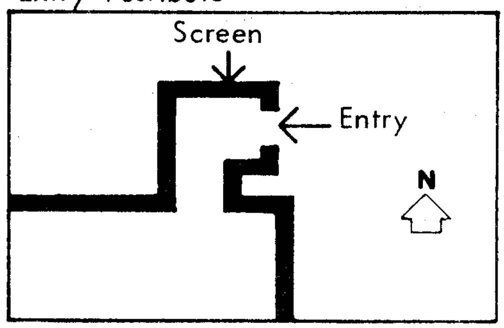
Building Orientation



Sun Heat in Living Room

Worst	Best
Summer	
●●●●●●◖ Maximum	●◖ Maximum
●●●●● Average	● Average
Winter	
●●● Maximum	●●●●●●●●●●◖ Maximum
●◖ Average	●●●●●● Average

Entry Vestibule

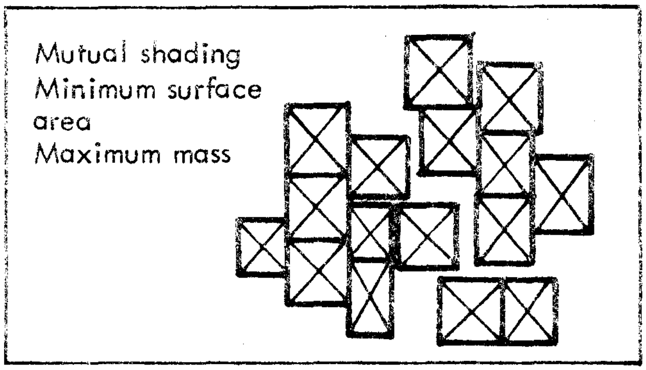


Shading

Shading surfaces from the sun is a very important element of thermal control.

There are many ways to avoid the sun's direct radiation. Among these are clustering buildings for mutual shading.

Clustering for Mutual Shading in Hot Arid Climates[8]



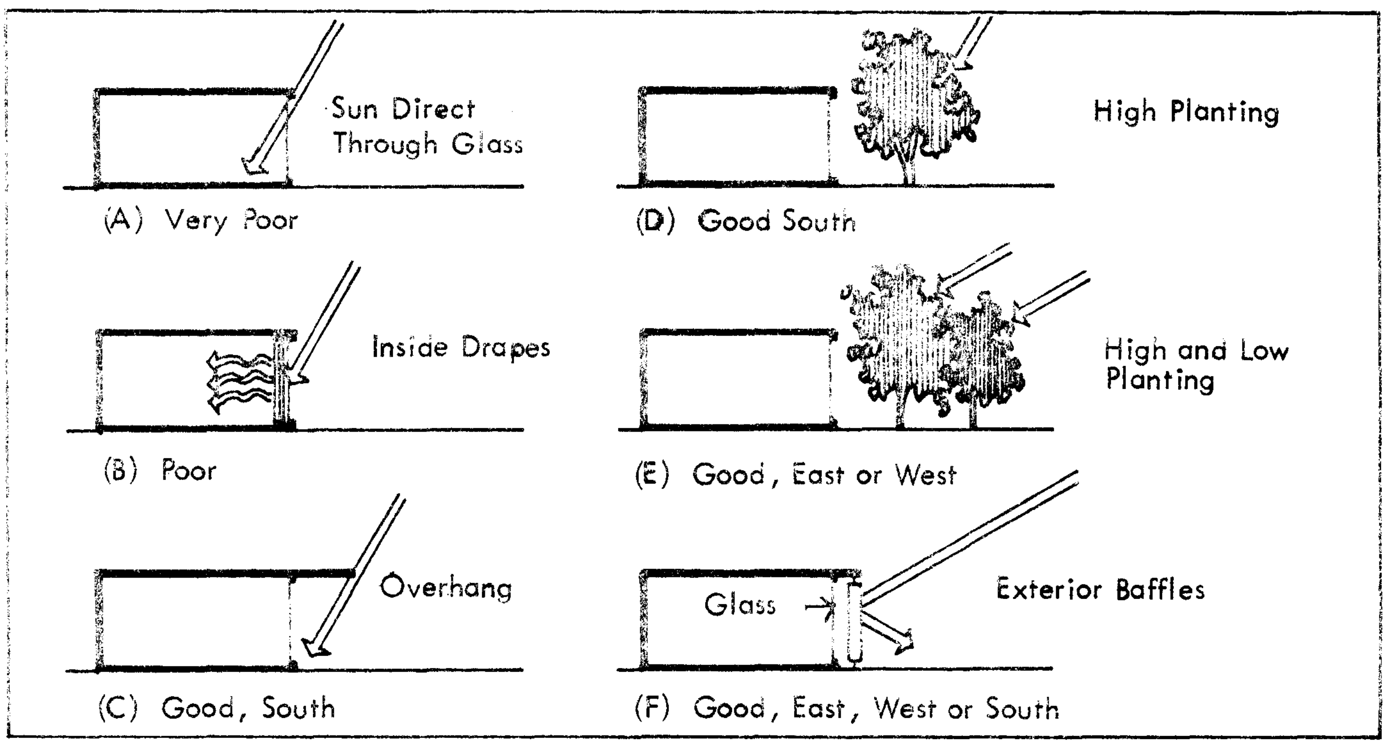
Careful placement of structures near hills, cliffs, or shade trees and vegetation is also effective. See section 3.1.2 for discussion of trees as shading devices.

Among built shading devices, those located inside (e.g. venetian blinds) are approximately 35% less efficient than identical ones located on the outside.

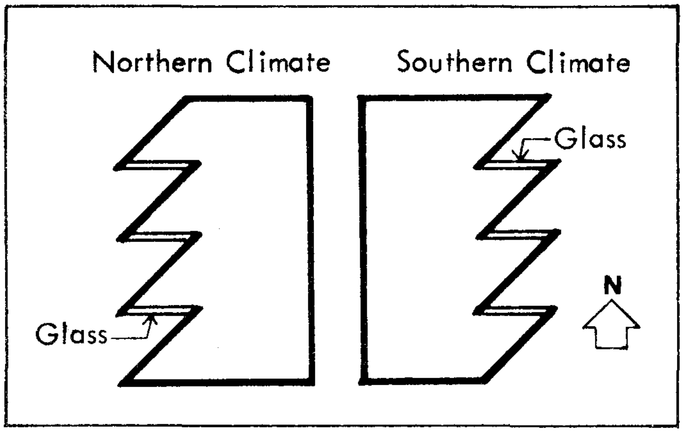
Simple roof overhangs designed to shield the south walls and windows from the sun can be very effective. Roof overhangs cannot protect east and west walls from low morning and afternoon summer sun. Nor will overhangs screen the early morning or late afternoon sun in the summer on the north walls of buildings. Overhangs are also useful in that they can provide rain protection and will allow breezes to blow through a structure even on rainy days. Fine antebellum houses in the South demonstrated this fact.

A variation of the horizontal overhang might be termed the vertical overhang, for example the zigzag walls (opposite). Saw-tooth walls are used for placement of windows in east or west walls that might otherwise receive solar radiation.

Indoor Comfort in Summer related to Sun on Glass[9]



Sawtooth Pattern

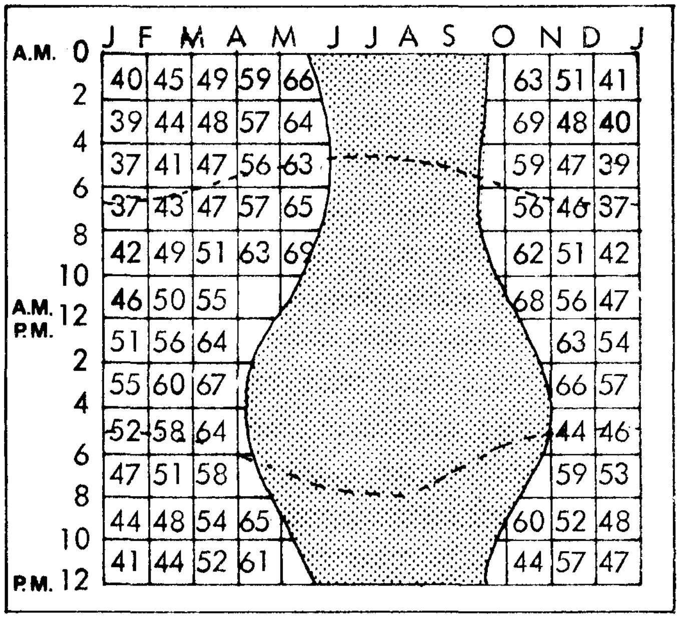


Another useful shading device is the louver (see figures) which is helpful in controlling the sun's heat. By using engineering principles the exact degree of slant for the louver blades can be determined. Louvers placed across the windows need not interfere with the line of sight and can also be coordinated with the prevailing breezes for maximum ventilation.

Olgyay employed painstaking methods in designing the shading for a Dallas factory.[10] Its long side faces north and south. Shading needs were plotted on a yearly shading chart (above right). The tone indicates overheated periods.

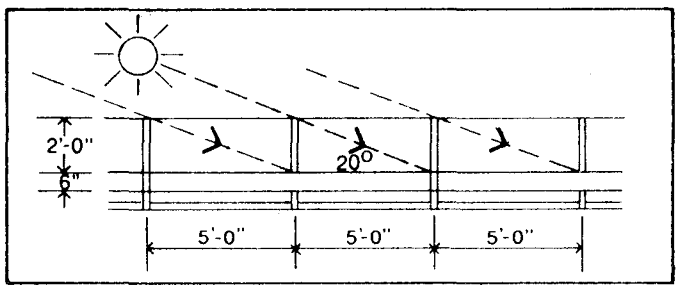
Vertical fins were used at the north wall and various arrangements of horizontal devices were

Yearly Shading Chart-Dallas, Texas

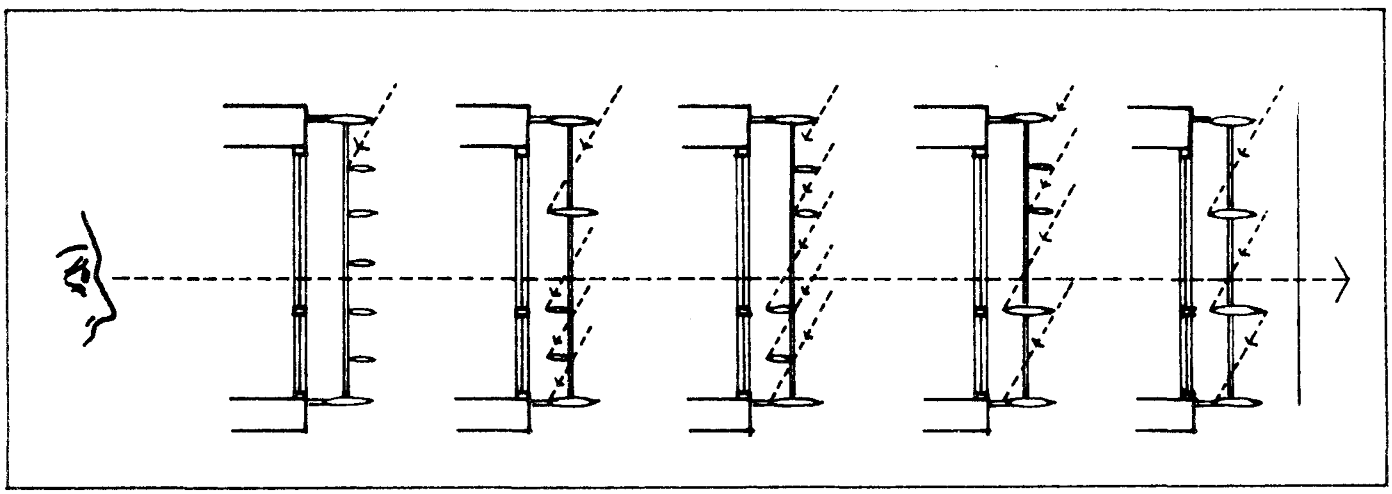


used on the south side. All have the same shading characteristics and all allow vision at normal eye level.

Vertical Sun Shades



Horizontal Sun Shades



Natural Ventilation in Buildings

Henry Wright, the noted environmental technologist describes the hermetically sealed modern building as an environmental monster. He says any modern building should include four types of space where environmental management is concerned. First is the zone in which the thermal-atmospheric controls are automatically controlled to provide the optimum conditions for most efficient work. The second zone would be one in which manual control of air conditioning equipment is possible, where windows can be thrown open in fine weather. A third type of space would include such spaces as corridors, vestibules, etc., in which only minimal environmental control is necessary because people don't remain in them for extended periods. These are transition zones between more carefully climate-controlled zones of the structure in which one might experience an exhilarating change while walking from one place to another. Finally, Wright believes that every sizable building should have some accessible open-air spaces where the occupants of the building can "step out for a free restorative - thus providing the range of olefactory, auditory, sensory, tactile, and psychological experience that is the prerogative of every member of the human race. When one has been immured in the synthetic environment for a protracted period, the sound of a distant auto horn or even the squeal of brakes can be almost as pleasant as the evening call of the whippoorwill".

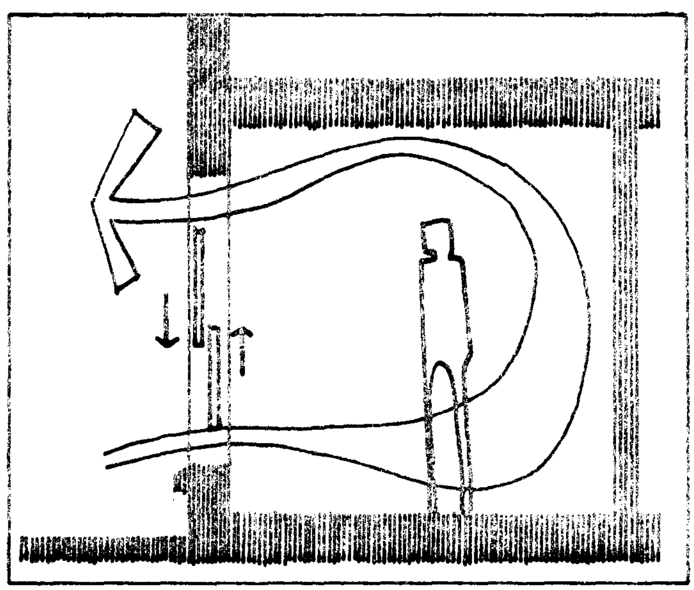
There are two principles involved in providing natural ventilation in a building. First, provisions must be made so that cool air currents can enter and warm air can be exhausted, because only so much air can be put into a box without allowing some to escape. The second basic concept is that hot air rises and cool air settles thus setting up convective currents in the spaces. Failure to provide an opening for warm air to be expelled or displaced by the cool incoming air will defeat the purpose of natural ventilation.

If the openings on the incoming sides are smaller than those on the outlet side a greater air flow results. Although the incoming air may not be cool if measured by a thermometer, the effect of it can be cooling because at 90° F. and below heat is carried away from the body and the process of evaporation, a cooling phenomenon, is hastened.

Generally it is good practice to have incoming air cross the upper half of the body rather than the feet. Studies have shown that lack of circulation air around the head area tends to produce a feeling of stuffiness while at the same time low air currents can produce complaints of cold feet.

Natural ventilation begins with advantageous placing and sizing of openings. Even if the outside breezes are small, the setting up of convention currents inside can draw in air thus producing stronger currents than are measured outside. In old Texas buildings, tall vertical double hung windows were used. These permitted an opening at the bottom for the cool air to come in and an opening at the top to allow the warm air to escape. With such windows cross ventilation or through ventilation is not necessary. The whole ventilation process is accomplished by the convective current in the room.

Convective Currents from Doublehung Window



The amount of air flow is affected by the size of the window opening. A general rule of thumb for deciding on window sizes says the opening should exceed 10% the floor area. (Most building codes or housing codes require that livable rooms have a window area equal to at least 10% of the floor area with one half of that openable.) Flues can also be used to improve ventilation. A study showed that a window open 2 inches produced 1.8 air changes per hour.[11] The use of an open flue increased the air change to 5.4 air changes per hour with the window still having a 2 inch opening. Since flues gain efficiency with height the higher the flue outlet the greater the volume of air flow.

The special conditions one must take into account when ventilating in hot climates have to do with humidity, whether high or low. The climates of arid regions are characterized by high day temperatures. It is interesting to note that the vernacular structures in such climates tend to have very few windows and those are placed high allowing heat to escape, while avoiding radiation from the ground and reducing glare and solar radiation. Planting vegetation to shade walls can also help to cool the air.

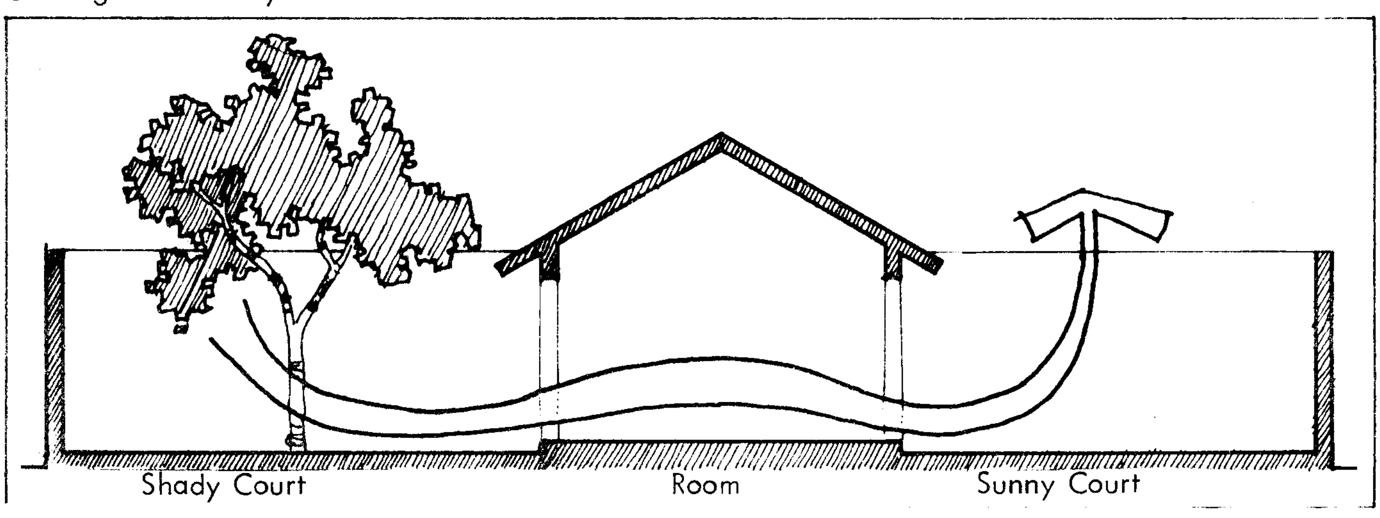
An ingenious solution that works in hot, dry regions is the utilization of two courts, a sunny one and a shady one, disposed on opposite sides of a room. With this arrangement cool air from the shady court will replace the rising hot air from the sunny court by flowing through the room - thus setting up a cooling air current.

Structures best suited for the hot, humid regions differ greatly from those for dry areas previously discussed. This is due mainly to the high moisture content of the air. Typically in humid areas, there is little temperature variation between night and day. As a result, maximum ventilation is needed to combat the high humidity and heavy masonry construction is useless. In fact, heavy masonry construction will only tend to store the solar heat during the day and radiate it to the interior of the house after dark.

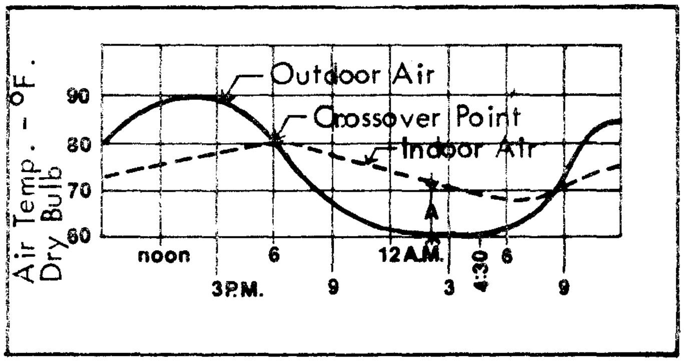
Advantageous construction for hot humid climates includes lightweight structure, elevated floors, continuous porches, balconies and overhangs. The elevated floors permit maximum air circulation and large overhangs allow for shade and ventilation in the rainy weather common to these areas. Vernacular structures in these areas show these particular details along with floor to ceiling openings and high ceilings move the accumulated hot air farther away from the occupant's head.

With the light construction and the openness of the structure there is a considerable loss in acoustical privacy. Some special provisions (thoughtful room arrangement and/or some sort of acoustical barriers) are necessary to restore the lost privacy. Because heavy masonry or similar separations are antithetical to the overriding climate control considerations, some other type of barrier must be used. Storage walls, combinations of dissimilar materials or heavy limp materials (e.g. roll roofing) are effective.

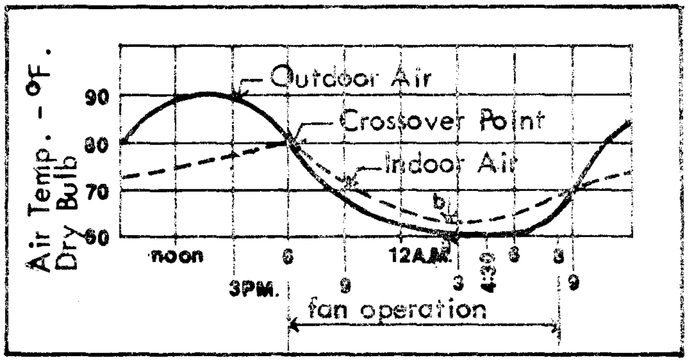
Cooling with Courtyards



12a
Indoor/Outdoor Temperature w/
Natural Ventilation



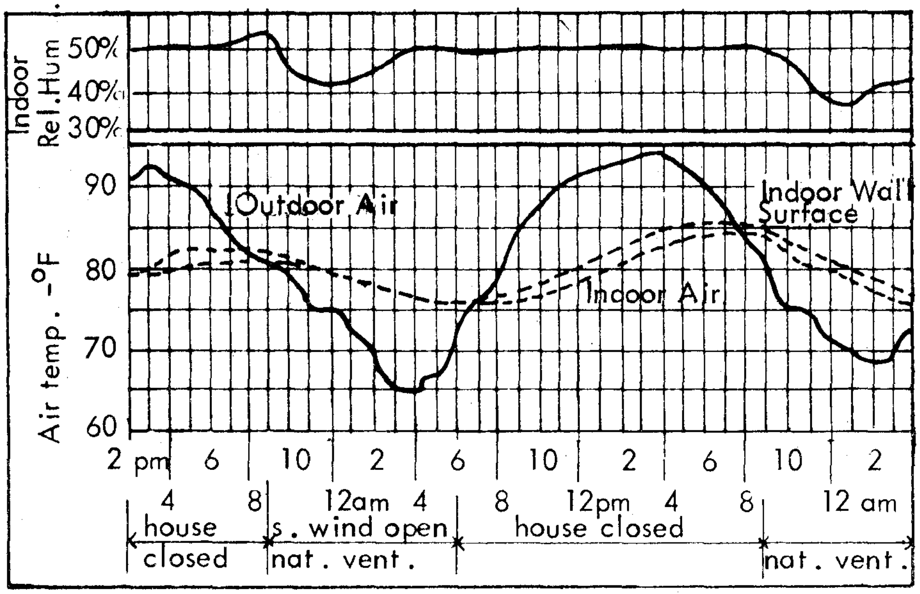
12b
Indoor/Outdoor Temperature w/
Forced Ventilation



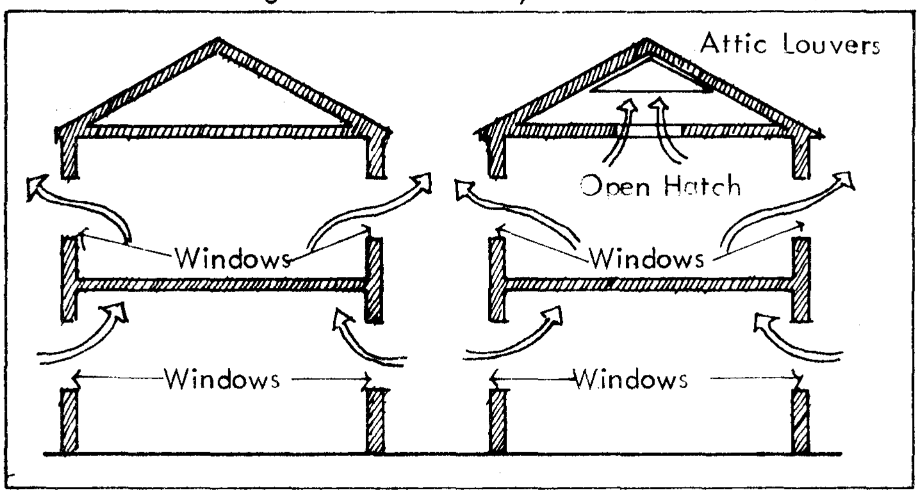
On still summer nights about 6:00 p.m. the outside air cools off dramatically faster than the inside air, particularly if the skies are clear. Due to the stillness natural ventilation often proves inefficient in providing comfort. If a large quantity of the cooler nighttime air could be introduced the structure would experience a rapid temperature drop and would be able to start the day with a greater resistance to heating (for greatest effect, the house must be closed up early in the morning). In order to achieve this end, attic fans can be used to expel hot air through attic louvers (see graphs 12a, 12b above).

Results of a study of a two-story house:[12]
a) In Figure 13a are shown curves for indoor relative humidity, outdoor-air temperature, indoor-air temperature, and inside-wall-surface temperature for a 38-hour period during which natural ventilation was provided during the night hours only. A similarity can be observed between the air-temperature curves of Fig. 13a and those on Fig. 12a.
b) In Fig. 13 a the minimum indoor-air-temperature was 76° F. at about 6 a.m., whereas the minimum outdoor-air temperature was 65° F. at 4 a.m. That is, the lowest indoor-air temperature was 11° F. higher than the lowest outdoor-air temperature.
c) Eight windows in the residence were open at night but closed during the day. Note the steady rise of the indoor-air temperature during the entire day until the evening hours when the windows were opened again. The maximum value was over 80° F. at this time.
d) Moisture apparently was accumulating indoors all during the day, for after the windows were opened a sharp and noticeable reduction in relative humidity was experienced, as shown by the dips in the topmost curve.
e) The performance curves of Fig. 13c show the conditions for night-air cooling by means of an attic fan in the same residence. These curves bear a close resemblance to those in Fig. 12b and illustrate another 38-hour period in which an attic fan was used to flush air from the house for 12 hours, beginning at 6 p.m. Note that the attic fan operated continuously during this 12-hour period, and not only during the evening hours.
f) The minimum indoor-air temperature dropped to 68° F. at 6 a.m. even though the outdoor-air temperature did not go below 64° F. The 68° F. value was 8° F. lower than the low point shown in Fig. 13 a.
g) The house was closed during the day and the indoor-air temperature rose steadily until it reached a peak value near 80° F. at 7 p.m. The storage of coolness attained during the preceeding night was almost sufficient to last during the entire following afternoon.
h) When the windows were opened at 6 p.m. a noticeable and sharp drop in indoor relative humidity occurred again. However, as cool outdoor air was pumped into the house during the night, the indoor relative humidity gradually increased, until at 6 a.m. the value was in excess of 70 percent.

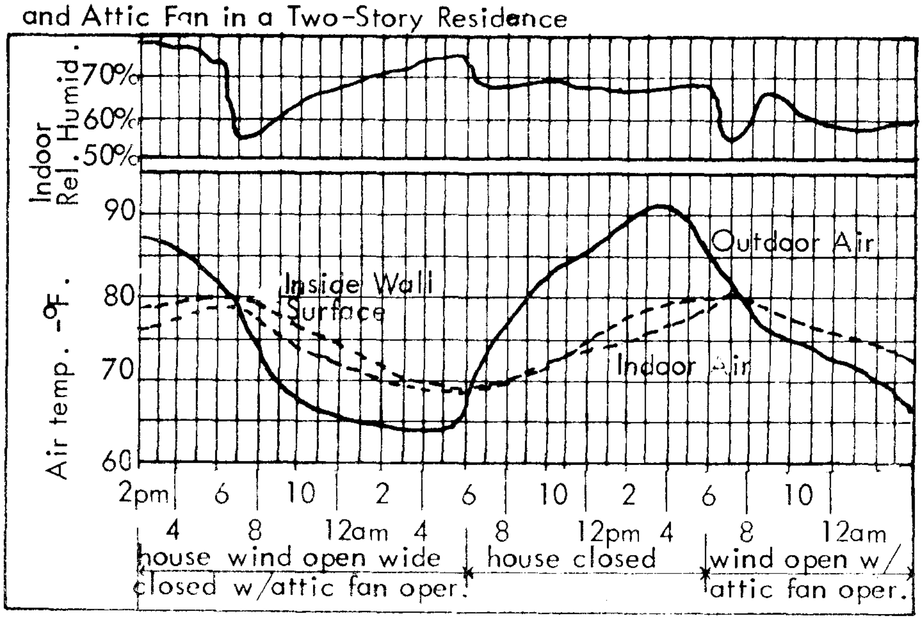
13a
Indoor-Air Temperatures w/Natural Ventilation in a Two-Story Residence



13b
Natural Ventilating Action-Two Story House



13c
Indoor Air Temperatures w/Night Air and Attic Fan in a Two-Story Residence



Insulation

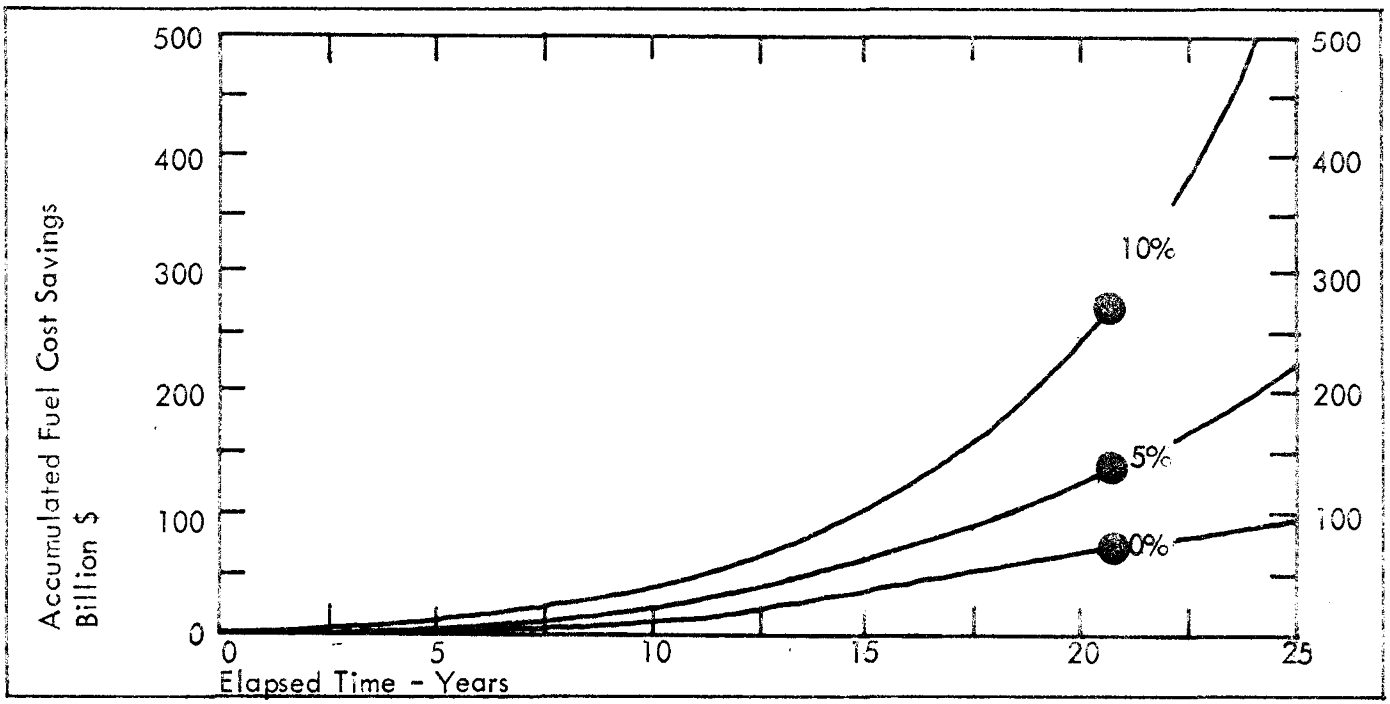
One of the basic truths of environmental management is that adjacent spaces and objects tend to share the same temperature. Since one cannot stop heat movement, the best one can do is to slow it one way or the other. One way to do this is by the addition of thermal insulation.

There are two basic types of insulation: the capacity type and the resistive type. Two other types of insulation are used but are seldom considered as insulation in the usual sense. These are the ones that use heat reflective materials and color for heat absorption or reflection control.

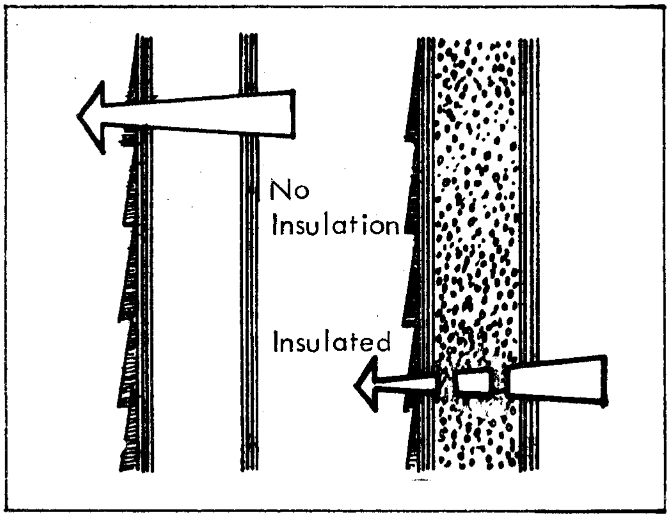
In section 3.2 it was illustrated that by using the FHA recommended insulation standards in a typical frame house approximately 40-50% of heating/cooling energy can be saved. Estimates of return on construction dollars invested in insulation can exceed 100% per year.

"For example, in a region of relatively mild winters where the average temperature between October 1 and April 30 is 45 F. (e.g. Abilene, Dallas, El Paso) your insulation investment will be returned by fuel savings within one year and thereafter give you annual savings greater than your initial investment. Even if you now have three or four inches installed, increasing the thickness to six inches will pay for itself in eight to twelve years and thereafter return you an annual dividend of some 12 to 15% on your investment. In colder regions, comfort improvement, savings, and the annual return will be even more favorable."[13]

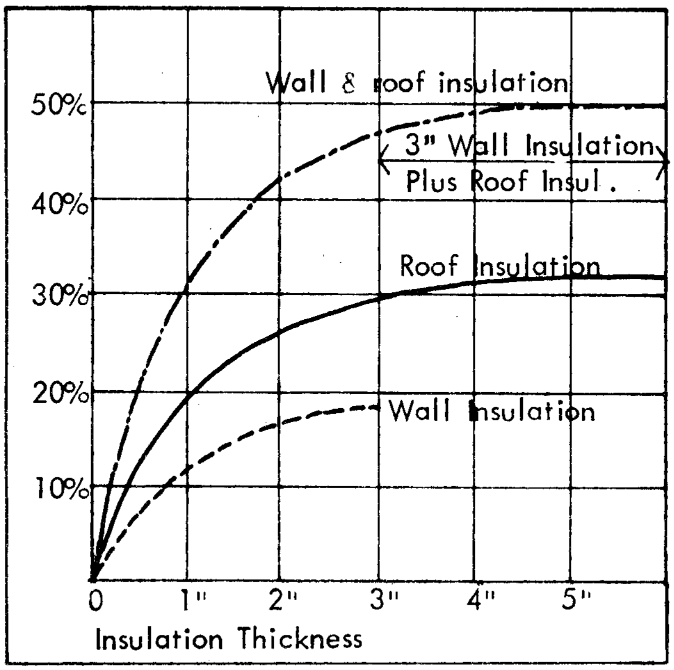
Accumulated Fuel Cost Savings from Improved Insulation for Various Annual Percentage Increases of Fuel Prices[14]



Heat Flow Through Walls[15]



Fuel Savings vs. Insulation Thickness[16]



Percentage of fuel savings for a typical residence for various thicknesses of insulation is given in the chart above. It should be noted that at a certain point there is very little to be gained by adding further thicknesses of insulation.

The types of insulation selected for use in a building will depend, of course, on the local climate. In hot dry areas (e.g. West Texas) capacity type insulation, that is heavy brick or adobe masonry, is desirable because it tends to work with the hot days and cool nights, absorbing heat only to its capacity (hence the name) as the day progresses and then at night reradiating the heat to the outside air. This phenomenon is called "flywheel effect". It should be emphasized that only very thick masonry will serve this sort of capacity insulation function.

Another type of insulation useful in hot dry areas is reflective material, e.g. shiny metal, marble chip roofs, light colors, etc.

In hot humid areas or in temperate areas where the nights tend to remain cloudy and warm, where the humidity is high, and the weight of construction has to be kept down, the better insulation to use is the lightweight resistive type insulation such as rock-wool, fiberglass, etc. These can be combined with a reflective foil type insulation in the attic and a vapor barrier on the warm side (normally considered the inside) to prevent condensation weeping through the wall finishes and destroying the effectiveness of the insulation.

Reflective insulations are distinguished from other types of insulation by the fact that they depend on their surface characteristics for their heat resisting properties. Therefore, it is important for these materials to be installed in conjunction with air spaces so that the reflective surface is adjacent to the air space. There are many types of reflective insulation including foil-surfaced blanket or gypsum board and reflective coatings applied to paper or other surfaces.

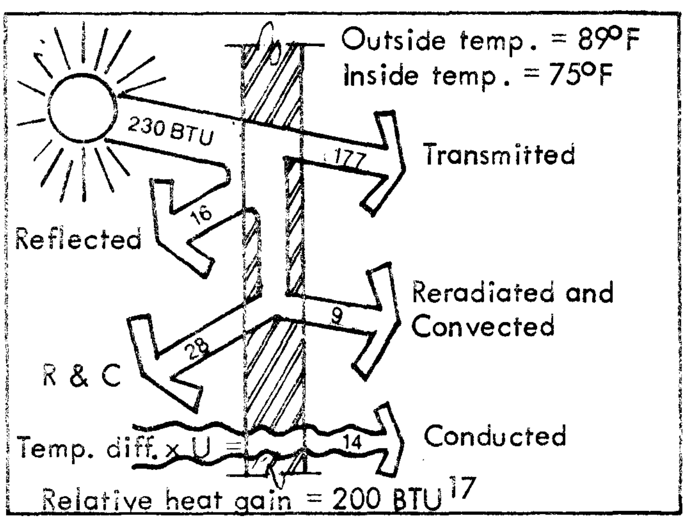
Glass

Much of the energy demanded for operation and maintenance of a building is predetermined by the building design. General building design practice over the past decade has been to utilize large expanses of glass, with most commercial buildings having 50-60% of the exterior surface area occupied by the transparent surfaces. In contrast to their favorable characteristics, windows can have a significant impact on the building since glass transmits more heat rapidly than almost any other material. Except for the use of multiple surfaces with air spaces there is little that can be done to reduce this rate.

Designing buildings without glass is probably easier than designing them with glass, but such buildings do not rent well, since people do not seem to like them. Their employee turnover is high.

The orientation and placement of glass can do much to admit solar energy during sunny hours but, since heat losses are calculated for critical dark hours, the standard U coefficients of windows, skylights, and light transmitting partitions must be used. For example, figure below, depicts a typical process occurring during the summer, with solar radiation impinging on one quarter inch clear plate glass, and the energy being conducted across it as a result of hot outdoor air.

Solar Heat Gain



In the winter time a different type of problem exists. The ability of ordinary plate glass to conduct heat is 5-10 times more than that of typical, well-insulated walls and so they become a source of heat leaks in cold weather. In addition, their high conductance results in a cool interior surface which is detrimental to thermal comfort.

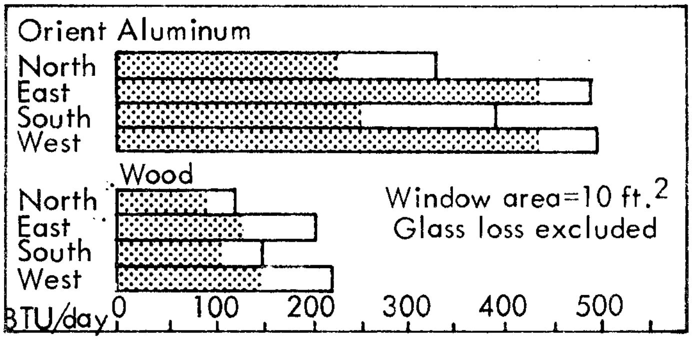
Where opportunities arise in the design of commercial buildings, consideration can be given to the use of other than single clear plate glass. Most glass manufacturers have available a wide variety of glasses that are more efficient from the thermal standpoint and yet allow visual communication with the outside.

Operating costs were probably the deciding factor in the choice of mirror glass for the Toledo Edison building, designed by Samborn, Steketee, Otis and Evans.

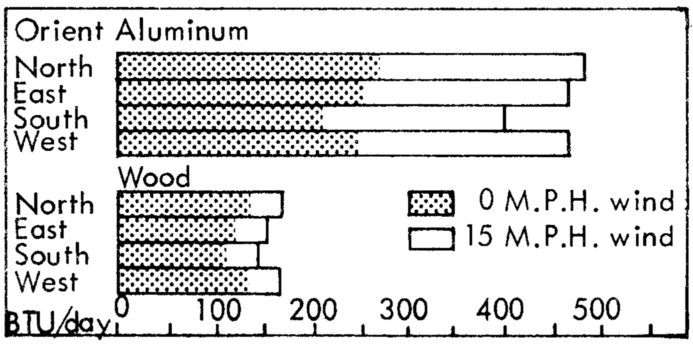
The story of the reduced costs starts with an added expense--$122,000 more for the chromium coated dual wall insulating glass than conventional 1/4" plate glass would have cost. But offsetting the initial expense was a saving of $123,000 in initial costs for heating and cooling equipment (a heat recovery system), ductwork and the like. Beyond that the yearly operating cost is about $40,000 less.

In designing the building, the architects, along with Libbey-Owens-Ford, did a detailed computer study of the effects of a variety of glasses on the building's construction and operating costs. Compared to 1/4" plate glass, the glass they finally selected offers: (1) a 64.7 percent reduction in the capacity of the central refrigeration system, (2) a 67.9 percent reduction in the capacity of the distribution system, (3) a 53.2 percent reduction in the capacity of the central heating equipment. Plus, of course, the savings in initial and operating costs. In terms of energy the savings are equally impressive: 729.4 kilowatts per hour over the 1/4" plate.[18]

Summer Daily Heat Gain-Window Components

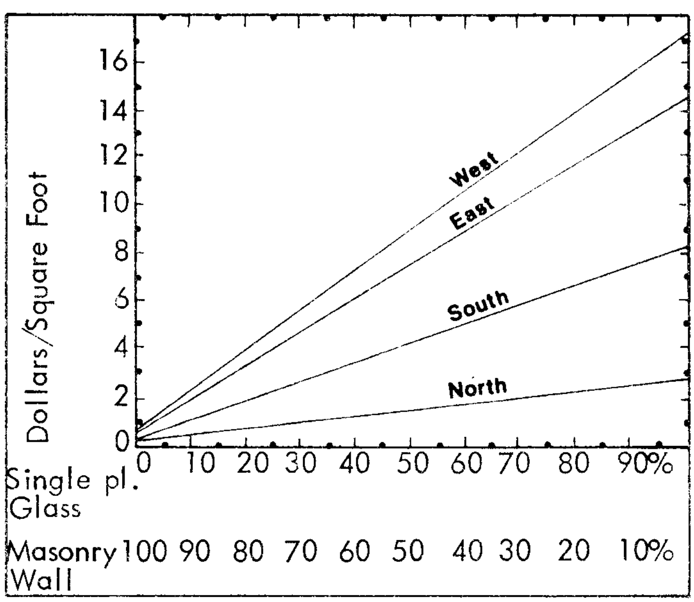


Winter Daily Heat Loss-Window Components



It should also be noted that the window framing itself is important. It has been found that aluminum windows loose approximately 25% of the total window loss through the frame assembly. In contrast, wood assemblies lose only approximately 13% of the total. The figures below compare total loss and gain for the two types of window frames. In all cases window area is 10 sq. ft. and glass loss is excluded.

Installed Cost of A/C (cooling)



There are many elements that affect the amount of the sun's heat that reaches a particular wall. Among those that the designer cannot control are the time of the year, the day, the haze or clouds in the sky, and geographical location. Among those the designer may or may not control are the orientation of the building relative to the sun and the amount of solar heat reflected by, transmitted directly through, and/or absorbed by the exterior walls.

The amount of solar heat transmitted directly through a particular wall depends in part on the opaqueness or transparency of that wall: a brick wall will keep all the solar heat from being transmitted directly through, while a single pane of glass will transmit up to 87% of the solar heat. The amount of sunshine absorbed by a wall is that which has been neither reflected by nor transmitted through the wall.

Graph lower left shows the estimated installed cost of a cooling system per square foot of exterior wall for various percentages for masonry and single plate glass for four exposures. The per-square-foot-of-exterior values shown in the charts were computed by using only the heat gain or loss caused by the exterior conditions and the inside design temperatures. They do not include heat gain from people, equipment, lights and outdoor ventilating air.

The masonry wall used was composed of 4 inch face brick, 8 inch block, lath and plaster (slightly better than typical exterior construction for commercial buildings). This chart shows that the amount of air conditioning required increases with an increased percentage of glass. It also indicates that the larger the percentage of glass the more important the orientation of the wall becomes. A square foot of glass on the west required approximately 6 times as much cooling as a square foot of glass on the north.

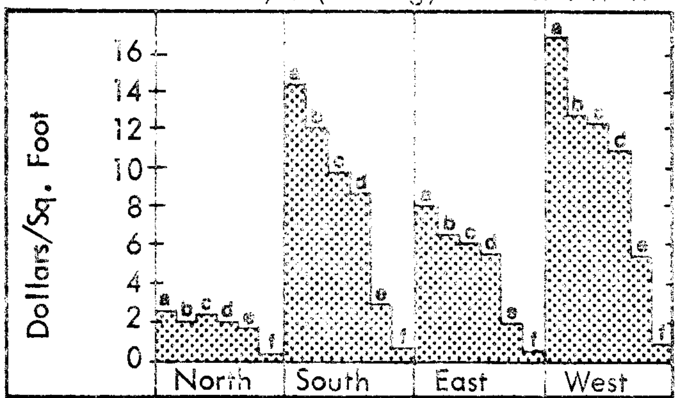
The bar graph at right shows the air conditioning requirements per square foot for various glazing conditions as well as for masonry for different exposures. This graph indicates that almost any amount of shading of a plain glass opening will reduce solar gain and thereby reduce the air conditioning requirements. It is possible, in some instances, that the savings resulting from the reduced cooling requirements could pay for the additional cost of blinds, shading, screens, etc. The chart indicates that this would be more likely for the east or west exposure.

It should be noted also that the option shown in the bar graph which is most effective in terms of reducing solar air conditioning load (option E) is eminently feasible for incorporation into existing buildings where retrofitting to reduce energy consumption is desirable.

It is not strictly true that an air cooling system can be contrived to ensure comfort with any condition of glass plus sun in critical summer weather.

Often it is not merely a question of reducing a cooling load, but also one of avoiding uncomfortable solar radiant areas next to the glass. These may develop as a result of the "greenhouse effect", the principle of which is as follows: the major part of the solar radiation spectrum is in the wave length between 0.1 and 2.5 microns. Window glass and many transparent plastics are opaque to wave lengths much shorter or longer than this. When the sun heats objects behind glass they absorb the radiation causing a rise in temperature. They then re-radiate their excess heat to their surroundings. However, the wave length of the radiation emitted is longer than 2.5 microns, i.e. in the infrared spectrum, and cannot escape through the glass which is opaque to radiation of this wave length. This causes heat to build up behind the glass.

Installed Cost of A/C (cooling) from Ext. Wall



a. single regular plate glass; b. double plate glass; c. single heat-absorbing plate glass; d. single regular plate glass with venetian blinds inside; e. single regular plate glass with shade screen outside; f. masonry.

The greenhouse effect is an important consideration in the design of buildings. A simple and cheap way to use the sun's energy in house design is to orient a great deal of the window area toward the south, double glaze the windows, and install insulated shutters. These shutters are closed at night so that the heat gain during the day is kept inside at night. This combination of extensive areas of windows, double glazing, and shutters can cut heating power requirements considerably.

A heavy masonry or rammed earth wall may be used to absorb solar heat during the day, store it, and readmit it at night (see sketch below). The ducts are closed during the day and opened at night when the shutters or blinds are closed to insulate the windows. The air is circulated by natural convection.

Masonry/Rammed Earth Wall Construction

Solar Heating

The greenhouse effect is the operative phenomenon employed in many if not most, solar heating designs. A black metal plate placed in the sun gets hot. When the plate is covered with glass the sun's light can get in to heat it but when it tries to re-radiate the infrared, the energy is trapped. If we introduce built-in channels through which air or water can be pumped to carry the heat away to where it can be used we have a device called a flat plate collector.

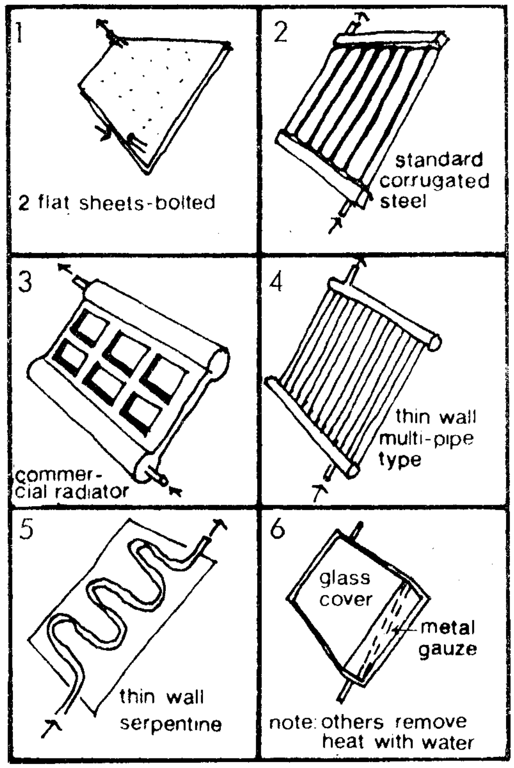
The other principal collector type is the concentrator collector in which the sun is reflected and focused onto a small collection area, a tank, a network of pipes, etc.

The advantages of flat plate collectors over focusing collectors are as follows: 1) they collect the diffuse radiation through clouds as well as direct sunlight - this is very important especially in areas where periods of sunlight can rarely be relied upon, e.g. the gulf coast of Texas; 2) the orientation to the sun is not critical (focusing collectors need a constant tracking system so that they can "follow the sun"); 3) they are easily made in a workshop with simple materials; 4) they may be easily integrated into the design of the building; 5) less maintenance is necessary (the reflective surfaces of a focusing collector need a lot of care).

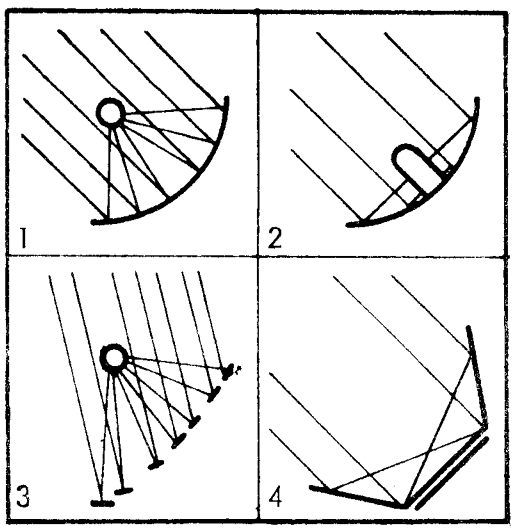
Advantages of the focusing collector include: 1) you can achieve higher temperatures; 2) it is useful in the early morning and late afternoon because it can be oriented to gain full advantage of the low sun; 3) it can be very light in weight and can fold up small.

Typically, whether the collector is of the flat plate type or the concentrator type, the device has served as only a collector and there has been a dependence upon flowing air or water through pipes, ducts, or other device

Six Types of Flat Plate Collector

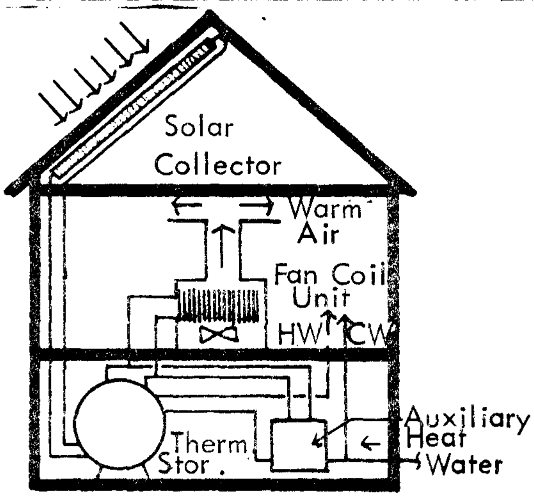


Four Types of Concentrator Collector



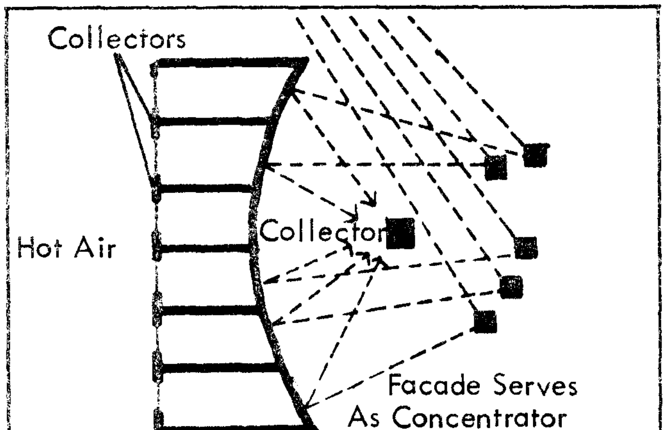
Note: No. 4 combines reflective panels w/ flat plate collectors

Solar Heated House [19]



Contrary to many opinions, solar collectors need not be ugly, but can become a new design element for a building project. While some studies call for collectors that sit on a site like a billboard, there are subtler ways to design collectors. Recently a man put a solar collector on his home's property and designed the collector to serve as a fence around his terrace. An architect can choose to see the solar collector as a design constraint, or he can see it as a new architectural element that can be used effectively and attractively. The collector can be on the roof of a building or designed as a part of its roof, its wall, or as a solar shading device. It can also be constructed over parking lots and service buildings.[20]

Office Building - Pyrenees, France [21]



to carry the solar energy from the collector to other heat exchangers in the buildings. With such systems there is an implicit loss in efficiency owing to the transfer of heat between the collector and where the heat is going to be used. In addition, such systems employ some amount of moving equipment, which of course presents maintenance problems.

A different basic concept has been employed by inventor Harold Hay in his experimental house in Phoenix, Arizona and more recently in Atascadero, California. For natural air conditioning of manmade structures economic heat storage is possible using water (because of its high heat storage capacity) as a logical medium. Mr. Hay uses ponds of water in plastic bags (like water beds) above the ceiling as inert collectors and storers of energy. In effect, Hay is using the great mass of water in the ponds on the roof as a capacity type insulation. The water is not circulated but instead moveable insulation panels over the ponds operate as thermal valves directing heat flow to produce desired thermal effects. This system works with the climate, not against it, since it utilizes and controls radiation, absorbtion, reradiation, evaporation, and air movement.

Roof ponds can maintain comfortable temperatures throughout the year withou supplementary heating or cooling devices. For winter use they are uncovered during the day to absorb as much sunshine as needed and covered at night to retain the collected heat. For summer cooling, the insulation panels are moved to allow the water in the ponds to cool by radiation to the night sky and to insulate it against the sun's heat during the day.

In his first experiments with natural air conditioning in a small prototype house built in Phoenix, Arizona, Hay used ropes and pulleys for moving the insulation panels over the ponds. In the newer, more sophisticated house in California, he uses a thermostatically controlled one-quarter horsepower motor to move the panels which are mounted on tracks over the roof.

Reflection by the white uppe surface of the moveable insulation and the low thermal conductance of the cellular plastic reduce the roof heat load to an amount readily absorbed by the high heat capacity of the pond. The transparent plastic pond bags and the underlying black liner for radiation absorption can be made of polyethylene or polyvinyl chloride which have great resistance to deterioration by solar radiation.

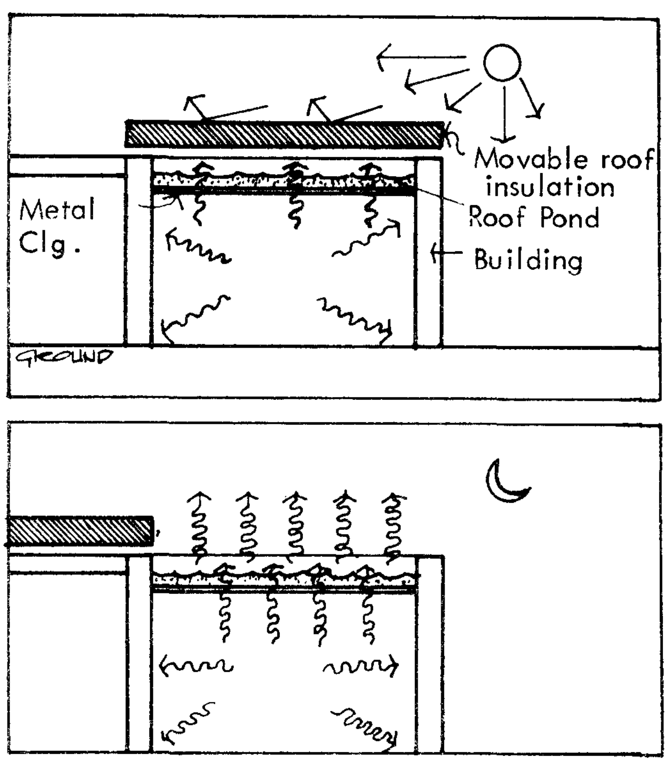
New plastics have increased the economic feasibility of use of solar radiation. Most earlier forms of insulation would have required hermetic sealing to prevent moisture uptake and loss of insulating value if used over ponds or exposed to rain. Established sandwich panel technology using cellular plastics permits new and highly desirable types of construction including exterior thermal insulation and internal heat storage materials.

Natural air conditioning calls for unconventional building design. In northern latitudes, where low winter sun angles prevail (e.g. Texas's Panhandle) drums of water can be built into the south wall of a house with moveable insulation panels over them. Steve Baer of Zoneworks Corp. has employed this method of heat storage in houses in Albuquerque, New Mexico.

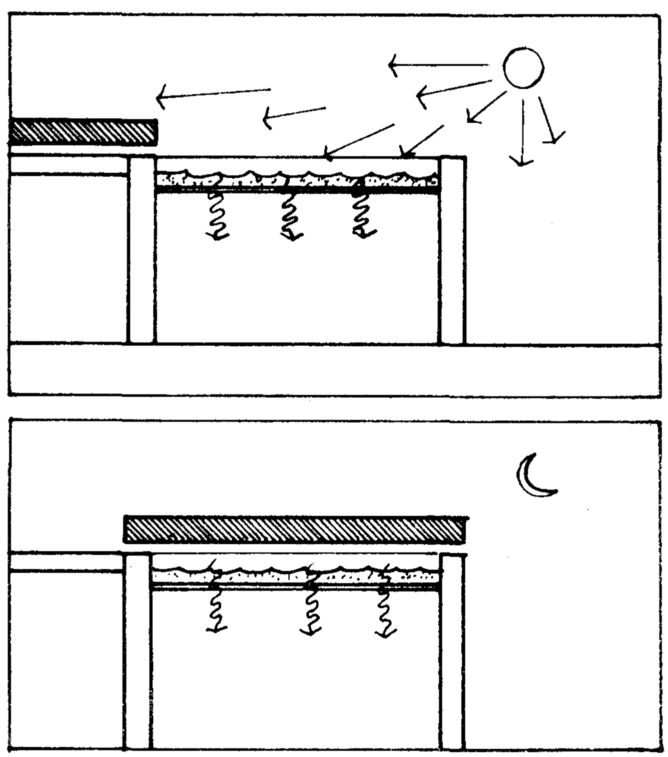
Roof pond economics are reasonable when you deduct normal ceiling and roof costs from those of ponds and moveable insulation.

Harold Hay's natural air conditioning is feasible in West Texas or the high plains where the humidity levels are relatively low compared to the ambient sensible temperatures. However, where the humidity is high, as along the coast or in the central region of Texas, it is likely that the dew point would be reached on the metal ceiling adjacent to the pond of water and condensation in the rooms would obviate the possibility of using such a system.

Harold Hay's Roof - Summer [22]



Harold Hay's Roof - Winter



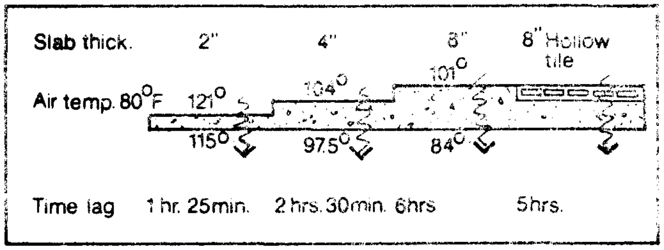
Roofs

Due to its orientation and comparatively large area the roof tends to absorb great amounts of heat during the day. Harold Hay's experiments with the water ponds on the roof are only one recent example of specialized roof treatments for dealing with that energy. There are several roof treatments which can reduce the heat that penetrates to the interior of the dwelling: 1) increase the roof thickness; 2) insert additional insulation of a resistive type; 3) provide false ceilings; 4) shade the roof; 5) provide surface treatment with reflective paints; 6) install a roof spray; 7) use pooled water; 8) use wetted gunny sacks.

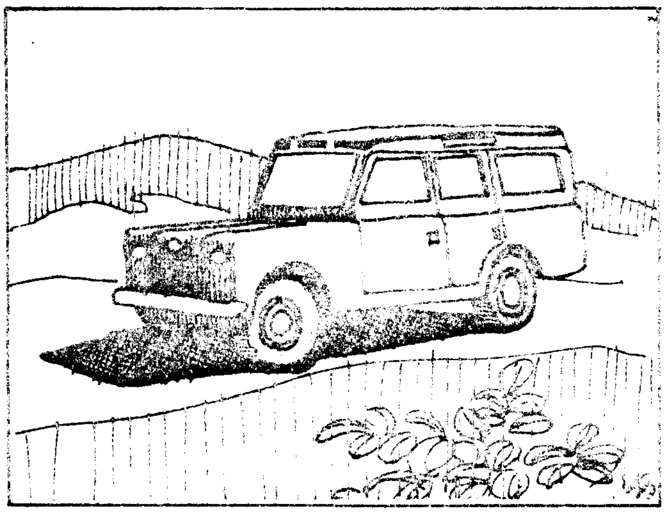
The diagram (right) compares temperatures of concrete slabs of different thicknesses. The interval or "lag" between the upper and lower temperatures of a 2 inch slab is one hour 25 minutes and for the 8 inch slab it is 6 hours. This shows that when you increase the mass you increase the heat lag and provide heat radiation during the night unless the thickness and diurnal temperature range are great enough to cause the flywheel effect mentioned in the discussion of capacity insulation above.

A parasol or protection that receives or throws off a high proportion of the sun's heat between the ceiling and the sun can be very effective (see illustrations). In humid tropics the roof can have an upper surface of fairly reflective quality (asbestos sheet or corrugated aluminum) held above a ceiling layer with an adequate air gap. By sloping the roof one way a ridge is avoided and rain is collected on one side

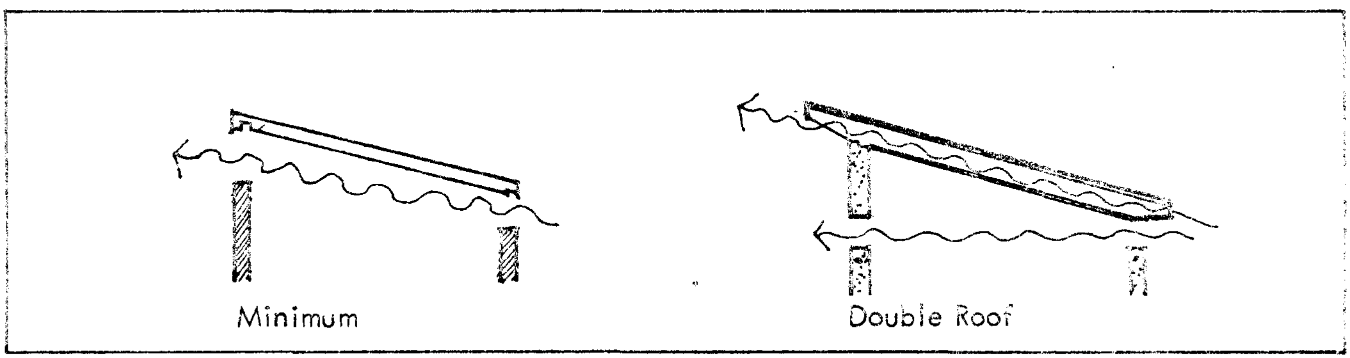
Temperature Lag in Concrete Slabs[23]



Land Rover with Double Roof



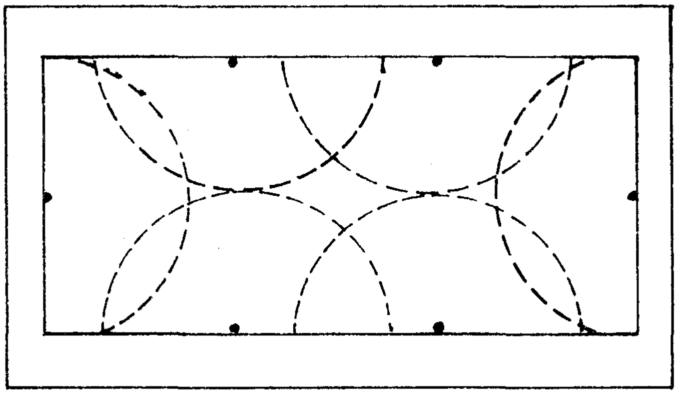
Sun Protection by Air Gaps Under Roof [24]



only. But the hot air that might accumulate between the upper and lower layers is, by the natural properties of heated air, let out at the higher side of the roof.

The heat transmission may also be reduced by the roof spray system in which an automatic intermittent water spray with a booster pump and time cycle arrangement sprays water often enough and insufficient quantity to keep the roof flooded to a desired depth.

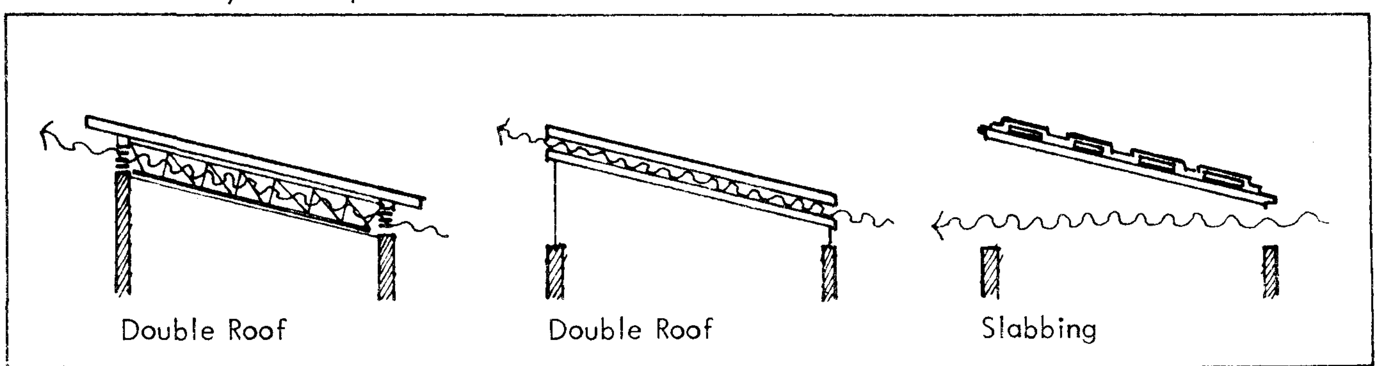
Sprinklered Roof



If the roof is covered with a 1 inch deep pond of water the heat transmitted is only 35% of the amount which would pass through a dry roof of similar construction (6 to 7 inches of water is equal to the heat capacity effect of a foot of concrete and only weighs as much as a 3 inch concrete slab). In an experimental study on the effect of roof spray cooling compared with a water pump and "wetted gunny sacks", empty cement bags were spread over tar and felt roof which was sprinkled 3 times a day. The wetted gunny sack system proved to be the one that provided the more comfortable conditions inside.

Nicholas Laing has developed two surface treatment materials for reflection or absorbtion of solar rays. His "super black" material extracts 20 times more heat than a perfect "black body". Similarly, the "super white" material will stay cooler than a perfect reflector. In the Sahara, tests of heat rectifying roofs using only a combination of melting salts in a honeycomb ceiling and a super white roof showed that a house can be kept completely cool in the desert. If reflective paints are to be used white-washed or white painted surfaces are the best.

Sun Protection by Air Gaps Under Roof



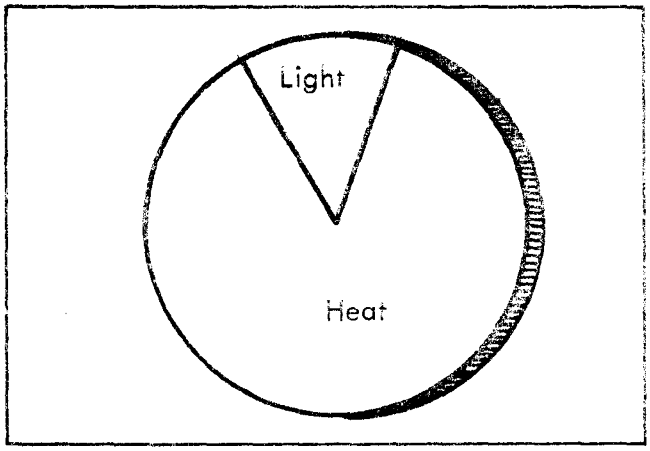
Lighting

Lights are a major source of heat gain for large structures. In all lamp design, the light is a by-product of a heat reaction. For each watt of energy a light source uses, about 75% is given off as heat while only 25% of the input energy is converted to light in the most efficient lamp design. Each watt of energy is equivalent to 3.41 BTU. If a building is to be lighted with several watts per square foot, it would not be hard to exceed 40% of the cooling load for the entire structure.

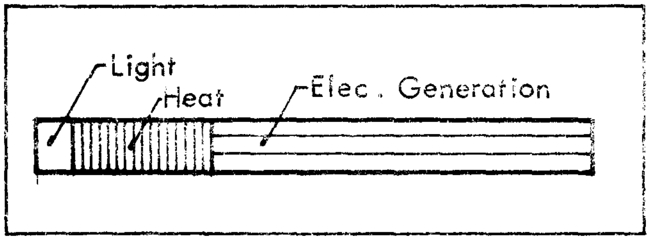
Current lighting standards are excessively high. In general, they are set above the minimum recommended lighting standards of the Illuminating Engineering Society (whose standards have more than tripled over the last 15 years). Some infrequently used corridors in buildings are lighted to levels adequate for drafting rooms when a well designed lighting system could light the corridor to safe levels at half the wattage requirements. Work spaces are also often overdesigned and could be redesigned with local task lighting instead of general lighting and thereby reduce energy requirements by one-third.

Lighting accounts for much of the electrical requirements for a commercial structure. Energy conscious light design could reduce this figure considerably without sacrificing seeing comfort. The heating, ventilating and air conditioning system represents the greatest energy demand for a large structure. By removing most of the heat from light fixtures during the cooling season and recovering the heat for use in the heating system, efficient design could reduce energy demand by a practical 10-20%. In addition, if lighting levels varied from space to space or area to area the variety would stimulate the eye muscles helping to maintain muscle tone while perhaps obviating some of the boredom of commercial interiors.

Typical Lighting Dollar



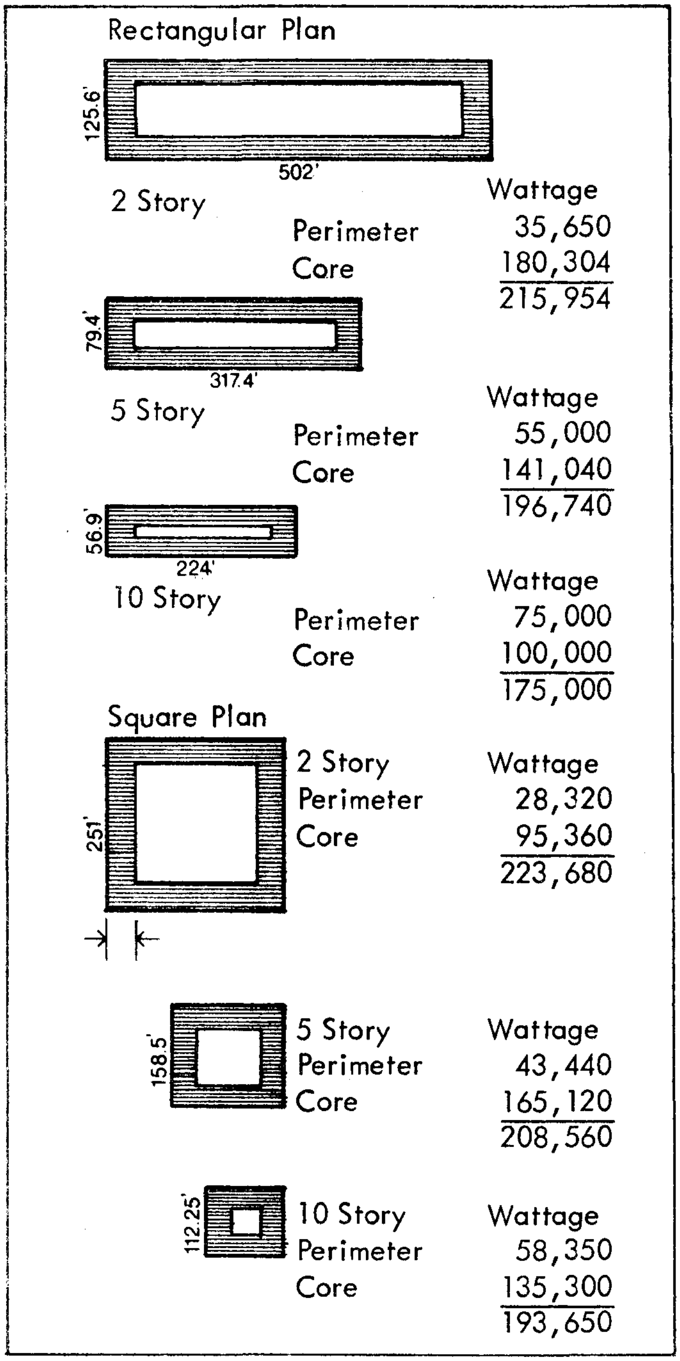
Lighting: Basic Energy



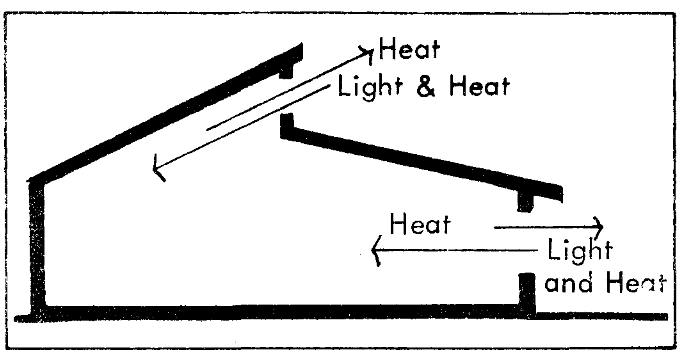
At a conference on energy conservation in Chicago in May, 1974, Richard G. Stein, a New York architect, condemned his colleagues for their lack of concern about designing buildings to save energy. He described one building in Michigan that was designed to be lit constantly; the excess heat was supposed to warm the building. Supposedly this would require fewer bulb replacements. Stein found that light bulbs had to be replaced more than twice as often and that they used nine times as much energy than would have been consumed if switches had been installed. He said, "The only less efficient way to heat a building is to burn it down."

Stein went on to criticize engineers who set overly high standards for lighting--England's school children get along well with a 15-footcandle intensity, while we require 70 footcandles--and ventilation. [25]

Building Perimeter vs. Consumption [26]



Clerestory Heat and Light



Daylight is a 'free' light source that can be easily utilized in smaller structures. Skylights, clerestorys and windows can significantly reduce artificial lighting requirements and provide pleasant effects and atmosphere. However, this free energy source is not without some limitations. Daylighting can supplement artificial sources in perimeter zones but is not easily transmitted to interior zones. Fiber optics offer a design solution in this area, but the high costs of materials and the relatively inefficient light transmission properties make the use of these systems as yet impractical.

The ratio of perimeter to interior space can greatly affect artificial lighting requirements. In general, a rectangular plan uses less wattage than a square plan because the rectangle offers proportionately greater perimeter space. The plans at left illustrate how much wattage can be saved in varying the height of a 126,000 sq. ft. of perimeter space and 2 watts per sq. ft. of interior space. Rectangular shapes offer even greater efficiencies.

In areas where codes, esthetic or design considerations establish sizable amounts of glazing, the luminaires at the perimeter should be on a separate switch or photo cell so they are turned on only when there is insufficient natural light. In multistory office buildings or schools, about 25 percent of the energy normally used for lighting can be saved in this manner.

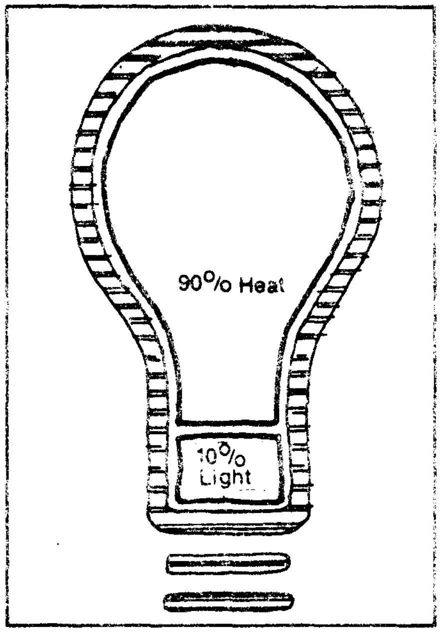
Designs for natural lighting do not make these sources 100% free. Even the most reflective or heat absorbing glazings permit the transmission of heat to the conditioned spaces. Clerestorys and window walls to the north sky increase heat losses in winter and heat gains during the cooling season. In all designs incorporating natural light it is necessary for the designer to weigh and evaluate the loads imposed on the HVAC systems and compare them to the energy requirements for artifical lighting. In some structures it may or may not be more energy conserving to use natural daylight.

Incandescent light sources are the least efficient light sources but the cheapest and easiest to maintain and install. Only 8 to 10% of the energy used by an incandescent light is converted to light. The higher the wattage of the incandescent lamp the more efficient it becomes but efficiency will not exceed 12% light to energy. Color coatings and filters reduce the light output of an incandescent lamp from 20% to 50%. Incandescent lamps have short life expectancy, also. Commonly these light sources will not exceed 1000 hours of service, and 750 hours is closer to the normal lamp life.

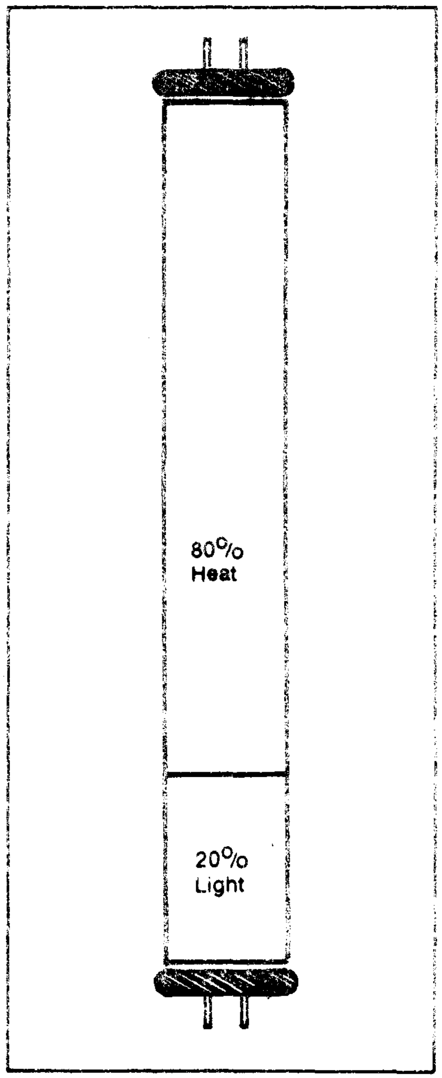
However, incandescents can operate at lower and higher voltages than the rated voltage. A 120V lamp operated at 125V will produce 15% more light and consume 7% more energy, but will have half the normal rated life. Whereas, the same lamp operated at 115V will extend the life 70% but a reduction of 15% of the light output and using just 7% less energy.

By far the most common gas-discharge lamp is the fluorescent lamp. Light is created by inducing a current to arc between cathodes in an enclosed tube of a fluorine gas compound. The electro-chemical reaction produces light in the invisible ultraviolet spectrum. The ultra-violet light in turn excites the phosphorous coating on the inside of the tube emitting a white light. These lamps operate most efficiently at the recommended voltage and at a temperature of 100° to 120°. A 40 watt fluorescent lamp produces the lumens equivalent to a 120 watt incandescent lamp. Fluorescent lamps are very efficient, passing along 20% of the input energy as light. Common service life for a flourescent lamp is from 8000 to 12,000 hours. The burning life is considerably reduced if the lamp is frequently turned on and off but the energy savings resulting may compensate for that loss of lamp life.

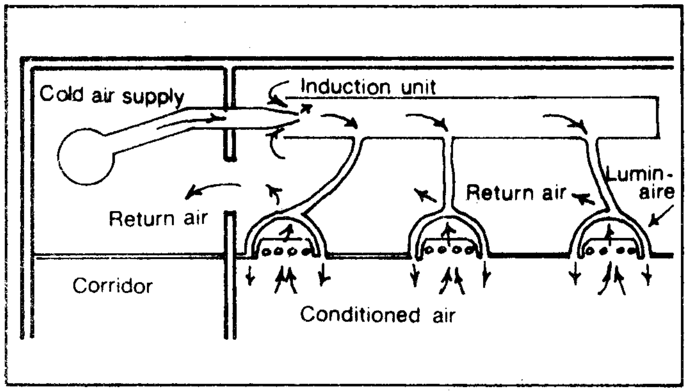
Incandescent



Fluorescent

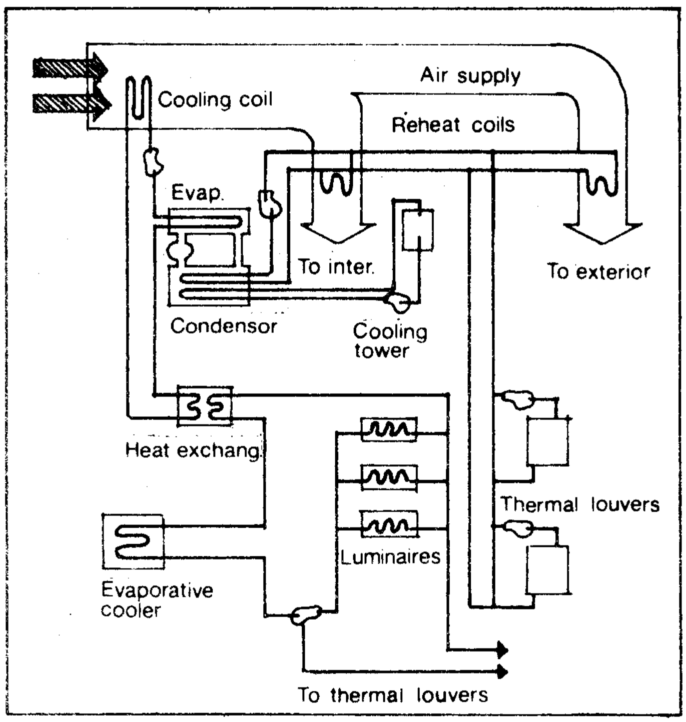


Heat From Lights - Air System



Heat from lights may be captured for use elsewhere by either an air system or water system. The water system (below) conveys heat to a refrigeration unit through a heat exchanger. The water reheats supply air and also warms the window louvers.

Heat From Lights - Water System



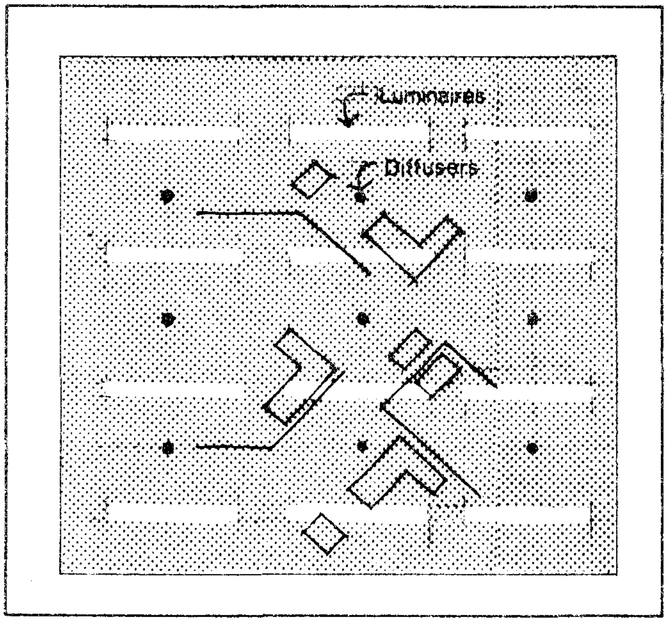
The technology and systems for saving energy in lighting is on the market but not widely used because of relatively high installation costs. However, these energy saving systems can recover the initial costs in a few years by saving on fuel costs.

Wherever illumination footcandle levels exceed 75, consideration should be given to heat-of-light systems, which transfer energy from interior zones to the perimeter as needed. These systems reduce the amount of sensible heat entering the space as well as the amount of air which must circulate in the air-conditioning system, consequently reducing fan horsepower and energy consumption.

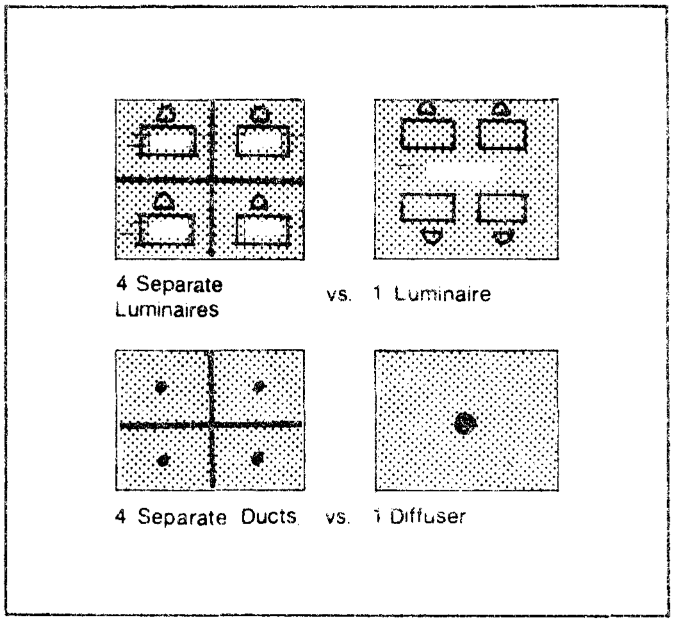
About 80% of the lighting fixtures for commercial structures comprises enclosed fluorescent luminaires. The heat generated from the lamp radiates to the enclosure and tothe occupants and furniture of the room. The use of air handling luminaires can remove nearly 65% of the radiant and sensible heat gain from the conditioned spaces. In the summer cooling season this heat can be vented to the outside directly or conditioned for cooling. In the heating season the recovered heat can be redirected for space heating. A well designed luminaire cooling capacity requirements for an air conditioning system by as much as 30%. In addition, there is the extra benefit of increased light output: a cooled fluorescent lamp produces 13% more light for the same input energy.

The wet troffer heat-of-light system saves an even greater amount of energy and also some capital costs of the air conditioning system, since it results in a smaller refrigeration plant and in smaller air handling units and ducts. Both systems, of course, reduce the quantity of sheet metal for ducts.

Office Landscape



One Office vs. Four Offices



A recent development in office planning promises sizeable energy savings. Studies by Dubin-Mindell-Bloome have shown that for a given amount of illumination on work surfaces, an office landscape consumes 25 percent less energy in lighting than a partitioned floor. The two most obvious reasons are that fewer light fixtures can serve a larger space and that wall partitions in conventional office not only reflect light, but absorb it, depending on color and texture, etc.

Where need for privacy, security, etc., will not permit a completely open plan, intermediate solutions such as that illustrated at right offer reduced initial and long term costs.

As to exterior lighting, European cities have long managed to light the streets by lighting the architecture. Those urban streets have far more psychological brightness, not to mention drama and beauty, than do our own cities lit by highway standards of illumination. Sensitivity and a new rule of the specific lighting could only enrich our environment.

Machinery

The heat from machines operated in environmentally controlled spaced is sometimes overlooked by designers. Electric transformers, cold storage equipment and large horsepower electric motors can contribute significantly to cooling loads. A large horsepower motor can generate about 2400 BTU for every horsepower of its rating. Often the heat from these machines is compensated for by increasing the size and air flow of the cooling equipment, and the heat from these machines is simply vented to the exterior. By water cooling some of these machines the heat can be dissipated outside the cooling plant, thus reducing cooling requirements in summer, and can be used for heating in the winter. In addition the efficiency of the equipment would be improved.

Energy Conservation Checklist [34]

To make an existing building more efficient:

1. Analyze the fuel and electrical bills in terms of consumption patterns and equipment needs.
2. Analyze the potential ways to conserve energy given existing life-styles and working patterns.
3. Use a computer program to establish an energy profile of the building - hour by hour, day by day, month by month, etc., separating the energy requirements of each building system.
4. Analyze where energy is going in the building and the relative effects of exposure, infiltration, ventilation, etc.

To make a new building more efficient:

1. Reduce environmental requirements:
   a. Maintain lower temperatures in winter, except in such special facilities as those for health care of the elderly.
   b. Design for 95%, nor 97.5% minimum standards.
   c. Do not heat, cool or illuminate unoccupied spaces to same degree as occupied spaces. Passages, lobies and other non-work areas are included.
   d. Provide lower level but better quality illumination (with less glare and contrast) than current standards. Maintain lower levels in non seeing task zones.
   e. Limit the flow of cold and hot water at each tap in lavatories, showers and sinks.
   f. Prepare energy/benefit, as well as cost/benefit analyses for all mechanical and electrical systems and for all building materials, such as insulation, windows, etc.
2. Make energy conservation integral to design and construction:
   a. Reduce glazing to vision strips or spots where extensive exterior views are not required.
   b. Use double and triple glazing, heat-absorbing glass and reflecting glass on east and west exposures not economic in Texas.
   c. Insulate walls and ceilings to a U factor climates.
   d. Employ external solar control devices such as fins, eyebrows, awnings, special blinds in double sash, moveable louvers, trees, and site to take advantage of surrounding buildings for shade.
   e. Specify thicker walls and roofs so that mass can provide insulation and noise reduction qualities.
   f. Build all or partially below grade and employ earth berms to reduce solar loads and transmission losses.
   g. Consider multi-use panels that integrate thermal, acoustical, power and structural functions to reduce energy requirements and capital costs.
   h. Use light-reflecting wall finishes.
   i. Construct models and make wind-tunnel tests on all new buildings with objectionable emissions.
3. Refine calculations to prevent oversizing mechanical equipment:
   a. Use computer programs for load calculations and for energy load profiles to prevent overdesign.
   b. Make realistic heating and cooling calculations taking advantage of lights, people and storage effects.
   c. Do not use excessive safety factors.
4. Practice heat conservation in specifying heating, cooling and illumination systems:
   a. Employ heat-recovery devices.
   b. Employ heat-of-light systems when light requirements are necessarily high anyway.
   c. Use rejected heat of compression from refrigeration units for space heating or process.
   d. Recover heat from solid and liquid waste disposal plants.
   e. Use large heat pump systems.
5. Select efficient mechanical and electrical systems:
   a. Use low-resistance filters, ducts (material and size), registers, grilles and coils to reduce air horsepower.
   b. Employ modular design on boilers, cooling towers, pumps, etc.
   c. Provide sufficient zones of temperature

control so areas are not overheated or over-cooled.

d. Use more sensitive and heat-anticipating temperature controls and computerized systems to avoid wide temperature swings.

e. Install capacitors where necessary to correct power factor.

6. Recycle water, sewage and solid wastes:

   a. Pipe hot water discharge from kitchens, laundries and lavatories through heat exchangers to preheat service hot water.

   b. Use effluent from the sewage system for irrigation and flushing purposes, reducing water requirements and sewage and water treatment plant requirements.

   c. Recycle water within buildings, using "grey" water for flushing.

7. Use building materials that require less energy to produce. For example, it takes six times more energy to produce a ton of of steel. However, it takes only 5% as much energy to produce recycled aluminum as it does virgin aluminum.
8. Avoid non-biodegradable products.
9. Choose materials with long useful lives.
10. Operate and integrate building facilities and systems for maximum efficiency:

    a. Precool buildings - start the system later and turn off earlier.

Conclusions

- There are four broad areas of energy use in the life of a building that should be given consideration in attempting to conserve energy: production of construction materials; assembly of materials into finished products; maintenance and operation of buildings; demolition of buildings.
- Minimizing the surface area of buildings can contribute to conserving energy. Building form, therefore, can be used effectively to minimize heat transfer through wall and roof surfaces.
- Shading surfaces from the sun in summer can reduce radiant heat gain significantly and thereby reduce cooling loads.
- Buildings should be designed so as to employ natural ventilation during those times of the year when it is feasible to do so.
- Adequate insulation in walls and roof can achieve considerable fuel savings.
- The orientation, placement and quantity of glass used in buildings can significantly affect energy consumption levels.
- Solar heating systems offer a viable alternative to conventional mechanical heating systems.
- Appropriate roof design and construction can assist in reducing heat gain.
- Lights are a major source of heat gain for large structures and lighting accounts for much of the electrical requirements for commercial structures. The shape of a building can effectively contribute in achieving reduced electrical energy requirements.
- Fluorescent lamps are more efficient lighting sources than incandescent.
- Heat from machinery operated within environmentally controlled spaces can offer significant loads to cooling systems.

References

1. Memorabilia (III, vii 8-14) by Xenophon, regarding the teachings of Socrates.

2. "A Bucket of Oil", by Caudill, Lawyer and Bullock.

3. Typical Electric Bills, Federal Power Commission, Washington, D.C., 1972.

4. FORUM, July 1973.

5. Ibid.

6. Technical Options for Energy Conservation in Buildings, U.S. Department of Commerce - National Bureau of Standards, Note 789, July 1973.

7. "Buildings that Save a Watt, and More", Progressive Architecture, October 1971, pp. 104-111.

8. Rapoport, Amos, House Form and Culture, New Jersey: Prentice-Hall, Inc., 1969, Clustered Houses.

9. Olgyay & Olgyay, Solar Control and Shading Devices, New Jersey: Princeton University Press, 1957.

10. Ibid.

11. Bedford, Thomas, Basic Principals of Ventilation and Heating, Vol. 1, London: H.K. Lewis & Sons, Ltd., 1964.

12. Ibid.

13. Ways to Reduce Fuel Consumption in Household Heating through energy conservation U.S.G.P.O., Stock No. 0303-01086, Washington, D.C.

14. Technical Options for Energy Conservation in Buildings, U.S. Department of Commerce, National Bureau of Standards, Note 789, July 1973.

15. Ways to Reduce Fuel Consumption in Household Heating through energy conservation U.S.G.P.O., Stock No. 0303-01086, Washington, D.C.

16. Technical Options for Energy Conservation in Buildings, U.S. Department of Commerce - National Bureau of Standards, Note 789, July 1973.

17. Ibid.

18. Progressive Architecture, October 1971.

19. Dubin, Fred, "Energy for Architects", Architecture Plus, July 1973.

20. Ibid.

21. Ibid.

22. Hays Roof, Mechanical Engineering, October 1972, pp. 24-29.

23. Mechanical Engineering, January 1970, pp. 19-25.

24. Fry, Tropical Architecture.

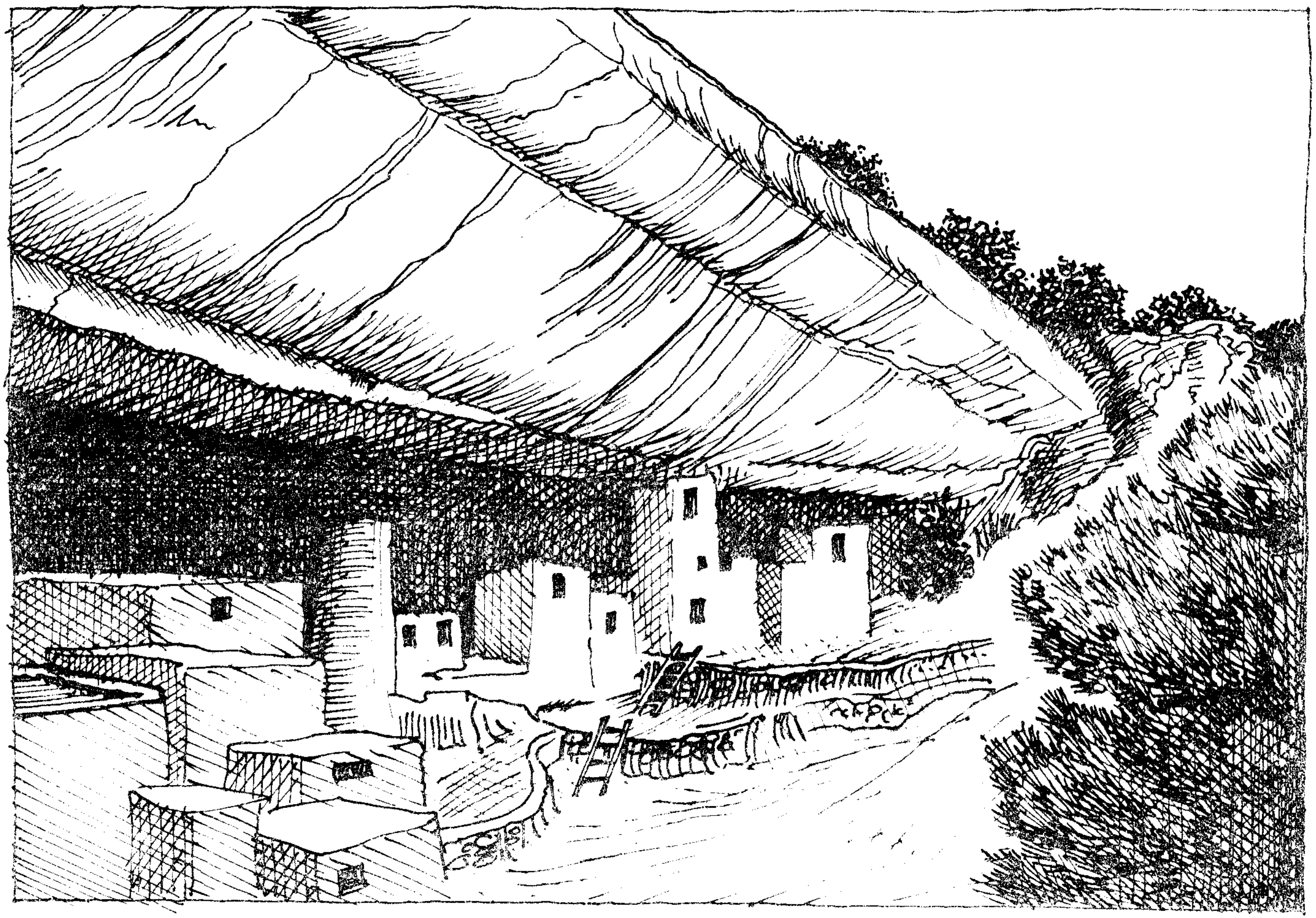
25. Stein, Richard G., Proceedings of 40th Annual A.S.P.O. National Planning Conference, Chicago, May 11-16, 1974, Planning, July 1974.

26. Dubin, Fred, "Energy for Architects", Architecture Plus, July 1973.

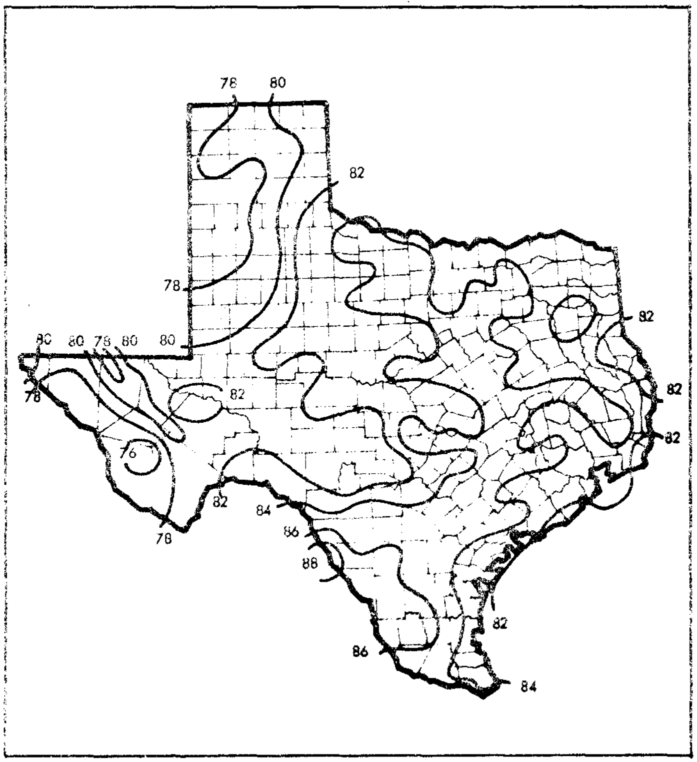
3.1.2 Climatic Influences

The expenditure of energy to modify the climate of dwellings has been with us for some time. Egyptian Pharoahs had air conditioning in 2500 B.C.[1] Slaves were employed to fan air over porous earthen jars filled with water. This created evaporative cooling as the moisture was carried away from the wet surfaces. Today energy comes from other sources but the principle is the same. Architecturally, the problem is not whether to employ energy to ameliorate the indoor climate but how to do it most efficiently. Buildings that are structured to take advantage of existing natural possibilities minimize the amount of energy needed to mechanically modify these indoor climates. A look at the Mesa Verde cliff dwellings in Colorado is instructive in this regard. Although the dwellings were built over 700 years ago, the inhabitants' knowledge of advantageous natural possibilities was quite good. The dwellings, built under the overhang in the side of a cliff, are situated so that in the winter when there is need of solar heating, the sun, being low in the sky, strikes three-fourths of the cave's inner walls during the day when the sun is out and then slowly release it during the night. In the summer the sun is more directly overhead and strikes only the well insulated roofs of wood and grasses. Moreover, never more than one-fourth of the cave's inner surface receives sunlight during the summer.[2]

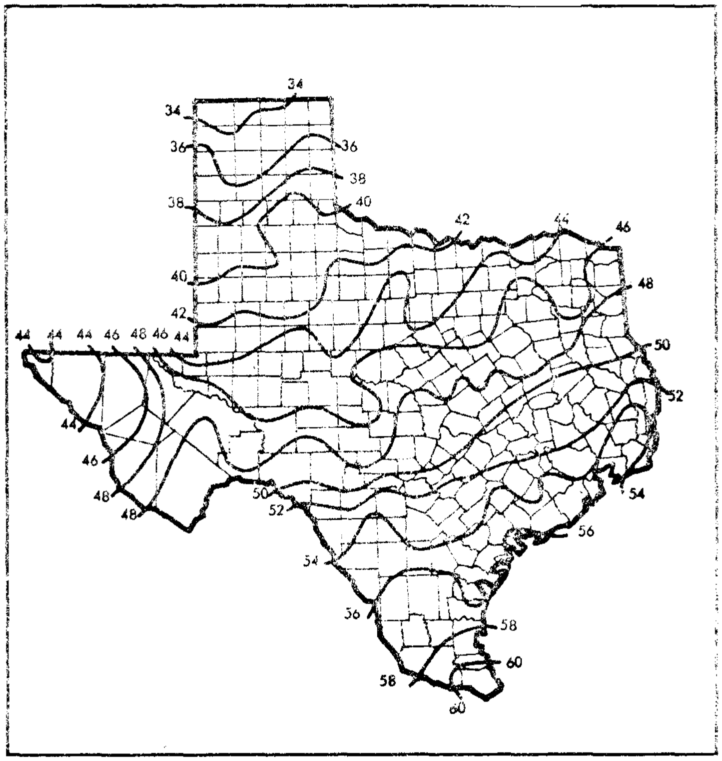
To understand the influence of climate on energy used for heating and cooling in Texas it is necessary to understand the enormous range of climatic conditions across the state. The following figures illustrate these various factors.



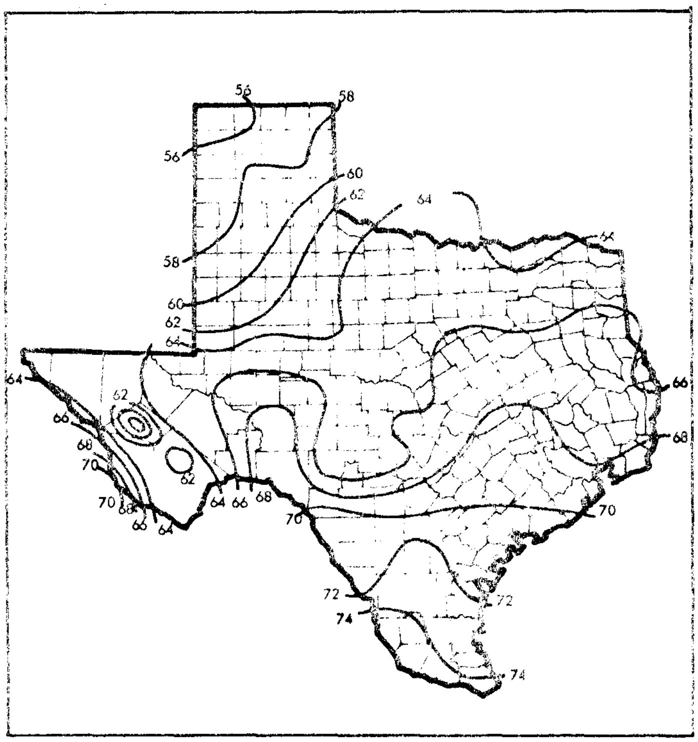
Average July Temperature (°F)[3]



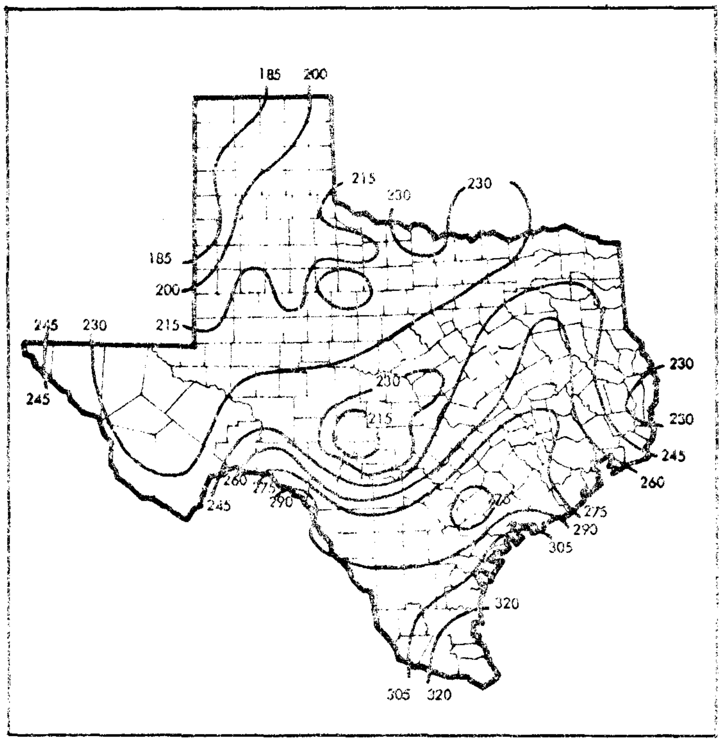
Average January Temperature (°F)[4]



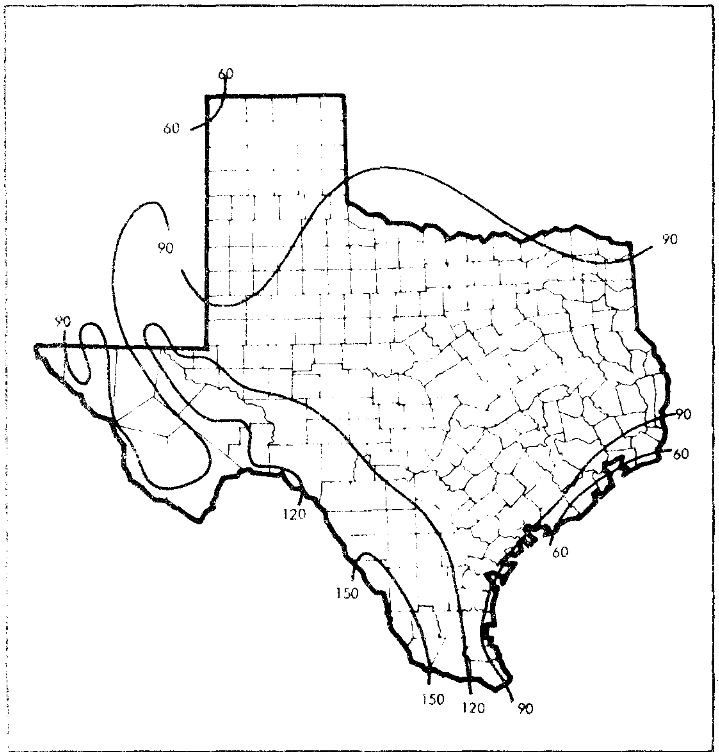
Average Annual Temperature (°F)[5]



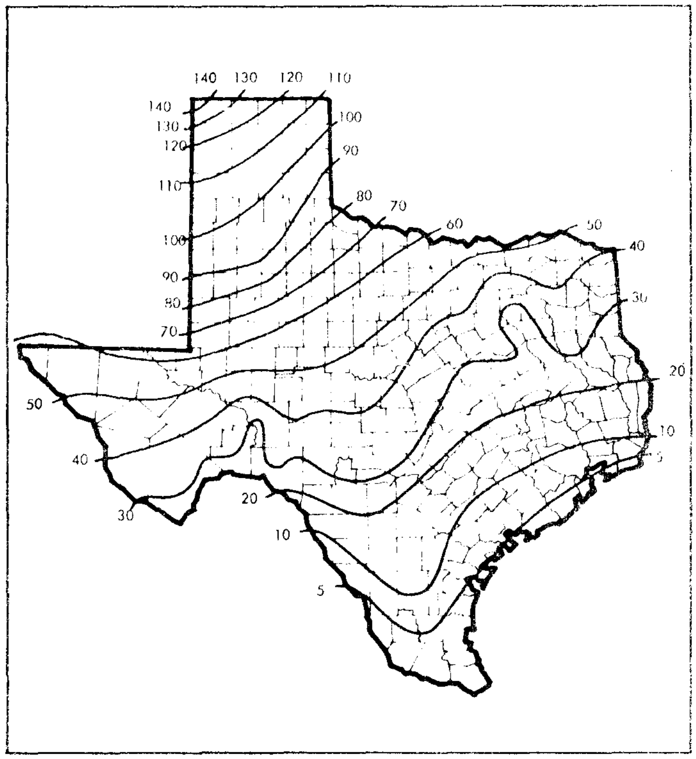
Average Length of Freeze Free Period (Days)[6]



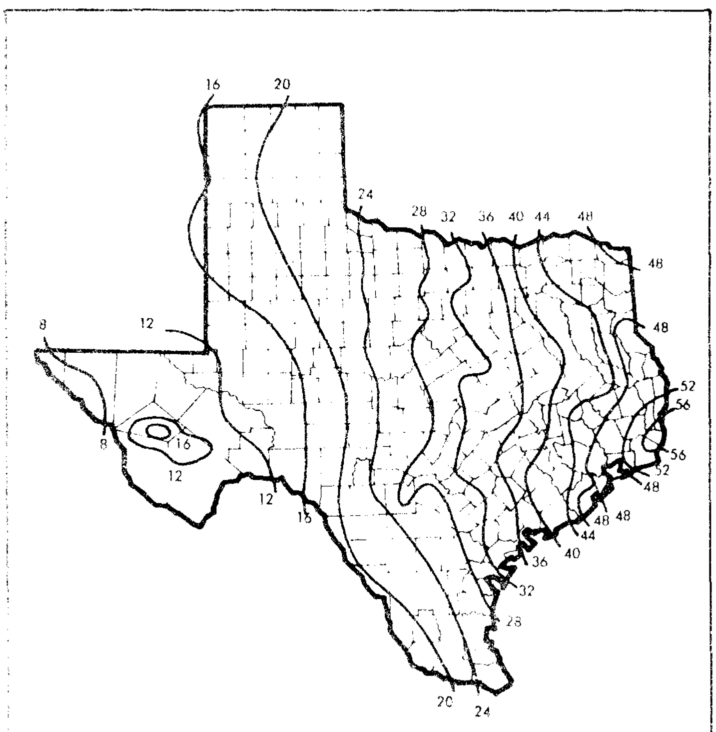
Average Number Days of 90° F and Above[7]



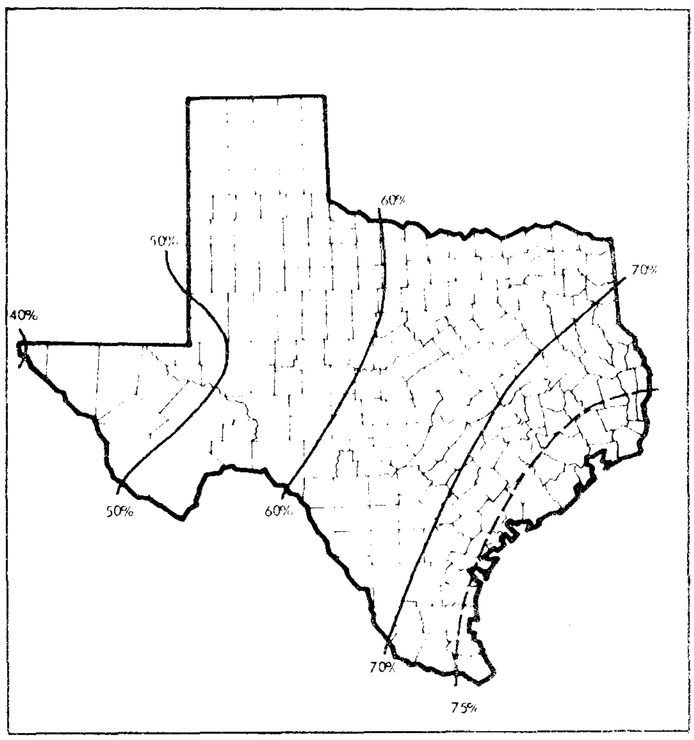
Average Number Days of 32° F and Below[8]



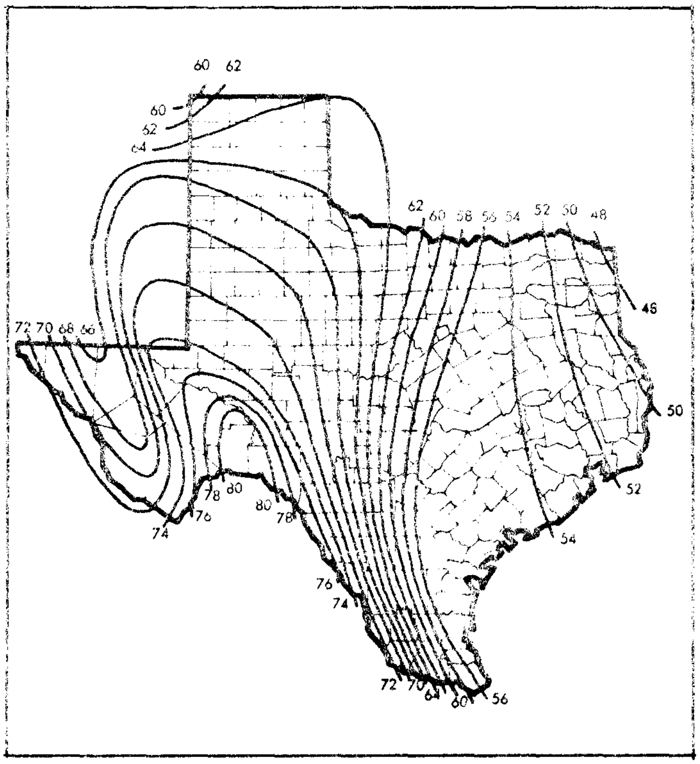
Average Annual Rainfall (Inches)[9]



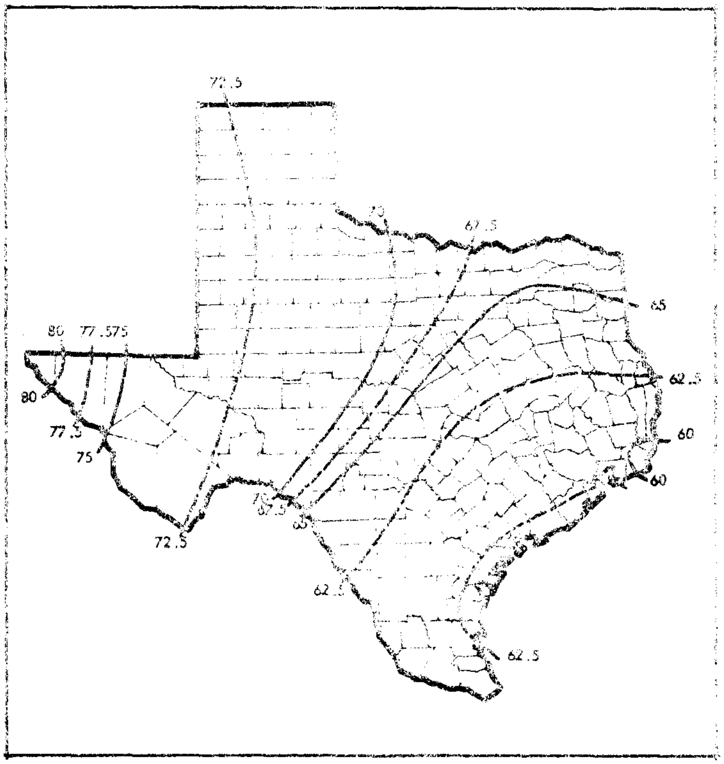
Average Relative Humidity[10]



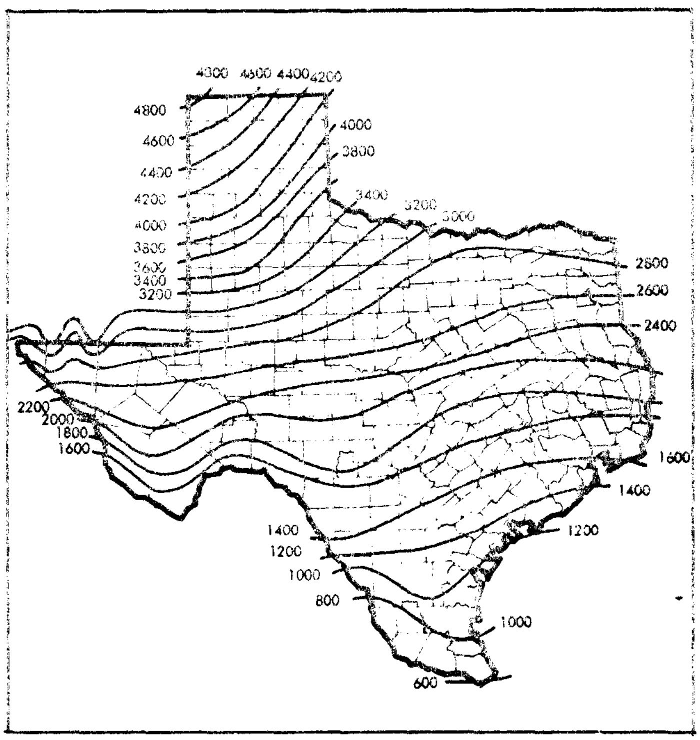
Annual Lake Evaporation (Inches)[11]



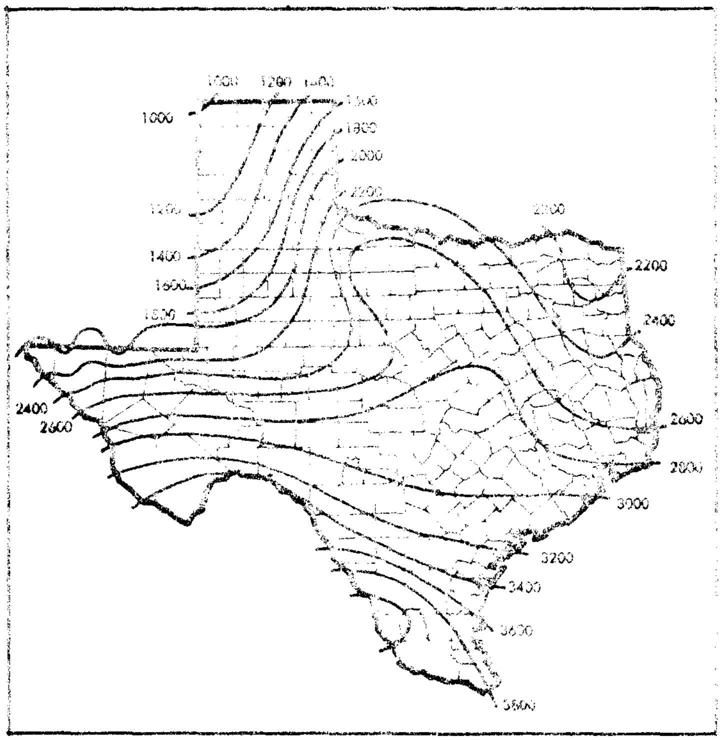
Percent Possible Sunshine[12]



Heating Degree Days[13]



Cooling Degree Days[14]



The heating and cooling degree days are not climatic factors but rather a measure of the impact of those factors upon the extent to which we must consume energy to bring those climatic extremes into the comfort range. A heating degree day is a day in which the average mean temperature drops below 65° F. by one degree. The annual measure is cummulative for a years time. The cooling degree day measurement is not only a function of a rise in temperature which requires energy consumption for cooling but also makes allowance for the influence of humidity on the need for cooling.

It is clear that climatic influences will vary greatly in a region as extensive in size and circumstances as the state of Texas. However, it is also difficult to assign precise limits to various climatic regions around the state. Basically there are about four climatic zones as illustrated on the previous figure. These climatic types may be best described by comparing profiles of specific cities located within them. For that purpose the cities of Amarillo, Dallas, El Paso and Houston have been chosen.

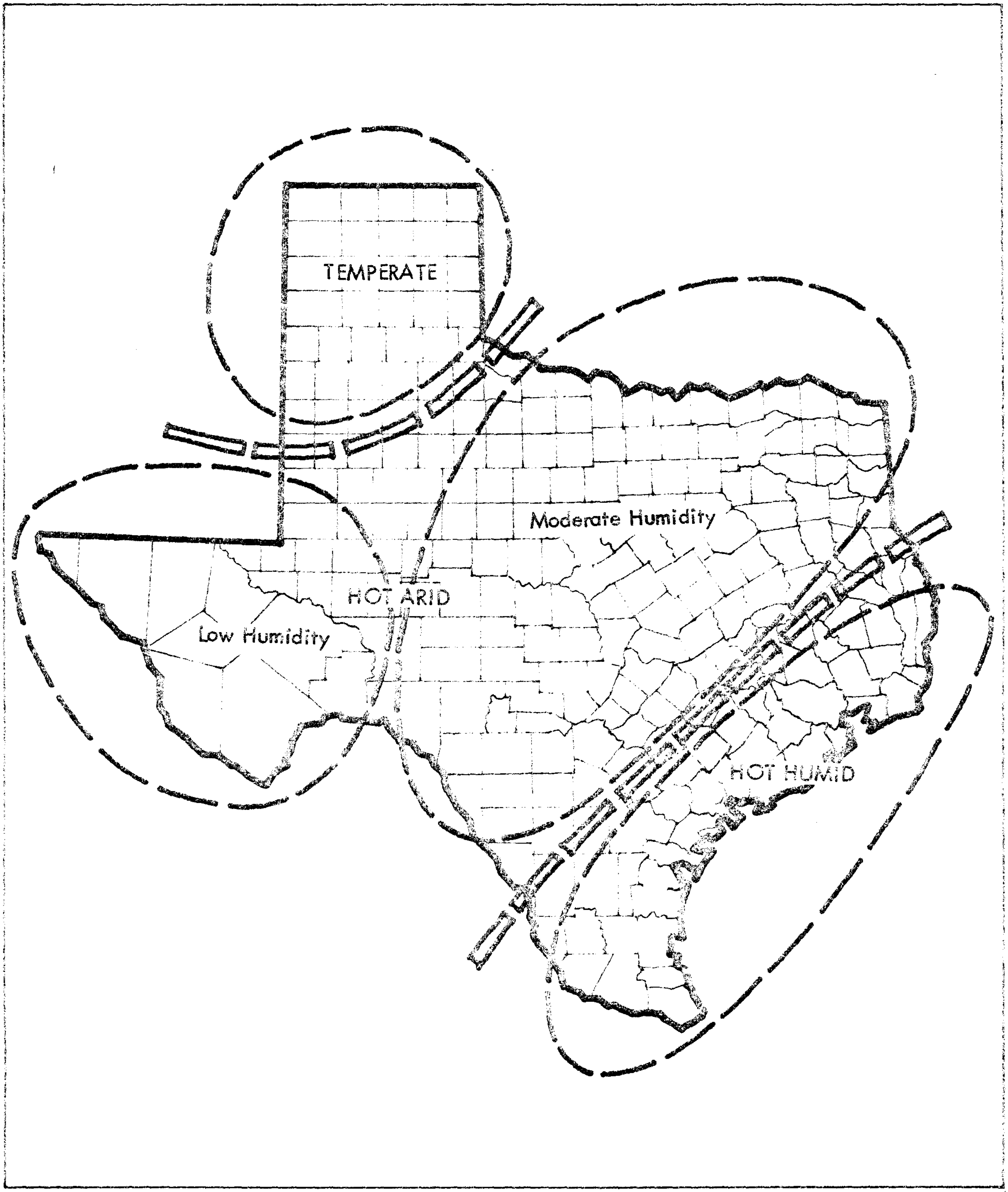
The figure below illustrates that while the extreme high temperatures vary very little for these cities, the extreme lows have a spread of almost 30° F. The lengths of the warm season for each location is also quite similar while the length of the cold season in Amarillo is considerably longer than those elsewhere. This of course illustrates that while energy consumption in Amarillo is generally divided between cooling and heating, the energy consumption in Houston is largely oriented toward cooling.

Comparative profiles of the cities show the variations of these factors:

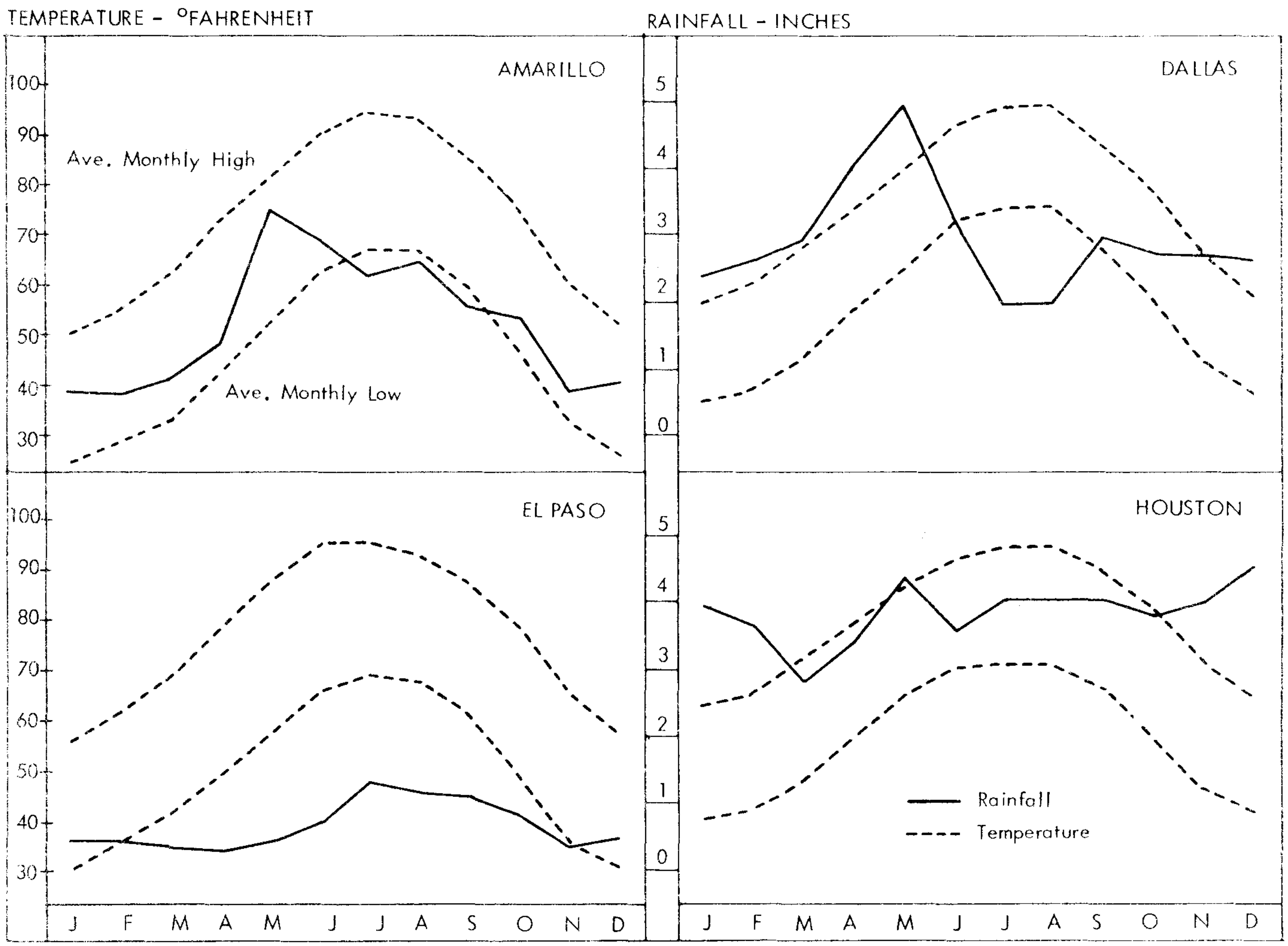
Climatic Variables for Texas Cities[15]

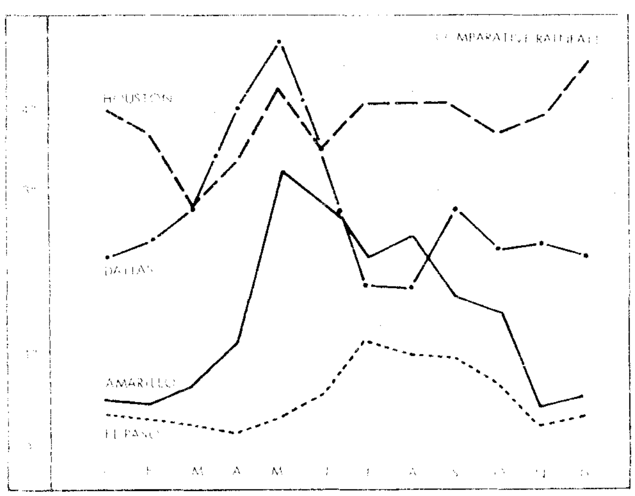
	Amarillo	Dallas	El Paso	Houston
Record High Temperature	104°	107°	106°	101°
Record Low Temperature	-9°	8°	-8°	19°
No. Months 80° & Above	5	5	5	6
No. Months 60° & Below	4	3	2	0
Annual Rainfall	20"	35"	8"	46"
Annual Relative Humidity	54%	63%	39%	77%
Prevailing Summer Breeze	S	SSE	S	SSE
Prevailing Winter Breeze	SW	S	N	SSE
Max. Sun Angle Winter Sol.	31°	34°	35°	36°
Max. Sun Angle Summer Sol.	78°	81°	82°	84°
Annual % Possible Sunshine	73%	65%	83%	58%
Annual No. Days w/ Trace Rain	67	79	45	98

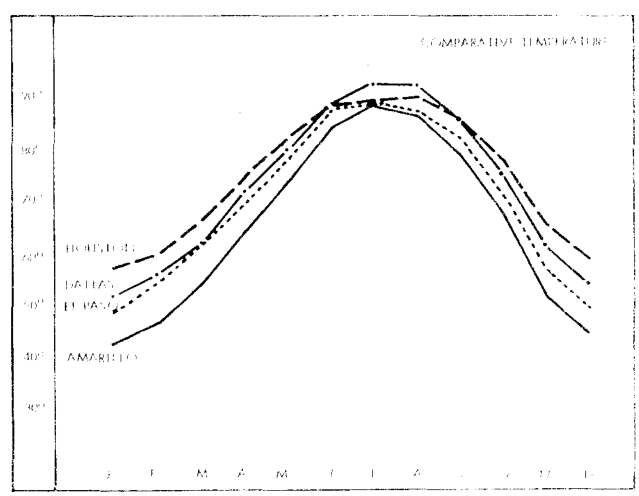
Climatic Zones of Texas



Comparative Climatic Factors in Four Texas Cities

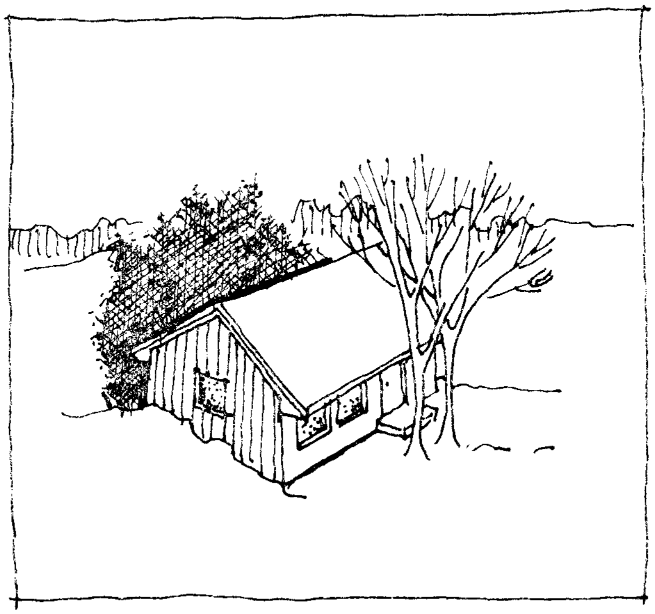






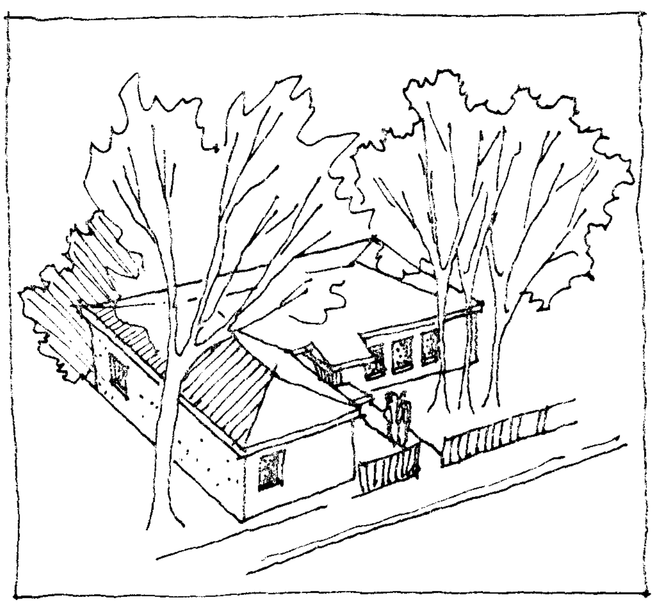
Until about 50 years ago residential design responded to these climatic variables in a variety of ways.

Such variations in building configurations are not merely styles but attempts to deal with different climatic situations.



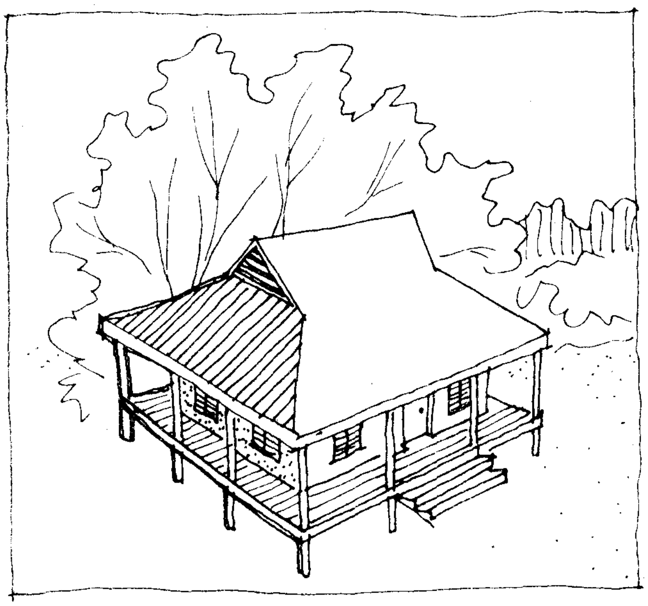
Cool Climate

The dwelling responds to the cool climate with a compact plan, elongated side oriented to the south. Deciduous trees placed on the south side of the house provide shade in the summer and in winter when the leaves have fallen permit the sun to strike the south walls for heat. Evergreens are located on the north side for protection from winter winds. There is minimum glass on the north, east and west walls with double glass in all windows. Plan openings permit summer cross ventilation. Ideal location is on a southeast slope. Good insulation is imperative.[16]



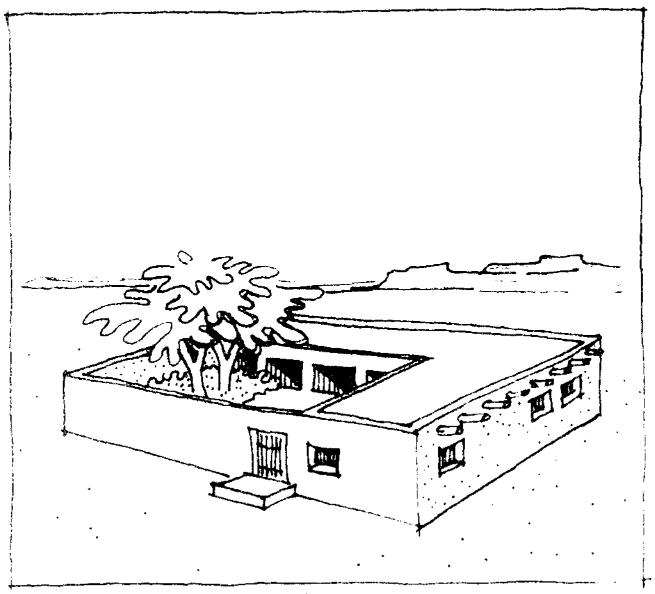
Temperate Climate

The plan is not as compact as that of the cool climate because the need is not as critical for conserving heat. Evergreens protect from winds on the north and deciduous trees on the south yield shade in summer and sun in winter. Minimum glass is desirable on north, east and west sides. Double glazing is also desirable. Plan openings permit cooling breezes in summer. High insulation is critical but heat lag materials are not. The ideal site is on a southeast slope oriented south or southeast.



Hot Humid Climate

The roof has wide overhangs for shade and rain protection. Verandas provide for outdoor living. The large white roof is well insulated and ventilated. Low heat lag materials are used. Big louvered openings provide for good cross ventilation. High ceilings permit hot air to drain up and out of the living zone. Grass lawns cut solar reflection. No undergrowth is permitted to avoid blocking breezes. Big Trees for shade are highly advantageous. Siting is high to capture the breeze.



Hot Arid Climate

The plan is compactly arranged with morning or unused rooms employed as a buffer to the west sun. The courtyard employs evaporative water and vegetation for cooling. Plan is designed for indoor-outdoor living options. Small windows are well protected. Roof and walls are white reflective color and high heat lag material. The dwelling is sited for protection from hot winds.

To deal with the different climatic factors as they effect the energy consumed for cooling and heating it is useful to look at the various factors separately. By far the most significant of these factors is thermal impact.

Thermal Impact

The typical residence has a rectangular configuration. Each of its four walls is effected differently as a result of its relationship to the sun's rays. The following comparison of these variations in radiation effect on walls is representative of the four major climatic types in the United States - cool, temperate, hot arid and hot humid. Three of these four regions are found in Texas. The cool region, not found in this state, is included for comparison. In the table the coldest period (January 21) and the warmest (July 21) days were chosen in each region as indexes for the winter and summer conditions. The radiation effect on the various sides of a building is expressed in Btu/ft.^{2}/day.[17]

At the northern latitudes, the south side of the wall receives about 50% more radiation in the winter than in the summer. In the southern latitudes this is even more pronounced with the figure more like 4 to 1. Also in the northern latitudes, the east and west sides receive about 2.5 times more radiation in the summer than in the winter. This ratio is not as large in the southern latitudes; however, it is noteworthy that in summer the east and west walls receive 2 to 3 times as much radiation as the south wall. In all cases the north wall receives only a small amount of radiation, this occurring in the mornings and evenings of the summer. But in the South, the summer impact on the

		Btu/ft^2/day	
		Winter	Summer
Cool Region (Minneapolis, Minn.)	E	416	1314
	S	1374	979
	W	416	1314
	N	83	432
	Roof	654	2536
Temperate Region (New York-New Jersey Area)	E	517	1277
	S	1489	839
	W	517	1277
	N	119	430
	Roof	787	2619
Hot Humid Region (Miami, Fla.)	E	620	1207
	S	1606	563
	W	620	1207
	N	140	452
	Roof	954	2596
Hot Arid Region (Phoenix, Ariz.)	E	734	1193
	S	1620	344
	W	734	1193
	N	152	616
	Roof	1414	2568

north wall is nearly twice that of the south because of the high sun angle at the time that the sun is in the southern part of the sky, and because the sun rises and sets north of the east-west line. This also accounts for the high heat impact on the roof during the summer. However, when the sun angle is very low in the winter the radiation received by the roof is only about half that received in summer for southern latitudes and one-fourth that for the northern latitudes. The relative importance of regional thermal stress plays a major role in shaping the structure. Generally low temperatures tend to press the building into a compact form, and heavy radiation impacts tend to elongate the shapes into rectangular forms oriented mostly on an east-west axis.

Optimum Building Form
for Residences

Optimum configuration is considered to be that which loses the minimum amount of outgoing energy in winter and accepts the least amount of incoming energy in the summer. To evaluate the thermal effect on building configuration each of the four climates was analyzed by Olgyay.[18] A house having insulated frame construction (U=0.13), with 40% glass (single pane) on the south side, and with 20% glass surfaces on all other sides was used for the model.

As a reference for comparison, a 1000 square foot house with equal sides was computed. Only the heat impacts of the walls were calculated since the roof impact would be constant regardless of form. The summation of the hourly heat flows indicate a total daily figure. The square house showed the following incoming and outgoing energy flows for the different locations.

Total Btu Impact/Day

	Winter	Summer
Minneapolis	352.400	196.600
New York	194.300	140.300
Phoenix	42.500	338.500
Miami	171.800	231.000

The results of the house with the square plan was then compared to houses of the same construction, characteristics and area, but having different forms. The ratio column shown indicates the north-south side: east-west side. Thus a 1:2 ratio indicates a north-south axis side of 1 and an east-west axis side of 2. The results are as follows:

Btu Impact/Day-Minneapolis

	Total Btu impact/day	
Ratio	Winter	Summer
5:1	-491.300	295.500
4:1	-455.600	272.500
3:1	-418.000	247.400
2:1	-380.200	220.800
1.5:1	-363.600	207.700
1:1	-352.400	196.600
1:1.5	-355.500	193.300
1:2	-366.800	196.600
1:3	-395.200	206.400
1:4	-425.500	220.600
1:5	-455.400	235.000

Btu Impact/Day-New York

	Total Btu impact/day	
Ratio	Winter	Summer
5:1	-300.900	296.300
4:1	-275.300	272.000
3:1	-247.900	245.600
2:1	-221.100	217.300
1.5:1	-207.000	203.400
1:1	-194.300	190.300
1:1.5	-189.000	184.700
1:2	-190.700	185.500
1:3	-199.600	193.300
1:4	-211.000	203.600
1:5	-222.900	214.500

Btu Impact/Day–Phoenix

Ratio	Total Btu impact/day Winter	Summer
5:1	-15.400	489.600
4:1	- 7.600	452.400
3:1	2.600	413.100
2:1	16.700	372.200
1.5:1	26.800	353.100
1:1	42.500	338.100
1:1.5	59.900	337.200
1:2	73.300	344.800
1:3	95.700	367.900
1:4	113.900	394.000
1:5	129.800	419.700

Btu Impact/Day–Miami

Ratio	Total Btu impact/day Winter	Summer
5:1	160.100	364.400
4:1	155.800	334.200
3:1	152.900	301.100
2:1	154.100	265.900
1.5:1	158.900	248.200
1:1	171.800	231.000
1:1.5	191.300	223.200
1:2	209.500	223.400
1:3	243.400	231.500
1:4	273.800	243.400
1:5	301.300	256.000

To define the most desirable form for a given environment, the criterion of "optimum shape" was applied. However, to leave some latitude whereby the proportions of a plan could be considered generally good, the criterion of "elasticity" was adopted. The upper limit of variation from the optimum was defined as that shape that was subjected to the same heat impacts as the square form.

These criteria resulted in the following conclusions:

Minneapolis: Winter optimum is achieved with a form of 1:1.1. Summer optimum with 1:1.4. Since the winter stress is about twice that of summer and the duration of the overheated period about 20% of the year the winter index was adopted. The elasticity of the shape is 1:1.3.

New York: Winter optimum is 1:1.56, summer is 1:1.63. Adopted index is 1:1.6. Elasticity is 1:2.4.

Phoenix: Summer optimum is 1:1.26. Due to the large solar effect in the winter there is no specific limit but a large southern side is desirable. Since the summer stress is nearly 8 times that of winter, the optimum shape is 1:1.3 is selected. Elasticity is 1:1.6.

Miami: Summer optimum is 1:1.7, winter is 1:2.69. Here the winter shape is quite liberal, but of less importance due to the very short under heated period. Optimum is 1:1.7. Elasticity is 1:3.

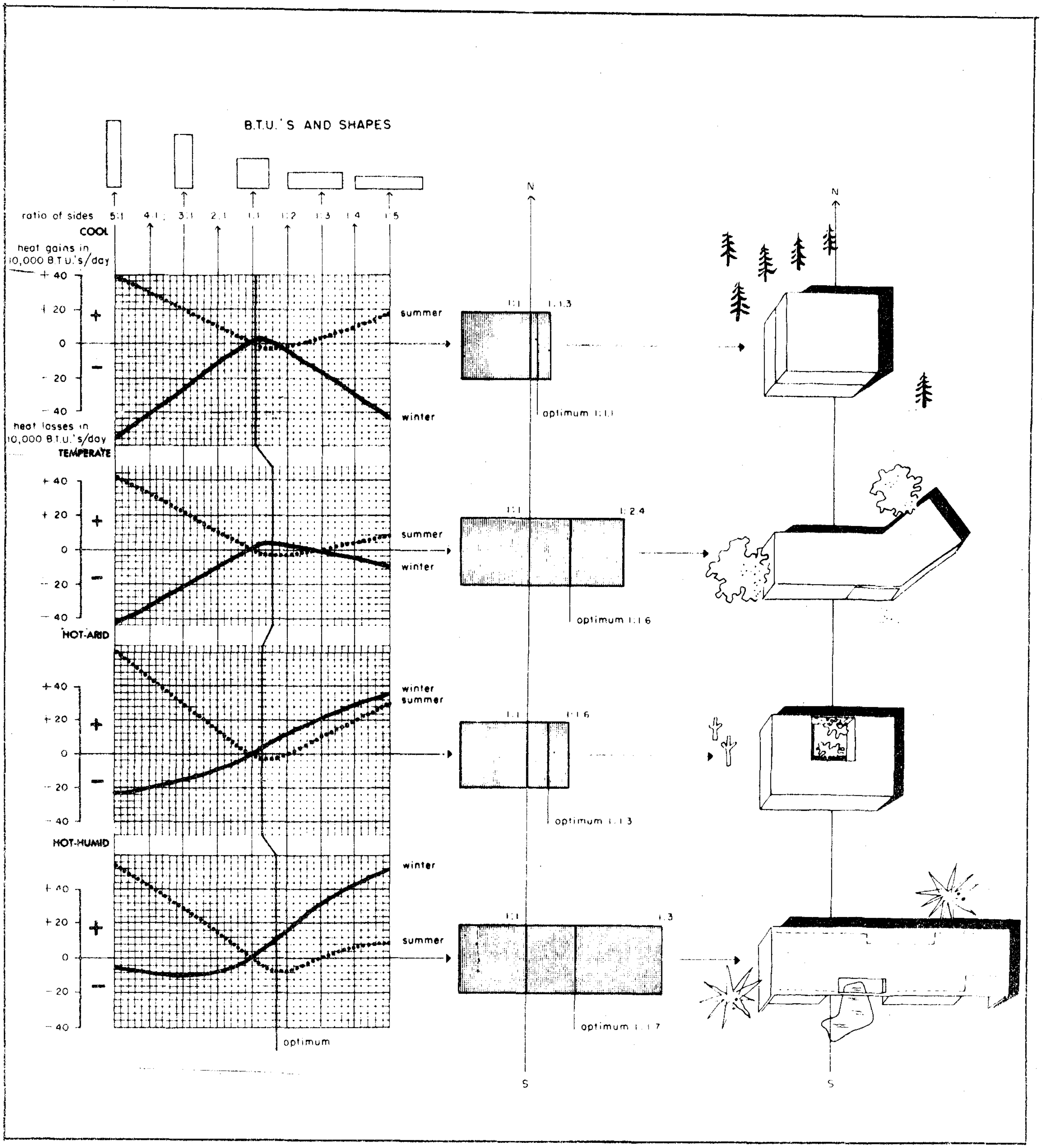
The following observations can be made:

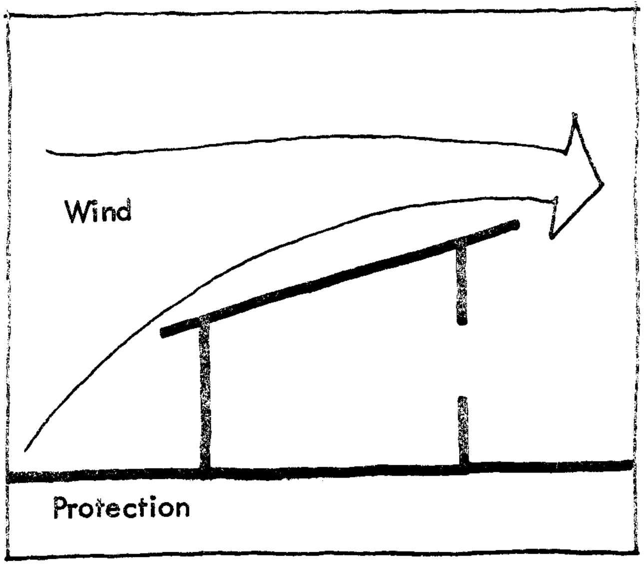
1. The square form is not the optimum form for any location.

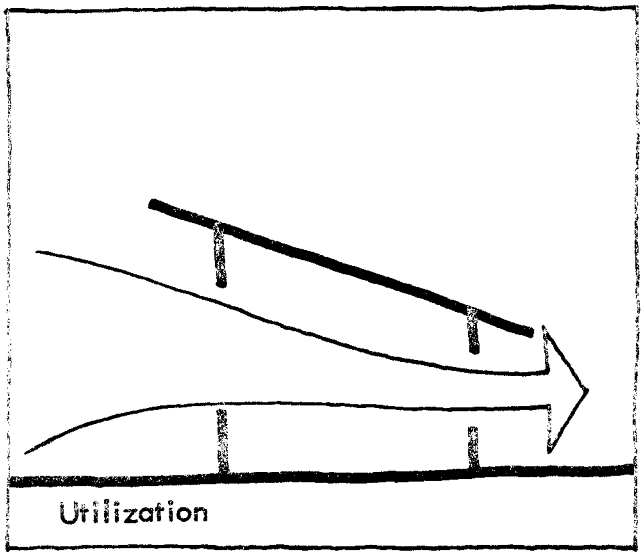
2. All shapes elongated on a north-south axis are less efficient than the square in both summer and winter.

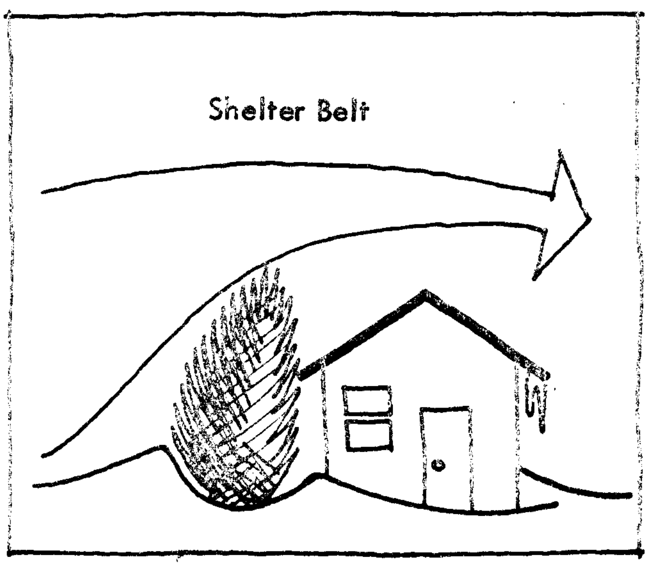
3. The optimum for each climatic condition was a form elongated on an east-west axis.

Basic Building Form by Region[18]









Wind Effects

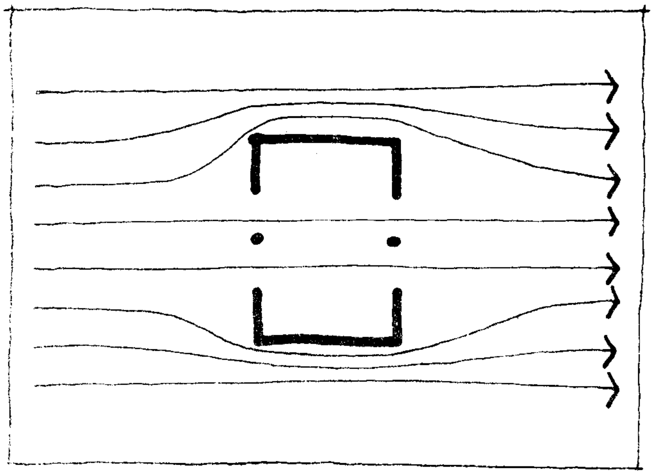
Architectural consideration of air flow lies in two major areas. Protection from undesirable winds and the utilization of desirable ones for ventilation and cooling.

A principal consideration is the effect on house heating. Calculations by Woodruff[19] indicate that the heating load of an unprotected house with a 20 mph wind is approximately 2.5 times as great as that for a 5 mph wind under the same temperature conditions. Employing shelter-belts for protection from winds indicates a savings in the heating load. The heating load for a protected house at 20 mph wind velocities was found to be approximately twice that for a similar house exposed to a 5 mph wind.

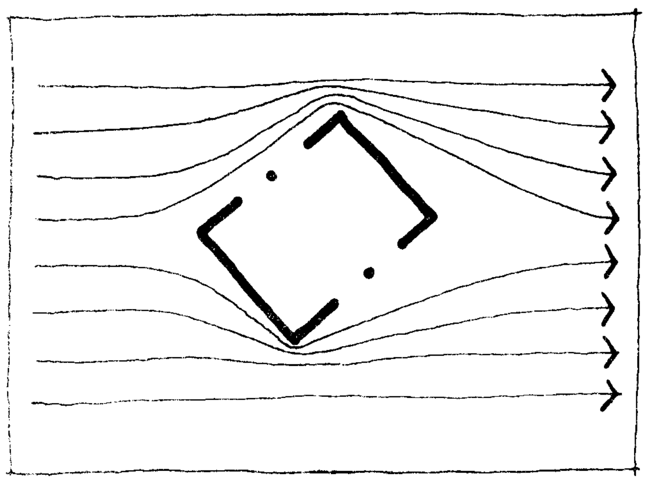
Similar results were reported by Stoeckeler and Williams,[20] who experimented with two identical houses; one was exposed to the winds and the other was protected from it. By recording the exact fuel requirements it was possible to calculate the savings. Under conditions of a 70° F. constant house temperature the amount of fuel saved by the protected house was 22.9%. Clearly, substantial energy savings can be derived from adequate protection from undesirable winds.

The consideration of air flow for ventilation has application in some areas but not in others. The hot humid climate of the Houston area does not lend itself to this kind of cooling effect because of the adverse influences of the extremely high humidity of the region. However, natural ventilation can be useful for a substantial amount of time in the dry west or panhandle regions. The high diurnal range with its associated evening breeze is quite helpful in carrying the day's heat build-up out of the structure. To capture and employ this air flow requires both the proper orientation of the dwelling to the breeze and the appropriate relationship between the building inlets and outlets.

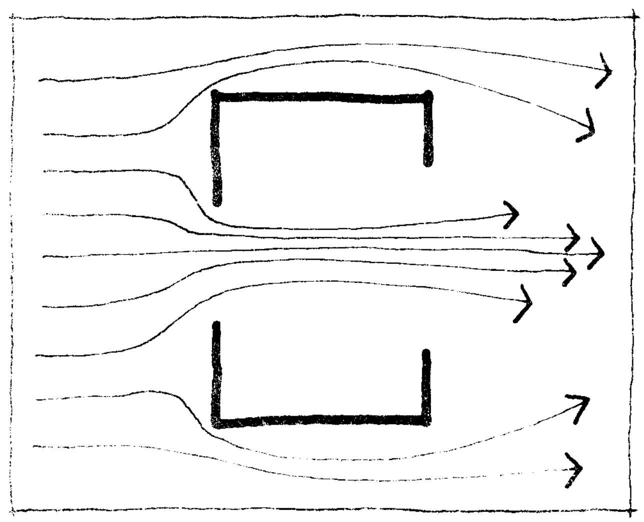
House Plan Favorable to Air Flow



House Plan Unfavorable to Air Flow



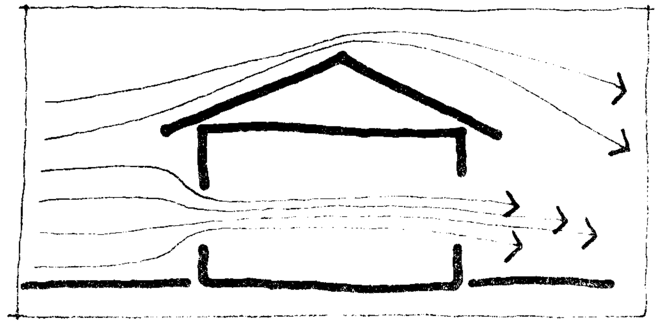
Plan-Openings



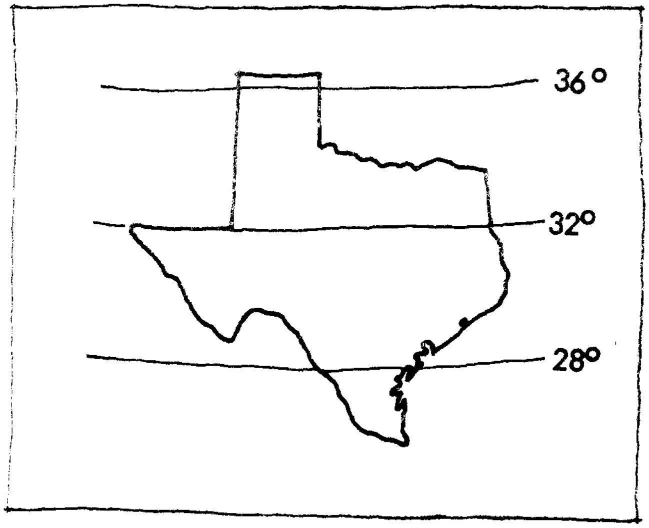
Experiments at the Texas Engineering Experiment Station indicate two major areas of consideration. To properly capture the incoming air flow, the building openings need to be situated approximately perpendicular to the approach of the wind. Without this orientation much of the air flow is deflected around the structure and is therefore unavailable to pass through it. Secondly, there must be attention given to the flow pattern of air as it passes through the dwelling. As a general rule, the greater the air speed, the greater its cooling effect. Therefore it is important that the inlet/outlet relationship be designed to promote the speed of the air flow. This is accomplished by insuring that the inlet size is equal to or smaller than the outlet. If the outlet is smaller than the inlet the amount of air plus the speed of the air flow are reduced as it passes through the dwelling.[21] Of course, the path of the air flow must be more or less directly through the dwelling in order to maintain movement. Complex interior arrangements of partitions greatly reduce the effectiveness of air flow through the house.

The location of the inlet and outlet openings is of considerable importance. If the air flow is to be effective and produce a cooling effect for the occupants, the stream has to be directed to the living zone. The placement of the inlet is the governing factor in directing the flow pattern. Locating the inlet within the lower half but off the floor of the windward side of the room will direct the air flow into the desired pattern.[22]

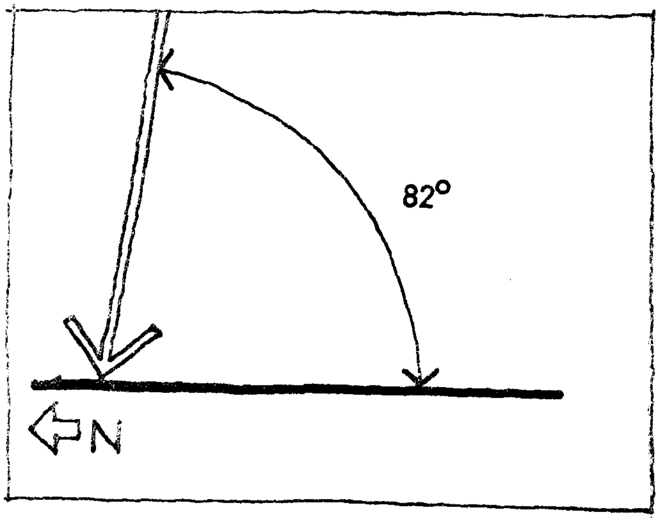
Section - Openings



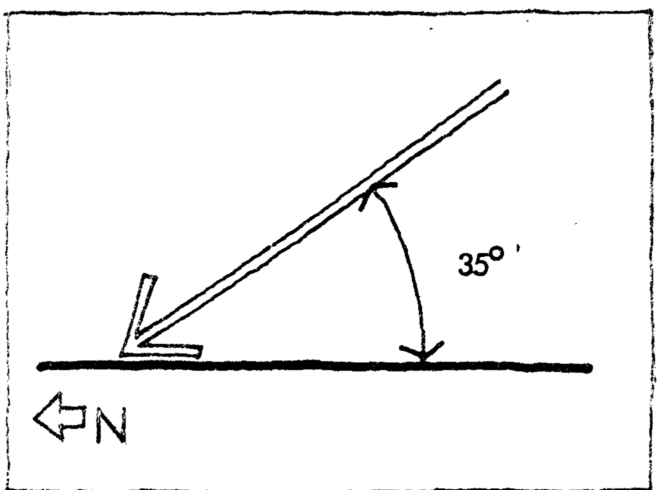
Degrees Latitude North



Noon Sun Angle-Summer Solstice



Noon Sun Angle-Winter Solstice



Sun Angle

The angle at which the sun's rays strike the earth is of considerable importance in determining the degree to which radiation affects the earth's surface. For example, radiation striking a surface at a 90° angle delivers twice the energy as radiation striking a surface at 30°. This variation roughly corresponds to the seasonal change in sun angles as it strikes the earth's surface. The angle at which the sun's radiation strikes the earth is constantly changing from summer when the sun is high to winter when the sun is low in the sky. On a line through the central part of the state (32° N. Lat.) the maximum sun angle is 82°. This occurs at noon of the summer solstice (June 21). The minimum noon sun angle for the year occurs at the winter solstice (December 21) and is 35°.[23]

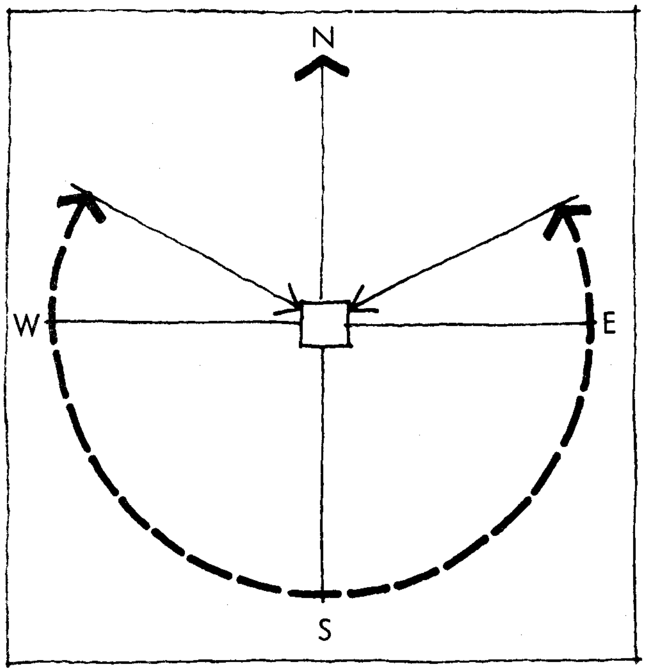
Another factor to be considered is the length of the sun's arc in the sky. During the summer when days are long, the sun's path follows a long arc in the sky. The sun rises north of east, arcs high into the southern sky and sets north of west. In the winter the sun rises south of east, remains in the southern sky (at a lower angle) and sets south of west.

The influences of these factors, once understood, can be easily dealt with. The high sun angle of the summer provides the opportunity to screen out the undesirable summer sun without blocking the entry of desirable winter sun for heat and light.

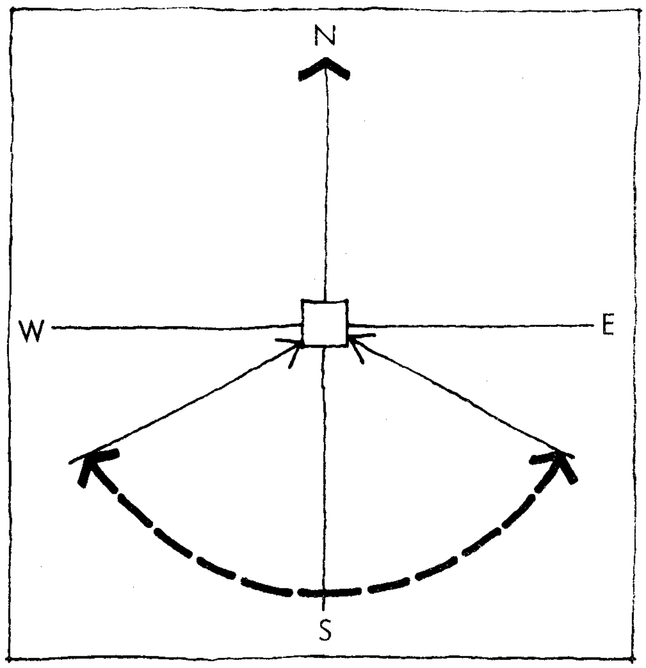
The long arc of the sun's path in the summer indicates that protection from solar impingement on the east and west sides of the dwelling are of as much importance as that on the south sides. There is also a need for solar protection on the north wall. During mid summer the thermal impact is almost the same on the north wall as on the south at this latitude.

The arc of the sun is only low in the southern sky during the winter and consequently provides the opportunity to capture radiation on the south wall during that low temperature period. Provision of generous glass surface on the south wall permits a high level of heat penetration during the winter months. This is of particular advantage in Texas due to the general absence of interfering cloud cover over much of the state.

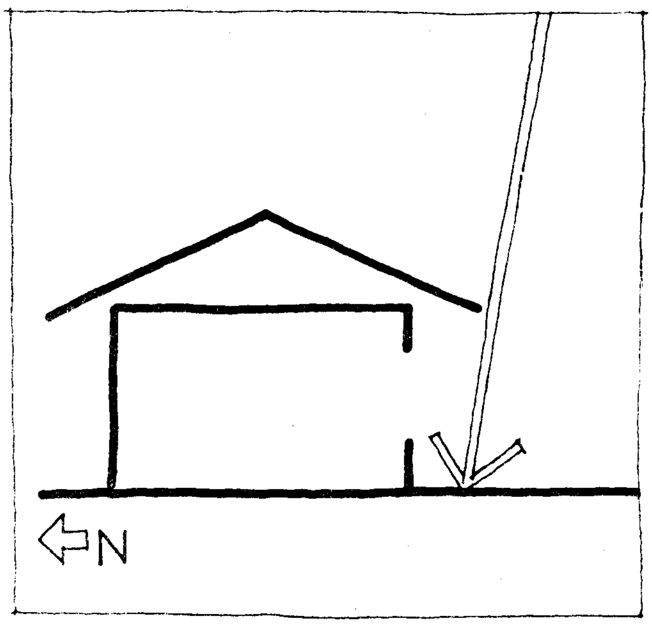
Sun's Path–Summer Solstice



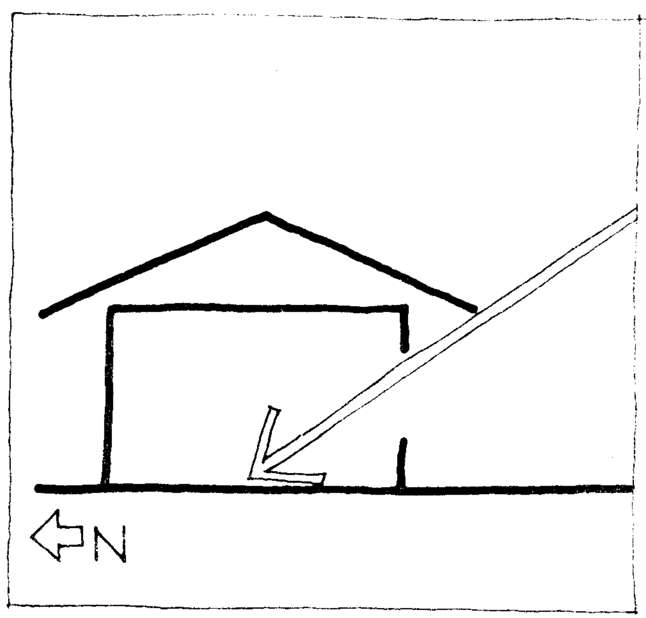
Sun's Path–Winter Solstice



Summer Sun Angle–Window Shaded by Roof Overhang



Winter Sun Angle–Radiation Enters Window for Heating

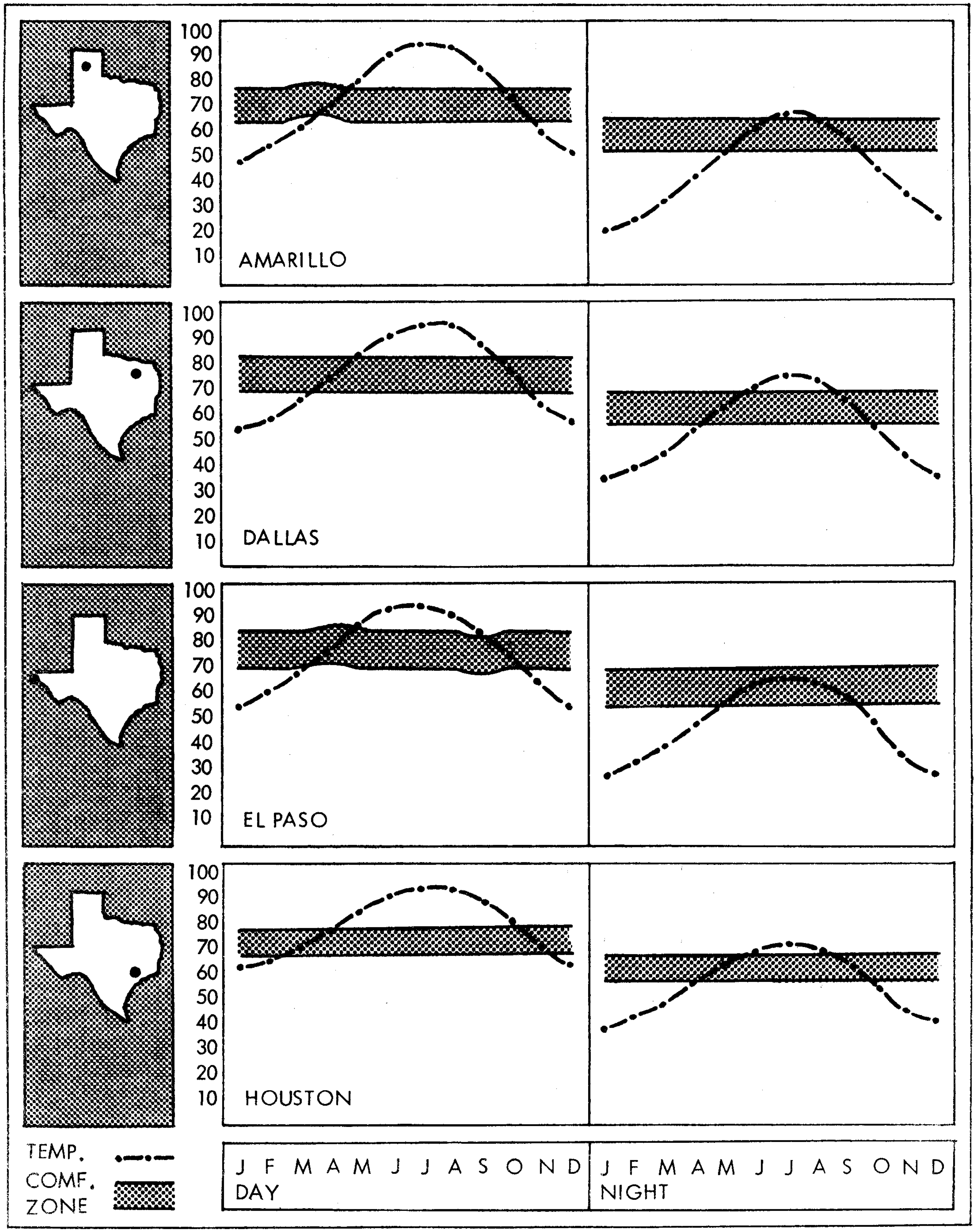


Humidity

Humidity is most significant in determining the extent to which we feel the effects of temperature. High relative humidity heightens the experience of both high and low temperatures. Conversely, low relative humidity tends to diminish the experience of both extremes. Low humidity encourages evaporation during hot periods. This has the effect of cooling a person due to the heat loss by convection as prespiration is evaporated. On the other hand, high relative humidity causes evaporation to occur more slowly, thus, this cooling influence is negated.

A comfort index has been calculated for each of the four cities.[24] These comfort zones vary from place to place due to the differing humidity factors in each location. The following diagrams illustrate the periods of comfort for both day and night according to temperature. It can be seen that El Paso has comfortable nights throughout late spring, summer and fall. All other locations have short periods of comfortable climate in the spring and fall only. Those periods in which the temperatures do not fall in this humidity influenced comfort zone generally represent the portions of the year when energy is consumed for either heat or cooling.

Comfort Zones for Selected Texas Locations



Siting Influences

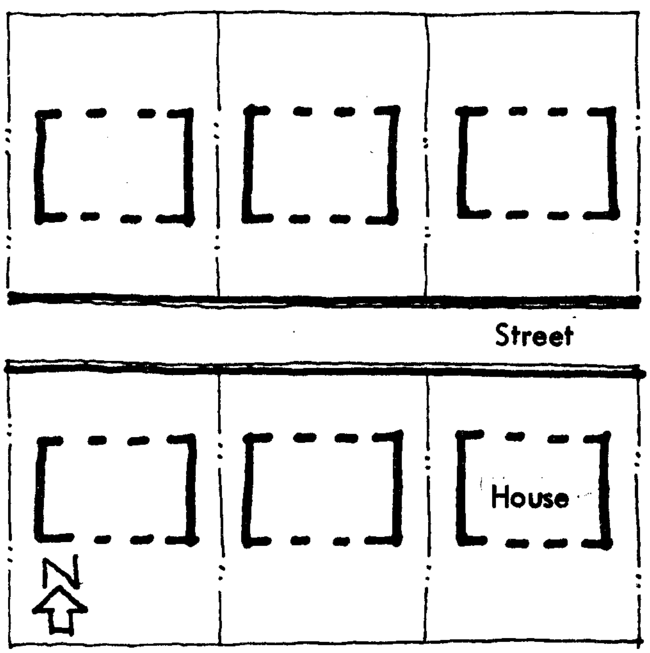
The macro climate of a particular setting is generally stable and rather difficult to change. However, micro climatic conditions are extremely variable as the influences of different climatic factors become expressed to a greater or lesser degree. Although preferable micro climates cannot always be chosen for building sites, it is possible by careful arrangement to promote favorable situations where none existed before. Consideration of the various climatic factors illustrates these opportunities.

Temperature

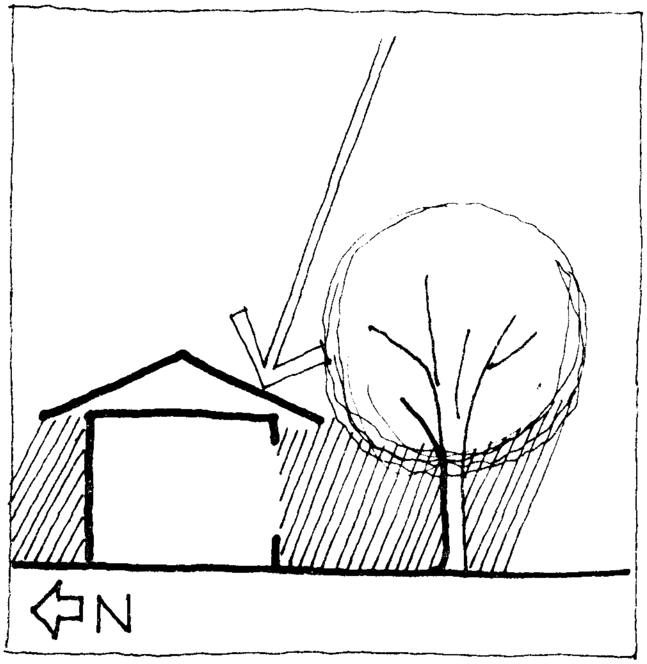
It is possible to orient the building walls to maximize the thermal impact during underheated periods and minimize it during overheated periods of the year. As previously illustrated, the thermal impact varies depending upon the orientation of the wall. In Phoenix, which has approximately the same latitude as Dallas, the thermal impact of the south wall is greater than that of all the other walls combined during the winter. Therefore, by enlarging the south oriented wall, the structure can function to reduce the degree of interior underheating during the winter. The influence of this is to create an elongated building configuration that has the long axis oriented in an east-west direction.

The influence of a high degree of glass on the elongated south wall improves the situation to an even greater extent by allowing radiation to penetrate the structure and warm the interior of the building. This is translated into the typical building configuration with the street to the south or north of the long side of the dwelling. The east and west sides, which have the least openings are oriented toward the adjoining residences. This yields a situation of maximum openings for ventilation, sun and view while providing maximum privacy and screening from the nearest neighbors. For this typical arrangement to have beneficial thermal effect, however, requires that the street be oriented in an east/west direction. If the street is

Proper Street Alignment for Advantageous Building Orientation



House in Summer



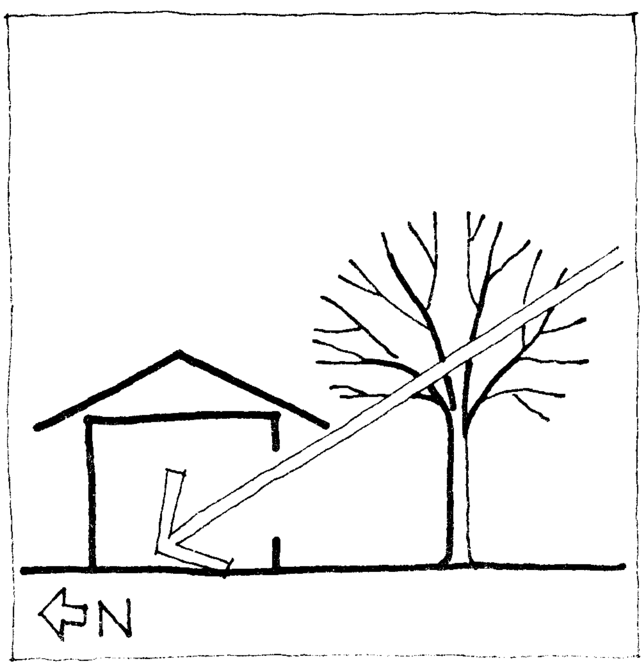
not so oriented, the thermal advantage is not only lost but the negative impact is increased dramatically.

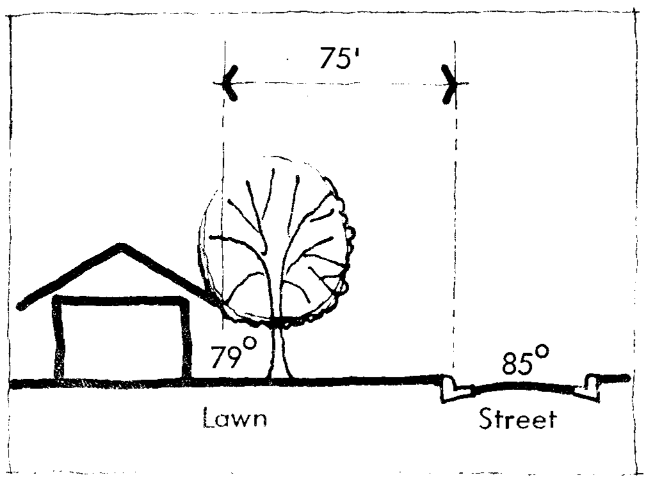
The adjacent figure illustrates how the glass on the southern wall of a properly oriented residence can be protected with a roof overhang of sufficient dimension. Even greater protection can be derived from the proper location of shade trees. Deciduous trees placed on the south side of the house have the advantage of screening out undesirable radiation in the summer and in the winter, when the leaves have fallen, permit the sun to penetrate the windows on the south wall and warm the structure when the added radiation is desirable. The reduction of surface temperatures is significant under shade trees. Variations in surface temperatures can be quite high. With an air temperature of 77° F. the following surface temperatures have been recorded:[25]

Concrete walk in the sun	95°
Dark slate roof in the sun	110°
Short grass in the sun	88°
Leaves of oak tree	81°
Soil in the shade of oak tree	79°

These variations have resulted in substantially improved temperature relationships when employed in the design of the dwelling. The observations illustrated below reveal the significance of this advantage.[26]

House in Winter

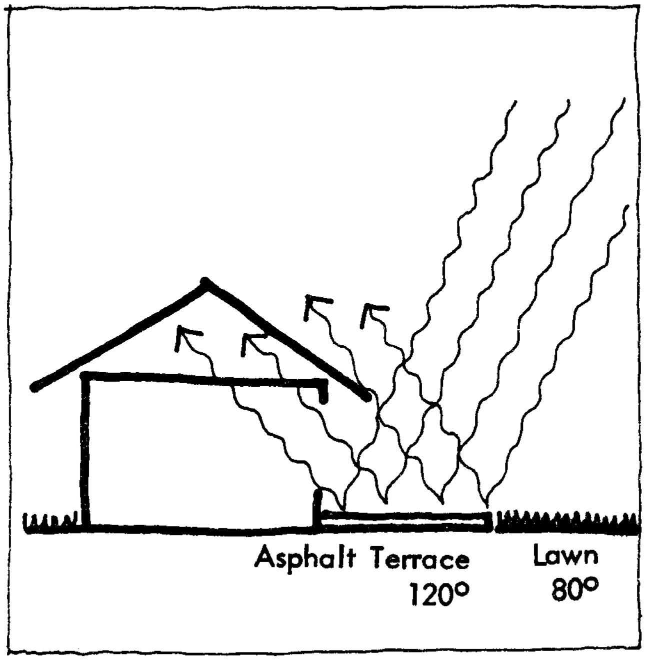




Surface Temperatures

	June 1925	Jan. 1925
Asphalt paving	90.5° F	44.2°
Sand	78.5°	41.8°
Earth	77.0°	41.8°
Gravel	70.0°	42.0°
Grassy ground	60.8°	38.0°
Air Temperature 1.2 meters	57.5°	44.0°

Differentiated Surface Temperatures



Surface Materials

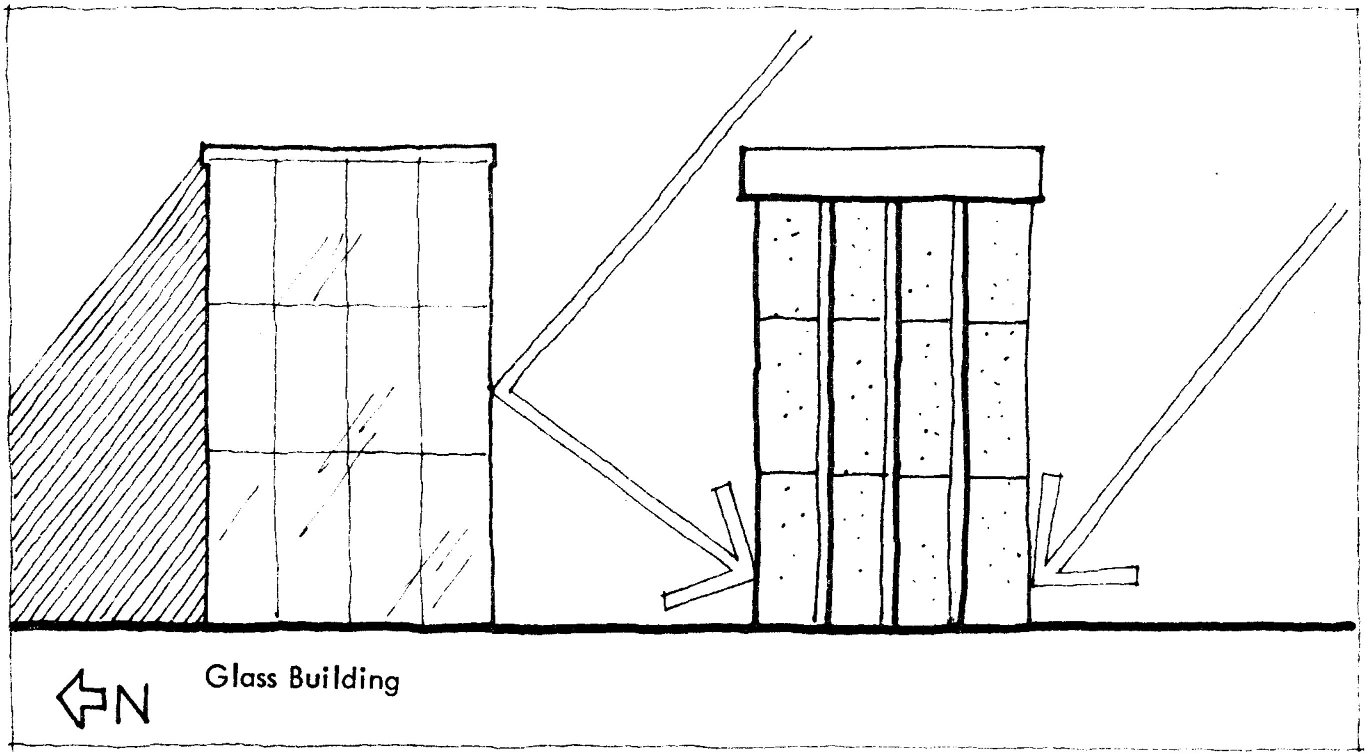
A table prepared by Geiger illustrates the range of temperature in June and January over different surfaces.[27]

The disposition of various types of surface materials in relation to the dwelling can have considerable impact on the influence of radiation on the structure. Fitch, recorded a difference of 40° F. within a distance of twenty feet between a lawn and a blacktop surface.[28] The lawn registered 80° while the asphalt terrace registered 120°. In this situation the terrace was located adjacent to the south side of the house. The terrace served as a heating system radiating heat directly into the house. While this could be an advantage in the winter, it is an extreme hardship during the summer. Obviously the energy consumption for air conditioning under such circumstances would be increased greatly.

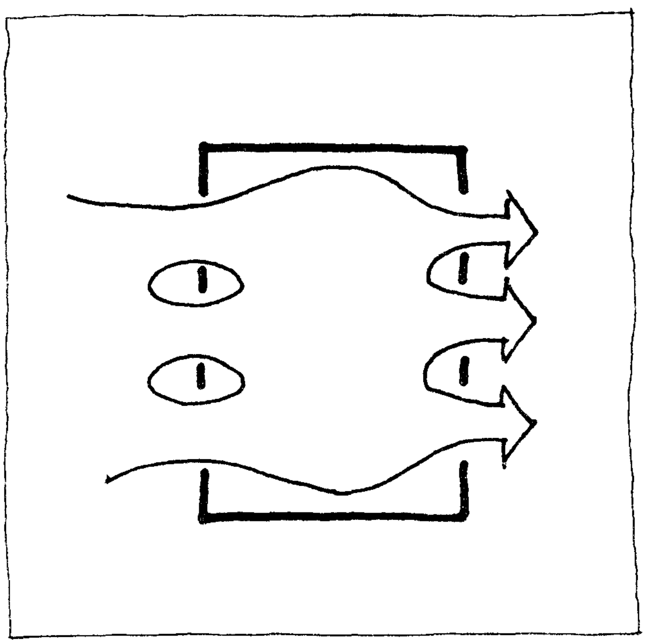
The location of such paved surfaces as patios or drives should be placed with great care to prevent undue heat gain from reflected or reradiated heat. The ideal location for these surfaces would be on the east or north sides of the dwelling. Proximal location on the south or west sides of the house greatly enhances summer heat loads and thus energy consumption.

The contemporary use of glass surfaces for building walls has been quite disruptive in many urban situations. Large areas of glass on building walls utilize highly reflective surface treatments to prevent unacceptable levels of radiation entry. These surfaces often simply redirect the radiation onto other adjacent buildings which must then increase their cooling loads to handle the heat gain. A glass covered building could create a situation whereby an adjacent building would have the effect of two south exposures and greatly increased radiation exposure. This exposure greatly increases the heat load for the building and requires substantial increases in energy consumption to reduce these loads.

Reflected Radiation from Glass Building



Air Flow in House Plan



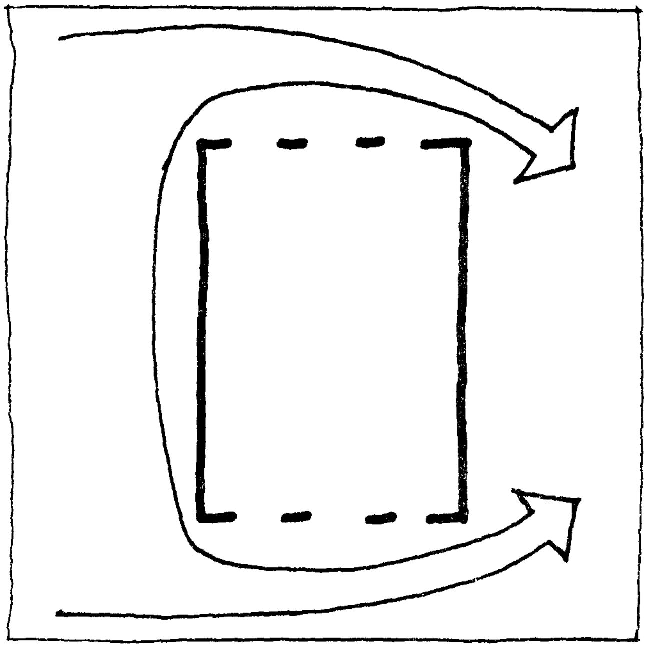
Wind

In seeking protection from undesirable winds and the advantages of useful ones, orientation and land or plant forms adjacent to a structure play an important role. If the dwelling has its openings oriented to the direction of the wind, air movement easily flows through. If, on the other hand, the openings are perpendicular to the direction of the air flow no movement through the dwelling may be anticipated.[29]

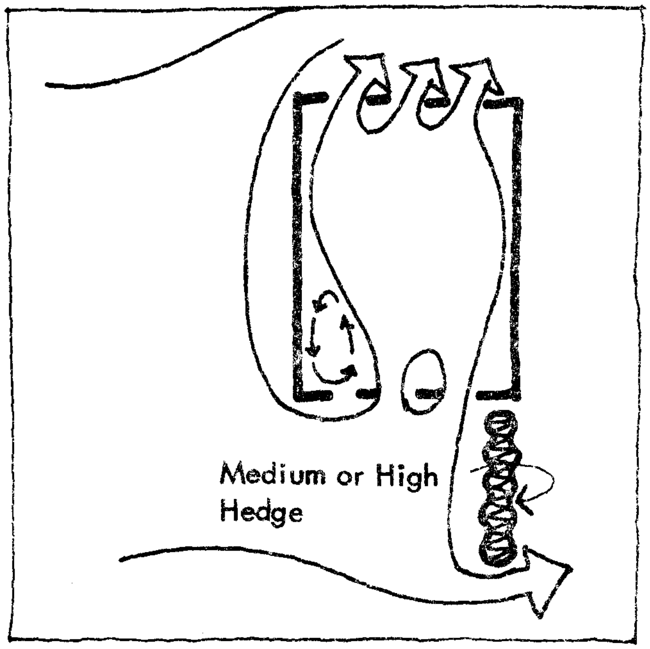
The influence of carefully located planting adjacent to the poorly oriented window openings can be of benefit in redirecting the flow of air through the dwelling. Although planting was used in the experiment described here, other wind control devices such as a structural screen would have similar influences.

Planting can be used to redirect winds away from the structure as well as through it. The windbreak of the prairie is well known in this regard. An area of relative calm is created near the windbreak on the leeward side. If the windbreak is dense enough to prevent the passage of air through the screen there will also be a smaller area of wind protection on the windward side.

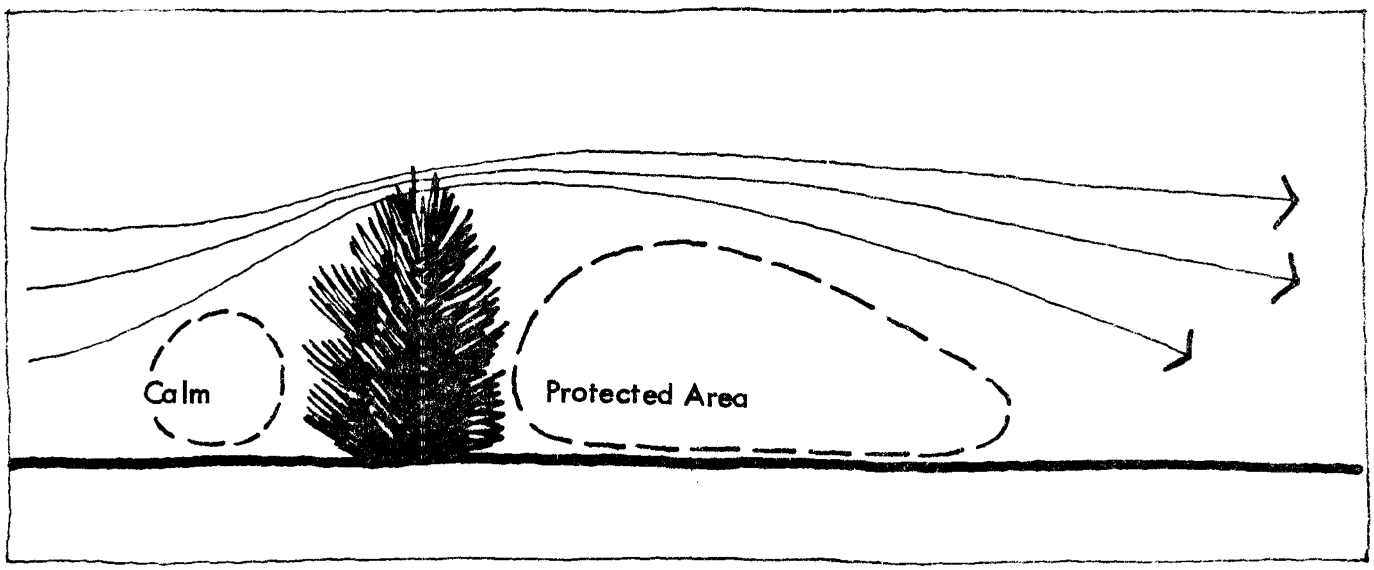
Openings Oriented to Eliminate Air Flow Through House



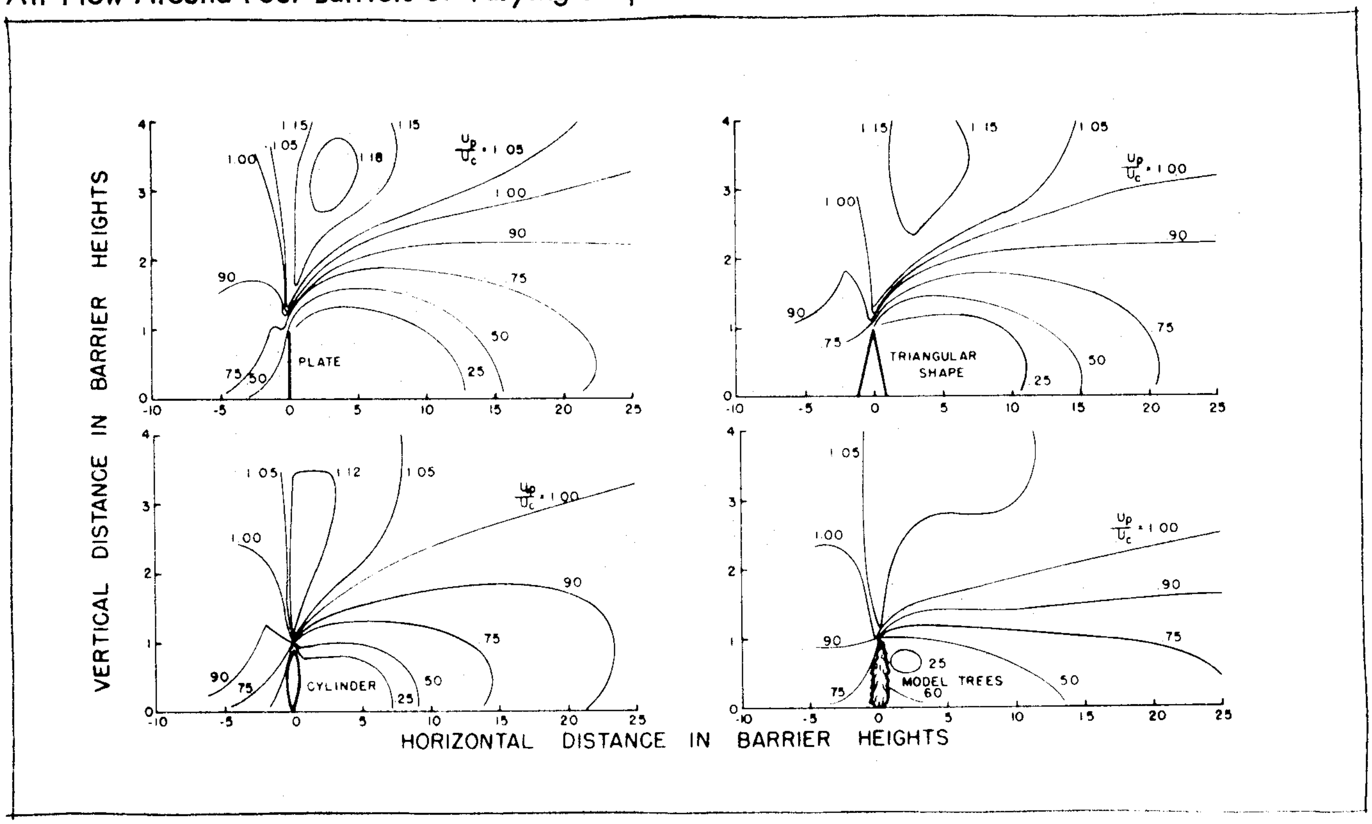
Redirecting Air Flow Through the House



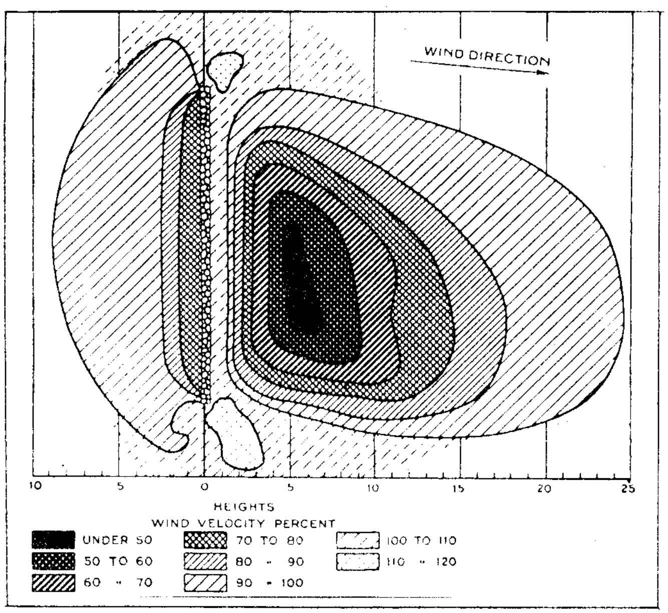
Windbreak



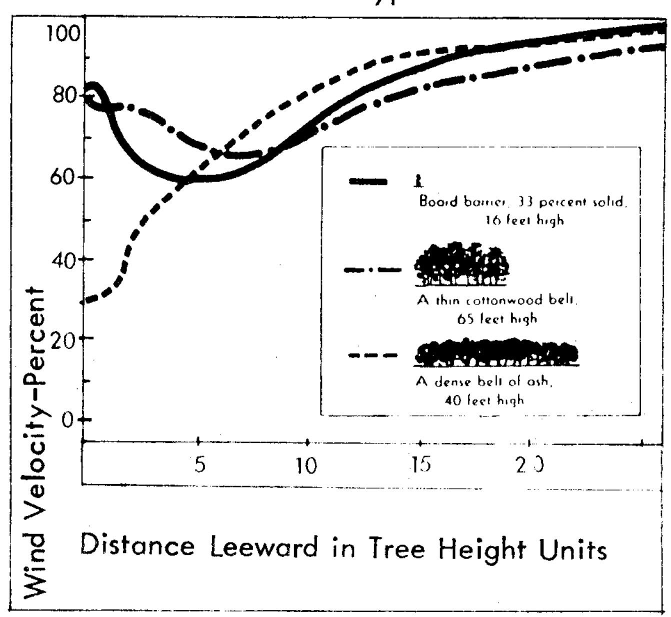
Air Flow Around Four Barriers of Varying Shapes[30]



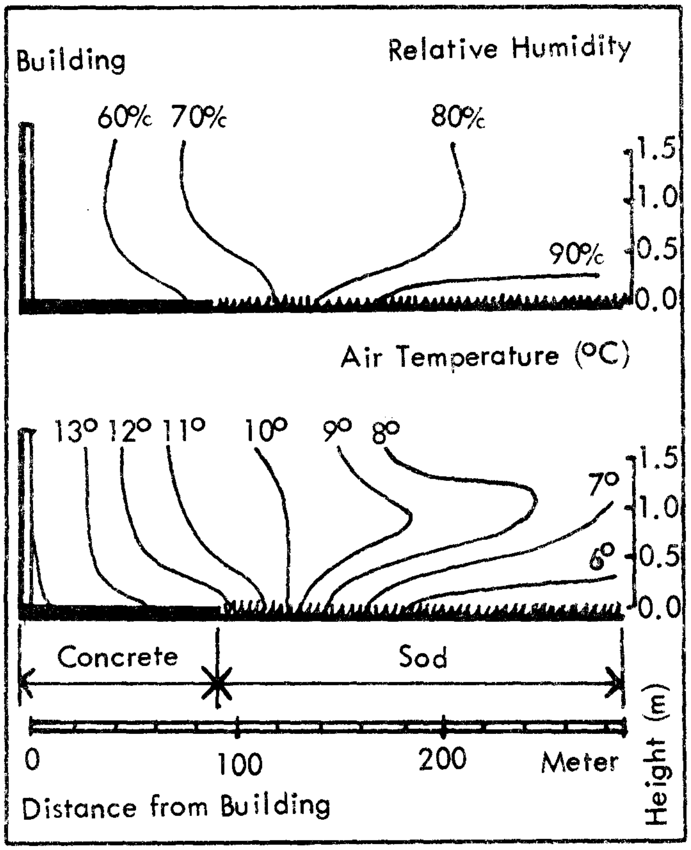
Field Protection of Windbreak[31]



Wind Velocities at Three Types of Windbreaks[32]



Paving Influences on Temperature and Relative Humidity



Humidity

Although the local modification of high humidity is quite difficult, low humidities can be increased with the addition of moisture from pools, fountains and vegetative respiration. In this way local microclimates can be modified to improve the experience of comfort to those within them.

The introduction of a water mist in an El Paso patio would produce perceptible benefit. However, the use of water fountains in Houston would have no benefit since the humidity is already too high for comfort. For this reason evaporative coolers are not satisfactory for air conditioning in high humidity areas.

Relative humidity, just like temperature, can vary greatly over different surface treatments. The accompanying diagram illustrates the relationship between temperature and humidity over proximal turf and concrete surfaces. The lines of equal temperature and equal humidity run vertically rather than horizontally. It is warm and dry near the building but cool and moist over the grass. The drying effect of the concrete surface is so significant that 130 meters are required for the two conditions to become balanced with vertical lines of equal temperature and atmospheric moisture.[33]

The modifications of the building's surrounding environs can greatly enhance the climate within and near the dwelling, thus, greatly reducing the need for compensating heating and cooling.

References

1. Everetts, Jr., John, Analysis and Influence of Climatology Upon Air Conditioning Design, in Climate and Architecture, Jeffery E. Aronin, Reinhold Publishing Corp., New York, 1953.

2. Stein, Jane,"There are Ways to Help Buildings Conserve Energy," Smithsonian, October 1973.

3. Climate and Man, 1941 Yearbook of Agriculture, United States Department of Agriculture, Washington, D.C.

4. Ibid.

5. Weather Bureau, Office of the State Climatologist, Austin, Texas, October 1968, Environmental Science Services Administration.

6. Climatology of the United States No. 60-41, June 1969, U.S. Environmental Data Service.

7. Ibid.

8. Ibid.

9. Center for Applied Geosciences, College of Geosciences, Texas A&M University, Miscellaneous Publication No. 1 (O.S.C.), July 1974.

10. Climatologist for Texas, National Weather Service, July 1971.

11. Climatology of the United States No. 60-41, June 1969, U.S. Environmental Data Service.

12. Ibid.

13. Ibid.

14. Handbook of Air Conditioning, Heating and Ventilating, Clifford Stock, ed. Industrial Press, 93 Worth St., New York, 1969.

15. Local Climatological Data, Annual Summary with Comparative Data, 1972 for: Amarillo, Dallas, El Paso, and Houston, Texas, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

16. After Gary Long, "Energy is the Issue", The Texas Architect, May/June, 1974.

17. Olgyay, Victor, Design with Climate, p. 86, Princeton University Press, Princeton, New Jersey, 1963.

18. Ibid, p. 87.

19. Woodruff, N.P., "Shelter Belt and Surface Barrier Effects", Agricultural Experiment Station, Manhattan, Kansas, Technical Bulletin 77, December 1954, in Design With Climate, Victor Olgyay, Princeton University Press, 1963.

20. Stoeckeler, Joseph H., and Williams, A. Ross, "Wind Breaks and Shelter Belts," in Trees 1949 Yearbook of Agriculture, United States Department of Agriculture, Washington, D.C.

21. Holleman, Theo. R., "Air Flow Through Conventional Window Openings", Texas Engineering Experiment Station, College Station, Texas, Research Report 45, March 1954.

22. Caudill, W.W., Crites, S.E., and Smith, E.G., "Some General Considerations in Natural Ventilation of Buildings", Texas Engineering Experiment Station, College Station, Texas, Research Report 23, 1954.

23. Ramsey, C.G., and Sleeper, H.R., Architectural Graphic Standards, Sixth Edition, 1970, John Wiley & Sons, Inc.

24. Mahoney Tables, Climates and House Design, Vol. 1, Department of Economics and Social Affairs, U.N. Publication, 1971.

25. Landsberg, H.E., "Microclimatic Research in Relation to Building Construction" in U.S. National Research Council (Building Research Advisory Board) Weather and the Building Industry, Research Conference Report No. 1, Washington, 1950.

26. Ibid.

27. Geiger, Rudolf, The Climate Near the Ground, Cambridge: Harvard University Press, 1950.

28. Fitch, James M., "Buildings Designed for Climate Control", in U.S. National Research Council (Building Research Advisory Board), Weather and the Building Industry Research Conference Report No. 1, Washington, 1950.

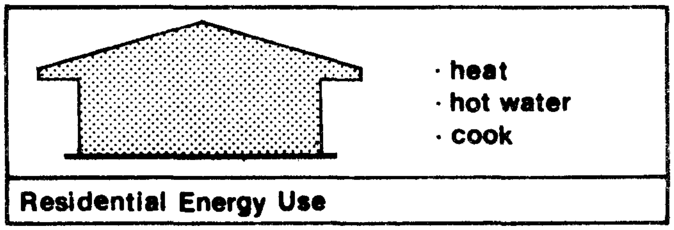
29. White, Robert F., "Landscape Development and Natural Ventilation", Landscape Architectural Quarterly, January 1955.

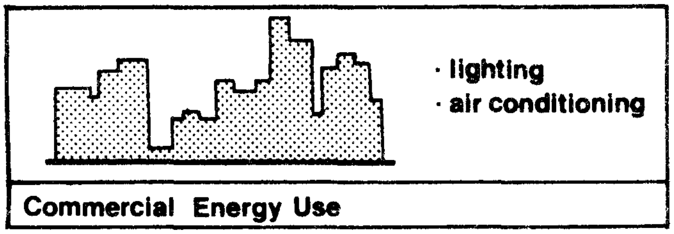
30. Olgyay, Victor, Design With Climate, p. 98, Princeton University Press, Princeton, New Jersey, 1963.

31. Ibid, p. 99.

32. Ibid.

33. Aronin, Jeffery E., Climate and Architecture, Reinhold Publishing Corp., New York, 1953, p. 144.





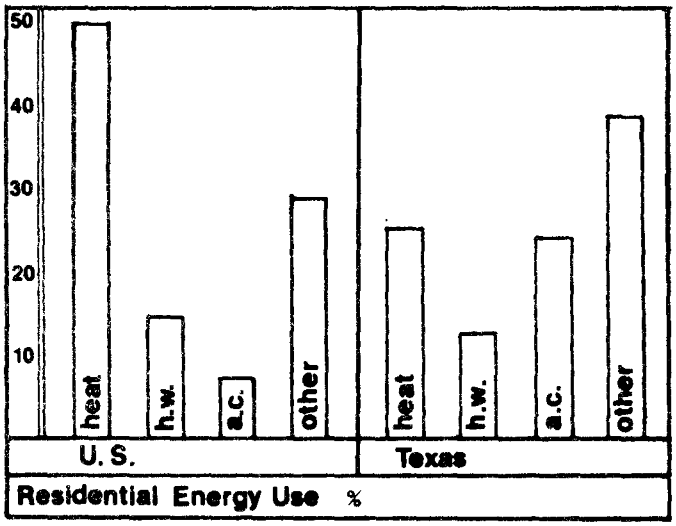
3.2 Residential Buildings

Introduction

This study's focus is energy use in buildings in Texas. Four consuming sectors or activities are typically identified in national studies, the area described as "Residential/Commercial" is the basic concern.

National studies indicate that between 19 and 24% of total U. S. energy consumption occurs in the Residential/Commercial Sector. Additionally, this sector uses a large quantity of the primary energy expended to generate electricity. Experts differ over exact end use percentages but nationally it is safe to say that more than a third of the primary energy expended in the U. S. is consumed by Residential and Commercial buildings.[1]

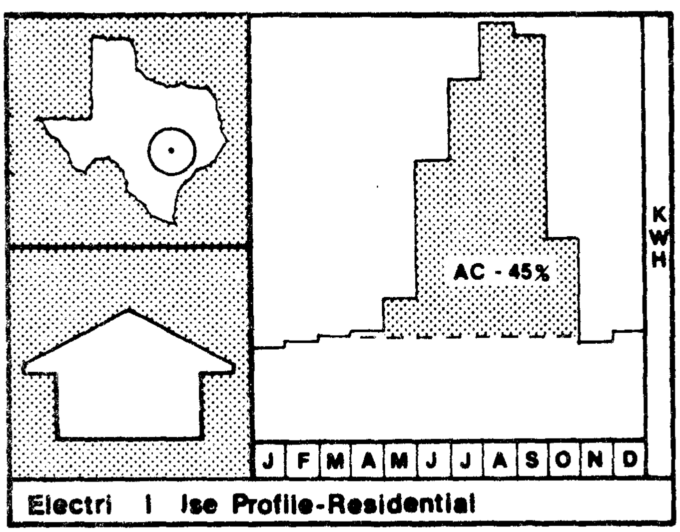
What is the energy use pattern or profile in the Residential/Commercial sector? Unfortunately, the consumption patterns are totally different. Residential users direct much of their energy to heating, hot water, and cooking; while Commercial users (from laundries and barber shops through shopping centers and office complexes) consume most of their energy for lighting and air conditioning. Residential and Commercial energy consumption will accordingly be analyzed separately.



Texas Energy Use

1970 National Figures for Residential energy consumption show heating and water heating as the significant elements of the sector's energy consumption.[2] However, National figures are not appropriate for Texas. An automatic heating plant located in the center of Texas may be expected to operate approximately 1000 hours per year. Chicago and New York City operate similar plants nearly 2000 hours per year.[3] Conversely in the air conditioning season Texans will operate their equipment 2000 hours compared to 900 in Chicago or New York City.

Thus the gross pattern of Texas energy consumption (disregarding significant variations across the State) places significant emphasis on cooling at the expense of heating. State-wide figures show that more than 30% of the State's Residential electrical use is air conditioning equipment and this percentage is increasing as more and more residences install air conditioning.[4]



The electrical use profile at left is an average of billing data for four staff residences surveyed. Air conditioing accounts for nearly half of the total annual electrical consumption suggesting that as more and more residences are air conditioned the State's residential electrical demand peak will become considerably more pronounced.

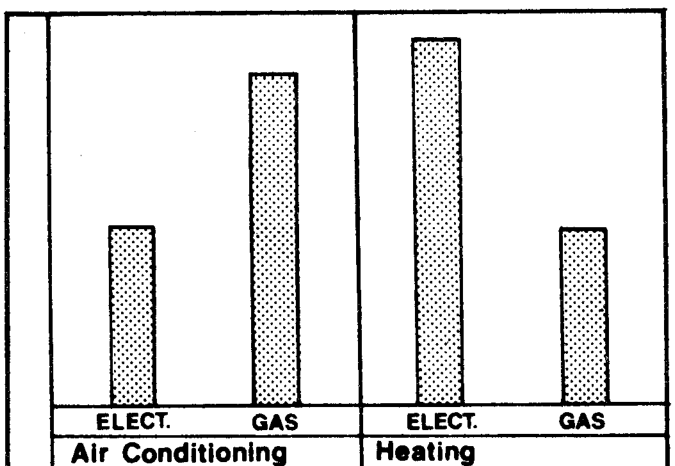
Electrical	Gas (heating)
11,000 btu yeilds 1 KWH	11,000 btu yeilds 7,700 btu

Prime Energy Conversion

Energy Conversion

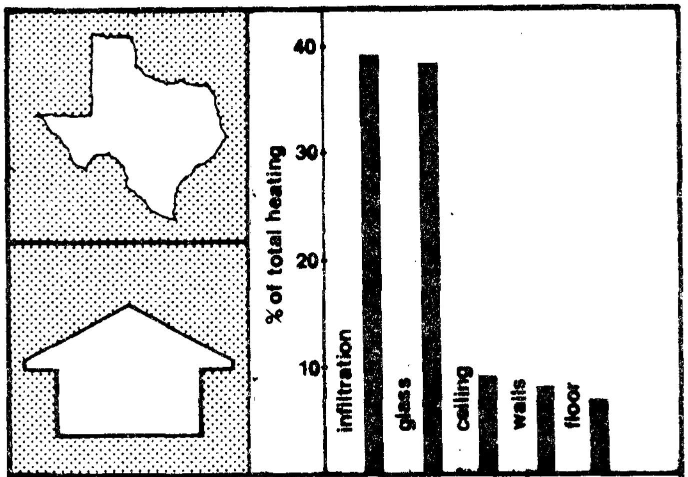
Energy consumption involves both direct use of fuel and indirect use of fuel (i.e. electrical energy). This analysis charges electrical energy at the rate of 11,000 BTU (heat units) of fuel per KWH (thousand watt hours) of electrical energy. The 11,000 BTU/KWH figure represents a reasonable estimate of generating and transmission losses for electrical energy. Direct use of primary fuel (typically burning natural gas for heat in Texas) also involves energy losses through flue gasses and inefficient heat exchangers. Debated efficiencies for gas furnaces range from 60-80% with many electric utilities suggesting less than 60% efficiencies, 70% is assumed in this study.

It should be noted that both electrical and gas utilities are involved in dedicated efforts to promote "off season" use of their products to level the demand on their production and distribution systems over the year. A flat demand curve means efficient operation for either company - unfortunately, it does not imply minimal consumption of primary energy.

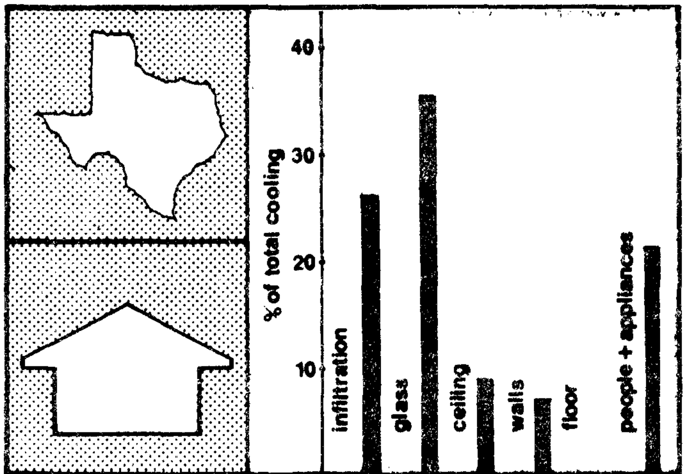


Primary Fuel Consumption

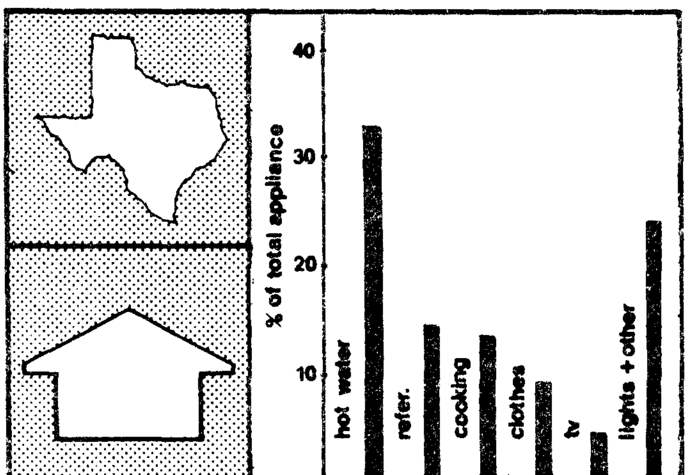
Electrical heating and gas air conditioning are offered as two examples. Natural Gas is the major Texas fuel for electrical generation and residential heating. Burned in a generating plant natural gas will produce 1 heat unit via electric resistance heating in the home. Burned at home the same quantity of gas will produce 2 to 2 1/2 units of heat. (Note: in Texas climates the electric heat pump - essentially a reversible air conditioner - can approach gas in heating efficiency.) In air conditioning electric power has a clear edge. One unit of gas will provide 6 units of cooling at the home via the electrical distribution network. Burned at the residence the same quantity of gas will produce only 3 to 4 units of cooling through a gas absorption cycle air conditioner.



Elements of Heating Load (Model)



Elements of Cooling Load (Model)



Elements of Appliance Load (Model)

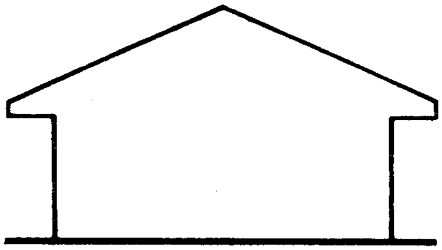
Energy Consumption

It is interesting to note the elements of heating and cooling energy consumption which are depicted in the next two graphs. In both cases infiltration (air leakage) and glass are the major contributors to heating and cooling requirements. Changes in glass area and air infiltration then, should provide the most rewarding avenues for for reduction of energy consumption in the well insulated residence.

A significant element of Residential energy consumption falls under the general heading of "appliances". Cooking, refrigeration, washing, drying, lighting, etc., although not large individual users of energy, make up a substantial portion of residential energy use as a group.

In general it can be demonstrated that gas provides the most efficient heating devices in terms of energy use while electrically powered devices are more efficient in the lighting and cooling sectors. An electric dryer for example will use 50% more primary energy doing the same job as its gas counterpart. The issue becomes more complex when you compare electric and gas cooking. A gas range tends to put more waste heat into a home than its electric counterpart. Thus a gas range is advantageous in a home with large winter heating requirements, but disadvantageous in a mild climate where air conditioning is a larger energy consumer than heating.

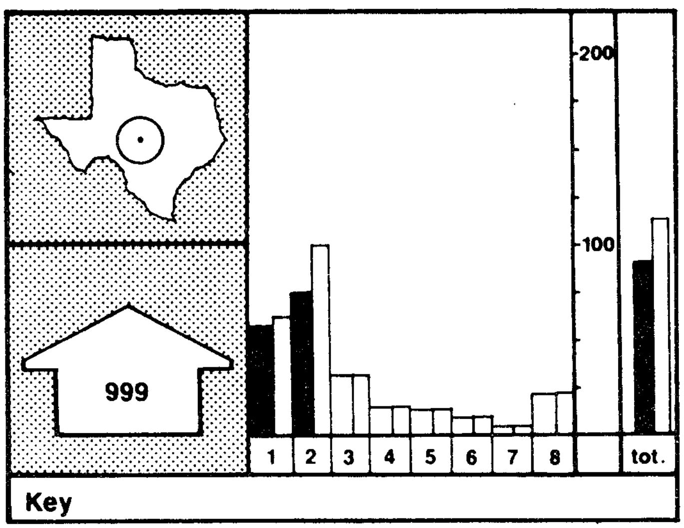
Energy consumption for appliance purposes is depicted at left. Hot water, refrigeration, cooking and clothes drying are significant elements of these appliance loads. The lighting and other category covers a multitude of devices from electric tooth brushes to exhaust fans as well as lighting. Though a significant element of energy consumption this is a difficult category to break down in detail.



Model Residence Description

area 1500 sq. ft. dimensions 30' x 50'
orientation 50' sides face North-South
glass single, 280 sq. ft.
walls 1000 sq. ft. net, brick veneer, insulation R=11
ceiling 1500 sq. ft. vented attic above, insulation R=19
floor concrete slab on grade, no insul.
infiltration 1.5 air change/hr. winter
1.0 air change/hr. summer
climate 2000 degree days heating
2000 compressor hours cooling
occupants family of 5

appliances	gas	electric
	heat	air conditioning
	hot water	cooking
	clothes dry	light etc.



Model Residence

As a starting point we assume a Model residence located near the geographic center of the State with 2000 degree days of heating and 2000 compressor hours for cooling.[5] Indoor temperature is 75°F year round.

Cooling requirements were calculated using "manual J" methods WAHACA;[6] heating requirements by ASHARE.[7] Electrical consumption is estimated for specific high use appliances, and total electrical consumption was estimated at 14,000 KWH per year - higher than State average bills but conservative for a centrally air conditioned residence like the Model.

The key diagram format at left will be used to illustrate annual energy consumption. The diagram depicts consumption of primary energy by end use; results for the Model residence are shown on the following page.

Energy Profile Key

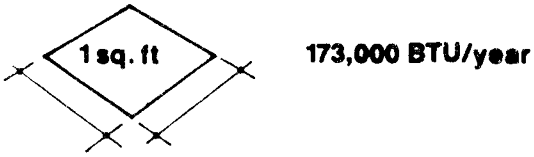
(•) = location of example

999 = Prime energy use; BTU/sq. ft./yr. times 1000

1. = Heating
2. = Air Conditioning
3. = Hot Water
4. = Refrigerator (frost free)
5. = Cooking
6. = Washer/Dryer
7. = TV (color)
8. = Lighting and Other

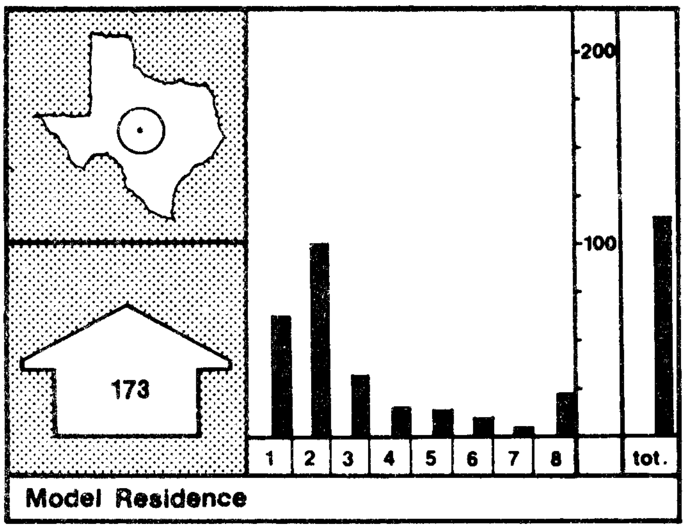
left bar = example; right bar = Model residence; black bar = change; Scale = million BTU/yr. prime energy

tot. = Relative energy use per sq. ft. per year comparison. Black = example; white = Model Residence. DO NOT READ SCALE VALUES AT LEFT.



Model Residence Energy Consumption (psf)

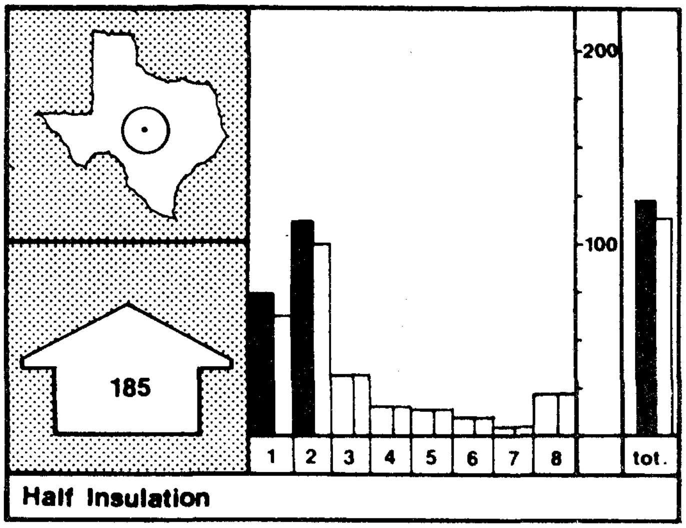
Energy consumption levels per square foot of building area should provide a meaningful way to compare both large and small dwelling units although larger residences are favored by the results if the appliance loads are assumed constant. This index, primary energy consumed per square foot of building per year, will be used in the following analyses.



The Model residence consumes 260 million BTU of primary energy per year (173,000 BTU/sq. ft./yr.). 60% of its energy use is electrical and 40% gas.

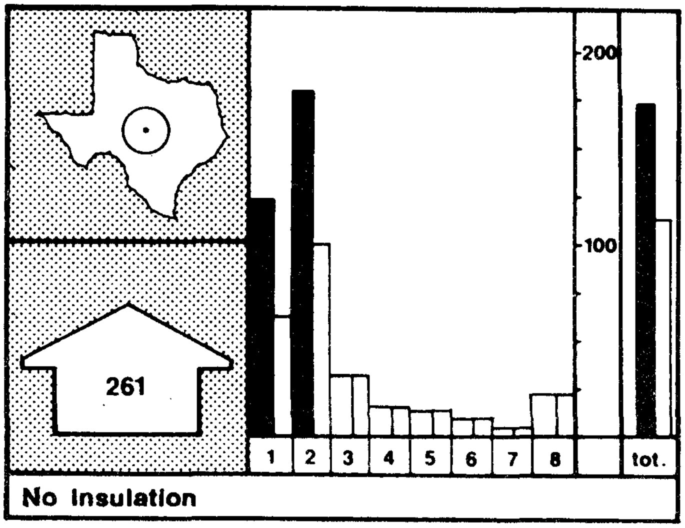
Although wide variations in life style and personal habits can exert severe impacts on energy consumption, the base residence figures were considered realistic when a similar analysis of several actual research staff residences yielded nearly identical energy consumption figures per square foot of building area based on actual 2 to 4 year utility billings.

Having established a Model residential energy consumption pattern, what impact will Model changes have on energy consumption? The following diagrams indicate the impact of various alternatives; architectural, appliance, location and temperature changes are considered. Each diagram compares the impact of a specified change with the initial Model residence findings.

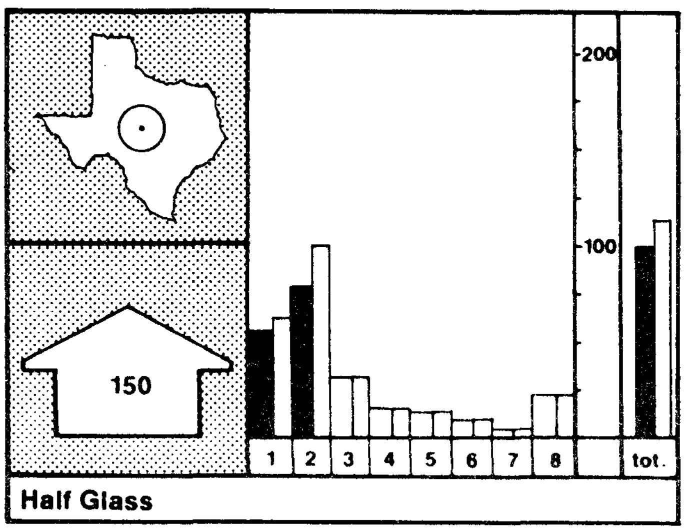


Alternatives

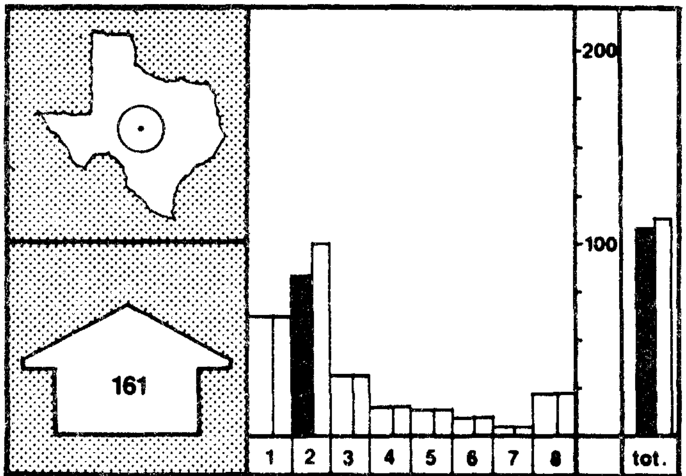
If wall and ceiling insulation are reduced to 1/2 of the base Model levels (Rw = 5.5, Rc = 9.5) heating and cooling loads increase substantially and total energy consumption is up 6.5%.



If the Model is analyzed without insulation in walls or ceiling energy consumption jumps a substantial 50%.

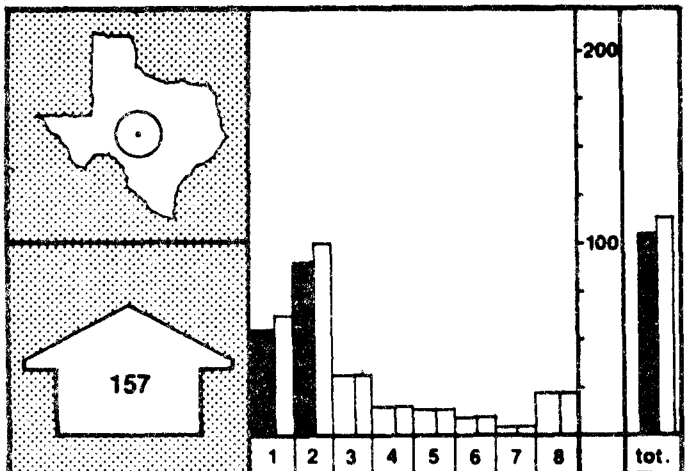


By reducing the rather large glass area of the base Model from 22% to 11% of the exterior wall area, a 13% saving in total energy consumption is possible.



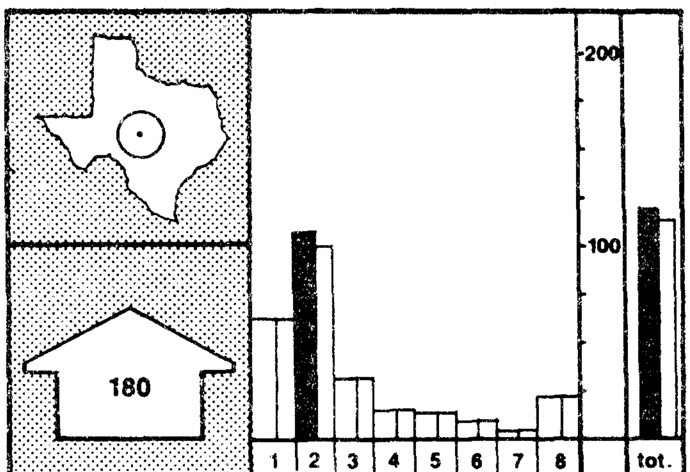
Shade Glass

By providing exterior shading for all Model glass areas (i.e. overhangs, sun screens or trees), cooling loads may be substantially reduced and a 7% energy savings is possible even though the Model home assumed interior blinds.



Half Air Change Rate

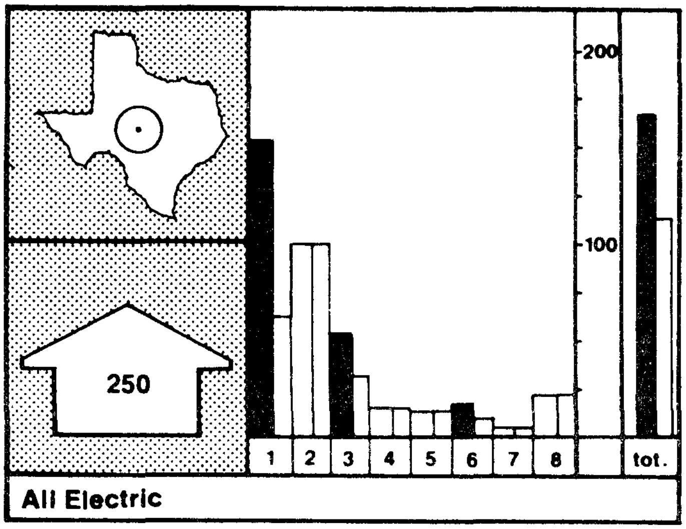
Tight sealing of the Model residence by weatherstripping and storm doors can substantially cut air leakage and thus reduce heating/cooling energy demand. Our base residence assumed a conservative 1.5/1.0 hourly air change rate winter and summer. By cutting this leakage to .75/.5 air changes per hours (electrically heated home standards) energy consumption can be cut 9%.



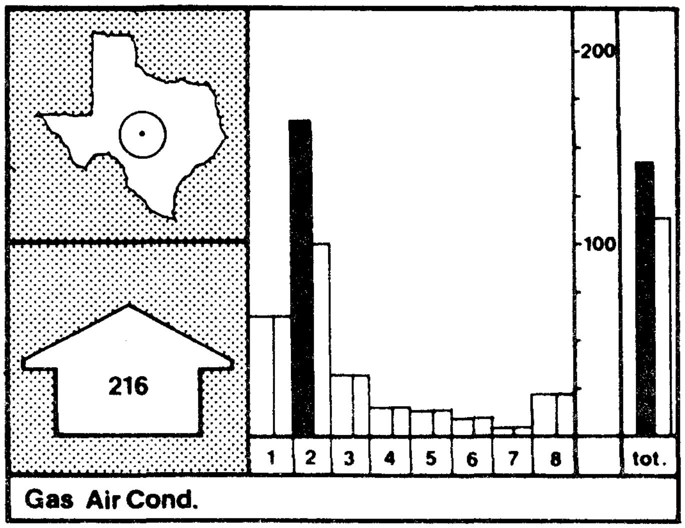
Worst Orientation

The Model residence was oriented with its long walls (and larger glass areas) facing north and south. If the home were rotated so that long walls faced east and west the increased cooling load would require 4% more energy.

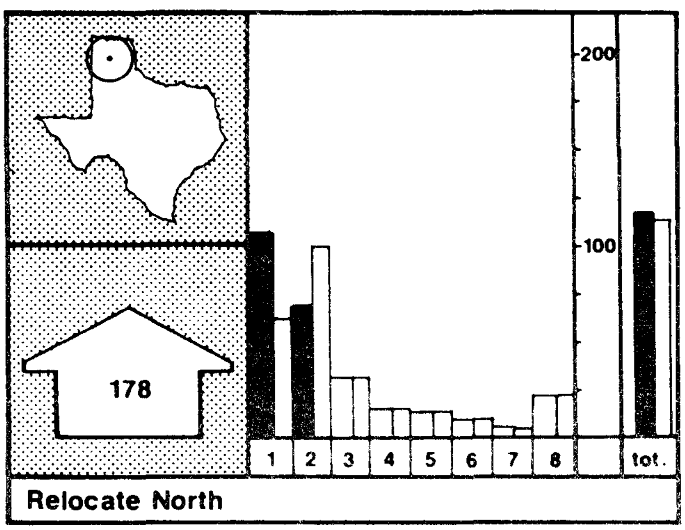
Changing the Model home's plan to one with greater surface area (20 x 75 in lieu of 30 x 50) or re-configuring the home as a 2 story building had negligible effects on total use.



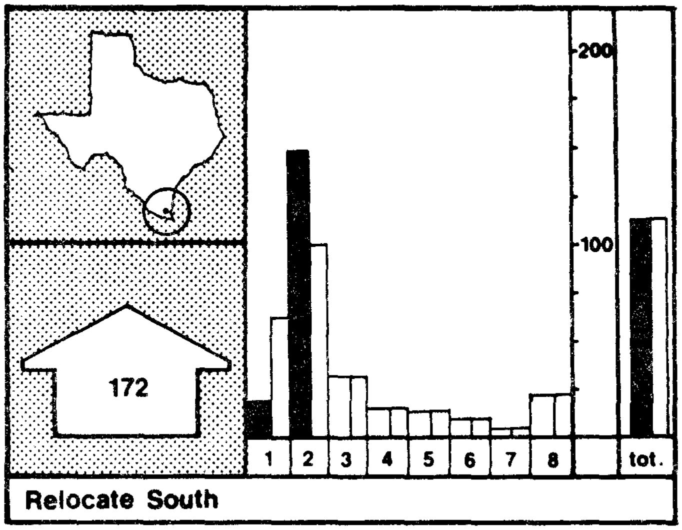
Changing the Model residence to an "all Electric" home with resistance heating results in a substantial increase in heating, hot water, and clothes drying energy yielding a 44% increase in primary energy use. As mentioned earlier an electric heat pump can be competitive with the gas furnace in Texas climates.



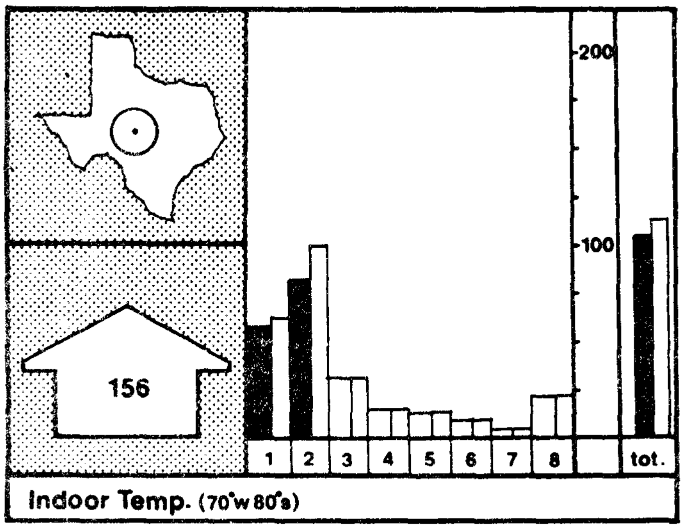
Changing the Model's air conditioning system to a gas fired unit adds 25% to the Model's energy consumption.



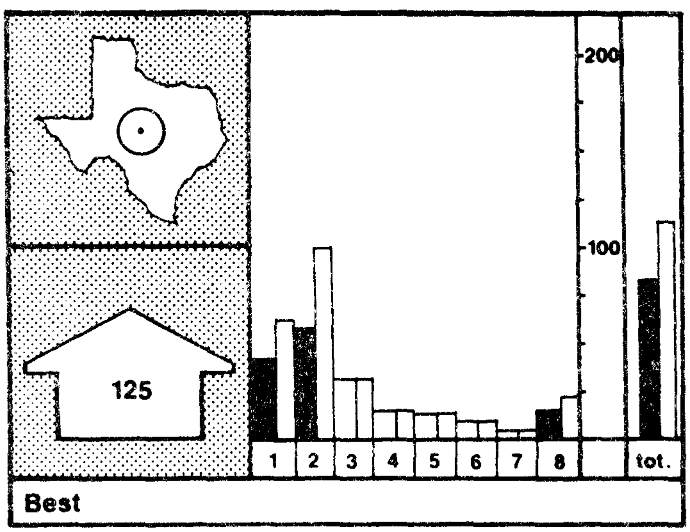
Relocating the Model residence to Amarillo increases heating demand and reduces cooling load. The net effect is 3% increase in energy consumption. (4000 degree days, 1400 cooling hours, 0^{o} winter design.)



Relocating the Model residence to Brownsville cuts heating needs and increases cooling demand. Net energy use is unchanged. (600 Degree Days, 3000 cooling hours)

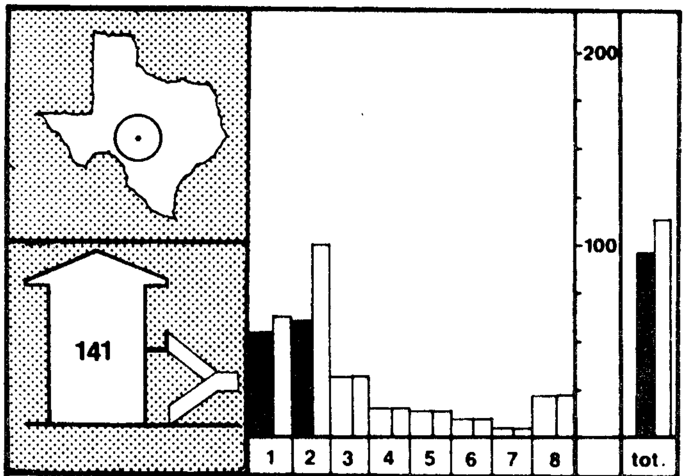


This graph shows the effect of higher summer and lower winter interior temperatures on energy use. Departing from the year round 75° inside temp and using a summer temp of 80° and a winter of 70° a 10% energy savings can be realized.

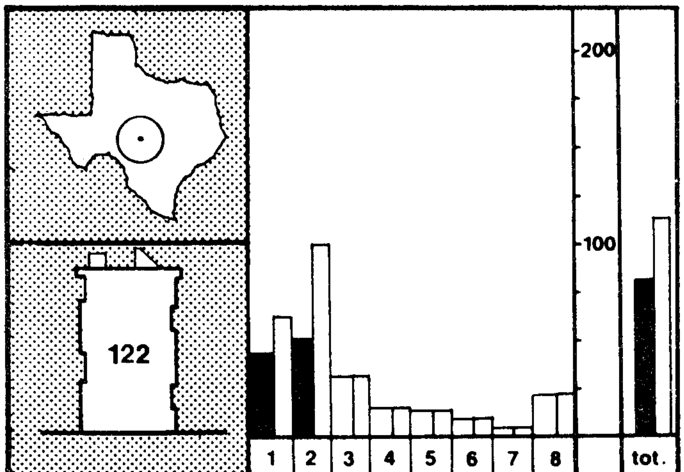


Of course our percentage energy changes are not additive. Taking the most productive findings and applying them to the Model residence could yield a total 30% energy savings for new construction.

- Indoor temp 70 winter, 80 summer
- 11% glass in exterior walls
- cut infiltration to .75/.5 air changes
- exterior shade all glass
- cut lighting use 25% (education)



Apartment (low rize)



Apartment (high rize)

Apartments

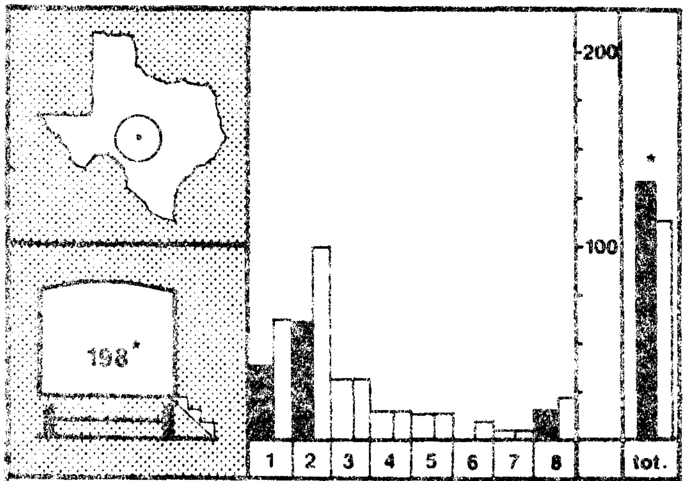
What about Apartments" By sharing walls and reducing the total exposed roof area apartments are, theoretically at least, less energy consuming in the heating and cooling sectors than their counter-part detached single family residences. For comparative purposes an apartment was modeled equally in floor space, location, construction, and appliances to the basic residence. The apartment model was developed first in a low rise configuration (2 story) where 1/2 the apartments have roof heating and cooling loads and then in a multi-story configuration where roof loads per unit were negligible.

The model apartments had less exterior surface and less glass than the base residence. It should also be noted that 1500 sq. ft. is an unusually large apartment area.

Theoretical energy consumption for the low rise model apartment is 19% less than the base residence. The high rise (with even less exposed surface per unit area) should consume 30% less than the detached single family home base.

To verify theoretical energy use profiles utility bills were obtained for a number of large apartment projects in Texas cities. The energy consumption levels indicated by this billing data were less than helpful because of the variety of construction details and appliance mixes involved. Apartment energy consumption varied from 150,000 BTU/sq. ft./year to 250,000; in most cases substantially exceeding the projected consumption rate of 126,000 to 146,000 (all electric apartments generally performed better than the theoretical model all electric residences). Some of this variation is undoubtedly a result of less insulation etc. than the model assumes. A majority of the overage, however, is believed to be a result of renters habits in the apartment projects. The apartments surveyed are typically "all bills paid" type with the electricity and gas billings at a lower rate thru a single project master meter. Informal discussions with utility company personnel indicates that when metered apartments are changed over to master metering a 30% increase in consumption is not unusual. There is little incentive for a renter to conserve energy when energy costs have no visible impact on his rent payments.

Mobile Homes



Mobile Home (±900 sq.ft.)

The final dwelling type considered is the mobile home. Most conditions were assumed to be the same as for the Model residence except a 900 square foot floor area was used (1500 sq. ft. mobile home not realistic). Since the mobile home is smaller, clothes washing and drying were not included and the lighting demand was reduced 25%; 3 occupants were assumed in lieu of 5. Theoretical energy use projections showed the mobile home used less total energy but more energy per square foot than the residential model. The greater exposed surface area of the mobile home accounts for some of the increase in energy consumption and the example is penalized by its smaller floor area.

Analysis of recent utility bills for three mobile homes indicated energy consumption approximately 15% higher than the theoretical projection.

Conclusions

With their 40 to 50 year life expectancy the State's homes represent a long term committment to the patterns of energy consumption described in the preceeding analysis. Although older less weather tight homes are continually being replaced with new well insulated dwellings, our new inventory is typically outfitted with more energy consuming devices. The result is a pattern of continual growth in residential energy consumption.

Significant reductions in energy consumption (up to 30%) were projected for the initially well insulated Model residence. The Model residence is just that, a Model, and not exactly representative of any specific dwelling in our housing inventory. However, it is safe to say that the Model's energy consumption savings can be easily duplicated in new construction; and that we can do half as well (15% savings) in our inventory of existing dwellings with techniques such as higher summer and lower winter temperatures, conservative use of lights and careful selection of appliances, all of which involve minimal capital outlay for the homeowner.

In the short run (next 10 years) conservation is the only viable approach to residential energy savings. A major technological or equipment breakthrough today (e.g. economical solar heaters) would not begin to accomplish a significant reduction in the established residential energy consumption patterns for at least 10 years even if the device could be economically retrofitted to our existing housing inventory. Conservation techniques, therefore, offer the least costly, most effective method of reducing residential energy consumption in the near future.

A unique characteristic of Texas's residential energy use is its growing summer air conditioning peak. Although conservation can significantly reduce overall consumption the techniques described here are not likely to reduce the residential sector's peak demand. On the season's 100° days air conditioners will be on. Peak demand is the fly in the ointment of conservation strategies. If the residential sector reduces consumption by 15% or 20% and requires the same peak capacity, utilities are forced to build and operate plants to meet the peak. Actual fuel costs are a small portion of total utility costs and a 20% reduction in consumption can easily result in a 20% or 25% increase in utility rates. To accomplish energy savings without reciprocal cost increases the residential sector will require new equipment which can draw power for cooling in off peak hours. This equipment implies a costly storage system and could probably be encouraged by reduced summer night rates (midnight to 8 a.m.) or by establishing peak demand charges for residential consumers.

Findings

1. Public education is the appropriate beginning point for residential conservation efforts. An energy budget or energy use goal should be established based on consumption rates for the best of the preceeding example residences. The budget would show expected monthly utility bills per square foot of residence so that the homeowner could establish his goals based on the size of his home and appliance mix. Monthly utility bills would then become a constant basis for evaluation and improvement.

2. Beyond education utility rates could be used as a stimulant for conservation. A surcharge for consumption above the anticipated monthly level appropriate to the dewelling would probably be effective.

3. Energy consumption estimates should be provided to purchasers of new homes by builders. A standard basis of comparison is required, adaptable to degree day and cooling hour data. This would permit comparative shopping by home buyers seeking an energy efficient dwelling.

4. Equipment and appliances that utilize electric resistance heating or gas cooling currently waste primary fuel. Equipment efficiencies in terms of primary fuel consumption should be provided by manufactures.

5. Off peak or demand charge residential rates should be established to encourage peak reducing energy storage systems.

References

1. Exploring Energy Choices Preliminary Report: Ford Foundation, 1974.

2. Ibid.

3. Handbook of Air Conditioning, Heating and Ventilating, Clifford Strock, Industrial Press, New York, 1959.

4. Estimate by Texas Utility Companies (see Section 2).

5. Energy Savings in Residential Buildings, Lorne Nelson and James Tobias, ASHARE Journal, February 1974.

6. National Warm Air Heating and Air Conditioning Association.

7. Americal Society of Heating, Refrigeration and Air Conditioning Engineers.

3.3 Commercial Buildings

The commercial sector may be thought of as a catch-all classification between residential and industrial users of energy. In general, utility companies within the state tend to classify non-residential users of energy which do not manufacture a product as commercial customers. Some of the energy use reported by utility companies as commercial may actually be consumed in small industrial operations. The bulk of commercial energy reported by utilities serving the state is consumed in master metered apartments, stores or mercantile buildings, banks and office buildings. Commercial buildings use energy primarily for lighting, cooling, heating and miscellaneous uses (business machines, elevators, water heating, etc.). This evaluation of commercial energy use will focus in general on these various energy consuming activities, followed by an analysis of energy use in two distinct variations of commercial buildings. Opportunities for energy reduction in commercial buildings will also be illustrated.

Air conditioning load can be divided into two very distinct components, the internal load and external load. Internal load is the requirement for cooling which is created by internal heat sources such as lights, people, and equipment within the building which give off heat. External loads are created by heat transmission and solar gain through the building envelope plus the requirement to temper outside air required for ventilation and air leakage. Generally, internal load creates the need for most of the energy consumed in a commercial building. It is not uncommon to find the cooling system of a commercial building operating at more than 50% capacity on the coldest day of the winter. External loads obviously vary with the types of building envelope. Masonary or concrete and glass generally are used to enclose the building. The ratio of each will dictate the nature of the external gain. Clear unshaded glass allows more heat to enter the building than any other component because of direct sun rays entering the building. Reflective or shaded glass greatly reduce the heat gain from direct solar radiation. Glass, however, is not a good insulation. A square foot of glass will transmit 3 to 4 times more heat into a building than will a masonary section of the same area.

Energy use for ventilation is determined by the volume of ventilation required and the difference between inside and outside temperature. The volume of outside air is primarily a function of the need for odor and humidity control. The volume required for oxygen replacement is much less than normally introduced for odor and humidity control.

Energy for lighting is typically the largest electrical input into the commercial building. Lighting not only consumes energy directly but also requires additional energy input to remove the heat produced by lights.

The energy required to heat a commercial building is a function of its envelope or skin design and the difference between inside and outside temperature. The requirement for heating occurs at the perimeter of the building. It is common to simultaneously experience the need for heating on the perimeter as a result of low outside temperatures and the need for cooling on the interior as a result of internal heat gains.

Along with the use of energy for heating, cooling and lighting, commercial buildings also require energy for miscellaneous uses such as business machines, elevators and water heating. These uses are not considered major in most buildings.

Existing Buildings

Unlike residential buildings, which have a high degree of uniformity in construction, commercial buildings are quite varied in construction and use. The more obvious variations include shape, height, percent of exterior glass, insulation, type of environmental or comfort control system, lighting level and occupancy. All these variations have impact on the energy use in the building.

Existing commercial buildings were built in an era of unlimited energy availability. Because it was readily available and relatively in low cost, energy has been used as a substitute in buildings. The use of energy has been a substitute for materials, time, convenience, capital, labor. Many existing commercial buildings are committed to high levels of energy use because of design decisions made long ago. Yet in most buildings significant energy savings can be made.

THE REDUCTION OF ENERGY USE IN EXISTING AND FUTURE BUILDINGS IS NOT A TECHNOLOGICAL PROBLEM. Major reduction can be made through the application of the existing body of knowledge of building and environmental design. The problem is one of incomplete knowledge of and general indifference to the need for conservation. Reduction of energy use in buildings, both existing and new construction, can be accomplished when the users are willing to reverse past trends. Reducing the demand for energy in existing buildings can be accomplished by a variety of actions which can be categorized as either "belt tightening" or "leak plugging".

Belt tightening measures are actions taken by the consumer, either voluntarily or involuntarily, to reduce his energy demand at the consequence of some real or imagined amenity. Simple examples are raising and lowering thermostats and humidstats, reducing lighting levels, turning off buildings when unoccupied, etc. These actions will usually be accepted on a short term basis only when the consumer is convinced a shortage exists.

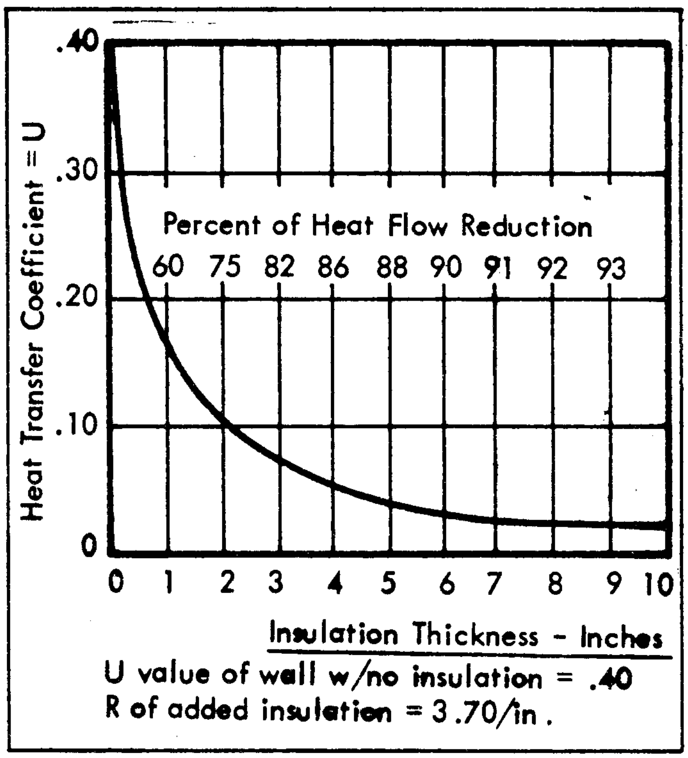
Leak plugging measures are those undertaken to reduce or eliminate unnecessary waste by adding insulation, using efficient lighting, etc. In existing buildings, leak plugging actions generally require expenditure of additional capital. Building owners will make these investments if the cost of living with the waste is greater than the cost of the leak plugging modification. Currently, when investment capital is limited, the building owner will pass on the expense of energy waste through increased cost of his goods or services.

Both "leak plugging" and "belt tightening" may be induced by higher prices for energy. In the commercial sector, it is more likely that higher cost energy will simply be viewed as increased cost of doing business to be passed on with little attempt to conserve. Conservation may be encouraged or required by a variety of policies such as public information and education programs, minimum performance standards and energy budgeting, or rationing. The degree of governmental involvement should be determined by the severity of energy shortages.

Insulation

Improved insulation is probably thought of as the most important treatment to reduce energy consumption. However, the following graph indicates that added insulation has a diminishing effect in reducing heat flow into or out of a building.

Effect of Insulation Thickness



If a building wall or roof section already has the equivalent of two inches of insulation (with R = 3.70/in.) the addition of two more inches only reduces the heat flow by 11 percent. Adding 2 more inches for a total of 6 inches only reduces the heat flow by an additional 4 percent. If the external transmission load is not the primary energy use, little can be gained by adding more insulation. More can be accomplished by concentrating on those buildings which have little or no insulation.

All buildings will not respond to the addition of insulation in the same way. A single story building may expose as much as 6 times more exterior surface area per square foot of floor space than a 20 story building. Energy consumption in a single story building will be more sensitive to insulation than in a high rise building.

Shading

Exterior glass shading can significantly reduce energy loads in any building which allows direct sunlight into the building. Reflective plastic films have been developed which can be added to glass in existing buildings. Currently, extensive glass is used in high rise buildings. Glass shading is essential to reduce energy use in those buildings.

Lighting

REDUCTION OF LIGHTING IN EXISTING BUILDINGS OFFERS THE GREATEST POTENTIAL FOR CONSERVATION. LIGHTING IS ESTIMATED BY THIS STUDY TO BE 45.4% OF THE DEMAND FOR ENERGY IN COMMERCIAL BUILDINGS OF TEXAS. The heat added by lighting systems increases the air conditioning load. Energy required to remove heat from lights could increase the energy demand of lighting systems to 60% of the commercial demand. In the analysis of one high rise office building I.A. Naman[1] illustrates the source of energy demand for various building requirements as follows:

Energy Demand

	% Cooling Load	% Total Energy Input
Glass	26	10
Walls & Roof	3	1
People	7	3
Lights & Power	44	71
Fan Motor	6	10
Outside Air	14	5
TOTAL	100	100

The problem of reducing lighting in existing buildings is complex. Uniform, rather intense lighting has become standard in most commercial space. Office space is flexible when uniform lighting is installed. This allows work station movement without lighting modification. Merchandising establishments use high lighting levels to display their goods. The current cost of energy to support high uniform light levels is insignificant when compared to the problems associated with reducing lighting levels. At recent energy rates, four watts of lighting energy per square foot of building space cost approximately 20¢ per square foot per year. The same space may rent for $5.00 to $8.00 per square foot per year. Reducing lighting energy, at the risk of tenant or employee dissatisfaction, may not be an attractive alternative to the building owner. Yet reduction in lighting energy is the key to energy reduction in most commercial buildings.

THERE IS NO CODE FOR LIGHTING IN TEXAS. Designers rely on experience or the recommendations of the Illumination Engineers Society (IES) as design guidelines. IES publishes guidelines for both illumination levels and design practice for lighting systems. IES guidelines do not advocate uniform lighting. IES design guidelines are presented for task lighting.

In an attempt to conserve energy in federal buildings various federal agencies have undertaken recent lighting studies to provide better design guidelines for their buildings. The most comprehensive lighting study was accomplished by Ross and Baruzzini [2] consulting engineers for the General Services Administration. This study indicates that a lighting input of 2.3 watts per square foot of rentable space and 2 watts per square foot of total space is sufficient to provide adequate lighting for office buildings. To accomplish this, designers must carefully design the lighting for each work station. This requires a point-by-point design consideration for each task center in a building. Ross and Baruzzini suggest a 35 percent reduction in lighting energy can be accomplished by this procedure.

High lighting levels are often promoted as a compliment to the heating system. Heat from lights can reduce the heating input for a limited part of the heating season. During the remainder of the year the heat from lights must be removed. Lighting systems should accomplish the required lighting task with as little energy input as possible. In most of Texas, commercial buildings experience many more hours of air conditioning than heating.

Ventilation

Outside air is introduced into a building to replace exhausted ventilation air. In general, the purpose of ventilation is to remove moisture, smoke, odors, dust, etc., from the building. The quantity of air removed is a function of the presence of those undesirable elements which must be removed. Restaurants, auditoriums, meeting rooms, and hospitals are examples of buildings which require large volumes of air for ventilation purposes. Outside air brought into the space must be tempered before introduction into the conditioned space for obvious comfort reasons. Air removed via the ventilation system is at indoor conditions. This exchange of air imposes a considerable demand for energy in those buildings which require large volumes of ventilation air.

Alternative processes are available to reduce air contamination and recirculate treated inside air. Heat exchanges which allow partial exchange of heat between indoor and outside air without blending of the two air streams are also available. The use of heat exchangers or recirculated air clean-up is not extensively practiced for two primary reasons. (1) The past and present costs of energy to exchange indoor and outside air is generally less expensive than the cost associated with installing, operating and maintaining air clean-up or heat exchange devices. (2) Most buildings are designed to meet a first cost budget and any unnecessary system which adds to the first cost of the building will not be considered unless its presence greatly decreases future operating cost. This trend will be reversed by increased energy cost or regulations which require conserving alternatives rather than air flushing to remove smoke, moisture, dust, etc.

The addition of ventilation energy conservation apparatus may be difficult in existing buildings. Extensive duct modifications would be required for many systems. Most existing buildings could reduce ventilation requirements by reducing the source of contaminants and operating the ventilation system only during occupied hours.

Improved Building Operating

Many systems waste energy providing service to buildings which are unoccupied. Air conditioning and heating systems in many buildings use as much energy to move air and water around the building as is expended to operate chillers or boilers. One building reviewed in this study had 2,500 horsepower of pumps and fans to move air and water to accomplish heating and air conditioning. These systems generally operate continuously to provide air and water circulation even after the building control temperature is attained. During unoccupied hours of the evening and weekends these systems continue to function and require large energy inputs. If commercial building mechanical systems could be turned off in late afternoon and on weekends considerable energy could be saved. In a computer simulation of a model high rise office building, Slater and Norris[3] learned that 14 percent of the annual energy demand could be eliminated by this measure. The primary consequence of this procedure would be the reduced utilization of the building by the occasional late night or weekend user of the building. These consequences must be weighed in the interest of significant energy demand reductions.

This activity will not significantly reduce the chiller or boiler load on a building. The building will experience a temperature gain or decrease during the off cycle which must overcome early in the morning before the building will become occupied again. The savings to be accomplished is in turning off the auxiliary equipment such as fans and pumps. Experiments with several buildings on the Texas A&M University campus reveal the overnight temperature gain to be only a few degrees and is easily overcomed by returning the system to operation in advance of building occupancy. Some difficulty might be experienced during extreme cold weather if the systems were off for extended periods. This could be accommodated by automatic controls which would return the system to operation if a 10 to 15 degree reduction in building temperature occured during an off cycle.

Existing building control systems are not arranged to provide automatic off and on operation. These systems are generally arranged for manual switching because they are so infrequently turned off. This would require operating personnel available to manually turn systems off in the evening and back on early in the morning. With modification these activities could be accomplished by automatic time controls.

Increasing and decreasing thermostat settings in summer and winter also reduce energy requirements in commercial buildings. Energy saving during winter heating is obvious since heating load is directly dependent on the difference between inside and outside temperature. The National Bureau of Standards[4] estimates that a 3% increase in energy demand per degree of thermostat setting above 70°F. For example, if the control setting is 75°F , 15% more energy will be required to heat the building than would be needed if this building were maintained at 70°F. This example applies only to heating cycles and may not apply to buildings with large internal loads. Decreasing the thermostat setting for a building with significant internal heat gains may require added cooling energy input to overcome the internal gain.

Summer air conditioning energy savings may not be so readily accomplished by increased thermostat settings. If a major portion of the load is internal, that load will not decrease if the thermostat setting is raised. The heat gain from lights, people, and other internal gains will go on at the same rate and will simply be removed from the building at a higher temperature. The human body will be more sensitive to humidity in the air if the control temperature is raised. Therefore, more energy may be required for dehumidification to maintain satisfactory comfort conditions at increased thermostat settings. These possibilities must be evaluated on an individual building basis.

All building systems should be examined to determine their operating condition and efficiency. Dirty filters, coils, and fans require more energy than normal operation. Boiler air/fuel ratios can get out of adjustment and cause the boiler to operate inefficiently. Operating schedules for all energy using devices should be reviewed to be sure they are operating only when needed. Obviously, lights should be utilized only when needed.

Building Analysis

The inventory of existing commercial buildings is so diverse as to make accurate projections about consumption rates and possible conservation benefits very hazardous. This study has reviewed energy consumption of many commercial buildings in an attempt to establish representative patterns of consumption for specific type and use buildings. All the buildings reviewed were in the same city and were of modern construction. The following chart indicates type of building, number of buildings reviewed and the annual energy consumption in thousands of btu per square foot of buildings space of the most and least energy intensive building.

Commercial Building Inventory

Type Building	No. of Bldgs. Reviewed	Most Consumptive Bldg. (1000 BTU/sq. ft.)	Least Consumptive Bldg. (1000 BTU/sq. ft.)
Bank	14	940	150
Restaurant	11	910	190
Drug Store	8	380	190
Furniture	7	330	130
Office Building	16	715	170
	56		

As can be seen from the chart there are no typical buildings when considering rate of energy consumption. Shape of building, glass exposure, amount of insulation, hours of operation, heat gain from internal equipment are a few of the possible variations. To eliminate construction variations, energy consumption in a number of identical take-out food service stores were reviewed. Even though buildings were identical, energy consumption varied widely. The most consumptive store used twice as much energy per square foot of building as the least consumptive building.

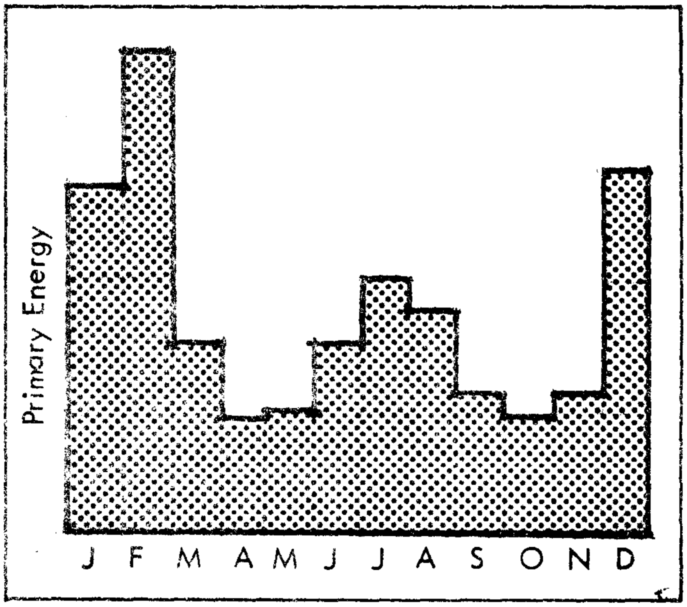
This illustration points out the difficulty in making generalization about energy consumption in commercial buildings. Each building must be reviewed individually to determine its potential for conservation. There are no convenient indices to serve as benchmarks with which to judge all buildings.

Low Rise Buildings

In an attempt to quantify potential conservation benefits an energy audit was made for two distinctfully different building types. The audit process could be carried out for any building. The first building to be analyzed is a single story, well insulated, small bank building with little glass. It is not an energy intensive building but some opportunity for conservation may exist.

The audit should begin with a simple chart which shows monthly primary energy consumption. To simplify the process of determining primary energy input the utility statement for a month can be used. Electric bills are stated in kilowatt-hrs (KWH) and natural gas is billed for thousands of cubic feet (MCF). To reduce those units to thousands of Btu of primary energy, simply multiply KWH by 11 and MCF by 1000. A plot of each months energy input to the building produces the energy use profile shown below.

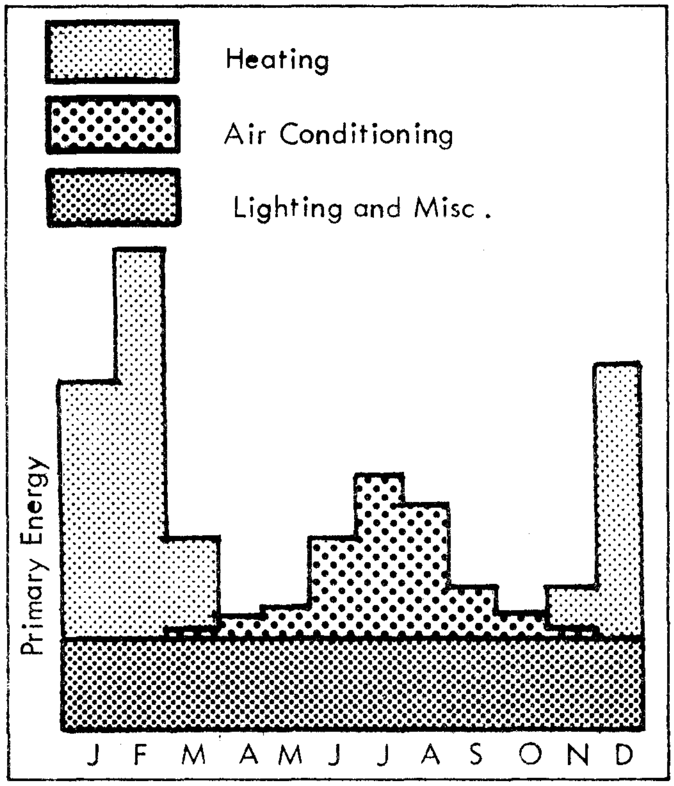
Primary Energy Profile - Low Rise



This profile reveals obvious energy demands for heating in the winter months, cooling in the summer months, and a base requirement for lighting and miscellaneous use. A profile such as this is easy to prepare and can be used as a guide to determine what techniques might be used to reduce energy consumption. A profile with sharp changes in energy demand as seasonal weather patterns are experienced indicate that added insulation to reduce heat flow into and from the building might be in order.

By separating the elements of energy requirements for the building, the profile can be divided into distinct segments of energy use as shown on the following page.

Low Rise Energy Use by Category



Totaling energy use for each function reveals the approximate percentage and total annual consumption.

	% of Total Consumption	Total Consumption (1000 Btu)
Lighting & Misc.	45.7	480,000
Air Conditioning	18.0	190,000
Heating	36.3	380,000
	TOTAL	1,050,000

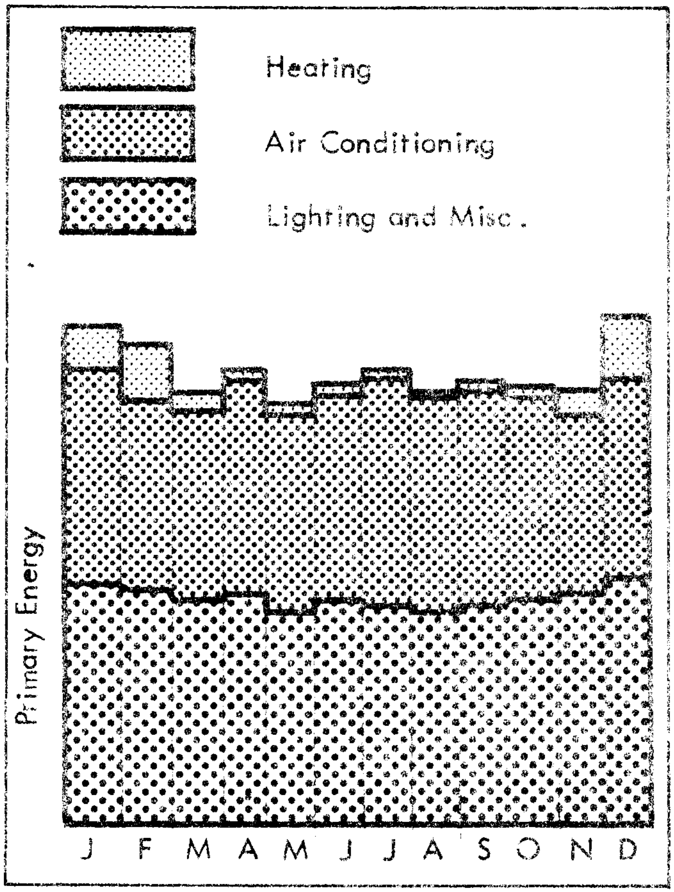
Since the building has a very little exterior glass area, a wall U-factor of .34 and a roof-ceiling U-factor of .04, little benefit could result from added insulation. The sharp peaks in demand for heating and air conditioning is a result of the buildings shape which exposes 1.57 sq. ft. of exterior for each square foot of floor space. Any reduction in energy consumption must be accomplished by reducing the lighting requirements. The building lighting system was designed with 3.5 watts of lighting per square foot of floor space. If that lighting level were reduced to 2 watts per square foot the total energy demand for the building would be reduced by 25%. This savings includes a reduced air conditioning demand as a result of the decreased internal load of the lighting system. Critics of reduced lighting levels point out that the higher lighting level reduces heating requirements and that any savings resulting from reduced lighting would be consumed by increased heating demand. This particular building was analyzed to determine at what outside temperature the lighting internal load would be offset by heat loss through transmission at the walls and roof. That temperature was 51°F. In other words, that portion of the lighted hours of building use when the outside air temperature is below 51°F , added heat would be required it lighting levels were reduced in this building. Therefore, the full 25 percent savings would not result because of increased demand for heat as the lighting levels were decreased. It would be safe to assume a 20% reduction possible by reducing the lighting level.

The annual energy consumption per square foot was 166 thousand Btu. That consumption was among the lowest for bank buildings reviewed during the study. The analysis of this well insulated building does not establish that all buildings of this type can be adequately served with this quantity of energy but does serve as an example of the results of good design and operation.

High Rise Building

The second building analyzed required much more energy per square foot of building than the first example. This building is a high rise office building which does not expose as much exterior surface per square foot of floor space as does the single story building. A typical 20 story building might expose no more than .3 sq. ft. of exterior surface per sq. ft. of floor space. This reduces the impact of external conditions and makes the internal load more predominate in the building's energy use profile shown on the following page.

High Rise Energy Use by Category



Again the elements of energy use have been separated to illustrate possible opportunities for energy savings. It is immediately obvious that this building is dominated by internal load as changes in weather patterns have little influence on the energy use profile. The ever present light and miscellaneous power requirements create a high air conditioning demand throughout the year. If the building is lighted 2600 hours per year, the light and miscellaneous power requirements for the building average 12.3 watts per sq. ft. This is an unusually large power requirement which indicates an excessive lighting or the lighting system is operated too many hours of the day. This increases the annual primary energy consumption to 668 thousand Btu per square foot of floor space. To further determine the nature of energy demand for this building, the load was separated into internal and external influences.

Approximately 85 percent of the building load is created by internal influences. Since the exterior load is such a small percentage of the demand for energy, little benefit could result from expensive double glazing with insulating glass. The exterior glass is well shaded with exterior shading devices to reduce the solar gain.

The internal gain can be reduced by reducing the lighting level, reducing the hours of lighting use, and night shut down or setback of the air conditioning system. If all these modifications were pursued it would be possible to reduce the consumption in this building by 32%. A reduction in lighting by removing 1/3 of the existing fluorescent tubes has been carried out and resulted in a significant energy savings.

New Construction

As stated earlier, significant reductions in energy requirements can be made with current building technology. The degree of reduction will depend on the degree of change in current practice. At present, energy consumption is not the predominate influence in the design of most buildings. Energy consumption levels are the result of other design considerations such as first cost, flexibility, speed of construction, and rentability. Building designers and owners are becoming more sensitive to energy consumption because of increased energy cost and the concern that future energy cost will be much greater.

Extensive energy consumption reductions can be accomplished in future commercial buildings through energy-conscious design. Much has been written concerning specific applications which will save energy in buildings. The purpose of this section is not to assemble a building design manual detailing energy conserving techniques but to discuss what could be done by State government to promote energy conservation in future buildings. It is a foregone conclusion that energy conservation is or will become a high priority state and national program and therefore some positive control influence is required.

An initial reaction to the problem indicates that we should simply develop a set of procedures which can become a design manual with which all buildings could be designed to accomplish the desired savings. Some energy savings concepts are so obvious that many feel a set of building codes would fit all buildings and provide the solution. However, the building standards approach can be very rigid and allows no opportunity for individual professional evaluation of potential conservation measures and how they relate to a particular building and site. Legislated standards for commercial buildings would lead to institutionalization of the present technology and thus discourage innovation.

Another approach would mandate an annual energy consumption rate for each building. The building designer would then have the freedom to incorporate whatever systems were desirable in a particular building provided the annual energy budget was not exceeded. This concept is now being followed by the federal government through the General Service Administration. After extensive analysis and research, GSA is seeking to limit the primary energy requirements for their buildings to no more than 100,000 Btu per square foot per year. When compared to energy requirements of many existing office buildings in Texas, the GSA energy budget seems very optimistic and possibly unattainable. At least, one demonstration building has been designed and its eventual operation will soon test the reasonableness of 100,000 Btu per square foot as a guideline budget for office buildings. Design of the demonstration building was accomplished with extensive use of computer simulation. Energy conservation was the prevailing criteria in all aspects of the design.

Use of an energy budget as a design goal introduces a positive control influence very early in the design of a building. It does not restrict the designer to a limited set of conservation alternatives and therefore should generate new conservation techniques. Unfortunately, there is insufficient knowledge of energy requirements for all types of buildings. The variability of energy requirements because of climatic variation has not been evaluated. Therefore, the present data base is insufficient to establish an energy budget for all commercial buildings in any geographic location.

Both building standards and fixed energy budget systems of control have serious limitations. Codes which are sufficiently comprehensive to accomplish required energy reduction would likely unduly limit the construction industry. Lack of knowledge of energy use in all buildings types and locations prevent the establishment of reasonable design budgets at this time. A blend of these two concepts could provide a workable mechanism to control energy use in future buildings. A set of performance criteria or standards for various energy consuming features of a building can be established. By applying performance criteria to a proposed building, the designer could determine the quantity of energy required to service that building if the building met performance standards. That quantity of energy would become the design budget for the actual building. The designer could incorporate whatever features he felt were desired in the actual building provided he did not excede the energy budget. The designer would make whatever trade-off he felt necessary to stay within the budget and would have the freedom to determine how much glass or what kind of heating and cooling system to use.

Evaluation of energy for the "standard" building could be easily accomplished and would not delay or unduly burden the construction process. This evaluation would simply totalize a system of "energy credits" which reflect the need for energy to service the proposed building and its activities. This system would provide a flexible budget plan which would make allowance for climatic and building use variations.

At present two groups with national scope are working to establish a set of building performance guidelines which could be the basis for energy budget establishment. Those two groups are the National Bureau of Standards (NBS) and the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). NBS prepared a set of standards at the request of the National Conference of States on Building Codes and Standards. ASHRAE prepared its standard because of objections that the NBS standard was too restrictive and inflexible. The resulting standard proposed by ASHRAE is less restrictive and would accomplish a lesser degree of conservation. As written, the ASHRAE standard is a set of legitimate recommendations which can establish an energy budget for any commercial building by establishing performance criteria for the following:

1. Heat transfer rate through building envelope
2. Ventilation rates
3. Lighting System Energy Requirements
4. Heating, ventilation and cooling equipment efficiencies
5. Building and building service operation schedules

It should be emphasized that the standards developed for these basic building functions would be for budget preparation only.

3.4
Modular Integrated Utility Systems

Modular Integrated Utility System (MIUS) is a total energy system which utilizes recycling of waste to reduce the requirement for external utility services. The concept is being developed by NASA and will include the design and testing of a demonstration system to verify the concept.

Under present utility concepts, much heat energy is wasted in the generation and transmission of electric energy (65 to 70% wasted). This heat is rejected to air and water because it is too low in temperature to be utilized by the generation process. When the generation facility can be located near facilities which utilize low temperature heat the waste heat can be used to satisfy that demand. Rejected heat can be used in residential and commercial sectors to provide domestic water heating, comfort heat, and to drive absorption air conditioning systems. Complete utilization of this waste heat increases the utilization of input energy to 65% or greater.

MIUS is an extension of the total energy concept which also collects and recycles waste from the facility served. Solid waste is recycled and used as fuel to reduce the need for heat input to the generation cycle. This also reduces the waste disposal requirements of the facility. Water waste is recycled to serve functions which do not require potable water. A MIUS system would integrate all utility systems into a single function which would provide electric power, heat, water, and waste collection into an operation which would more completely utilize energy and material inputs than do individual utility functions under present service.

MIUS will most likely experience the same difficulties which have limited total energy systems. To accomplish the expected or designed utilization of input energy there must be a balance of electric demand, which produces waste heat, and a use or demand for low temperature heat. Many total energy systems do not experience simultaneous demands for electric energy and low temperature heat. If excess electric energy is demanded, the accompanying heat must be rejected. Periodically more heat will be demanded than is produced by electric generation.

Another problem is the requirement to install a generation system which is capable of meeting the peak demand of the facility being serviced. This often increases the first cost of the system to a prohibitive level.

Both these problems could be solved if the MIUS system were integrated one step further and made a part of the electric utility. During periods when the served facility required more heat than would be produced by the on-site generation plant, excess electric energy could be produced and the excess allowed to flow into the electric utilities distribution system. This would allow more complete utilization of the input energy. During periods of reduced heat demand the MIUS system could accept part of the required electric energy from normal electric distribution since no use could be made of waste heat.

MIUS systems could also be sized to meet the normal demand with on-site generation and take its peak demand from the electric utility system if the two were integrated. This would reduce the initial investment of the MIUS system and yet provide reliable service to the facility being served by MIUS.

NASA reports energy reductions of 33%, reduced water requirements of 9%, reduced liquid waste treatment requirements of 48%, and reduced solid waste of 74% through the use of a MIUS as compared to normal utility services.

Conclusion

The MIUS concept should be encouraged in residential and commercial facilities which have sufficient utility requirements to warrant their use. The MIUS should be connected to the area electric utility to allow thermal balance and reduced first cost.

4
Conservation Potential from Implementing Planning Concepts

Introduction

This report concerns some of the primary energy uses in our urban systems and describes various energy flows that have been most important to community development. It looks at the manner in which these energies affect community (neighborhood) form and development within the urban system. It also discusses some of the broad effects of transportation modes on community patterns, relative efficiencies of energy use, and the way urban community patterning might be arranged to provide for better use of available energy resources.

With the energy crisis becoming more of a reality, many of our institutions and professions are trying to develop survival programs for the future. Within the professions of architecture and planning, efforts are being made to find new methods of analysis and design that might respond to these highly complex questions. We are quickly realizing that we now need the full cooperation of our institutions and professions in order to become better prepared for the future. We are going to have to know much more about our society - the interactions of its institutions, industrial and social systems - so that we have enough control on future development to prevent chaos and to provide for quality growth.

One of the methodologies that has been developed in the study of complex organisms is the Systems approach. It is becoming a popular approach among problem solvers because the historic techniques of analyzing isolated events or situations is evidently not adequate to solving complex urban problems. We are living in a complex social structure with many integrated and overlapping subsystems. Whereas in the past there was a lag time between decisions and good or bad feedback by their effect, today the lag time is dangerously short. The Systems approach attempts to identify and define a set of interrelated parts of a system and the means by which they are connected. It is an effort to study behaviors through time, rather than to calculate isolated events disconnected from their changes in time. Linear approaches to problems often cause us to study the symptoms rather than the causes. The Systems approach has an advantage in that it tends to study causalities and works in the effort to identify universal principles which govern the behaviors of all natural and manmade systems. Its adoption to architectural planning problems has been very useful. One asset is that it allows us to more adequately comprehend our awareness of the natural world and how we might allow both systems to survive together in a better way.

Prior sections of this report dealt with the economic aspects and impact of energy supply and demand as affected by varying densities of population, increasing community amenities and services, and the institution of mass transit alternatives. It is necessary to study the problems of structure, population densities, and the costs of transportation from this energetic approach because it gives us a more accurate perspective of future urban development.

The conclusion of the study suggests that while increasing densities of people and structure on one hand gives us energy savings in construction and utility costs per person, the total fossil fuel costs of an urban system that tends to increase its densities incurs a correspondingly higher energy drain. If the efficiency of Rapid Transit Systems seems worthwhile from the viewpoint of the number of people moved, it may cost more in total fossil fuel use than before the transportation problem was solved by a more expedient solution. The question of which alternative transportation community pattern cities should try to achieve during the depletion of fossil fuels should depend on total energy budget studies similar to those studies presented in this report.

Methodology

The following is a summary of the procedure that was followed during the development of this phase of the project.

1. Investigation of existing and available research work that suggests potential solutions to the energy use questions of community density and the corresponding transportation modes.
2. Development of energy models of an example urban system that defines the type of information required for computation of total energy budgets of alternative urban configurations. The case study presented in this report is for Houston, Texas and similar city types.
3. Analysis of an energy model of the analog computer that suggests the energy use levels of alternative density-transit mode configurations and which of these configurations would be most efficient in terms of total fossil fuel use.
4. Development of graphs which display the energy use interrelationships of the various hypothetical city systems that were suggested by analysis on the analog computer.

The investigation of available research material that would suggest energy conservation patterns in urban systems did not produce adequate information for confirmation of urban density levels. Therefore, a methodology was developed to tentatively explore the potential of a solution through a systems approach as suggested by the work of Dr. H.T. Odum, Department of Environmental Engineering, at the University of Florida. Dr. Odum has developed a systems language called Energese which is useful in investigating the behavior of energy movements in various natural and manmade systems. (See Environment, Power, and Society in Bibliography)

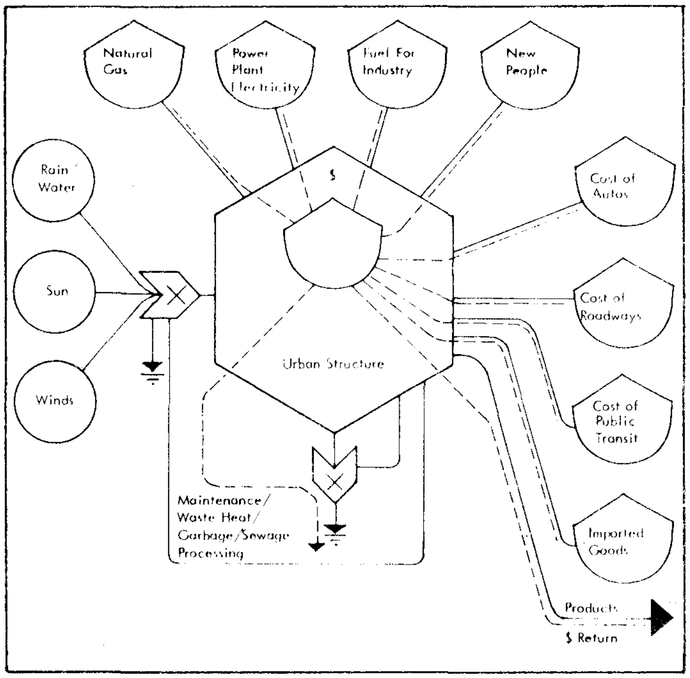
This language has an advantage over many other analysis tools because each module represents energy manipulations of corresponding real systems parts that are defined by the laws of thermodynamics. Therefore these Energese diagrams can be interpreted by specialists in diverse science disciplines. Since all systems through which energy flows, whatever the form, follow the energy laws of thermodynamics, a system can be diagrammed through various levels of complexity and still express the same behavior. This is one method by which generalized principles and environmental concepts can be developed.

The Energese symbols are reproduced in this report. It is hoped that the reader will quickly review the explanation of each symbol so that the energy models developed for this study will be understood. The lines between the symbols represent real or equivalent energy flows between the component parts of the system represented by the symbols. It is a process to define the influences between various parts of a system and, with correlative evidence, to determine the principles of behavior of urban growth.

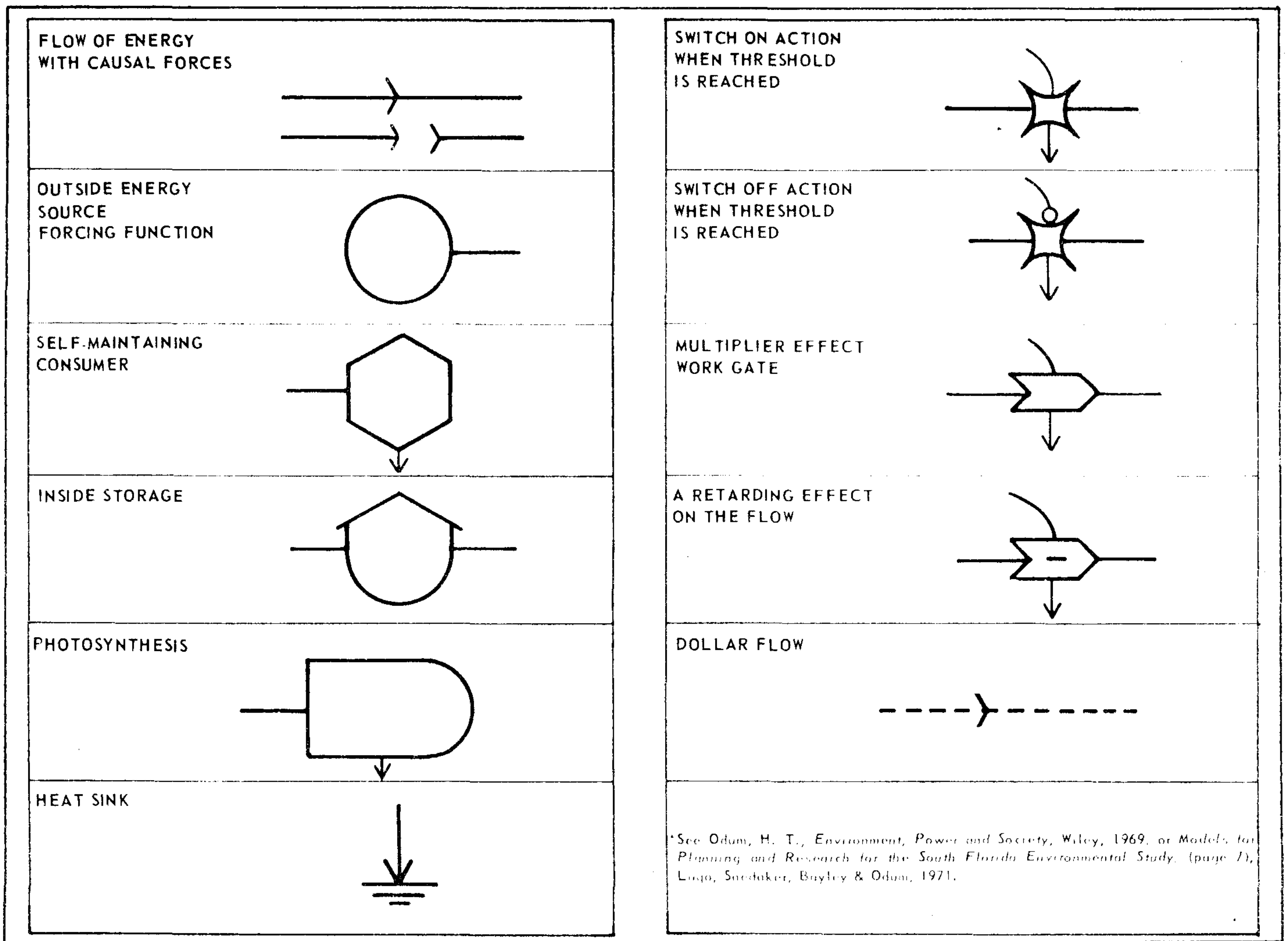
As in natural systems, all the component parts of the urban system are in balance with each other (that is, in Diagram No. 1, all the in-flows minus the out-flows should be approximately 0). If one in-flow changes it will affect a number of interconnecting flows either directly or indirectly. With energy diagrams it is possible to estimate and define the energy flows in urban systems and to evaluate on the analog computer the accuracy of the energy model. If the analog machine produces curves of the energy flows through time that matches with the historical behavior of the real system, then the model can be considered as verified and used to forecast energy uses in all major parts of the urban systems. While good progress has been made in some behavioral sciences as in ecology, very little has yet been made in urban science. The effort of this project, then, was to investigate the method by which accurate maximum density values might be calculated and to give an estimate of the relative total energy costs of existing and alternative city configurations.

The Energese diagram (right) shows city size, or the amount of urban structure, as a function of the pathways listed. If we want to know what cities cost, we can total these major cost requirements. If we want to know the energy cost, we can translate the material or dollar values to equivalent units in BTU's. Energy Diagram No.1 shows the primary energy and material in-flows and out-flows of an urban system. The <u>in</u> values should approximately equal the <u>out</u> values.

Energy Diagram No. 1

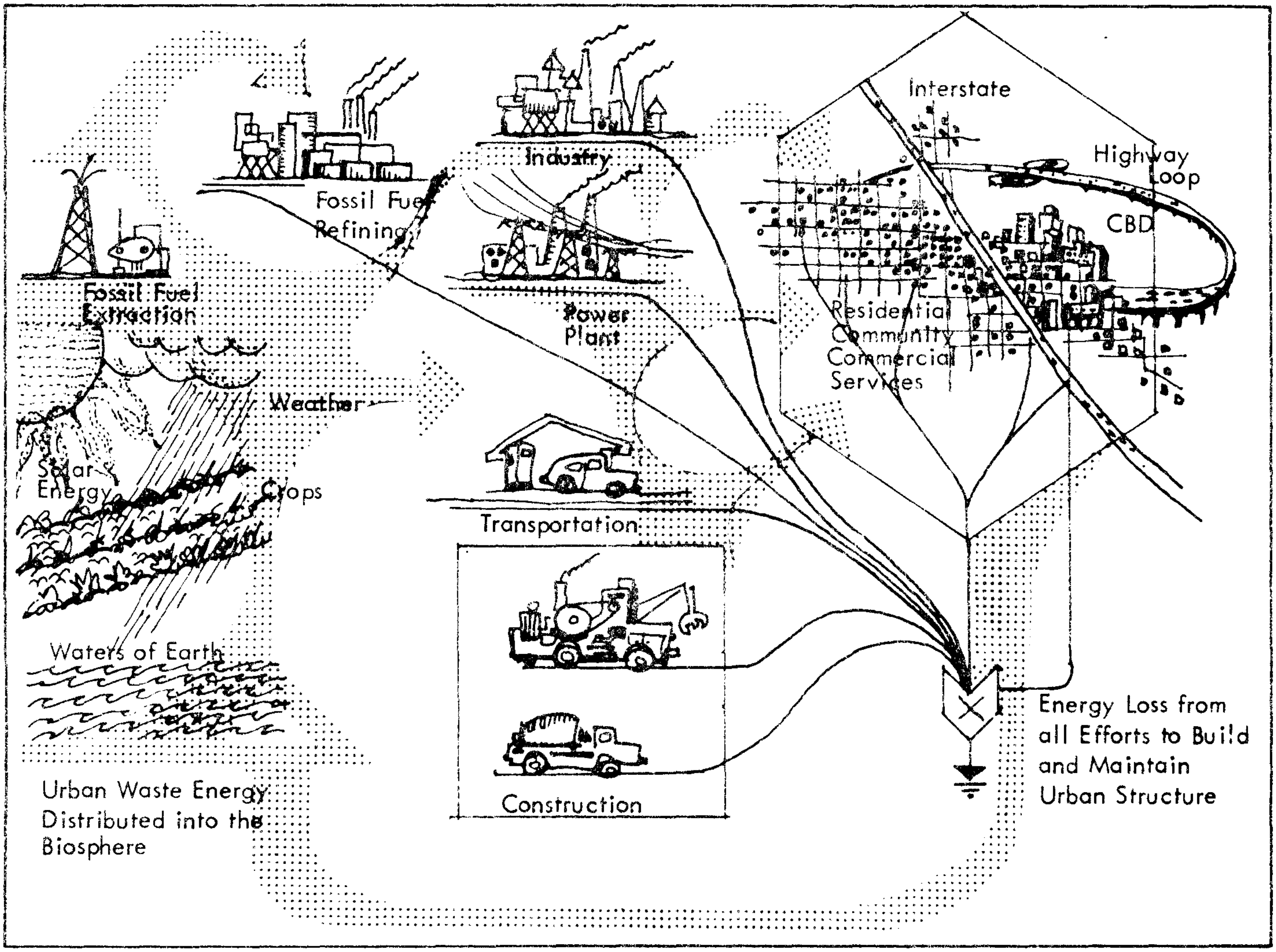


Symbols for Energy Network Diagram



*See Odum, H. T., *Environment, Power and Society*, Wiley, 1969, or *Models for Planning and Research for the South Florida Environmental Study*, (page 7), Lugo, Snedaker, Bayley & Odum, 1971.

Primary Energy Flows to and From a City System

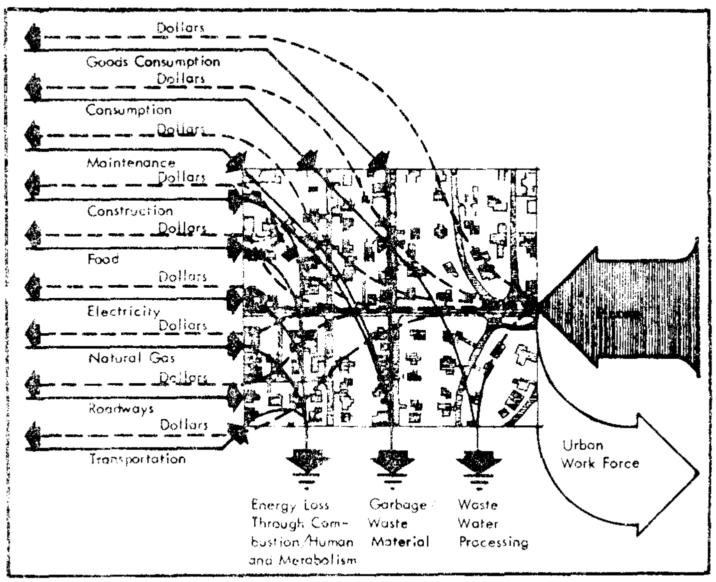


The pictorial diagram (above) shows the primary energy flows to and from a city system. These components and flows are represented by the symbols and flow lines in Energy Model No.1.

Urban systems are often analogous to natural systems and have living parts and material parts that interchange energy for the greatest survival value of the total system. Our cities provide the material fabric (or matrix) by which people are able to contract in density. They are the means by which we are able to concentrate power and provide a higher quality of life as defined by the total amount of urban material goods, the levels of information, and the diversity of choice.

The Community Energy Budget Diagram (right) shows the inputs and outputs of a typical urban community. The balance of these values determine the density and physical qualities of the community environment.

Community Energy Budget Diagram



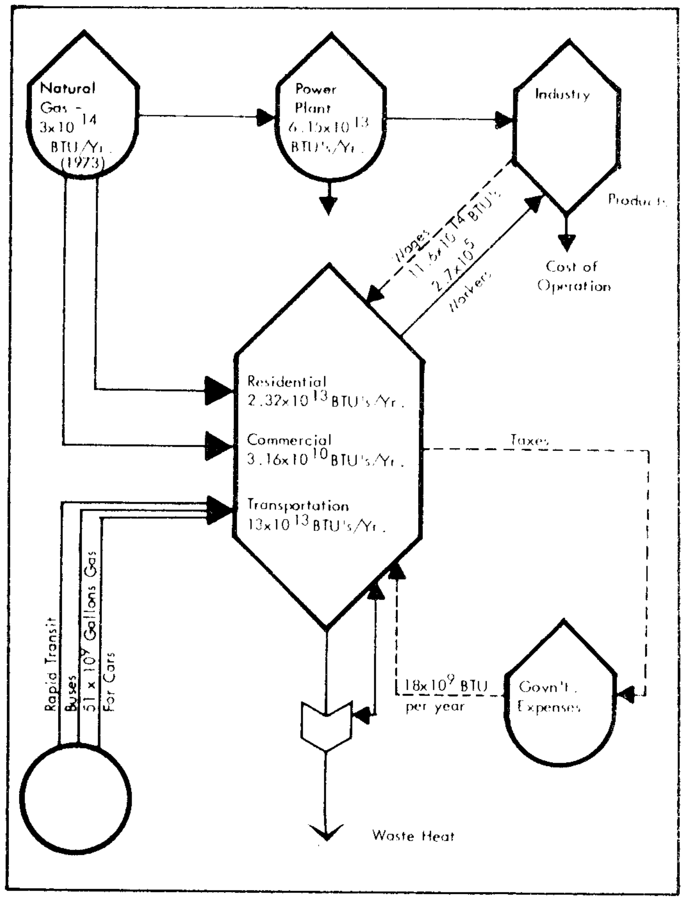
Explanation of Research Development

The following material is a description of the development of this research project:

- Investigation was made of the total energy flows affecting urban growth. This was to determine the major energy in the urban system. The energy model below right shows basic relationships between available power, land available for development, and the growth of urban structure. Simulation of this model on the analog computer would suggest maximum levels of urban structure determined by available fuel. This model was not run on the analog computer since proper data concerning the industrial output of the study case city of Houston could not be obtained.

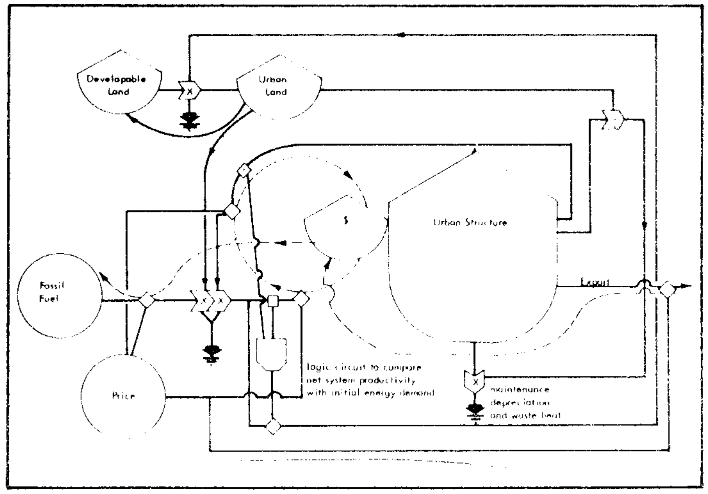
The Energese diagram of the Houston Energy Budget (right) shows the information obtained for this phase. Accurate data could not be obtained for the output of Houston Industry and therefore the total energy budget and the level of efficiency could not be determined.

Energy Diagram - Houston Energy Budget



This energy model (right) describes the basic assumptions about the macro-scale functioning of the industrial city system. Fossil fuel is drawn from the earth relationship to the amount of urban structure already existing. Its growth creates a greater demand on the primary fuel flows, and adds developable land to the urban land area causing further growth. In this model the land transaction is activated by a comparator when the net urban system production begins to equal the gross energy input. Money accumulates and flows more quickly with corresponding energy demand increases, but in the reverse direction. The price function is drawn in the model as a way of changing the money value per amount of fossil fuel (GNP) to adjust to increasing inflation values.

Energy Model No. 2 Showing Maximum Structure Levels w/Available Fuel



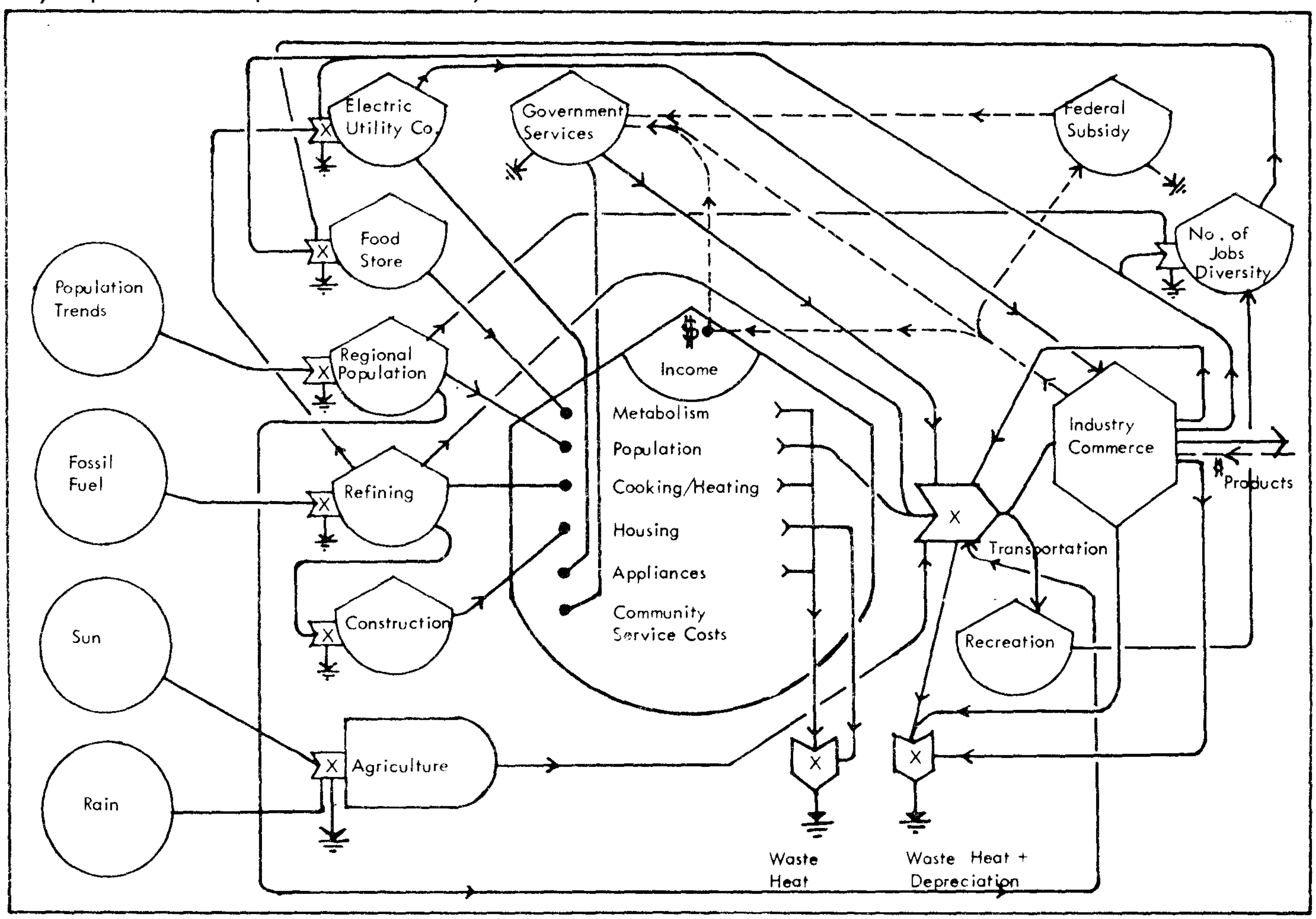
Metabolism Studies

This study was an effort to determine the amount of total energies required for typical residential functioning. It was also to assess the energy implications of increasing multi-family structures versus the single family residential community.

This study centered on the question "What is the energy cost of increasing residential density?" Therefore, the Residential Metabolism Model was developed to aid in the identification of all major resources used by community areas for survival and growth. It is an Energese diagram that expresses the parts of the city structure that contribute materials and energy to a residential community. The lines between components represent the flows of goods, energy, materials, people, food, etc., the exchanges between these various parts of the community system. Real information numbers are put with each component and flow, and then the numbers are converted to equivalent BTU energy units so that they may be totaled as individual parts or compared with other energy studies.

- Energy Model No. 2 was developed in order to identify the major energy flows affecting urban community growth, from which maximum community densities may be determined. This energy model is expressed pictorially at a smaller scale in the Community Energy Budget Diagram. This analysis of community energy flows led to the investigation of several community types represented in Houston, Texas, which are described in the following community metabolism studies.

Energy Model No. 2 - Energy Diagram to Identify Inputs and Outputs of Community Metabolism

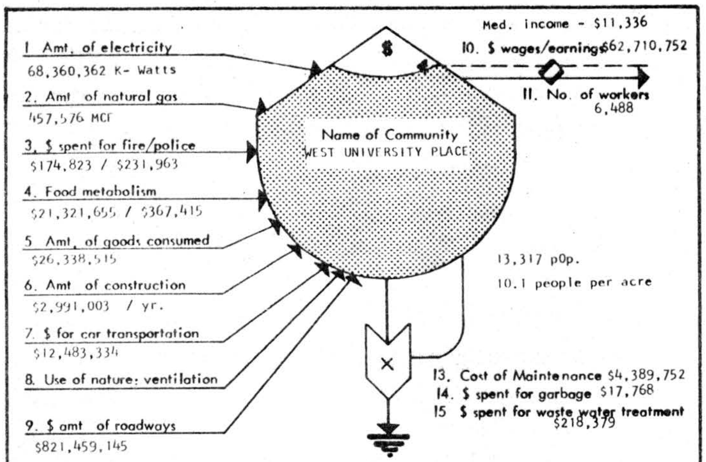


The energy model provided a conceptual base for further development of the study. The components defined in the energy model, with flow arrows going to the listed residential functions, are translated to the metabolism data sheets. Six residential communities in the city of Houston were selected as study areas because they offered varying densities, populations, incomes, and distances from the city core area. This would allow an adequate breadth of information for graphical analysis in the search for correlations between the variables of energy in-flows. Also, these communities were incorporated and therefore kept some records of services and expenditures during the year.

The storage tank in the middle of the energy model describes the primary energy uses in a typical urban community. The items are listed with the inputs on the left and the outputs on the right. The circles describe the energy sources necessary for survival of the system. The effort of this model was to define major community uses of energy and the major sources of this energy from the parent city system. The interaction of these forces determine the density and quality of the urban environment.

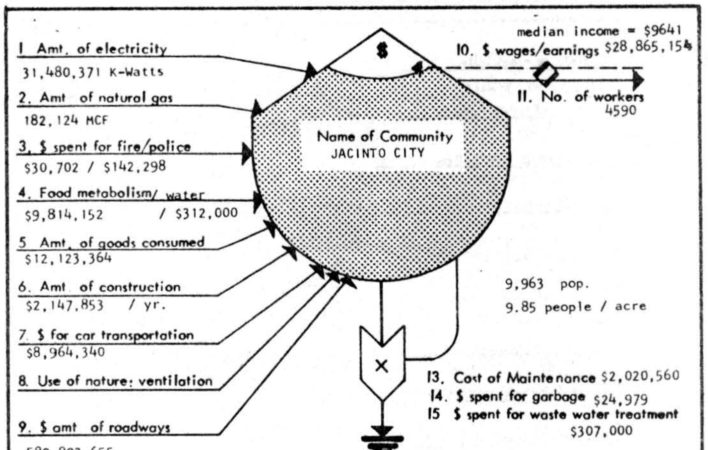
The community examples are represented in Energese symbols with all major energy, materials, and goods defined as inflows and outflows or drains. Below these diagrams are the data sheets with the dollar value translated to equivalent units in BTU's. This is done by multiplying the dollars by the ration of the national BTU per dollar of GNP. This was taken as 9.4×10^4 BTU per dollar. (It was 9.36 BTU per dollar of GNP in 1970.) In each case the total energy cost of operating each community is given as the total energy input in BTU's income is subtracted from the total energy output in BTU's, which is the total amount of expenditures. In each case the amount is negative which suggests that the amount of energy input (services) required from the parent city system is beyond the services directly paid for.

Metabolism Diagram/Data Sheet



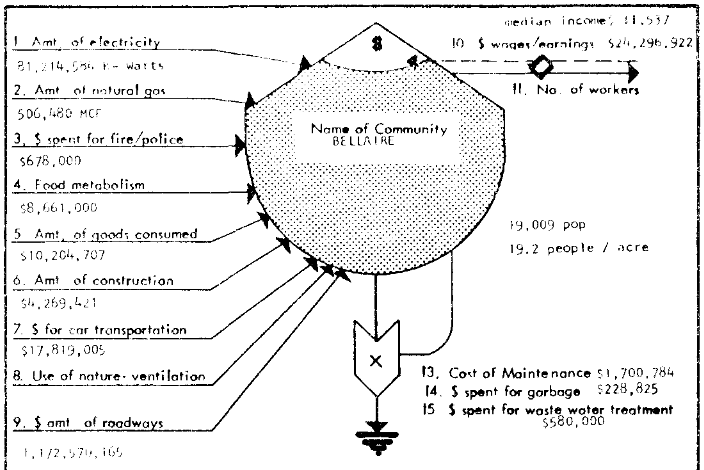
symbol	actual value	equivalent in BTU's	source of information
1	$2,365,254	233,450,636,230	Houston Lighting and Power Co.
2	$72,040	1,808,600,790	Houston Natural Gas and United
3	$406,786	40,149,778,200	City Budget - Fiscal Yr. 1973/1974
4	$21,689,070	2,140,711,209,000	Average amt. spent - see chart
5	$26,338,515	2,599,611,430,500	Average amt. spent - see chart
6	$2,991,003	295,211,996,100	Dodge Construction Report
7	$12,483,334	1,232,105,065,800	Average of 1.4 cars / person + maint.
8			
9	$8322	821,459,145	
10	$62,710,752	6,189,551,222,400	Census Data - median income
11			
12			
13	$4,389,752	433,268,522,400	City Budget - Fiscal Yr. 1973/1974
14	$17,768	1,753,701,600	City Budget - Fiscal Yr. 1973/1974
15	$218,379	21,554,007,300	City Budget - Fiscal Yr, 1973/1974
TOTAL ENERGY COST	6.99×10^{12} BTU/Yr. $- 6.189 \times 10^{12} = 8.01 \times 10^{11}$ BTU/Yr.		

Metabolism Diagram/Data Sheet



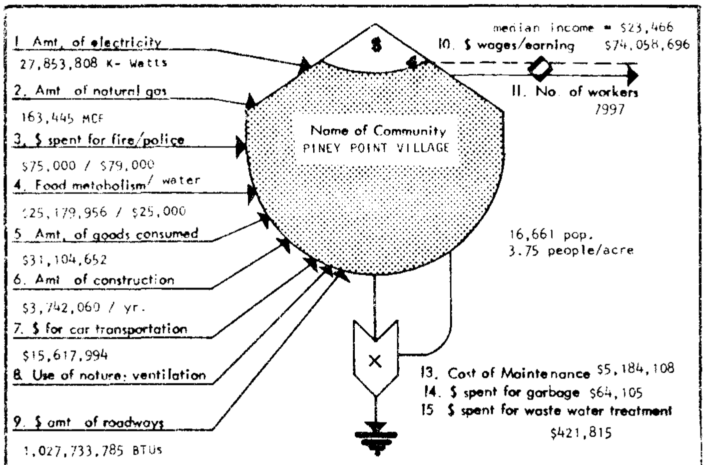
symbol	actual value	equivalent in BTU's	source of information
1	$1,089,210	107,505,125,465	Houston Lighting and Power Co.
2	$72,930	719,851,707	Houston Natural Gas and United
3	$173,000	4.325×10^9	City Budget - Fiscal Yr. 1973/1974
4	$10,299,152	1,016,526,302,400	Average amt. spent - see chart
5	$12,123,364	1,196,516,026,800	Average amt. spent - see chart
6	$ 2,147,853	211,993,091,100	Dodge Construction Report
7	$8,964,340	884,780,358,000	Average of 1.4 cars / person + maint.
8			
9	$5,976	589,893,655	
10	$28,865,514	2,849,026,527,900	Census Data - median income
11			
12			
13	$2,020,560	199,429,272,000	City Budget - Fiscal Yr. 1973/1974
14	$24,979	2,465,427,300	City Budget - Fiscal Yr. 1973/1974
15	$307,000	30,300,900,000	City Budget - Fiscal Yr. 1973/1974
TOTAL ENERGY COST	3.65×10^{12} BTU/Yr. $- 2.85 \times 10^{12}$ BTU/ Yr. $= 8 \times 10^{11}$ BTU/		

Metabolism Diagram/Data Sheet



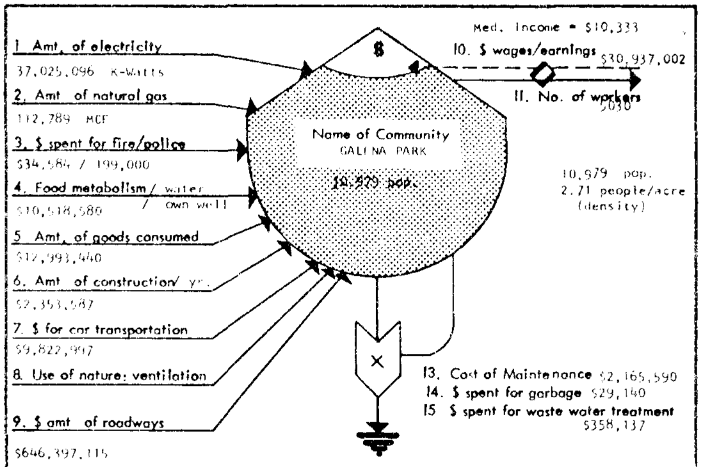
symbol	actual value	equivalent in BTU's	source of information
1	$2,806,484	277,000,000,000	Houston Lighting And Power Co.
2	$55,840	544,000,000	Houston Natural Gas AND United
3	$678,000	66,918,600,000	City Budget - Fiscal YR. 1973/1974
4	$8,661,000	854,840,700,000	Average amt. spent - see chart
5	$10,204,707	1,007,204,580,900	Average amt. spent - see chart
6	$4,269,421	421,391,852,700	Dodge Construction Report
7	$17,819,005	1,768,567,093,500	Average of 1.4 cars / person + maint.
8			
9	$11,380	1,172,570,165	
10	$24,296,922	2,398,106,201,400	Census Data - median income
11			
12			
13	$1,700,784	167,867,380,800	City Budget - Fiscal Yr. 1973/1974
14	$228,825	22,585,027,500	City Budget - Fiscal Yr. 1973/1974
15	$580,000	57,246,000,000	City Budget -Fiscal Yr. 1973/1974
TOTAL ENERGY COST	4.65×10^{12} BTUs - 2.40×10^{12} BTUs = 2.25×10^{12} Btu/Y		

Metabolism Diagram/Data Sheet



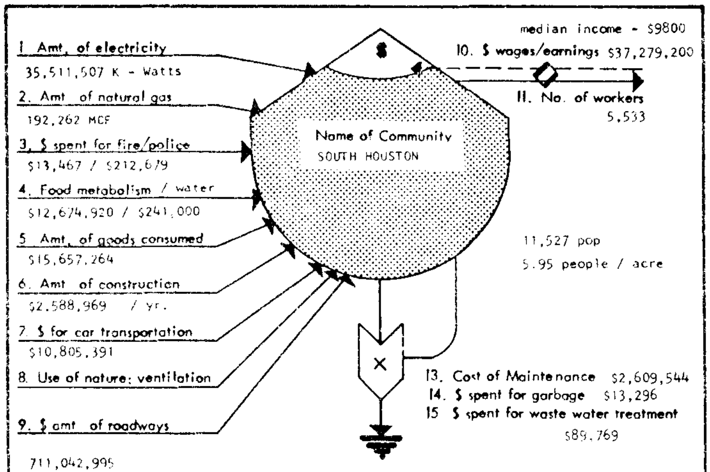
symbol	actual value	equivalent in BTU's	source of information
1	$963,736	95,120,754,320	Houston Lighting and Power Co.
2	$20,282	2,001,897,233	Houston Natural Gas and United
3	$154,000	15,199,800,000	City Budget - Fiscal Yr. 1973/1974
4	$25,204,956	2,487,729,157,200	Average amt. spent - see chart
5	$31,104,652	3,070,029,152,400	Average amt. spent - see chart
6	$3,742,060	369,341,322,000	Dodge Construction Report
7	$15,617,994	1,541,496,007,800	Average of 1.4 cars / person + maint.
8			
9	$10,412	1,027,733,785	
10	$74,058,696	7,309,593,295,200	Census Data - median income
11			
12			
13	$5,184,108	511,671,459,600	City Budget - Fiscal Yr. 1973/1974
14	$64,105	6,327,163,500	City Budget - Fiscal Yr. 1973/1974
15	$421,815	41,633,140,500	City Budget - Fiscal Yr. 1973/1974
TOTAL ENERGY COST	8.141×10^{12} BTUs - 7.309×10^{12} BTUs = 8.32×10^{11} BTU/Yr		

Metabolism Diagram/Data Sheet



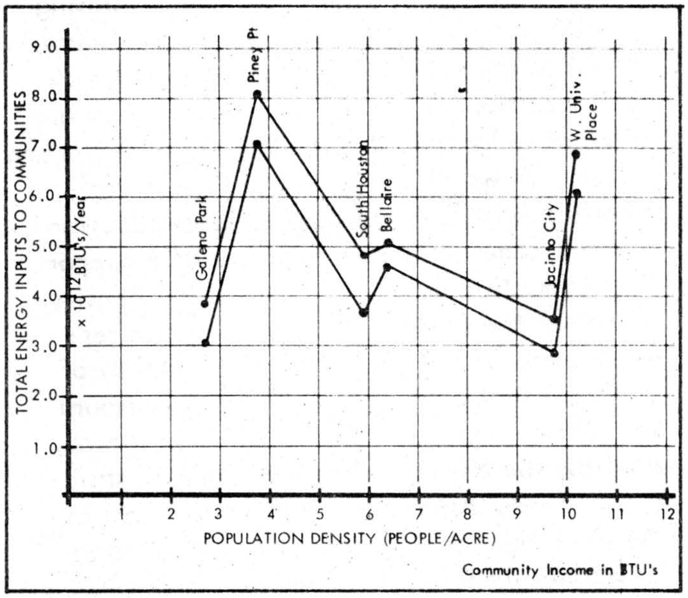
symbol	actual value	equivalent in BTU's	source of information
1	$1,281,060	126,440,702,840	Houston Power and Light Co.
2	$45,160	445,806,324	Houston Natural Gas & United
3	$233,584	23,054,740,800	City Budget - Fiscal Yr. 1973/1974
4	$10,518,580	1,038,183,846,000	Average amt. spent - see chart
5	$12,993,540	1,282,462,496,700	Average amt. spent - see chart
6	$2,353,587	232,299,036,900	Dodge Construction Report
7	$9,822,997	968,505,890,100	Average of 1.4 cars / person + maint
8			
9	$6549	646,397,115	
10	$30,937,002	3,053,482,097,400	Census Data - median income
11			
12			
13	$2,165,590	213,743,733,000	City Budget - Fiscal Yr. 1973/1974
14	$29,140	2,876,118,000	City Budget - Fiscal Yr. 1973 / 1974
15	$358,137	35,348,121,900	City Budget - Fiscal Yr. 1973/1974
TOTAL ENERGY COST	3.923×10^{12} - 3.05×10^{12} = 8.37×10^{11} BTUs/yr.		

Metabolism Diagram/Data Sheet

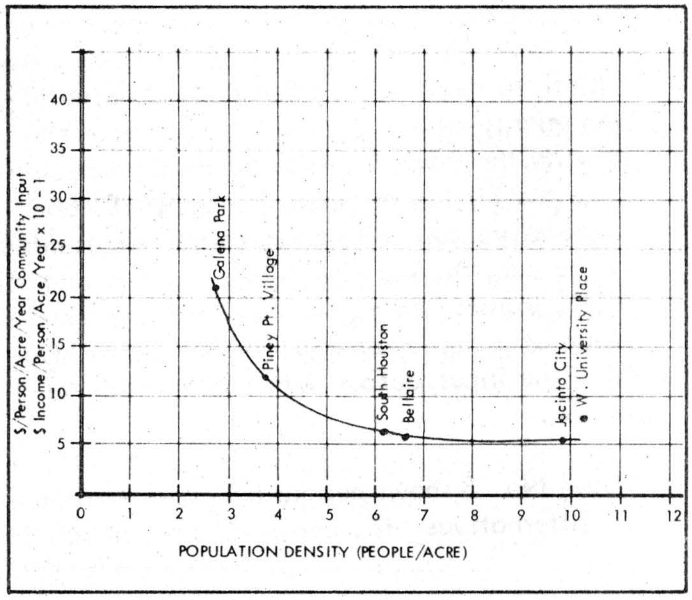


symbol	actual value	equivalent in BTU's	source of information
1	$1,230,766	121,476,696,405	Houston Lighting and Power Co.
2	$76,990	759,928,853	Houston Natural Gas and United
3	$226,146	22,320,610,200	City Budget - Fiscal Yr. 1973/1974
4	$12,674,928	1,251,015,393,600	Average amt. spent - see chart
5	$15,657,264	1,545,371,956,800	Average amt. spent - see chart
6	$2,588,969	255,531,240,300	Dodge Construction Report
7	$10,805,391	1,066,492,091,700	Average of 1.4 cars / person + maint
8	$3,093,912	305,369,114,400	
9	$7240	711,042,995	
10	$37,279,200		
11		3,679,457,040,000	
12			
13	$2,609,544	$.2574 \times 10^{12}$	City Budget - Fiscal Yr. 1973/1974
14	$13,296	$.001316 \times 10^{12}$	City Budget - Fiscal Yr. 1973/1974
15	$89,769	$.008803 \times 10^{12}$	City Budget - Fiscal Yr. 1973/1974
TOTAL ENERGY COST	4.837×10^{12} BTU/Yr - 3.679×10^{12} BTU/Yr = 1.158×10^{1}		

Energy Consumption vs. Population



Energy Consumption vs. Income



This information was then analyzed by plotting the information on graphs in several ways to determine characteristic relationships.

The graph above shows that income is directly proportional to energy expended on community services. This is similar to findings in earlier parts of this report that energy use is directly proportional to income.

There exists an exponential relationship between the energy expended per person per land area within increasingly denser communities as shown in the graph above right. The case studies presented here are not representative of other cities. For Houston the density levels between 7 and 10 per acre are least energy expensive. Similar studies for other cities might show other ranges of energy-conservative densities. Direct assumptions from this study would indicate that increasing densities to the range of 7 to 10 per acre, (since Houston's average density is around 3.5 per acre) would save large amounts of energy. This could be accomplished by zoning techniques and by encouraging inter-city residential growth.

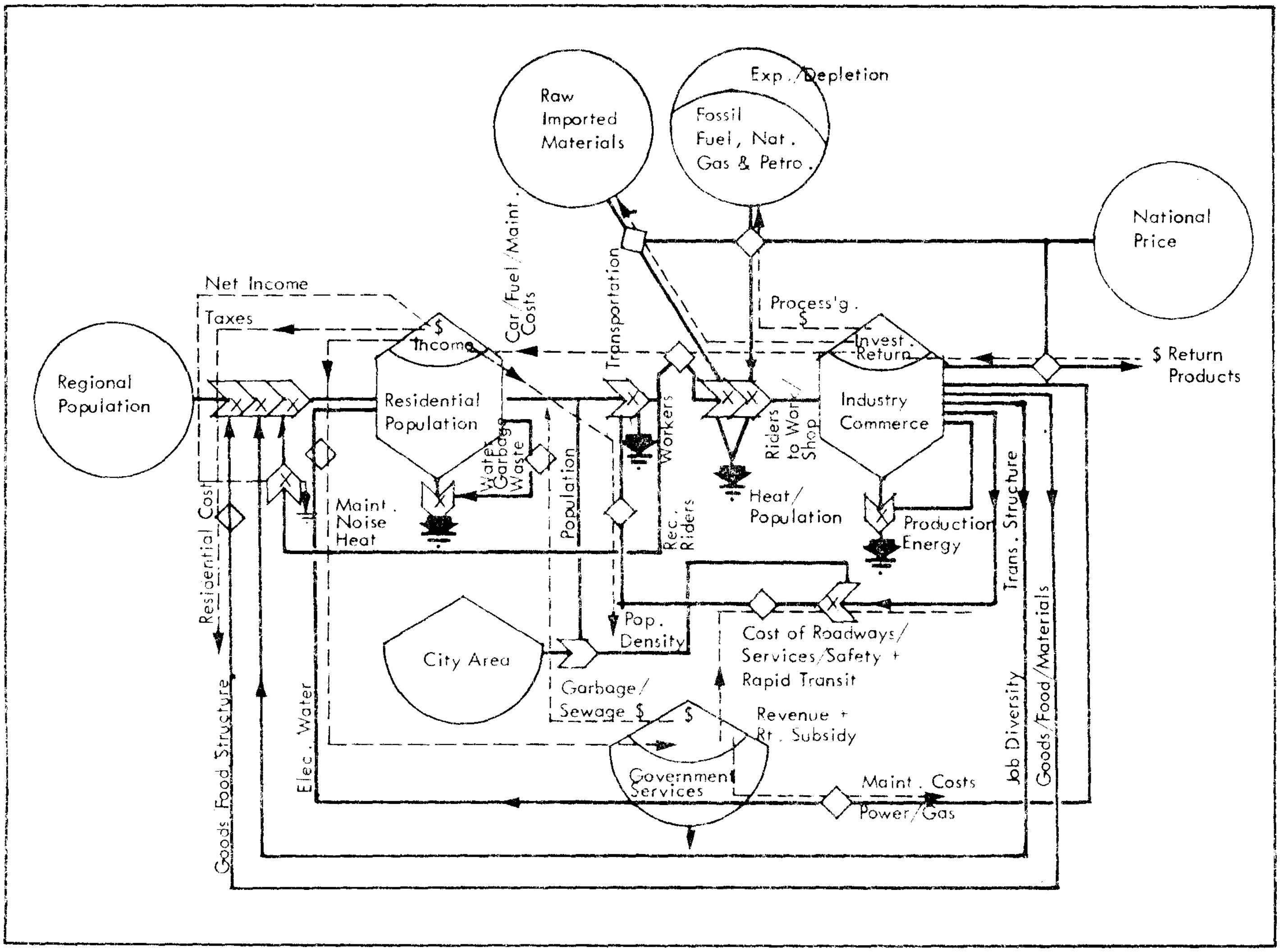
This study shows a decreasing value for the dollar input per person with increasing density at the rate of 1.25 dollars each additional person per acre until it tends to level off at 7 dollars per person per acre. While this study is not conclusive with such a small range of examples, it tends to suggest that for the communities studied the most efficient density levels are between 7 and 10 people per acre.

Analysis by energy flow diagramming (Energy Model No. 1 and Energy Model No. 2) suggested that structure might continue to grow as long as the primary energy resource is plentiful and the waste and maintenance energies are less than the initial energy inputs. The simulation of a similar model by Dr. Howard T. Odum in Energy, Ecology, and Economics, suggests that in order to determine potential urban growth potentials it is necessary to determine the net energies produced by our systems.

• Examination and analysis of the energy costs of various community densities versus transportation modes was undertaken. Energese model no. 3 was developed to identify the major energy flows as they are affected by transportation energy costs. This was also an effort to identify the relationship between the efficiency of the city as the input/output x 100 and the relative costs of transportation represented by the car, the car plus public transit, and all public transit modes. Analog computer simulation of a similar energy model was not made since the input/output data could not be obtained.

Model No. 3 shows people transportation as two alternatives: the car mode and the rapid transit mode. The basic assumption of this model is that the energy costs of maintaining the present level of residential income (quality of life in dollars) is affected by the costs of transportation and that these energy costs are influenced by the net productivity of the urban system. It was assumed that a linear relationship exists between industrial production and the community populations which support the production work; that population density increases the costs of maintenance and services exponentially; and that the amount of inflation (national price) affects the amount of urban net gain. This net gain, in return, controls the amount of new community structure. These assumptions follow from past experience but specific studies have yet to be developed to fully validate these assumptions.

Energy Model No. 3 - Residential Density Growth as a Function or Transportation Costs

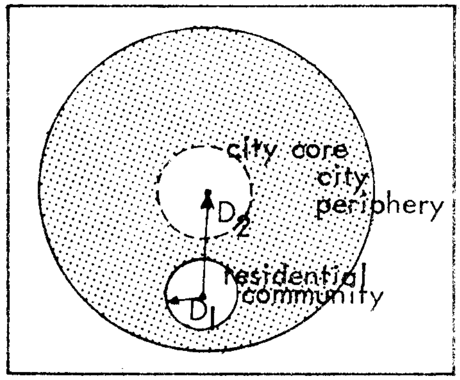


Explanation and Simulation of Energy Model No. 4 Transportation versus Residential Density Growth

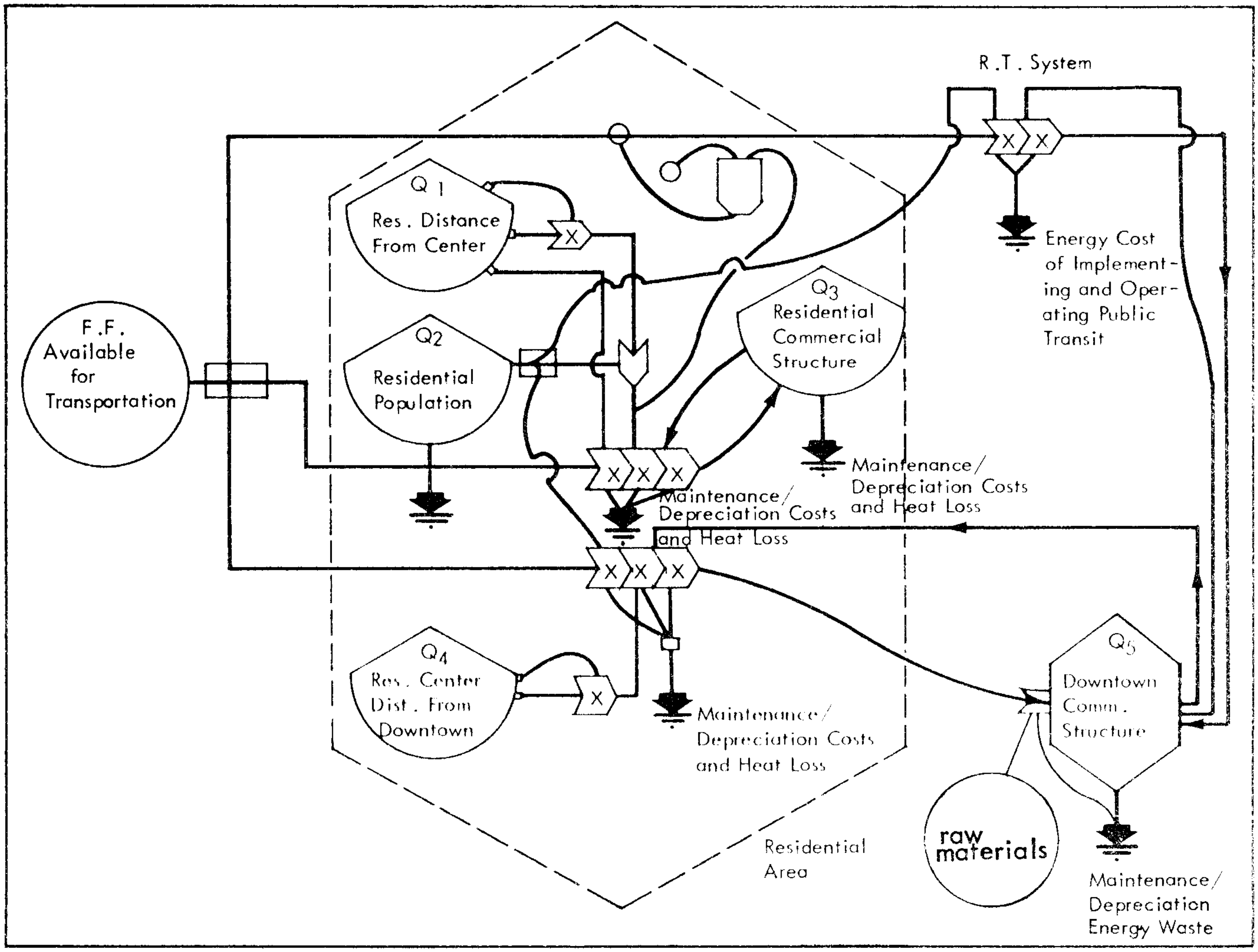
This model was developed to simultaneously compare the energy flows used for transportation within an urban residential area; of car use within the residential area; of car use in going to the central city area; and a public transit system. Earlier in the study it was hoped that a study of transportation energy use controlled by net gain from the industrial sector could be developed since that is essentially the controlling factor. Since industrial energy or dollar output information could not be obtained it was decided to compare transportation flows by potentiometer constructions on the analog computer.

The concept of the model is shown in the diagram below. It shows a smaller circle which is a residential area with a radius D^1 and is a distance D^2 from the Central Business District. The model scenario is that as the commercial and recreational structure increases in the community, local car use increases relative to a decreasing use of car use to town. When the community population density reaches a certain level,

Concept Diagram for Energy Model No. 4



Energy Model No. 4



Numbers and Items for Transportation Analog Model

16893203	TOTAL NATURAL GAS (cu .ft .) USED BY INDUSTRY
366, 359, 109mm BTU (73)	TOTAL NATURAL GAS USED BY HOUSTON POWER AND LIGHT
7708694930 KWHR	TOTAL KWHR OF ELECTRICITY IN RESIDENTIAL AREA OF HOUSTON
18048548856 KWHR	TOTAL KWHR USE OF ELECTRICITY BY INDUSTRY IN HOUSTON (SMSA)
6799298891 KWHR	TOTAL KWHR USE OF ELECTRICITY BY COMMERCIAL IN HOUSTON
29, 456, 548 MCF	TOTAL CU . FT . OF NATURAL GAS USED BY COMMERCIAL IN HOUSTON
26841385 MCF	TOTAL CU .FT . OF NATURAL GAS USED BY RESIDENTIAL IN HOUSTON
105228 .5	TOTAL ACRES OF RESIDENTIAL STRUCTURE IN HOUSTON
21742 .43	TOTAL ACRES OF COMMERCIAL STRUCTURE IN HOUSTON
20832 .01	TOTAL ACRES OF INDUSTRY STRUCTURE IN HOUSTON
	TOTAL AMOUNT OF INDUSTRIAL GOODS SHIPPED OUT OF HOUSTON (can be total dollar volume on return investment)
6,516,950 gals/bus 51,044,423,530/cars	TOTAL AMOUNT OF GASOLINE USED BY CARS & BUSES IN HOUSTON
1,232,802 (70)	TOTAL HOUSTON POPULATION 1970 Census, March 1971
493,121	NO . OF PEOPLE EMPLOYED BY INDUSTRY IN HOUSTON
642,289	NO . OF PEOPLE EMPLOYED BY COMMERCIAL IN HOUSTON
1970 - 97,391	NO . OF PEOPLE EMPLOYED BY GOVT . ETC ., IN HOUSTON
1973 - 690 acres	APPROX . ACRES OF CBD AREA
1971 41,250 thous . of sq .ft .	NO . OF FLOOR SPACE IN ACRES IN CBD AREA IN HOUSTON
1970 286,080 acres	TOTAL ACRES IN HOUSTON

an energy flow is turned on (by the comparator) and available residential transportation fuel is pumped into the R.T. system. The circle in the model is the amount of fuel available for all possible residential transportation use, but in the computer phase it is made a storage module since fossil fuel now has a defined unit. It then represents an amount which is assumed to be directly proportional to the present percentage of the total national fossil fuel use - 25%. Also included in the incoming energy flows is the initial costs, maintenance, and insurance costs per car. The energy drain symbols coming from the multiplier units are the energy losses from our city systems as the cost of moving the people to jobs and services.

Previous studies have shown that as urban structure increases, there is an expotential increase in maintenance and ordering energies, such as in building maintenance, air control systems, and fire and police protection. This means that energy use is required overall for correspondingly smaller additions of new structure (new construction).

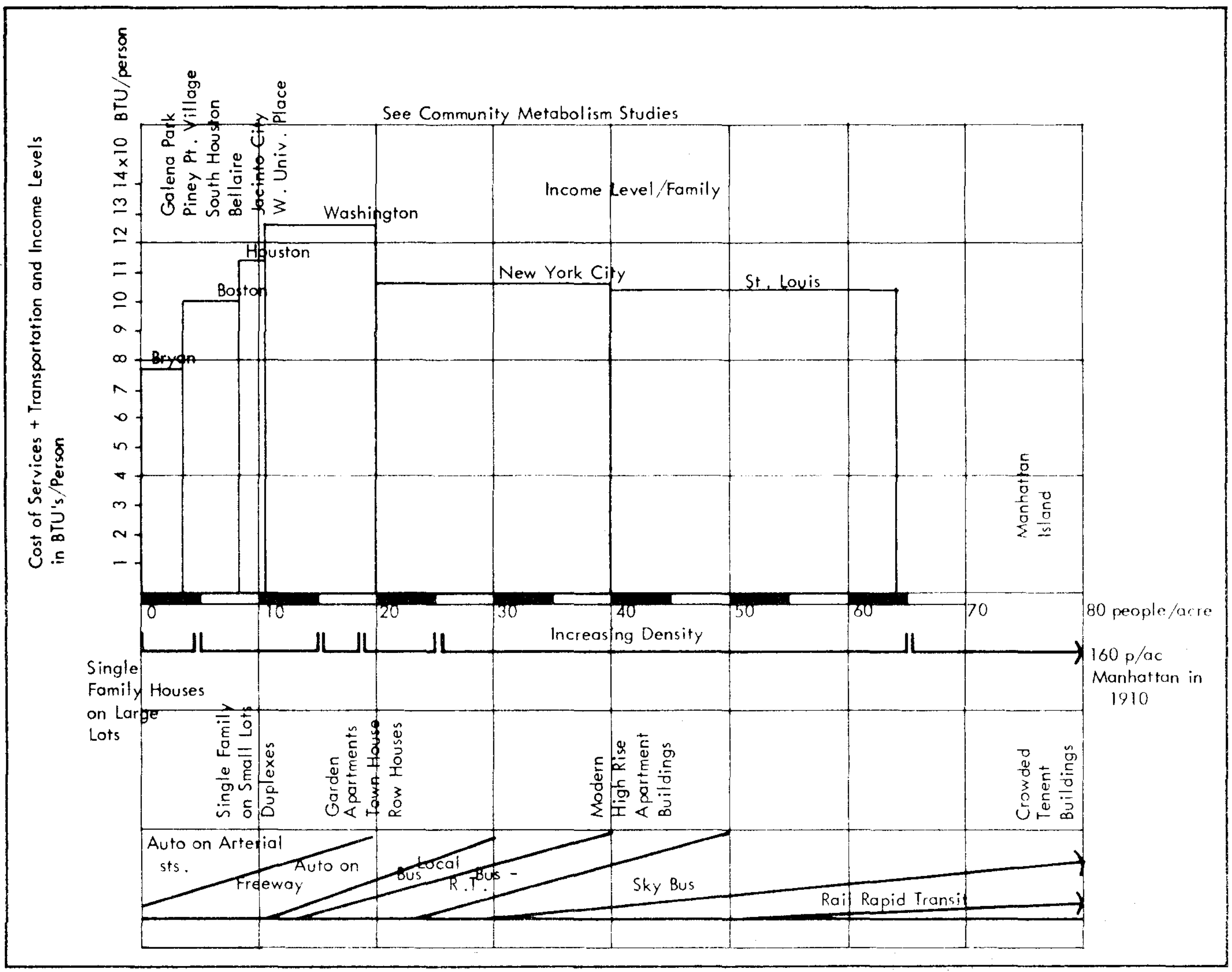
Once the model is diagrammed and the components and flows given data designations, the model is translated to an electrical circuit that is put on the analog computer. The analog machine puts voltages on the lines that represent the flows in the model. Since the model is given a mathematical time base, the computer model begins with the real data conditions and then projects the behavior of the model over 50 years. This does not mean that the city of Houston will necessarily follow the trends in the model but it expresses the growth aspects of model variables.

Energy Model No. 4 was developed in an effort to establish ranges of energy uses associated with the alternative transit modes and the densities of example urban communities and also their distances from the urban core.

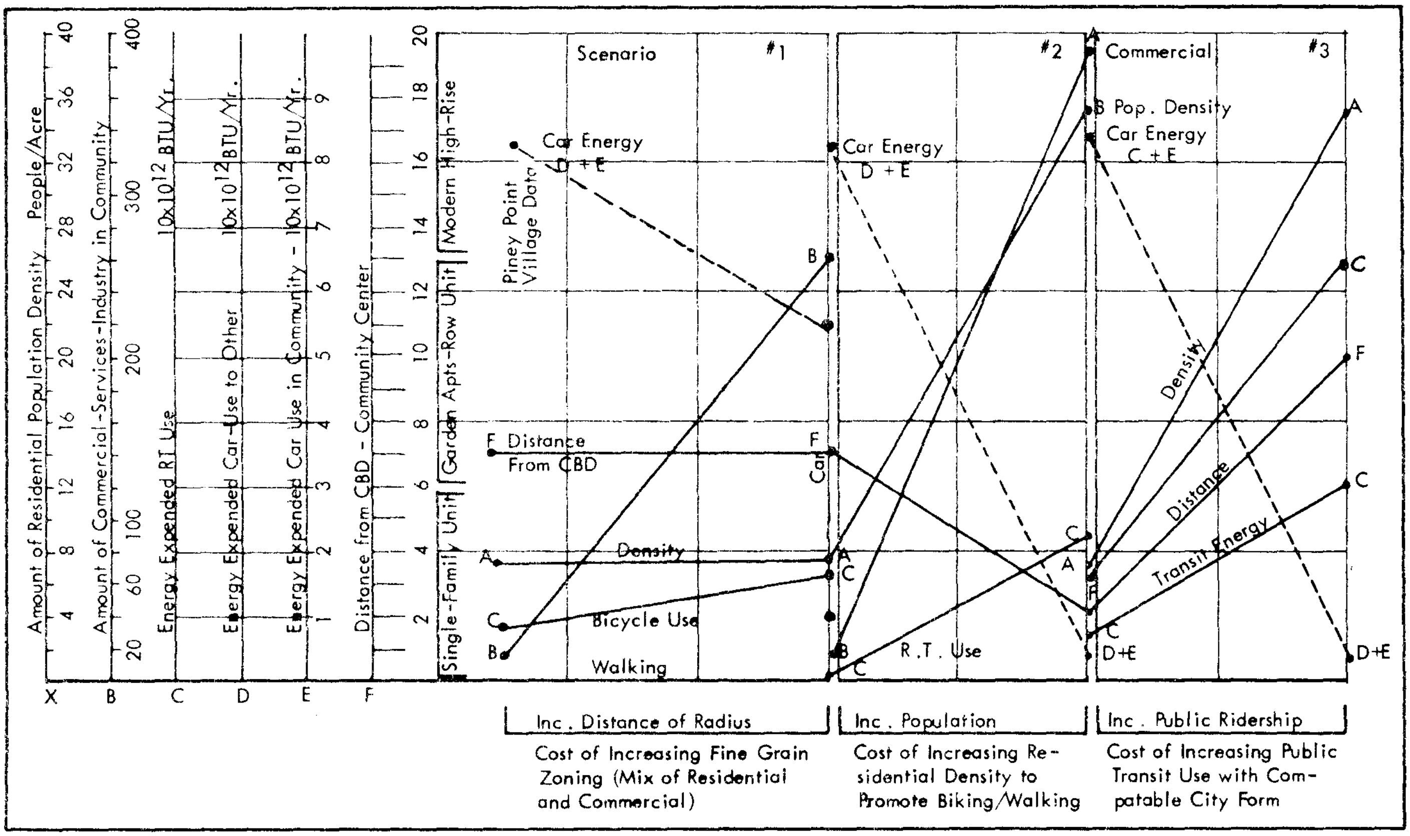
An explanation of the system components that were adjusted on the analog machine to characterize the alternative urban community patterns are given at the bottom of the Graph No. 4 that represents similar data for real urban systems. Graph No. 4 shows the type of urban structure associated with increasing densities and the corresponding primary transportation modes.

A study was made to develop the cost in BTU's that were generally required by various transportation alternatives. Total costs for manufacturing, distribution, sales, and maintenance were obtained for car systems, but similar data was not obtained for bus and rapid rail transit systems. The dollar costs for these systems were translated into BTU's as described earlier so total cost comparisons could be made.

Graph No. 4



Graph No. 5



The computer analysis generated a series of curves that were scenario constructions of urban patterns originally defined by the grant proposal. An explanation of the system components (identified by Energese symbols in Model No. 4) are given in brief at the bottom of the graph above.

Explanation of Scenarios

Scenario #1 begins with data from a typical community (Piney Pt. Village in Houston, Texas). Maintaining the population density level, the amount of commercial area is increased to a maximum level. That level was determined by dividing the total area of commercial in Houston by the population times the population of Piney Pt. Village (.0156 acres/person). The new transportation energy use was projected by the computer. This cost, which is identified as D + E in the graph above, was added to the community energy costs found in the metabolism studies. These costs were totaled in Graph No. 6 under the column of Scenario #1. This total energy cost is less than the existing cost by 9.3×10^{13} BTU's/yr. and is also much less than the projected costs of public rapid rail transit oriented configurations. A characterization of this scenario would be a much larger amount of commercial and light industrial structure within the community limits and therefore would provide jobs and services immediate to residential areas. Dependence on transportation would decrease correspondingly. Fine grain zoning is one tool that would encourage this configuration, although few examples exist in our present urban systems. The reason for this presents a cautionary remark to this optomistic solution. That is, as expressed earlier, urban systems and especially the dense core areas, concentrate energy (people and resources) and therefore, provide for further success in the competition for available fuel. This action gives us the physical quality of life as we know it. More

Graph No. 6

ENERGY BUDGET CHART SHOWING CONCLUSIONS OF ENERGY MODEL NO. 4		SCENARIO #1 Increasing the Amount of Commercial and Business in Residential Districts	SCENARIO #2 Increasing Residential Densities to Conform to Public Transit Use - Encouraging Multi-Family Structures	SCENARIO #3 Increasing Use of Public Transit to a Total Dependence on the Public Transit System
Category	Existing Energy Cost	Projected Energy Budget	Projected Energy Budget	Projected Energy Budget
TRANSPORTATION SYSTEM COSTS car ownership . . . . . . gasoline	 15 $\times 10^{13}$ BTU's 12.2$\times 10^{13}$ BTU's/Yr.	5.64$\times 10^{13}$ BTU/Yr	Decreases with increase in pop. density - see graph #	No inner city car use
TRANSIT USE COST	negligible	.16$\times 10^{3}$ BTU's/Yr.	2.2$\times 10^{13}$ BTU's/Yr.	.76$\times 10^{13}$ BTU's/Yr.
RESIDENTIAL METABOLISM	initial data from Piney Point Village	population - 155,000 at 35 people/acre		
housing costs	.125$\times 10^{13}$ BTU's/Yr.	maintain the density	35$\times 10^{13}$ BTU's/Yr.	see TTI Table
maintenance	.125$\times 10^{13}$ BTU's/Yr.	level - same community	1.4$\times 10^{13}$ BTU's/Yr.	III-1 for suggested
depreciation	.125$\times 10^{13}$ BTU's/Yr.	energy budget as shown		total lost
electric service	.125$\times 10^{13}$ BTU's/Yr.	in column 1	6.2$\times 10^{10}$ BTU's/Yr.	
gas service	.125$\times 10^{13}$ BTU's/Yr.			
food	.125$\times 10^{13}$ BTU's/Yr.		2.6$\times 10^{12}$	
goods	.125$\times 10^{13}$ BTU's/Yr.		3.7$\times 10^{12}$	
TOTAL METABOLISM	.73$\times 10^{13}$ BTU's	.73$\times 10^{13}$ BTU's	6.8$\times 10^{13}$ BTU's	8.0$\times 10^{13}$ BTU's
TOTAL ENERGY COST	12.9$\times 10^{13}$ BTU's/Yr.	3.59$\times 10^{13}$ BTU's/Yr.	9.85$\times 10^{13}$ BTU's/Yr.	8.76$\times 10^{13}$ BTU's/Yr.

simply, the greater the concentration of urban mass the better. Fine grain zoning obviously does not work well in this system since it tends to distribute the commercial mass. However, with the fossil fuel budget rapidly decreasing, the most successful survival pattern may be the community pattern suggested by this investigation. It would create more independent communities which could survive more successfully at a lower energy use level. As discussed earlier in this report, a more proper perspective of energy use is given by Energy Diagram No. 1. The greater the concentration of urban structure, the greater the energy demand. Therefore it is more important to develop city patterns that inherently use less energy than to institute slightly more efficient methods of construction or means of transportation. It is very possible that our present free enterprise system will begin to level off in growth and tend toward a steady state as the energy demand and the energy available find a more equal balance.

Scenario #2 expresses a projection of the study community data to one similar in area but at much higher density (up to the level characteristic of modern high-rise apartments). Also, the distance from the city core was decreased to be compatable with present density configurations. As the density increases, the dependence on car use greatly decreases and reliance on a public transit increases. This pattern is similar to New York City. This scenario suggests that the institution of successful public rapid rail systems would cause a correspondingly higher concentration of population and urban mass. The energy cost of this system is given in Graph #6 under Scenario #2. The value is less if the densities are less but is proportionally more than the values found in Scenario #1.

Scenario #3 was developed by increasing the reliance on a public transit system (which at some level goes from a public bus use to a correspondingly more efficient rapid rail system - see Graph No. 4). The analog computer then projected new values for the density level and the car energy use. This is given in Graph No. 6. This value is somewhat less than for Scenario #2 but they both project similar urban configurations.

The immediate conclusion of this investigation is that positive steps must be taken to develop alternative urban configurations that not only conserve energy, but also have inherently in their structure the ability to adapt to steady state energy systems. Until those configurations can be developed, a conservative approach would be desirable. This study demonstrates that in any case, the present car system is the most expensive. This adds impetus to the need to develop these urban alternative configurations. This study also shows that the least expensive immediate alternative is the public bus and private car system. This takes advantage of the existing investments and does not increase the stress on the future fossil fuel drains. The patterns of the present urban system are largely a response to the car and the connections that are inherent in its processes, which means that instituting rapid rail systems may simply add unnecessary structure to the existing urban mass. The present economic/industrial/commercial/urban system may not be able to adapt to the configurations required of an economical rapid transit city system. Disrupted communication and freight distribution connections could decrease the efficienyand the output level of the industrial system.

This study also suggests that it is possible through a systems approach to develop the best urban configuration patterns for energy conservation, before energy stresses become severe.

Conclusions

The energy budget - community studies show that more desirable living conditions exist on the city periphery. We cannot assume that the auto-transit system along forces urban sprawl, as available qualities for living appear to exist at lower density levels.

More BTU's are expended per person in larger cities so that it costs more fossil fuel in encouraging multi-family structures (see chart). It costs less in a structure $/person but more income per person - subtracting the two gives the BTU's expended per person in terms of the total stress on the remaining fossil fuel budget.

A report from the TTI (see bibliography) suggests that the RT system city costs somewhat more than an auto-city. The dangers in increasing density are that while it appears to cost less by reducing gasoline use - that use is only one part of the fossil fuel total use picture. The PRT system appears to be efficient in very large cities with great amounts of structure using F.F. more rapidly than less dense communities. The PRT system, when reaching greatest efficiency, has a higher structure/person ratio, even with some of our greatest present auto densities.

City high density core areas are not providing good places for people to live or to raise families.

The auto-bus system is overall the lowest cost transit system. Its success is due partly to the very extensive roadway systems that have allowed urban sprawl to become a great enterprise.

Cities have for centuries been the best means of competing for success and survival in energy-structure-production and will continue as the best means as energy becomes more and more expensive. The city once again will tend to gain in nighttime population levels. Since the present glass walled-multi-storied-all air controlled structures in the major city area are especially for workers during the day, families with the money to choose will continue to use gas in transit from their city paripheal residences.

Forcing residential densities to increase in the city proper will cause a greater slum action.

Residential ammenities are found to be:
- greater freedom of movement on site - the desire for land (70% of Texas population live in single-family detached)
- convenient access to shopping areas
- less air pollution (smell) and less noise (irritation) than in city areas
- land areas for children to play.

Green space as lawns, parkways, and woods will have to be considered more important land use than in the past. It is the one obvious means of preventing slums. We are very likely to cause even our middle-income classes to exist in city structures providing poor quality of life, when the energy crunch becomes more severe.

New planning tools will need to be developed in order to allow a pleasant and efficient transition to a lower energy-use level. As the premium on land use gets higher and effects the lifestyle of more people, planning tools and implementation and enforcement will need to be more effective.

Communities can group co-operatively around green areas, if the city government takes action with new zoning tools, and cause residential developments to use public transit more successfully and still provide good places for families to live.

There needs to be greater awareness and cooperation between land use, the land users, and governmental decisions.

Bibliography

Beall, Sam E. Total Energy Applications - Industrial, Urban, Agricultural. Oak Ridge National Laboratory. Tennessee, 1972.

Brown, Mark and Genova, Grant. Energy Indices in the Urban Pattern. Center for Wetlands. University of Florida. Gainesville, 1974.

Castillo, Leonel J. City Controller. Annual Financial Report of the City of Houston, Texas. December 31, 1973.

DeBell, Garrett, ed. The Environmental Handbook. Ballentine Books, Inc. New York, 1970.

Department of Architecture, University of Florida. Identification and Evaluation of Coastal Resource Patterns in Florida. University of Florida. Gainesville, 1973.

Elston, John C. "Criteria for Evaluating Vehicle In-Use Inspection/Maintenance Impact on Emissions and Energy Conservation" Energy and the Automobile. Society of Automotive Engineers, Inc. New York, 1973.

Flanagan, Dennis, ed. Energy and Power. Scientific American. Freeman and Co. California, 1971.

Greenwood, Ned and Edwards, J.M.B. Human Environments and Natural Systems. Wadsworth Publishing Co. California, 1973.

Hirst, Eric. Energy Consumption for Transportation in the U.S. Oak Ridge National Laboratory. Tennessee, 1972.

Holdren, John and Herrera, Philip. Energy. The Sierra Club. New York, 1971.

Holder, Ronald. Transit in the U.S. and Texas: Past, Present, and Future. Texas Transportation Institute. Texas A&M University, 1973.

Jacobs, Jane. The Economy of Cities. Unitage Books. New York, 1970.

Landsberg, Hans H. "Low-Cost, Abundant Energy: Paradise Lost?" Science, April 19, 1974, p. 247.

Liebman, Kirkland, and Pangaro. "Housing Criteria Drawn from Human Response". AIA Journal. March, 1974, p. 46.

Mattila, John and Thompson, Wilbur, ed. Proceedings of the Conference on Urban Economics. Wayne State University. Detroit, 1973.

Meadows, Donella; Meadows, Dennis; Randers, Jorgen; and Behrens, William. The Limits to Growth. Universe Books. New York, 1972.

Meyer, J.R., Kain, J.F., Wohl, M. The Urban Transportation Problem. Harvard University Press. Massachusetts, 1965.

Miller, David R., ed. (Barton-Aschman Associates) Urban Transportation Fact Book. Illinois, 1974.

Odum, Howard T. "Energy, Ecology, and Economics", Enfo Newsletter, December, 1973. Environmental Information Center of the Florida Conservation Foundation, Inc.

Odum, Howard T. Environment, Power, and Society. Wiley-Interscience. New York, 1971.

Spreiregen, Paul D. Urban Design: The Architecture of Towns and Cities. McGraw-Hill. New York, 1965.

Texas Transportation Institute. Transportation in the Texas Coastal Zone. Texas A&M University, 1973.

Wells, Asher, Flowers, Kamrcss, Nelson, Selover, and Thomas. Economic Characteristics of the Urban Public Transportation Industry. Institute for Defense Analysis. Virginia, 1972.

5
Political Ramifications

Introduction

The purpose of this section of this report is to discuss some of the political and legal considerations of limiting the perimeter growth of Texas cities to conserve energy.

Compared with other large American cities, large Texas cities are less dense and larger in geographical area. Among the 10 most populous cities in the United States, Houston has the lowest density of population. Its geographical area exceeds all the other top ten cities except that of Los Angeles. Dallas is the second least densely populated city among the top ten and is fourth largest in area.[1]

Likewise, the two largest SMSA's in Texas in 1970, Houston (13th largest) and Dallas (16th largest), are larger geographically and are less densely populated than is the average of the ten largest SMSA's in the United States.[2]

Geographical Area and Density of the Ten Most Populous Cities, 1970

Central City	1970 Population	1970 Area in Square Miles	Population Density in Square Miles
New York	7,895,563	299.7	26,344.8
Chicago	3,369,357	222.6	15,136.3
Los Angeles	2,809,596	463.7	6,059.1
Philadelphia	1,950,098	128.5	15,175.8
Detroit	1,513,601	138.0	10,968.1
Houston	1,231,394	433.9	2,838.0
Baltimore	905,759	78.3	11,555.0
Dallas	844,401	265.6	3,179.2
Washington, D.C.	756,510	61.0	12,401.8
Cleveland	750,879	75.9	9,893.0

Comparison of Houston/Dallas SMSA with Ten Largest U.S. SMSA's

SMSA's	Area, Square Miles	Density, Persons/ Square Miles
10 largest SMSA's in the U.S.	3,235.4 (average of 10 largest SMSA's)	1,668.1 (average of 10 largest SMSA's)
Houston SMSA	6,285	316.0
Dallas SMSA	4,508	345.0

Average Density/Area of Texas vs. U.S. SMSA's[2]

SMSA's (1970)	Area, Square Miles	Density, Persons/Sq. Miles
All (264) SMSA's in the U.S.	1,468.2 (average, U.S. SMSA's)	360.0 (average, U.S. SMSA's)
All (24) SMSA's in Texas	1,659.0 (average, Texas SMSA's)	188.0 (average, Texas SMSA's)

When the average area and density of all SMSA's of Texas are compared with the average area and density of all SMSA's in the United States the results are similar.[3]

Not only are the areas of Texas cities comparatively larger than those of other cities in the United States, but they are also continuing to grow according to the latest census data. During the two-year period 1970-71, municipalities in Texas with a population of more than 2,500 persons, reported the greatest total amount of territory annexed than did the municipalities in any other state.[4] Of the 1,517 square miles of territory annexed during this period by all municipalities over 2,500 population in the United States, Texas municipalities annexed 270 square miles or 17.8% of the total in the United States. Furthermore, annexation is going on in nearly all municipalities in the state. In 1971, for example, only five out of the 142 municipalities in Texas reporting to the Census Bureau did not annex territory.[5]

The most recent census data which covers the years 1970-71 also shows Texas to be leading all other states in newly-incorporated municipalities.[6] Of the 155 new municipalities in the United States, 39 of them were in Texas.[7] It should be noted that about 70% of the newly-incorporated municipalities in Texas are SMSA's.[8] The point is significant because in Texas the central city traditionally leaps over incorporated areas to annex additional territory located near its periphery. Furthermore, if the incorporated area is not proximate to the periphery of the central city, it is a usual pattern for development to occur between the two areas. Either case contributes to urban sprawl.

Scholars have not identified all the causes for Texas cities developing their dispersed, low-density character. One recent study, however, points out that the automobile is a significant reason for southern and western cities (including Texas cities) being more dispersed and less dense than eastern cities.[9] The study shows that the central cities of eastern SMSA's experienced most of their population growth prior to 1920 which was before the wide-spread use of the automobile. The central cities of almost all southern and western cities, on the otherhand, experienced more than half of their population growth after 1930 which was after the wide-spread use of the automobile. The resulting pattern for these SMSA's, including those in Texas, is that they have central cities laid out in large measure to serve by the automobile and truck and typically show a more dispersed and lower density pattern than the cities of the east.[10]

The dispersed character of Texas cities may be a luxury that Texans will not long be able to afford. Russel Train of the U.S. Environmental Protection Agency, in a recent speech, quoted from a study by the Real Estate Research Corporation that urban sprawl is costly when analyzed in terms of its impact on the environment, energy and public expenditures. The Real Estate Research Corporation study states the following points:[11]

1. A high density planned community is 44% less expensive in development costs than the low density sprawl community.
2. The high density planned community generates

45% less air pollution than the low density sprawl community.

3. In terms of water consumption, the high density community can save 35% over low density sprawl communities.

A study produced by the Regional Plan Association in collaboration with resources for the future, reveals additional data on energy consumption and costs in American cities.[12]

1. New York City consumes only about half the energy per resident that the rest of the nation does.
2. The typical spread-city resident uses up to three times more energy per dollar of income in his home than the resident of a high density development.

Increasing Texas population growth may require adopting policies for planning for the use of the state's energy resources that hitherto have not been seriously considered. One energy-saving policy that may be considered is to limit the perimeter growth of Texas cities. To implement such a policy will require changes in some of the traditional Texas political and legal institutions.

Constitutionally Permissible Growth Controls Policies

Although a good case may be made to show that limiting perimeter growth of Texas cities can produce energy savings, political and legal questions will be raised about the increased density of population and controls that will result from perimeter limitations. Expressed differently, perimeter limitations do not stand isolated from questions of population control and growth policies. Therefore, policy-makers wishing to control growth of the perimeters of Texas cities should consult four important judicial decisions for guideposts. The first pronouncement made by the U.S. Supreme Court on zoning, Euclid vs. Ambler (1926) is important to note because of the considerable flexibility it gives to local government under the Tenth Amendment's police powers to reasonably control property to improve the quality of life. One phase is specifically applicable to policy-makers needing judicial support to plow new legal ground in growth control: "while the meaning of constitutional guarantees never varies the scope of their application must expand or contract to meet the new and different conditions which are constantly coming within the field of their operations."[13]

Forty-eight years later the Supreme Court emphasized the considerable flexibility given to the states by Euclid. The Court majority in Village of Belle Terre vs. Boraas (1974) held that the police power "is not confined to elimination of filth, stench and unhealthy places. It is ample to lay out zones where family values and the blessings of quiet seclusion and clean air make the area a sanctuary for people."[14]

The flexible, innovative approach allowed in controlling the quality of life by the two Supreme Court decisions was recently applied in New York by the City of Ramapo. The city's use of the sequential development technique to control growth was found constitutional by the New York Court of Appeals. The Ramapo city ordinance can delay development for as long as 18 years based on the availability of city services. During this period tax relief is given to those holding the land for development. Significantly, the New York court found that the program in Ramapo is not designed "to freeze population at present levels, but to maximize growth by the efficient use of land and in so doing testify to this community's continuing role in population assimilation."[16]

The court found that state enabling statutes for zoning legitimately gives localities by implication the power to direct the growth of population by use of phased development. Constitutionally, the court based its opinion on the sufficiency of the 10th amendment police powers as originally set forth; in Euclid. The court did, however, find "something suspect in a scheme which, apart from its professed purposes, effects a restriction upon the free mobility of a people until sometime in the future when projected facilities are available to meet increased demands."[17]

Two years later a federal district court in California was faced with similar growth restrictions as set forth by the City of Petaluma, California. The city was concerned about projected growth of the city exceeding 55,000. To limit growth the city established an "urban extension line" intended to mark the outer limits of the city's expansion for twenty or more years. The plan further called for not allowing the city to annex or to extend city facilities to land outside this urban extension line. As in Ramapo the city also had a plan to allow only a limited number of building permits based on a rating scheme for builders. The federal court found the Petaluma scheme beyond the limits of the police powers of a community and in violation of the "right to travel" in Article I, Sec. 3 of the U.S. Constitution.

Because the fact situations in these two cases are similar yet the decisions different, policymakers working in the area of growth direction and control must move with some caution. Such assurance could come from one or preferably two actions: (1) the state could amend its enabling law on zoning to specifically allow local governments to establish growth control policies; and/or; (2) the U.S. Supreme Court could rule definitively in the growth control area by either positively accepting review of such a case or passively by refusing to exercise review in a significant number of cases.

Availability of Land Within the Existing Perimeters of Texas Cities

If policies are adopted to limit the perimeters of Texas cities, it will be necessary to determine the amount of land that is available for development within the city. Planners can determine from land use maps how much land is not available for development because it may be in flood-prone areas, or is devoted to green space, or to parks, or is set aside for other public purposes. It is much more difficult to determine how much land is not available because of estate difficulties, pending litigation, legal judgments on the land, tax encumberances or sales resistance of individuals owning the land within the city.

To determine how much land within the city is not available for development, planners can consult tax offices (city, county and school), real estate officials, bankers and law firms. Economists may be consulted if information is needed about the effect of limiting the growth of the cities' perimeters based on the price of construction and land.

Codes

Limiting the growth of the perimeters of cities will affect existing codes (fire, plumbing and building) and enforcement of those codes. For example, if density of population increases because the perimeters of the city are restricted, it will be necessary to change existing people-space limitations in present codes. Code enforcement must be improved to apply particularly to older construction as it does to newer construction to protect the public's safety in cities with more dense populations.

Zoning

Limiting the growth of city perimeters may result in pressure to down-zone in order to allow multi-family and/or commercial use of areas presently zoned as single-family. Court precedents show the fact situation strongly influences decisions in down-zoning cases although fairly strong precedents in these cases deny down-zoning on the "reasonable and compelling public interest" rule.[18]

Other zoning techniques used in various jurisdictions that might be applicable if a policy of limiting perimeter growth is adopted in Texas are: (1) "contract zoning" whereby a zoned area might be used for a limited time (based on agreement of homeowners and interests wanting to change the usage) for a purpose not allowed under the zoning ordinance.[19] (2) Transferable Development Rights which is a type of "substitute zoning" which allows for limits on the use of land, in accordance with a plan, while providing equal compensation to all landowners for their share in future development potential provided by the plan. It provides for the separation of land value and development values, grants more protection to the public interest against environmentally and financially unsound land use and development, while affording greater safeguards to the property rights of the non-speculative property owner.[20]

Deed Restrictions

A policy of restricting the growth of the perimeters of cities may affect existing deed restrictions. Breaking deed restrictions under a city's police powers appears to be constitutionally impermissible. However, deed restrictions typically run for only twenty years at which time they must be renewed. In other instances they may be changed by a petition process of home owners in the subdivision.

Power to Incorporate a City in Texas

To limit the growth of the perimeters of Texas cities it will be necessary to consider the rather easy method that exists for incorporating a Texas city.[21] It is likely that the present petition process, which requires only a small number (in some categories, only 20 persons required) or percentage of citizens to sign the petition requiring an incorporation election, contributes to urban spread of Texas cities. It is now a well-known national pattern that citizens or businesses for various reasons have left the inner city and moved to the outer fringes where they settle and incorporate. There they can enjoy the environment of their choosing while at the same time avoiding inner city taxes while enjoying some inner city services free of charge.

Annexation Powers of Texas Cities

Present Texas annexation laws may contribute to the spread of the Texas city. A city is allowed to annex up to 10% of its total area each year. Texas law does not permit one city to annex another without the consent of the latter city.

It can be argued that if central cities are allowed to annex larger portions of adjacent land than now allowed they will exercise stricter land-use controls in these areas than the county is now allowed by law to exercise. Following this line of reasoning, development will be inhibited in the newly annexed areas because the city will presumably adopt zoning ordinances that designate some land agricultural and/or use a variety of moratorium techniques to delay development and growth.

Conversely, it can be argued that allowing the city to annex greater portions of land might accelerate development rather than impede it because developers can pressure city councils to force annexation while at the same time preventing strict land-use controls.

Extra-Territorial Jurisdiction of Texas Cities

The extra-territorial jurisdiction of cities ranges from one-half mile for cities under 5,000 population to five miles for cities over 100,000 population. Although much development takes place in the extra-territorial jurisdiction of a city, it has only limited powers to control that development. Cities may extend their ordinances to apply plat approval for subdivisions in the area. It is not legally clear, however, whether they may extend their zoning ordinances to the extra-territorial jurisdiction area. The City of Austin has a provision in its charter allowing such an extension but has never applied it. Home rule theory would seemingly find such a provision constitutional but there has been no court case or advisory opinion to confirm this theory.

Percent Increase in Special Districts in the U.S. and Ten Most Populous States

	1962-67 % Increase	1967-72 % Increase	1962-72 % Increase
U.S.	16.1	12.3	30.4
California	10.4	2.5	13.3
New York	0.5 (decrease)	1.1 (decrease)	1.6 (decrease)
Pennsylvania	16.2	9.4	27.1
Texas	36.6	21.3	65.8
Illinois	8.8	4.1	13.2
Ohio	28.1	20.6	54.5
Michigan	11.1	26.4	40.4
New Jersey	5.4	9.6	15.6
Massachusetts	27.3	8.5	38.1
Florida	17.4	1.6	19.3
Average Top Ten States	16.1	10.3	28.6

Special Districts

Texas has 1,215 special districts ranking it fourth behind Illinois (2,407), California (2,223), and Pennsylvania (1,777). Furthermore, the rate of increase of special districts in Texas since 1962 exceeds that in the ten most populous states.[22]

Once the special district is created, often on the urban fringe, bonds can be sold to provide the financing for utilities that developers need to furnish potential industry and/or home owners. It should be observed that these bonds are often sold at a higher rate of interest than those sold in the inner city if the inner city annexes the area it assumes the bonded indebtedness.

Three important factors contributing to the proliferation of special districts in Texas are: (1) the constitutional provisions limiting the tax level of general-purpose local governments; (2) the ease with which they be established; and (3) industry moving from the inner city to escape taxes. Whatever the cause, the special district allows development in the area which brings people who in turn are likely to demand incorporation or annexation. The result is more urban spread.

County Land Use Control

County government in Texas is ill-equipped constitutionally to control urban spread. It has only limited power to control building standards and land use because it does not have ordinance power or the authority to adopt home rule charters. Counties may ask the legislature to grant land use powers by special law but only three counties have done so. Cameron and Willacy counties have the power to control land use (and to a limited extent building standards) in the Padre Island portion of their counties. Val Verde county has the power to control land in the Amistad Lake area. All counties may exercise some land use controls around airports. Coastal counties may exercise some control authorized under the national flood insurance program. The County Health Officer may exercise limited control of septic construction and quality in the unincorporated areas of the county. In Brazos County, the City of Bryan can exercise certain electrical code standards because the city owns the Rural Electrification System in the county.

If the county had the legal authority to establish codes and land use in the unincorporated areas it is probable that urban spread would be inhibited.

Conclusions

Texas cities are larger geographically and less dense than most of the other cities in the nation. Furthermore, they are probably expanding in area faster than any other of the nation's cities as witnessed by the number of annexations and incorporations in the past few years. Census data shows that they continue to grow in population. To meet increased population growth, Texans have often extended the peripheries of their cities. This course of action may become too expensive for Texans in terms of energy and development costs. One author of a recent study on urban spread presents a good example and summary of the cost of city perimeter growth:[23]

> As development moves further outward from the core, returns diminish and costs increase, and at an accelerating rate. Water distribution is an example. If you double the population within a given area, you can service it by enlarging the diameter of the present pipe system; if you try to take care of the population by doubling the area, however, you not only have to enlarge the present pipes, you have to lay down a prodigious amount of new ones, and as they poke out into the low density areas costs become progressively steeper. The same is true with mass transit and other utilities and services.

If Texans find the cost of urban spread too high they can reduce them by adopting a policy of limiting the perimeter growth of their cities. Such a policy may be implemented by the following recommendations:

Recommendations Relating to Limiting Perimeter Growth of Texas Cities

1. Studies should be made to determine the amount of land available for development within the existing perimeters of cities.

Studies should be made to identify and inventory the amount of land available for development within the existing perimeters of Texas cities by determining: (a) land that would be difficult to purchase because of legal encumberances; (b) land that would be difficult to purchase for development because of the unwillingness of the owner to sell; (c) public land that might be available for purchase and development; (d) land belonging to non-profit organizations that might be available for purchase and development; (e) land in deteriorating areas that might be purchased for development or redeveloped; and (f) vacant lots within subdivisions in the city that are available for development.

2. Studies should be made of the economic effects of limiting the perimeter growth of cities.

Studies should be made to determine the effects of limiting the perimeter growth of Texas cities on (a) the cost of land; (b) cost of construction; (c) tax revenue; (d) the cost of supplying public wervices to a more densely-populated city; and (e) the effect cost of insurance for commercial buildings and homes.

3. Existing codes should be reviewed to determine necessary changes.

Existing codes should be reviewed to determine if limiting perimeter growth and increasing density in the city require changes in the codes. Studies should also be made to determine the effect of limiting perimeter growth on code enforcement. The new special-revenue HUD funds may be available for financing such studies.

4. Cities should adopt limited growth policies.

(a) Cities, the Department of Community Affairs, the Governor's Division of Planning Coordination and the Attorney General's Office should cooperate in making, or contracting to have made, a thorough study of growth policies that can stand the test of constitutionality. (b) Special attention should be made to sequential development as set forth in

Ramapo as a technique of limiting growth in Texas cities. (c) The legislature should determine how the state zoning enabling act should be amended to give cities more specific legal authority to establish growth policies.

5. Home rule cities should extend land-use controls and building codes to their extra-territorial jurisdiction.

Home rule cities appear to have the legal right to adopt charter provisions allowing them to extend their ordinances on land-use control and codes into their extra-territorial jurisdiction. If such a method proves unconstitutional, the state annexation law should be amended to give such power to cities.

6. Incorporation of Texas cities should be made more difficult.

(a) The legislature should increase the number of people required to petition for an incorporation election should be increased. (b) Regional councils should receive a proposal for incorporation for review and comment. Such a procedure would have the effect of informing elected officials in the region of the pros and cons of the incorporation. (c) After the review and comment procedure, a county-wide election should determine the issue rather than only an election in the area wishing to incorporate.

7. Special districts should be made more difficult to establish.

(a) The regional council in which the proposed special district is located should exercise review and comment on the special distriction application. This procedure will have the effect of informing elected officials in the region of the pros and cons of establishing the special district. (b) After review and comment by the regional council, a county wide election should be used to create any type special district rather than allowing creation by present methods (by the legislature and/or local governmental approval).

8. Remove constitutional tax limitations on cities and counties in Texas.

Removal of constitutional tax limitations on cities and counties should have the effect of giving the general purpose the financial ability to provide the service otherwise to be provided by the special district. This should have an inhibiting effect on creation of special districts.

9. Strengthen county government's legal ability to control land and establish codes in the unincorporated area of the county.

(a) The best recommendation, because it would give the county a variety of options in dealing with land use control, would be giving home rule to Texas counties. Home rule is, however, politically difficult to consummate. (b) If home rule cannot be adopted in Texas for counties, the legislature should, by law, give counties ordinance power to control land use and establish codes for the unincorporated areas of the county. (c) If ordinance power cannot be given by law to all Texas counties, the counties should, as have Cameron, Willacy and Val Verde, proceed on their own to have special statutes passed giving them land-use control in the unincorporated areas of the county.

References

1. U.S., Bureau of the Census, 1970 Census of Population: Characteristics of the Population, U.S. Summary, Vol. 1, Part I, Sec. 1, Table 35, pp. 187-89.

2. Ibid.

3. Ibid.

4. U.S. Bureau of the Census, 1972 Boundary and Annexation Survey, p. 3.

5. Ibid., pp. 44-47.

6. Ibid., p. 3.

7. Ibid., p. 55.

8. A.H. Belo Corporation, Texas Almanac, 1974-75, pp. 193-206.

9. James Heilbrun, Urban Economics and Public Policy (New York: St. Martin's Press, 1974), p. 36.

10. Ibid., p. 37.

11. Information given by Russell Train is quoted from a report made for the EPA by the Real Estate Research Corporation and will soon be published by the Government Printing Office entitled: The Cost of Sprawl. Mr. Train's remarks in this text are taken from: American Institute of Planners, "New Study Shows that Sprawl Costs More," AIP Newsletter, October, 1974, p. 18.

12. Ibid., p. 19.

13. 47 S. Ct. 118

14. 94 S. Ct. 1541

15. 30 N.Y. 2d 359, 285 N.E. 2d 291 (1972). For a brief discussion of recent cases on growth limitations see: Barry Israel, "Increasing Interest Shown by Planners in Growth Control Techniques", AIP Newsletter, June, 1974, pp. 9-11.

16. Ibid.

17. Ibid., 300.

18. For a summary discussion of down zoning see: Jerome G. Rose, "New Directions in Planning Law: A Review of the 1972-1973 Judicial D Decisions", Journal of the American Institute of Planners, Vol. 40, No. 4, July, 1974, pp. 243-254.

19. Steven B. Fishman, "The 'Contract Zoning' Method and Public Policy", Urban Law Annual, Washington University, 1972. This article discusses the different ways courts have held in "contract zoning" cases.

20. Donald G. Hagman, Public Planning and Control of Urban and Land Development (St. Paul: West Publishing Co., 1973), pp. 548-49.

21. Perhaps a good example of the ease of incorporation in Texas can be seen in Henderson County. Since September of 1971, six municipalities all with a population of less than 600 have been incorporated.

22. U.S. Bureau of Census, Census of Governments: Governmental Organizations, p. 26.

23. William H. Whyte, "The Case for Crowding", North American Suburbs: Politics, Diversity, and Change (The Glendessary Press: Berdeley, 1972), p. 308.

6
Additional Research

This study reflects an attempt to identify those areas that could contribute to energy conservation in the State of Texas. This effort, of relatively short duration, has merely scratched the surface in terms of achieving conclusive results.

During the course of this study it became obvious that additional areas of research and investigation could contribute to achieving energy conservation on a statewide basis. Following is a list of suggested areas of study that should be considered:

- the State should consider a study to conduct an audit of State owned and leased buildings to determine possible conserving measures.
- Studies should be conducted to determine retrofitting procedures for all types of buildings in an effort to reduce energy consumption in the State.
- A study should be undertaken to develop performance standards which can be applied to proposed new buildings in order to determine energy allocations for that structure.
- Continuing education programs as well as mass media presentations should be developed as educational tools to enlighten the public as to the continued need for energy conservation.
- A study should be undertaken to determine the feasibility of applying a surcharge for energy consumption for excessive levels of energy consumption.
- A homeowner's guide should be developed and made available to all residential utility customers in the State to permit an intelligent evaluation of their energy consumption rates and how to effectively achieve conservation. In conjunction with this effort, an advisory service unit should be made available to assist homeowners in need of technical advice.
- Demonstration projects should be undertaken in the State of Texas to illustrate the feasibility of using solar heating systems in various parts of the state.
- Information centers should be established in various parts of the state to offer technical advice and services to those interested in conserving energy through retrofitting.