NATIONAL BUREAU OF STANDARDS

NBS SPECIAL PUBLICATION 608

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Research and Innovation in the Building Regulatory Process

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Research and Innovation in the Building Regulatory Process

Proceedings of the Fifth Annual
NBS/NCSBCS Joint Conference

Technical Seminar on Solar Energy and
Energy Conservation

Held in Denver, Colorado
on August 6, 1980

Sandra A. Berry, Editor

Building Economics and Regulatory
Technology Division
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
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Preface

This document contains the Proceedings of the Fifth Annual NBS/NCSBCS Joint Conference on Research and Innovation in the Building Regulatory Process,[1] held on August 6, 1980, in Denver, CO. This conference addressed the various aspects of energy conservation and solar energy.

These Proceedings contain all of the 13 papers selected for presentation at the conference as well as 4 additional papers selected for publication only. These additional papers are denoted by an asterisk (*) in the Table of Contents.

Acknowledgements

The editor expresses appreciation to the authors for their input to this publication. In addition, although their remarks are not published herein, appreciation is expressed to the Keynote Speaker and Session Moderators for their participation in the conference.

Keynote Address:	Ed Shackleford President, Solaron Corporation Englewood, CO
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Session on Solar Energy:	Bruce Baccei Solar Energy Research Institute Golden, CO

[1] Proceedings of the First through Fourth Annual Joint Conference on Research and Innovation in the Building Regulatory Process are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D C 20402, as follows:

1. NBS Special Publication 473, $6.00
2. NBS Special Publication 518, $6.00
3. NBS Special Publication 552, $7.50
4. NBS Special Publication 586, $7.00

SI CONVERSION

The following list of conversion factors for the most frequently used quantities in building design and construction may be used.

QUANTITY	INTERNATIONAL (SI) UNIT	U.S. CUSTOMARY UNIT	APPROXIMATE CONVERSION	
LENGTH	meter (m)	foot (ft)	1 m	= 3.2808 ft
	millimeter (mm)	inch (in)	1 mm	= 0.0394 in
AREA	square meter (m^2)	square yard (yd^2)	1 m^2	= 1.1960 yd^2
		square foot (ft^2)	1 m^2	= 10.764 ft^2
	square millimeter (mm^2)	square inch (in^2)	1 mm^2	= 1.55×10^{-3} in^2
VOLUME	cubic meter (m^3)	cubic yard (yd^3)	1 m^3	= 1.3080 yd^3
		cubic foot (ft^3)	1 m^3	= 35.315 ft^3
	cubic millimeter (mm^3)	cubic inch (in^3)	1 mm^3	= 61.024×10^{-6} in^3
CAPACITY	liter (L)	gallon (gal)	1 L	= 0.2642 gal
	milliliter (mL)	fluid ounce (fl oz)	1 mL	= 0.0338 fl oz
VELOCITY, SPEED	meter per second (m/s)	foot per second (ft/s or f.p.s.)	1 m/s	= 3.2808 ft/s
	kilometer per hour (km/h)	mile per hour (mile/h or m.p.h.)	1 km/h	= 0.6214 mile/h
ACCELERATION	meter per second squared (m/s^2)	foot per second squared (ft/s^2)	1 m/s^2	= 3.2808 ft/s^2
MASS	metric ton (t) [1000 kg]	short ton [2000 lb]	1 t	= 1.1023 ton
	kilogram (kg)	pound (lb)	1 kg	= 2.2046 lb
	gram (g)	ounce (oz)	1 g	= 0.0353 oz
DENSITY	metric ton per cubic meter (t/m^3)	ton per cubic yard (ton/yd^3)	1 t/m^3	= 0.8428 ton/yd^3
	kilogram per cubic meter (kg/m^3)	pound per cubic foot (lb/ft^3)	1 kg/m^3	= 0.0624 lb/ft^3
FORCE	kilonewton (kN)	ton-force (tonf)	1 kN	= 0.1124 tonf
		kip [1000 lbf]	1 kN	= 0.2248 kip
	newton (N)	pound-force (lbf)	1 N	= 0.2248 lbf
MOMENT OF FORCE, TORQUE	kilonewton meter (kN•m)	ton-force foot (tonf•ft)	1 kN•m	= 0.3688 tonf•ft
	newton meter (N•m)	pound-force inch (lbf•in)	1 N•m	= 8.8508 lbf•in
PRESSURE, STRESS	megapascal (MPa)	ton-force per square inch ($tonf/in^2$)	1 MPa	= 0.0725 $tonf/in^2$
		ton-force per square foot ($tonf/ft^2$)	1 MPa	= 10.443 $tonf/ft^2$
	kilopascal (kPa)	pound-force per square inch (lbf/in^2)	1 kPa	= 0.1450 lbf/in^2
		pound-force per square foot (lbf/ft^2)	1 kPa	= 20.885 lbf/ft^2
WORK, ENERGY, QUANTITY OF HEAT	megajoule (MJ)	kilowatthour (kWh)	1 MJ	= 0.2778 kWh
	kilojoule (kJ)	British thermal unit (Btu)	1 kJ	= 0.9478 Btu
	joule (J)	foot pound-force (ft•lbf)	1 J	= 0.7376 ft•lbf
POWER, HEAT FLOW RATE	kilowatt (kW)	horsepower (hp)	1 kW	= 1.3410 hp
	watt (W)	British thermal unit per hour (Btu/h)	1 W	= 3.4121 Btu/h
		foot pound-force per second (ft•lbf/s)	1 W	= 0.7376 ft•lbf/s
COEFFICIENT OF HEAT TRANSFER [U-value]	watt per square meter kelvin (W/m^2•K) [=(W/m^2•°C)]	Btu per square foot hour degree Fahrenheit (Btu/ft^2•h•°F)	1 W/m^2•K	= 0.1761 Btu/ft^2•h•°F
THERMAL CONDUCTIVITY [k-value]	watt per meter kelvin (W/m•K) [=(W/m•°C)]	Btu per square foot degree Fahrenheit (Btu/ft^2•°F)	1 W/m•K	= 0.5778 Btu/ft^2•°F

NOTES: (1) The above conversion factors are shown to three or four places of decimals.

(2) Unprefixed SI units are underlined. (The kilogram, although prefixed, is an SI base unit.)

REFERENCES: NBS Guidelines for the Use of the Metric System, LC1056, Revised August 1977;
The Metric System of Measurement, Federal Register Notice of October 26, 1977, LC 1078, Revised November 1977;
NBS Special Publication 330, "The International System of Units (SI)," 1977 Edition;
NBS Technical Note 938, "Recommended Practice for the Use of Metric (SI) Units in Building Design and Construction," Revised edition June 1977;
ASTM Standard E621-78, "Standard Practice for the Use of Metric (SI) Units in Building Design and Construction," (based on NBS TN 938), March 1978;
ANSI Z210.1-1976, "American National Standard for Metric Practice."
ASTM E380-79$^{\epsilon}$, "Standard for Metric Practice."
IEEE Std. 268-1979, "Standard for Metric Practice."

ABSTRACT

The Proceedings of the Fifth Annual NBS/NCSBCS Joint Conference on Research and Innovation in the Building Regulatory Process contain 17 technical papers. This year's joint conference addressed solar energy and energy conservation.

These proceedings include papers on:

- Energy programs in the State of Colorado
- Building energy performance standards concepts
- State energy audits
- Energy and building systems services
- Solar energy and building codes

Key words: ASHRAE 90-75; Class K code; computer modeling; electrical design; energy audit; energy conservation; HVAC systems; performance standards; solar collector; solar energy; space heating and cooling; thermal storage.

DISCLAIMER

Papers in this volume, except those by National Bureau of Standards authors, have not been edited or altered by the National Bureau of Standards. Opinions expressed in non-NBS papers are those of the authors, and not necessarily those of the National Bureau of Standards. Non-NBS authors are solely responsible for the content and quality of their submissions.

The mention of trade names in the volume is in no sense an endorsement or recommendation by the National Bureau of Standards.

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*These papers were not presented at the Seminar.

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EVALUATION OF THE NONRESIDENTIAL ENERGY CONSERVATION BUILDING STANDARDS OF THE STATE OF COLORADO

by

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The purpose of this study was to evaluate the effectiveness of and the energy savings due to implementation of the Colorado Model Energy Efficiency Construction and Renovation Standards for Nonresidential Buildings. This report is based on information derived from case studies of 30 selected buildings in three geographic regions of Colorado. Half the sample was constructed before local enforcement of energy standards (1974-1977) and half after local enforcement (77-78). Estimated energy savings were obtained by computer modeling 15 pre-code buildings on nationally recognized energy simulation programs, then modifying results to reflect design requirements of State Standards. Thorough plan and specification checks of design documents were made on 15 post-code buildings to determine degree of compliance with energy standards.

The standards were found to be effective in reducing annual energy consumption in all building types and locations studied. The average annual reduction was estimated to be 39.5 percent for office buildings three stories and under, 40.9 percent for office buildings over three stories, 6.1 percent for schools, 31.2 percent for retail stores, and 27.7 percent for warehouses. Cost avoidance due to the standards for all buildings which have or will be constructed from 1979 through 1984 is projected to be $102,266,571. No significant increase in nonresidential construction costs has been incurred due to the standards, including inflationary effects. Very few post-code buildings were in full compliance with the State Standards, and were especially deficient in the areas of ventilation air, lighting switching, service water heating recovery, and slab on grade insulation. But it is doubtful that additional efforts to enforce these minor provisions would produce significant additional energy savings. Finally, the percent deviation of Colorado code buildings from BEPS varied widely among building types and locations.

The study recommends that the State statute mandating local enforcement of nonresidential standards be continued beyond January 1, 1980. Additional training in code requirements is essential, with new emphasis on cost impacts and benefits. A more simplified approach to lighting is needed, and more written forms and procedures are urged.

Key words: ASHRAE 90-75; BEPS; building standards; code enforcement; energy conservation; energy costs.

INTRODUCTION

This report presents the study of Colorado's experience with nonresidential energy conservation building standards. This study was conducted by Energy Management Consultants, Inc., for the Colorado Office of State Planning and Budgeting, the Colorado Office of Energy Conservation, and the Colorado Energy Research Institute, and pursuant to 29-12-103 (4), Colorado Revised Statute (CRS) 1973, as amended:

> "The Office of State Planning and Budgeting shall evaluate the effectiveness of and calculate the energy savings due to the Standards promulgated by the Board and report the results of their evaluation to the General Assembly on or before December 1, 1979."

The information on which this report is based was derived from case studies of selected buildings in three geographic regions of Colorado, and a survey of local officials and building industry representatives throughout the State.

It is intended that this study will provide the State with suggestions for amendments to the technical provisions of the Colorado Model Energy Efficiency Construction and Renovation Standards for Nonresidential Buildings, the State enabling legislation, and State and local administrative procedures which might ease local implementation of energy standards, lessen their fiscal impact, and increase their energy and cost efficiency.

BACKGROUND OF THE COLORADO STANDARDS

In 1977 the Colorado General Assembly foresaw a critical energy situation and enacted Senate Bill 432, which required local adoption of nonresidential energy conservation building standards. Its action was timely; construction activity in the State was increasing and fuel prices would soon rise sharply. The legislature also had to consider Colorado's unique environment--climatic diversity, local building code enforcement, and the urban/rural dichotomy of the State.

Senate Bill 432 of 1977, "Concerning the Establishment of Energy Efficient Construction and Renovation Standards for Nonresidential Buildings," contained the following important provisions:

- It affected most new nonresidential construction and substantial renovations, but exempted buildings such as hotels, apartments, and historic structures from energy standards.
- It established a Nonresidential Board under the Office of State Planning and Budgeting (OSPB) and required it to adopt model standards for nonresidential buildings by November 1, 1977.

- It required local governments with building codes to adopt and enforce equal or more stringent nonresidential standards beginning July 1, 1978. There were no sanctions for non-compliance.

- It mandated that OSPB establish a continuing program of training and technical assistance.

- It appropriated Federal funds to OSPB for implementation of a State program.

- It sunset on January 1, 1980.

Following its appointment, the Board of Energy Efficient Nonresidential Building Standards reviewed energy programs on the Federal, State and local levels, finally choosing to follow the direction of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90-75. After public hearings around the State, the board adopted the Colorado Model Energy Efficiency Construction and Renovation Standards for Nonresidential Buildings on November 1, 1977.

In October of 1978, the Colorado Division of Housing reported that 73 percent of local jurisdictions with building codes had adopted nonresidential standards and 16 percent were in process. These 175 complying jurisdictions represented 95 percent of the State's total population.

TECHNICAL CONTENT OF THE COLORADO STANDARDS

The Colorado Model Energy Efficiency Construction and Renovation Standards for Nonresidential Buildings are based on the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) Standard 90-75, with minor revisions to make the standards Colorado-specific.

The standards establish specific, well-defined performance criteria for each of the elements involved in building design and construction which are related to the energy usage of the building. These elements or components include walls, ceilings, windows, heating, ventilating and air-conditioning (HVAC) systems, lights, etc. It allows the criteria of any one or more of these elements to be substantially relaxed, if it is offset by a corresponding energy reduction in other elements.

The standards consider local climate conditions, and most building types and materials. Credit for the use of non-depletable energy sources, such as solar, are allowed and it provides three different methods of compliance--including a procedure for small commercial buildings which requires no thermal analysis.

METHODOLOGY OF THIS STUDY

In order to evaluate the effectiveness of the Colorado Nonresidential Building Standards and determine any energy savings due to the standards promulgated by the board, the following methodology was used.

Selection of Geographic Regions

Three geographic regions in Colorado were selected. These regions represent a cross section of the economic, population and climatological factors in the State. They are also areas of considerable nonresidential construction activity.

- City of Denver and Surrounding Metropolitan Area. Represents the Front Range, East Slope and primary population areas.

- Grand Junction/Rifle Area. Represents the rural and urban West Slope and energy development areas.

- Eagle/Vail Area. Represents the mountain recreation and rural areas.

Selection of Building Sample

Five building categories were studied in each geographic region:

- Office buildings, three stories and under;

- Office buildings, greater than three stories;

- Schools (elementary, middle and high schools);

- Retail stores (discount drug, furniture, and lumber supply);

- Warehouses.

Two buildings from each region were investigated, 15 were constructed before local enforcement of energy standards, and 15 were designed and constructed after local enforcement of energy standards. In most cases, the pre-code buildings studied were constructed between 1974 and 1977, while the post-code buildings were designed and constructed after July 2, 1978.

In all cases, each building studied was considered "representative" of most buildings in that particular category, for the particular region, and for the time period when it was constructed. In order to determine the characteristics of representative buildings and to select the building sample, a building design criteria questionnaire was mailed to selected architects, engineers, and contractors. On-site building investigations were conducted and actual energy usage and energy cost experiences of buildings were considered in determining representative structures.

Thus, the study results are predicated on the assumption that these 30 buildings are, in fact, representative of most buildings constructed or designed in the specific region, building category, and time period under investigation.

Energy Analysis of Pre-Code Buildings

On-site surveys were conducted on 15 pre-code buildings to obtain physical data, which was then duplicated on computer models using nationally recognized energy simulation computer programs. The complex heated and air-conditioned buildings were modeled on the Energy Simulaation Program #1 (ESP-1) and the more simplistic buildings that were heated only were modeled using the Quick Energy Simulation Program (QUICKE). The model was validated by comparing the computer estimated energy usage of the pre-code buildings to the actual utility records of that building. In all cases, the accuracy of the computer simulation was within 10 percent of the actual metered data for the last year's historical energy consumption.

The computer model was then modified to reflect the design changes which would have had to be made to the building to make it comply with the Colorado Energy Conservation Standards for Nonresidential Buildings. The difference in energy usage between the two models thus represented the average energy savings which could be attributed to compliance with the State standards for each category of building in each region.

Computer modeling was used to estimate and compare the energy usage of a pre-code and post-code buildings because computer modeling cancels out variables not regulated by the State standard, such as daily operating schedules, quality of maintenance, etc. Through computer modeling a comparison was obtained based solely on the design factors which are influenced by the Colorado standards, such as changes to the building envelope, lighting, type and method of controlling mechanical equipment.

Investigation of Post-Code Buildings

The plans of 15 post-code buildings designed after local implementation of energy standards were examined to determine if they complied with the State standards. This investigation included a thorough plan and specification check of the design documents, and the completion of a Standards Compliance Check list. All 15 post-code buildings were certified by an architect or engineer as complying with local Energy Conservation Building Standards.

Survey of the Building Industry

Concurrently with the building analysis and investigation, questionnaires were mailed and personal interviews were conducted with representatives of the building industry across the State, including:

- Local building code officials
- Mechanical and electrical engineers
- Architects
- Contractors

- Materials and equipment suppliers

- Building owners and managers

The interviews and questionnaires were evaluated to:

- Help determine the extent of local enforcement and compliance of non-residential energy conservation building standards.

- Identify barriers to enforcement, compliance, and administration of energy standards, including conflicts with existing codes.

- Help evaluate the cost impact of energy standards.

- Help determine the energy savings as a result of the standards.

- Determine the effectiveness of the State program of training and technical assistance.

STUDY RESULTS

Energy Savings

Under strict interpretation of the Code, the Colorado Energy Conservation Standards for Nonresidential Buildings are effective in reducing annual energy consumption in all building types and locations studied. The energy savings resulting from the redesign of the pre-code buildings studied are shown in figures 1, 2 and 3.

The average (for all geographic areas) reduction in annual energy consumption for buildings constructed in compliance with the State Standards, as compared with buildings constructed immediately prior to Standards enforcement, was as follows:

AVERAGE REDUCTION IN ANNUAL ENERGY USAGE

(ALL GEOGRAPHIC AREAS)

BUILDING TYPE	PERCENT REDUCTION
Office buildings, three stories and under	39.5
Office buildings, over three stories	40.9
Schools	6.1
Retail stores	31.2
Warehouses	27.7

Figure 1: Pre-Code/Post-Code Energy Comparison-Denver

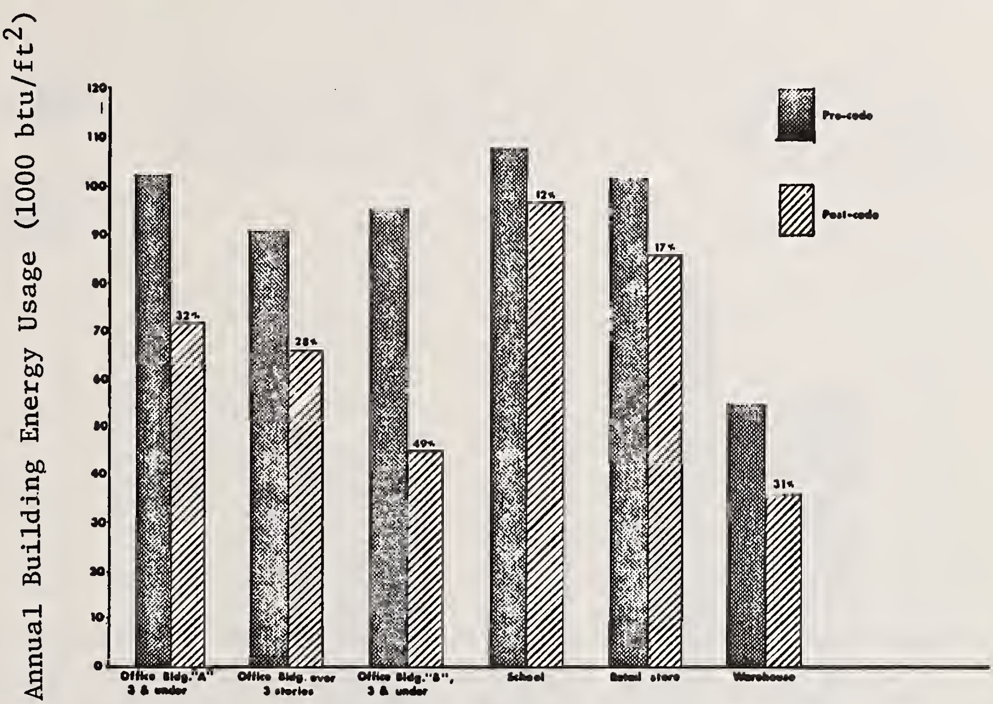
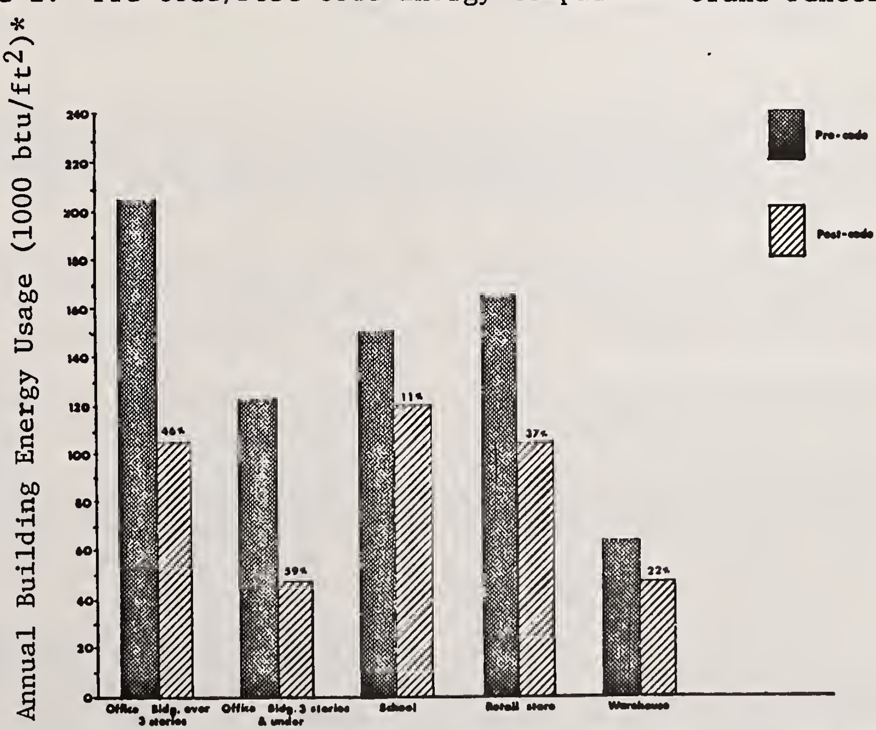
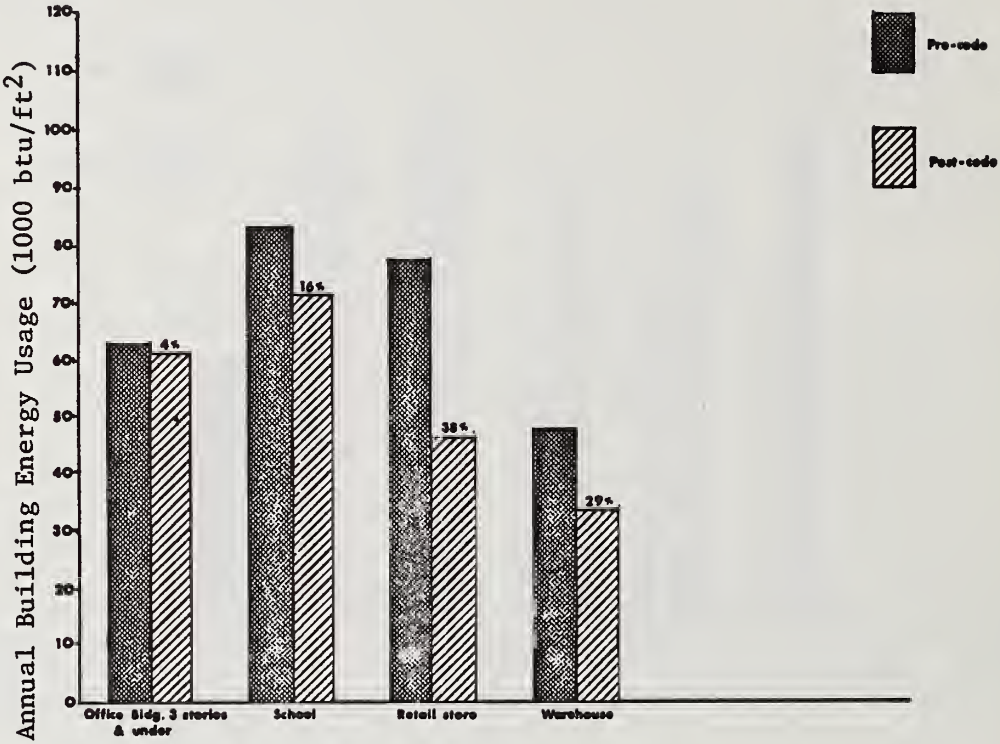


Figure 2: Pre-Code/Post-Code Energy Comparison-Grand Junction/Rifle



*Due to higher energy range of buildings studied in this area, a different scale was used then in figures 1 and 3.

Figure 3: Pre-Code/Post-Code Energy Comparison-Eagle/Vail



For the most part, this energy reduction was accomplished primarily by applying the following provisions of the State standards.

- o Night set back on permanent (24 hour) temperature set down
- o Control sequencing of the heating and cooling devices
- o Reduction in outside air provided to the building to meet other code requirements (i.e., reduced ventilation)
- o Upgrading of the building envelope primarily in the roof and window area and the addition of exterior slab insulation
- o Reduction in lighting capacity

Assuming that the pre-code buildings investigated are representative of the majority of pre-code buildings throughout the State, and assuming that the State standards are strictly enforced, the resulting energy savings can be projected through the end of 1984, by using construction projections developed by the Office of State Planning and Budgeting:

PROJECTED ENERGY SAVINGS

1979-1984

Building Type	Total Estimated Sq. Ft. of Construction (Thousands of Square Feet)	Total Estimated Energy Savings (Billions of Btu's)
Office buildings*	54,927	2,076
Schools	13,091	76
Retail stores	44,247	2,024
Warehouses	46,749	764
TOTAL	159,014	4,940

*Construction projections were not available for each office building category studied. The percent energy reduction determined in the study was averaged and applied to the total office building construction projection.

Energy Cost Impact

The projected energy savings were converted to energy cost savings or, more correctly, energy cost avoidance. The conversion to cost was based on the average energy costs during 1979 for nonresidential buildings in Colorado: $0.035 per kWh for electricity and $2.50 per MCF for natural gas.

These costs were then escalated at 15 percent per year through 1984. This rate of energy cost escalation is considered to be conservative for this period of time.*

The projected cost avoidance for all buildings in the categories studied which have or will be constructed from 1979 through 1984 which can be attributed to energy reduction from the State standards is as follows:

- Actual Total Dollar Cost Avoidance: 1979 - 1984 — $102,266,571
- In terms of January 1979 dollars (using 10 percent cost of capital), the cost avoidance is: — $ 57,726,810

* Since the study was completed in November 1979, electrical costs have risen 30 percent during the first 6 months of 1980.

ECONOMIC IMPACT

Initial Construction Costs

Analysis of actual cost data for the State of Colorado, compiled by the F.W. Dodge Division of McGraw-Hill, indicates no significant increase in nonresidential construction costs since the passage of energy conservation legislation in July of 1977. The trends for each building type from January 1977 through December 1979 are illustrated in figures 4 and 5. Actual contracts for new construction, additions, and major alteration projects are represented on the graphs by solid lines, and the average construction cost trends are represented by dotted lines.

Retail store and office building costs increased approximately $4.00/sq. ft. and $3.00/sq. ft. respectively, while school and warehouse costs decreased approximately $3.00/sq. ft. and $0.50/sq. ft., respectively. Since the overall changes in costs were less than the average annual inflation rate, in real terms the nonresidential construction costs have actually declined over the period. (Figures 4 and 5 illustrate the nominal price change.)

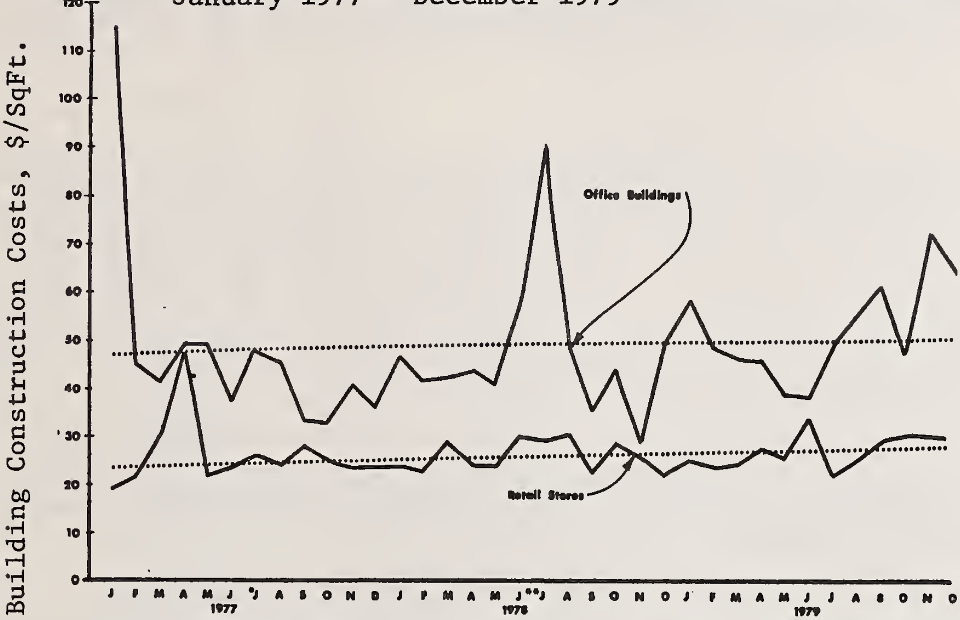
This data and interviews with representatives of the Associated General Contractors seems to indicate that construction costs are more dependent upon the competitive market at the time than any other factor. Other factors contributing to building cost changes include:

- Material shortages and allocations;
- Increased amount of construction in the area;
- Life/safety code modifications;
- Fuel cost and availability;
- Environmental standards and regulations;
- Contractor profit margin;
- Cost trade-offs in selection of building components.

The questionnaire results indicate a dual effect. Compliance with the State standards can cause an increase in the cost of certain building components. However, these costs are often offset by reduced costs in related building components. For example, the State standards require a minimum insulating value for the building envelope, which in most cases costs more. This increase is offset through a substantial reduction in the number and/or size of heating, ventilating, and air-conditioning systems.

The study concludes that the net cost effect directly attributable to the State standards for nonresidential buildings may vary among

Figure 4: Nonresidential Building Construction Costs, COLORADO
January 1977 - December 1979



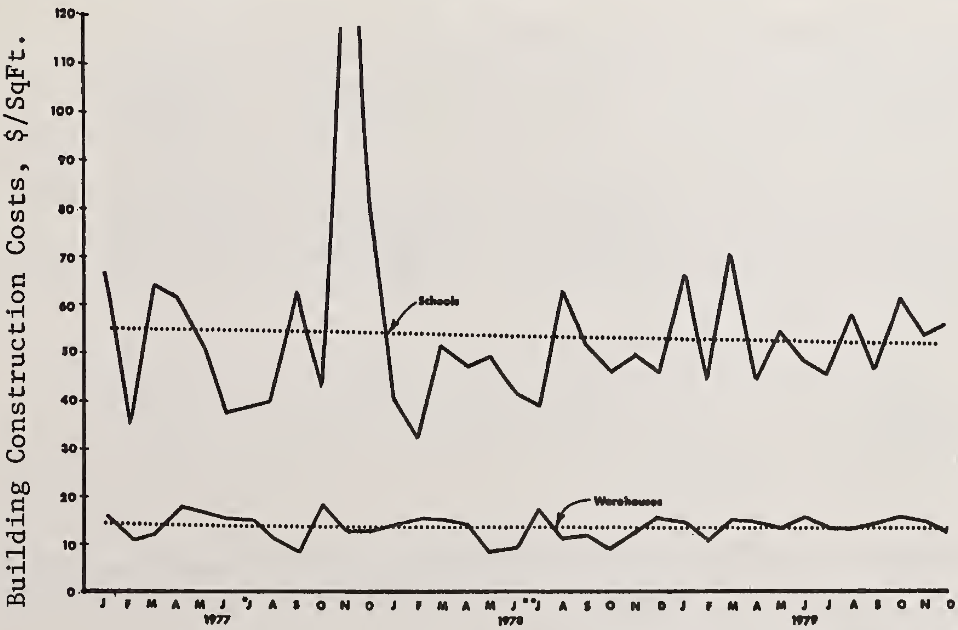
.... Average Construction Cost Trend

——— Actual Construction Costs

*July 1, 1977 Energy Legislation passed

**July 1, 1978 Local enforcement of energy codes required

Figure 5: Nonresidential Building Construction Costs, COLORADO
January 1977 - December 1979



.... Average Construction Cost Trend

——— Actual Construction Costs

*July 1, 1977 Energy Legislation passed

**July 1, 1978 Local enforcement of energy codes required different buildings, but it is minimal when viewed as a percent of the total building dollars. If additional costs are incurred as a result of the standards, owners of new nonresidential buildings can expect a substantial reduction in utility costs, and enjoy continued utility cost savings as a net annual benefit thereafter.

Local and State Administrative Costs

Local code officials reported an average increase of 5 percent in administrative costs as a result of implementation of nonresidential energy conservation building standards. Half of those responding, however, indicated little or no increase. All stated that they enforce energy conservation standards to the extent their existing budgets allow. Most relied heavily on an architect's or engineer's (A/E) certification as proof of compliance, and they perform spot checks as their time permits.

The Legislature's decision to allow a building official to accept A/E certification as proof of compliance appears to have significantly lessened the potential impact of nonresidential energy conservation standards on local government budgets.

Since July 1977, approximately $200,000 in Federal funds have been allocated by the U.S. Department of Energy to the State for the administration of this program. These monies have been used to provide training and technical assistance to local governments and members of the building industry; to coordinate activities with national organizations and code-writing groups; to develop, adopt, publish, and distribute the State Model Standards, related forms and procedures; and to support administrative staff.

Compliance With Standards, Post-Code Buildings

The plans and specifications of 15 buildings designed or constructed after local adoption of energy standards were reviewed to determine compliance with the State Energy Standards. Very few, if any, of the buildings were in full compliance with the State standards. Most of the difficulty was in meeting the requirements for mechanical service water heating, lighting, and below grade perimeter insulation. All of the building envelopes checked met the State standards with the exception of one warehouse in the Denver area.

The following deficiencies were found in more than one of the building plans investigated:

- Ventilation air too high;
- Window/door air leakage not specified;
- Light switching unspecified;
- Service water heater recovery efficiency inadequate;
- Slab on grade insulation missing.

While it appears that a majority of new buildings do not comply completely with the Colorado Energy Conservation Standards for Nonresidential Buildings, it is doubtful that additional efforts to enforce these minor provisions would produce significant additional energy savings.

BUILDING INDUSTRY FEEDBACK

Comments from representatives of the building industry were extensive. Some of the more significant statements from questionnaires and personal interviews are presented below.

Local Enforcement and Compliance

- Eighty-seven percent of the building officials responding stated they are enforcing Energy Conservation Standards for Nonresidential Buildings.

- Seventy percent of the building officials responding felt the standards are understood by the applicant; however, only 55 percent of the architects, engineers, and contractors believed the Standards are understood by local building officials.

- Building officials responding estimated that 15 to 20 percent of the plans submitted to them either failed to meet the standards or failed to provide sufficient information in the form of calculations, etc.

Administration

- Building officials felt they needed more support from local elected officials on nonresidential energy conservation building standards. They suggested increased communication with the local community and greater consideration of budgetary impacts.

- Almost no building officials allowed formal variances to the Nonresidential Standards (although enabling legislation permits variance proceedings). Building officials appear to be handling such problems informally and within the scope of the standards.

- Architects, engineers, and contractors expressed concern about the delays caused by the compliance review process. Delays should decrease, however, as industry becomes more familiar with nonresidential standards through usage and technical assistance.

Technical Provisions

There was general agreement among building officials and private industry regarding the following technical problems:

- Information on energy efficiency of new materials and methods is difficult to obtain. Manufacturers often do not provide it, and independent laboratory data is not readily available;

- o The lighting portion of the State Standards demands complicated calculations, and is difficult to meet and enforce. The Nonresidential Board should consider amending this portion of the standards;

- o Self-closing faucets and service water heaters that meet the requirements of the Standards are not readily available on the Colorado market. The Nonresidential Board should consider amending these portions of the standards until distribution of these materials is more widespread;

- o A few portions of the State standards appear to be in conflict with ventilation and electrical codes. Note, however, that the State standards do not take precedence over existing health and safety codes. It should also be mentioned that the code-change cycles of many organizations are not in sequence, and this may cause short delays in uniformity;

- o Although 85 percent of the building officials responding said they perferred a performance-based standard, they requested that simple language and methods be developed to ease enforcement.

Cost Impact

Most representatives in all categories agreed that it is very difficult, if not impossible, to estimate the actual cost-impact of the State standards because of the concurrent effect of inflation during the last few years.

- o Local building officials estimated that administrative costs have increased an average of five percent due to implementation of the standards. The ability to accept architect/engineer certification appears to have lessened potential impact;

- o Architects, engineers, and contractors estimated that their administrative and design costs have increased approximately nine percent as a result of additional review and calculations required by the standards. This impact should decrease as professionals become more familiar with the standards through usage and technical assistance;

- o Architects, engineers, and contractors estimate that overall nonresidential building costs have increased an average of 2.6 percent as a result of implementation of the standards.

Energy Impact

The following estimates of average energy savings were reported:

Respondent	Electrical	Fuel
Building officials	9.4%	13.4%
Architects, engineers, and contractors	14.8%	18.4%

State Program of Training and Technical Assistance

- o All but one building official responding had attended a State sponsored program. They suggested that training be more basic, more extensive, and for longer periods of time. They requested more easy-to-follow graphs, charts, and manuals. Many indicated they have problems getting time off for training;

- o Seventy percent of the architects, engineers, and contractors responding, had attended a State sponsored training program and most felt it was adequate. They requested smaller training groups and better notification of sessions;

- o A majority of the material and equipment suppliers responding had not attended State training.

Other Significant Comments

- o Architects and engineers believed that most owners of buildings in the private sector are not willing to spend more money than is necessary to meet the minimum standards because they perceive an additional cost impact. Owners also desire more glass than the standards consider energy efficient;

- o Architects and engineers believed few speculative buildings would comply with the State standards if they were not mandatory;

- o Building officials requested that State and local lawmakers consider the whole issue of code enforcement, including local budget and manpower impacts;

- o Almost all building officials, architects and engineers responding believe the Board of Energy Efficient Nonresidential Building Standards has been representative, fair and effective in carrying out its duties;

- o A majority of respondants wanted only guidelines from the Federal Government. They felt that State and local governments should be responsible for specific code language and code enforcement.

COMPARISON OF ENERGY CONSUMPTION PREDICTIONS AND STANDARDS

Tables 1, 2, and 3 present four energy consumption indices for each of the pre-code buildings at the three site locations. These four indices were computed on the following basis:

- Present Annual Building Boundary Energy Consumption (Btu/ft^2). These values of energy consumption index were obtained from computer simulations of the buildings as they presently exist. They represent an operational rather than a design condition;

- Redesign Annual Building Boundary Energy Consumption (Btu/ft^2). These values were obtained from computer simulation of operational consumption based on computer simulations of the buildings, incorporating design modifications necessary to bring the buildings within compliance of the State Code;

- "BEPS" Design Building Energy (Btu/ft^2). These are design values obtained from the Federal Building Energy Performance Standards (BEPS). They represent limiting consumption budgets for hypothetical buildings in each of the various categories under design rather than actual operating conditions;

- Redesign Operational Energy Consumption (Btu/ft^2). These values were obtained by adjusting the second group of values, according to BEPS guidelines, to reflect total operational consumption (i.e., including losses by electric power companies in providing energy to the building boundary).

The percent deviation from BEPS budget indicates the percent differences between the Operational Energy Consumption and the "BEPS" Design Energy Budget. This comparison is considered to be of limited value, because the Operational Energy Consumption reflects actual operating conditions, whereas the Design Energy Budget reflects assumed operating conditions.

CONCLUSIONS AND RECOMMENDATIONS

The Colorado Energy Conservation Standards for Nonresidential Buildings are unquestionably effective in saving substantial amounts of energy, which results in equally substantial energy cost avoidance. There is no significant overall cost impact to achieve those savings in the nonresidential sector, other than the administrative cost to State and local governments.

Where additional costs are incurred by some building owners, they can expect a substantial reduction in utility costs and enjoy continued utility cost avoidance as a net annual benefit thereafter. A program of efficient operation and maintenance of the resulting energy efficient building could provide owners even more opportunities to save energy.

The standards appear to be enforced to some degree in most locations in the State of Colorado. While most new buildings do not comply completely

Table 1: Comparison of Redesign Energy Consumption With Building Energy Performance Standards (BEPS) Budget

DENVER

BLDG. NO.	BUILDING CATEGORY	ENERGY CON- GROSS AREA FT^2	PRESENT ANNUAL BLDG. BOUNDARY ENERGY CON- SUMPTION BTU/FT^2	REDESIGN ANNUAL BLDG. BOUNDARY ENERGY CON- SUMPTION BTU/FT^2	"BEPS" DESIGN ENERGY BUDGET BTU/FT^2	REDESIGN OPERATIONAL ENERGY CON- SUMPTION BTU/FT^2(1)	PERCENT DEVIATION FROM BEPS BUDGET
1.	Office Building Over 3 Stories	484,523	91,995	66,110	109,000	171,961	+ 58
2.	Office Building A Under 3 Stories	65,610	107,000	71,000	109,000	186,466	+ 71
11.	Office Building B Under 3 Stories	20,760	90,500	45,600	100,000	120,282	+ 20
3.	School	42,845	110,907	97,540	97,000	159,222	+ 64
4.	Retail Store	30,000	105,000	86,500	137,000	266,420	+ 94
5.	Warehouse	84,256	54,800	37,300	71,000	73,983	+ 4

(1) Boundary consumption converted for BEPS comparison, using proposed BEPS weighting factors.

Table 2: Comparison of Redesign Energy Consumption With Building Energy Performance Standards (BEPS) Budget

GRAND JUNCTION/RIFLE

BLDG. NO.	BUILDING CATEGORY	GROSS AREA FT^2	PRESENT ANNUAL BLDG. BOUNDARY ENERGY CON- SUMPTION BTU/FT^2	REDESIGN ANNUAL BLDG. BOUNDARY ENERGY CON- SUMPTION BTU/FT^2	"BEPS" DESIGN ENERGY BUDGET BTU/FT^2	REDESIGN OPERATIONAL ENERGY CON- SUMPTION BTU/FT^2(1)	PERCENT DEVIATION FROM BEPS BUDGET
6.	Office Building Over 3 Stories	104,688	213,396	113,672	109,000	304,944	+ 280
7.	Office Building Under 3 Stories	52,600	121,000	48,600	109,000	120,518	+ 11
8.	School	43,492	115,000	102,000	118,000	140,078	+ 19
9.	Retail Store	27,100	162,000	102,000	137,000	272,611	+ 99
10.	Warehouse	181,000	60,900	47,300	71,000	79,469	+ 12

(1) Boundary consumption converted for BEPS comparison, using proposed BEPS weighting factors.

Table 3: Comparison of Redesign Energy Consumption With Building Energy Performance Standards (BEPS) Budget

EAGLE/VAIL

BLDG. NO.	BUILDING CATEGORY	GROSS AREA FT^2	PRESENT ANNUAL BLDG. BOUNDARY ENERGY CONSUMPTION BTU/FT^2	REDESIGN ANNUAL BLDG. BOUNDARY ENERGY CONSUMPTION BTU/FT^2	"BEPS" DESIGN ENERGY BUDGET BTU/FT^2	REDESIGN OPERATIONAL ENERGY CONSUMPTION BTU/FT^2 (1)	PERCENT DEVIATION FROM BEPS BUDGET
12.	Office Building Under 3 Stories	22,063	62,872	60,307	100,000	185,746	+ 86
13.	School	53,789	84,200	70,200	118,000	103,792	+ 12
14.	Retail Store	5,580	77,900	47,900	137,000	94,964	+ 31
15.	Warehouse	17,600	49,200	34,700	71,000	106,876	+ 51

(1) Boundary consumption converted for BEPS comparison, using proposed BEPS weighting factors.

with the standards, it is doubtful that additional efforts to enforce those minor areas of noncompliance would produce significant additional energy savings.

Problems with the State standards certainly do exist and continued efforts for improvement are in order. But these problems do not appear to be inordinate for the implementation of such a bold new concept.

There is a need for more training of the building industry, particularly at the local enforcement level. A special effort should also be made to include contractors and materials suppliers in the State Program. Additional training and information on cost impacts and benefits would also be worthwhile, especially in the private sector.

The following recommendations are offered:

- o The State standards should be continued and improved as problem area feedback is received and as the state-of-the-art advances;
- o The lighting portion of the standards should be completely revised to permit a more simplified approach;
- o Standard forms should be developed by the State and made available to local building code officials for checking compliance.

- The State program of training and technical assistance should be continued and improved, particularly for local enforcement officials;

- The State and the building industry should pursue additional energy and cost savings through a program of efficient operation and maintenance of existing nonresidential buildings.

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ALTERNATE OPTIMAL CONTROL STRATEGIES FOR RESIDENTIAL HVAC SYSTEMS

by

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The optimal control of HVAC systems on an hourly basis is determined both by the thermal inputs which precede the hour under question and by future thermal effects. Most simulation programs treat only the past history. This paper describes results obtained with a special program which optimizes the use of the HVAC system in conjunction with natural and artificial lighting and with other thermal load schedules by considering such future effects.

The results indicate that substantial savings can occur through such a look-ahead optimization and that the extent of the needed future knowledge for most residential structures is in the neighborhood of a few hours. It is also shown that such an optimization is more valuable for the gradual changes associated with the usual weather than with rapid changes of internal thermal loads.

Key words: Cost savings; energy conservation; HVAC systems; innovation; mathematical model; optimization.

INTRODUCTION

During recent years, changes in the availability, cost, and strategic value of energy have caused the conservation of energy to be both an economic and a social goal of all nations, but particularly of the highly industrialized countries. It is no accident that these countries also lie in climatic zones where substantial amounts of energy (approximately 20 percent) are used for space conditioning. Although it would appear that sizable reductions in overall energy usage could be achieved by modest reductions in the space conditioning requirements, such reductions are not easily realized since they often involve substantial modifications to the habitat, of the occupants' lifestyle, and particularly since they involve the sensory perceptions of human comfort. Furthermore, the indiscriminate alteration of the internal micro-climate may lead to unexpected side effects which are difficult for the technically inexperienced user to correct. For example, in the temperate zones of the United States it is possible to achieve a five-fold reduction in heating requirements by improved insulation, reduced infiltration and night set-back, and a general reduction of the space temperature. Unfortunately, such a strategy may result in inadequate fresh air supply and in unacceptable levels of moisture condensation. Alleviation of these effects can be achieved by installing air-to-air heat exchangers [2]* and insulated glazing. The owner of the structure may very well feel that the practice of conserving energy has gotten out of hand. For this and for other reasons, we find that really significant reductions in energy usage are often confined to the energy activist (e.g., solar enthusiast), to the technically trained (engineers) who practice on their own houses, or to the commercial building owners who can afford the detailed engineering analysis and the cost of such major improvements.

Another approach is possible, and it is associated with the availability of micro-processors by which the HVAC system may be controlled. Such micro-processors can be programmed to take into account the external weather conditions, the dynamic response characteristics of the structure and of the HVAC system and the internal loads of the space, and to operate the HVAC system in an optimal manner. In a forthcoming paper [3], Emery et al. discuss the use of a modern control theory to develop an optimal strategy for a residential HVAC system. They show that such a theory could be used effectively to reduce the total operating costs of residential space conditioning by controlling the operation of lights, shades, ventilation, and the HVAC system in conjunction with prescribed internal loads of people, equipment, moisture generation, and with the external weather conditions. They also demonstrate that the method can be used as a teaching tool to acquaint the building designer with the different thermal behavior of various building components and how the several components interact with each other and with external and internal conditions. This theory is based upon controlling the deviation of

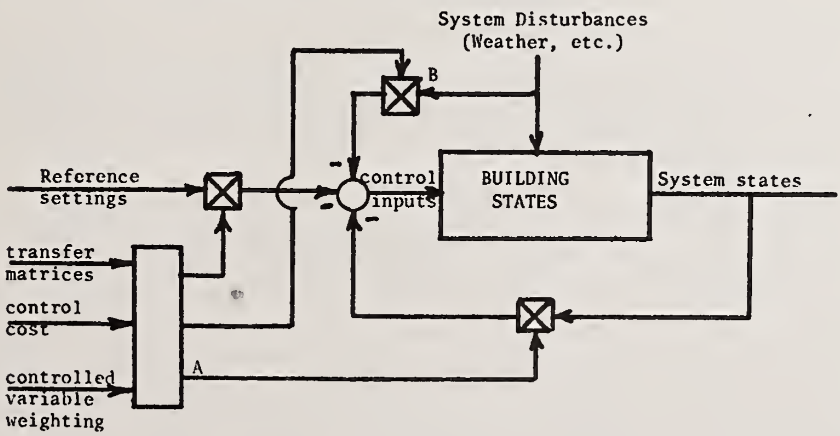
*Number in brackets refer to references at end of text.

several pertinent quantities from prescribed values (e.g., set points) in such a way as to minimize the cost of operation. In this approach, cost is interpreted in the most general sense, that is, as the value associated with the allocation of resources and with a specific penalty defined for not achieving a desired state. For example, an occupant can specify that the economic value of fuel is greater or lesser than the value associated with the discomfort which results from not maintaining a desired temperature or with an inadequate amount of daylighting. The results reported in Reference 3 are examples of the initial use of optimization theory to space conditioning. In this paper we wish to extend these previous results to show how further gains may be achieved. Although the optimization techniques presented here are capable of considering very complex situations and user requirements, the example presented is a very simple one. This simple example was used to show the basic usefulness of the method without confusing the reader by introducing too many refined details.

MATHEMATICAL MODEL

Consider the simple control schematic shown below:

Figure 1: <u>Schematic of Control System</u>



Here the definitions are:

- x the system state variable (e.g., room temperature)
- u the control variable (e.g., heating from HVAC system)
- e the external variables (e.g., ambient weather)
- A the function which relates the values of x at the next time to the values at the current time
- B the function which relates the values of x at the next time to the values of the external variables, e
- C the function which relates the values of x at the next time to control variables, u at the current time

These quantities are related through an equation of the form

$$x(i+1)=A(i) \cdot x(i)+B(i) \cdot e(i)+C(i) \cdot u(i) \qquad \text{Eq. (1)}$$

where the coefficients A, B, and C are determined through an energy balance on the structure. By using a network approach in which different masses of the structure are represented by nodes [4,5], one can write an equation like Eq. (1) for each node. Since the optimal control of the building requires many state and control variables, x and u are vectors, not point functions, and A, B, and C are matrices of influence functions (sometimes called gain, transfer, or transition functions). The control inputs, u, are determined through the feedback loop by

$$u(i) = -F(i) \cdot x(i) \qquad \text{Eq. (2)}$$

Because conditions change with time (e.g., surface heat transfer coefficients depend upon the wind velocity and direction), the matrices A and B also change with time. C usually changes only when the user wishes to change the manner or the degree to which a control variable affects the system. For example, if the HVAC system is turned off at a given hour, then the appropriate matrix elements in C must be set to zero. Since there are usually more system defining variables, x, than one wishes to consider as variables to be controlled, we introduce the subset of controlled state variables, z, and define the deviation of the system from the set points by

$$d(i)=z(i)-z^*(i) \qquad \text{Eq. (3)}$$

where z*(i) is the set point value. Finally, we define a penalty function J, whose value is a minimum whenever the system operating strategy is optimal. J may be expressed as

$$J = P(N)d^2(N) + \sum_{i=1}^{N-1} (R_1(i+1)d^2(i+1)+R_2(C)u^2(C)) \qquad \text{Eq. (4)}$$

or in the verbal form as

J = terminal cost	Pd^2
+ enroute cost	R_1d^2
+ control cost	R_2u^2

The terminal cost is that associated with not meeting the target values at the final hour; the enroute costs, with not meeting the intermediate target values; and the control costs, with the price of performing the control functions. The use of the sum in Eq. (4) is necessary since one frequently wishes the optimal strategy to be calculated over a given period of time, N hours, such that the system can anticipate changes in the set points or in the control functions (e.g., night set-back) or in the weather. In all of the results reported in Reference 3, no anticipation was considered, N=1, and there were no enroute costs.

Since the simulations were based upon a discrete sequence of events rather than a continuous system, Eq. (1), (2), (3), and (4) were applied on an hourly basis because: (a) weather data is usually available only on an hourly basis; (b) previous simulations have shown that the building response is adequately predicted using an hourly increment because of the thermal inertia of the structure; and (c) the expense of solving the matrix equations was much lower [4,5].

The solution to the optimal strategy problem outlined above is called the discrete-time deterministic linear optimal regulator problem, and is based upon dynamic programming [1].

In determining the optimal strategy, one must recognize that the system is subject to a number of constraints. These constraints are associated with the HVAC system, physical limitations on the system or the structural response, and with the demands of the occupants. Some of these constraints relate to those system variables which incur no penalty for a small degree of deviation from the set point, but a very high penalty for any deviation above a defined amount. Such a situation arises in the fresh air requirement. As long as there is a minimum amount of fresh air, no penalty exists. Whenever the fresh air changes fall below the health or occupational standards, then the penalty is set to such a high value that the required amount will always be made available. Others refer to variables which are assigned a penalty for any deviation, for example the room air temperature set point. Others refer to physical limitations on the control variable; e.g., a damper has a limited movement; or to user defined limits, e.g., the user may specify that the cost of a given control function cannot exceed a given amount.

To use Eq. (4) to determine the optimal strategy when one wishes to take future schedules or anticipated weather patterns into account, one must recognize that the coefficients of the equation change discontinuously. These discontinuous changes prevent the analytic determination of the optimal strategy and force the optimization to use an iterative procedure. These discontinuities are caused by constraints such as the shade position which is limited to range from fully open (1.0) to fully closed (0.0) rather than the open range from 0 to infinity. They are also caused by the nature of the HVAC system whose operation follows one of the following actions in an effort to provide supply air at a prescribed temperature:

1) Return air is mixed with the outside air to yield the required supply air temperature without any heating or cooling of the air - this is the economy cycle.

2) The system uses all outside air and tempers it accordingly.

3) The system uses the minimum amount of outside air which will satisfy the fresh air requirement and the maximum amount of return air.

In addition to following one of the above actions, the HVAC system is also constrained by the following:

4) The system can supply sufficient air to maintain the space at the thermostat setting.

5) The system has inadequate capacity to provide the desired supply air temperature.

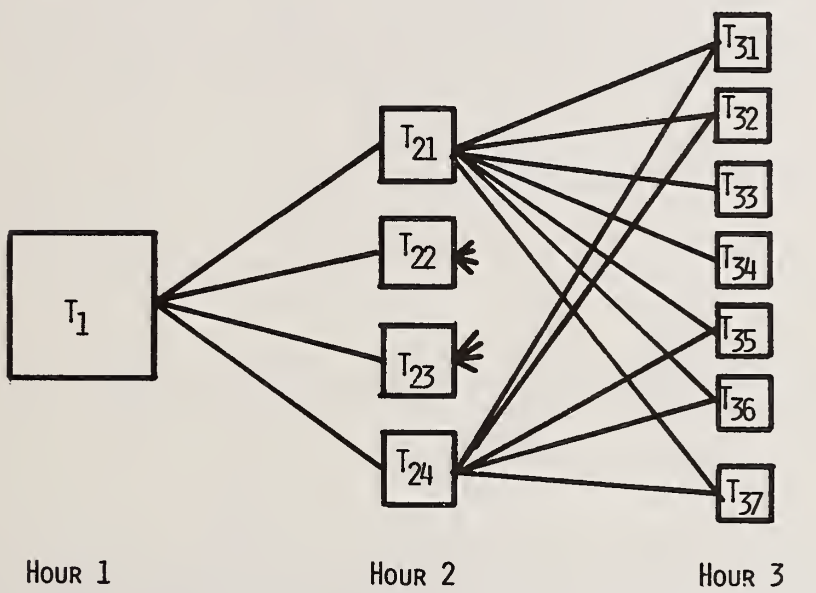
6) The system has adequate capacity, but the supply air rate is inadequate to convey enough heating or cooling energy into the space to satisfy the thermostat.

Of the above possibilities, only 4) is acceptable, while 5) and 6) lead to spaces which are too cold or too warm. Furthermore, the form of Eq. (4) which results from each of the possibilities (1-6) is substantially and significantly different with the consequence that one cannot define a continuous solution over the range of possible actions. The resulting iterative solution, using the dynamic programming technique of Reference 3 is time consuming, requires large amounts of computer core, and is computationally expensive.

Accordingly, we tested and adopted an optimization technique based upon a variant of the transportation algorithm. The process consists of starting from hour 1 with a given set of initial conditions, at room temperature T_1 and determining the minimum and maximum temperatures which could exist at hour 2 when the system was off and when operating at its maximum capacity, respectively. Only those temperatures falling within physically acceptable limits will be considered. This temperature range is then divided into i specific temperature values T_{2i} which are usually separated by a constant increment. Normally one uses a 1°F increment, but smaller or larger values can be used. A linear optimization approach which minimizes the cost function subject to constraints imposed is then used to evaluate the optimal cost of proceeding from T_1 to each of the T_{2i} temperatures, thus i linear optimization problems must be solved to go from hour 1 to hour 2. Another very important feature of this approach is that Eq. (1) need not be solved as a set of simultaneous equations as was done in the Reference 3. Because T_{2i} is specified, an explicit solution is used with a substantial reduction in solution time.

The j possible temperatures for hour 3, T_{3j}, are then determined for the physically acceptable values between minimum and maximum and the j optimization solutions are determined by assuming that each temperature T_{3j} is reached from each of the T_{2i} temperatures. Thus, i·j problems are solved. At this point, we can determine the optimal path from T_1 to each of T_{3j} using dynamic programming methods. This path optimizes the cost for the entire look-ahead period. In figure 2 the schematic arrangement of T_1, T_{2i}, and T_{3j} are shown. Of the i·j possible paths only the j optimum ones are retained. This process is repeated for hour 4, T_{4h}, hour 5, T_{5l}, et seq. At the completion of each hour's calculation, we know the optimal cost and the associated path for each temperature. Thus, we need to maintain only information for the current hour plus the control variables for the optimal path and information for the next hour in the computer memory. If the number of temperatures considered at each hour is a constant i, then over H hours, we must solve a maximum of (i**2)*(H-1)+i linear optimization problems.

Figure 2: Program Flow of Optimization Algorithm

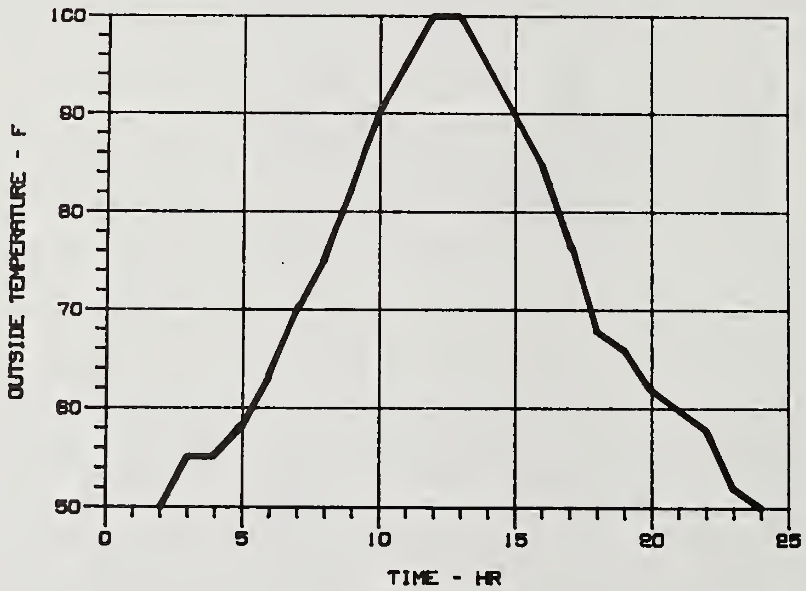


If future information, i.e., the look-ahead problem, is utilized, then we must solve the move from hour h to hH in a way that incorporates this information. This can be done in two different ways. We can go from hour h to h+H and then from h+H to h+2H et seq. without changing any intermediate results. Alternatively, we can go from h to h+H, then from h+1 to h+1+H et seq., changing the information used in the optimization whenever knowledge of such changes becomes available. Using this latter way for the simplest case of a two period look-ahead model (stages 1,2,3), the third hour's information will be changed when the next (2,3,4) optimization is performed. For the purpose of this paper, we have chosen the simple (no change) procedure and have implemented this for the two look-ahead cases. The other method is to be preferred if our future knowledge is limited to activity levels or schedules which are not precisely known but which change significantly hour by hour. For example, at 10 p.m. we may know that the occupants will retire at 11 p.m., but this information was not available earlier. For both ways the promptness of the thermal response of the building to any changes is the main determinant of which length, H, of the look-ahead to use. Because one rarely knows how a structure responds to different stimuli, we performed simulations based upon 0, 3, and 24-hour look-ahead periods. Of the three cases, we found that looking ahead 3 hours gave the same result as looking ahead 24 hours. This implies that the structure used in the example damped out changes within 3 hours and a greater anticipation period was not justified. These two look-ahead period computations are compared to the period by period (no look-ahead case) in the following example:

A CASE EXAMPLE: BASIC STRUCTURE, COSTS, AND WEIGHTS

The ambient weather conditions illustrated in figures 3 and 4 are contrived, but chosen to exercise all aspects of the program. The temperature was chosen such that both heating and cooling would be required during the period of computation. The solar radiation was modeled as an almost sinusoidal distribution, but with a heavy cloud cover from 1 to 3 p.m.

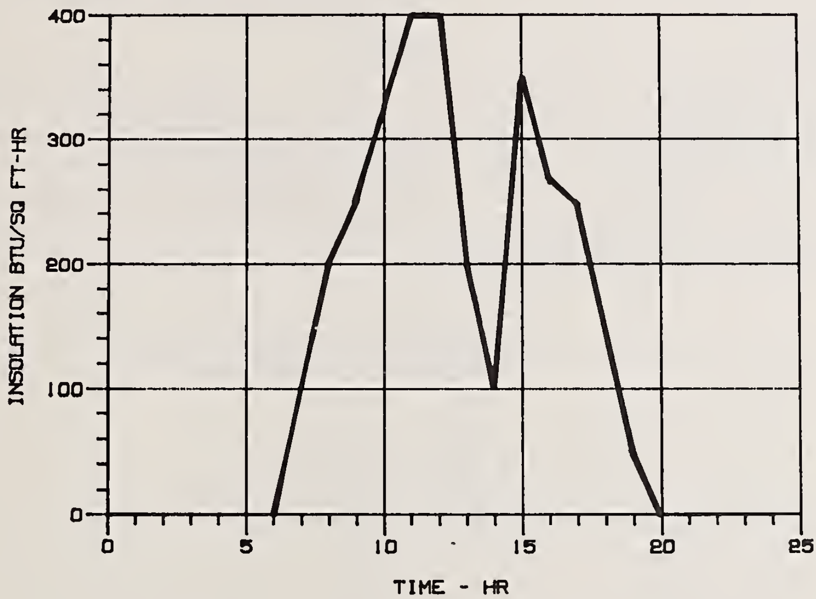
Figure 3: Outside Air Temperature - Input



The house is modeled as a six-sided box (20 x 10 x 10) composed of an insulated slab floor, four vertical walls (each with a single glazed 10 sq.ft. window and an insulated flat roof). All of the windows are equipped with shades, whose position is continuously variable. As many as three occupants reside in the space as shown in figure 5. An HVAC system provides forced air at a maximum rate of 10 air changes an hour. The fresh air requirement is met by a continuously variable damper which mixes outside air with the HVAC system return air. The lighting schedule imposed requires illumination (either artificial or natural, or a combination) to the level of 0 kW for hours 1 through 8, 0.1 kW for hours 9 through 23 and 0 kW for hour 24. The set point temperature is 70°F and a physically acceptable range is 65° to 74°F.

The control inputs are the following: the four independently operated window shades; the level of artificial lighting; the HVAC system operating duration; and the damper control for a total of seven control inputs.

Figure 4: Solar Radiation - Input



The environmental factors which were to be controlled include: the room air temperature; illumination level; external view from four windows; for a total of six. It should be noted that some of the variables which are listed as control variables may sometimes appear as environmental variables to be controlled. This interrelationship will often produce unexpected system strategies.

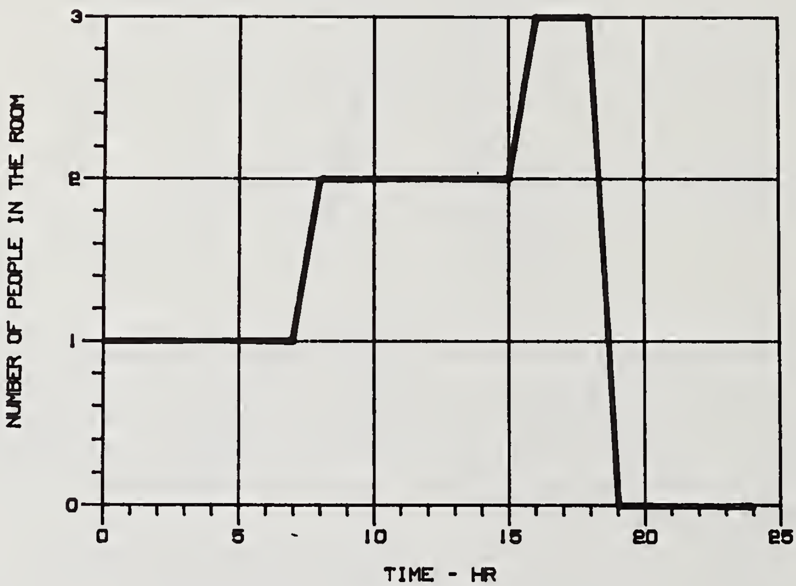
The complexity of even this one room structure can be appreciated by examining the cross coupling inherent in the control inputs. The window shades not only affect the view, but by virtue of blocking the solar input, influence the room lighting and the thermal input. The damper controls the fraction of outside air mixed with the supply air and this modifies the fresh air ventilation and the room temperature. Operation of the electric lights affects both the lighting level and the room thermal load. For this modeling we have forced the lighting requirement to always be satisfied (equality constraint), between artificial and natural. The occupant view is relaxed to accommodate the thermal and the lighting requirement, but it could have been included as additional constraints with an appropriate penalty cost.

The base and penalty costs used in defining the control system are listed in the following table.

BASE AND PENALTY COSTS

CONTROL INPUTS	COSTS
Damper position	No cost
HVAC system	$0.018/KBTU for cooling $0.014/KBTU for heating
Electricity	$0.1/kW-hr
Shades	No cost
PENALTY COSTS	
Room Temperature	$0.02/Deg F Deviation from set point

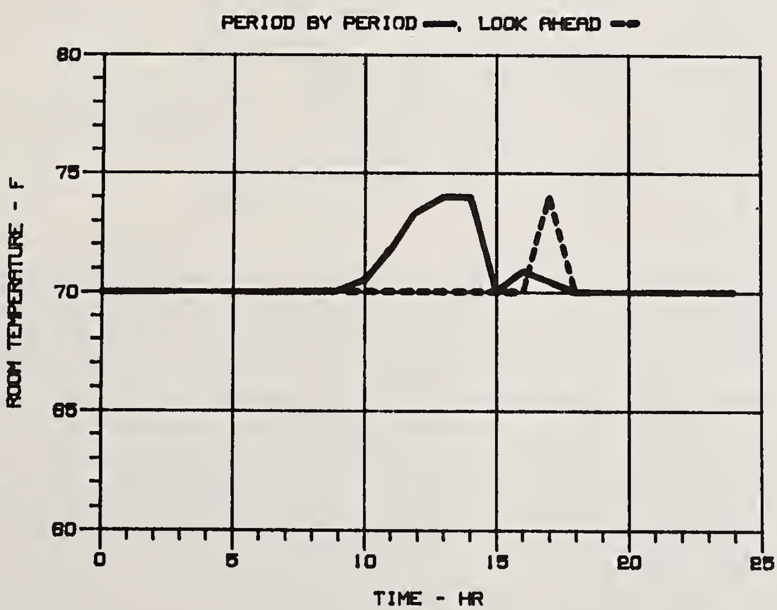
Figure 5: Occupants in the Room - Input



The computations were done for three different look-ahead periods, 0, 3 and 24 hours. The first to represent the usual simulation approach, the 3-hour look-ahead to represent about the maximum anticipation that an occupant can be expected to have, and the 24-hour case to represent the usual weather prediction. Two types of forcing inputs based upon weather and internal schedule changes were used - the first having very rapid and strong changes while the second had more gentle changes which are representative of the natural variations expected in the weather. Both of these forcing inputs had changes of the same magnitude, only the frequency changes, since the magnitude of any change is constrained by physical conditions. For example, the solar radiation can change only from 0 to that for a clear sky, regardless of the rate of the change. The results of the simulations were quite surprising at first glance, but after considerable examination were what one would expect. We must remember that the conditions at any hour are the sum of all of the past effects, but that the damping nature of the structure's thermal response tends to erase any effects after a time which depends upon the natural period of the structure.

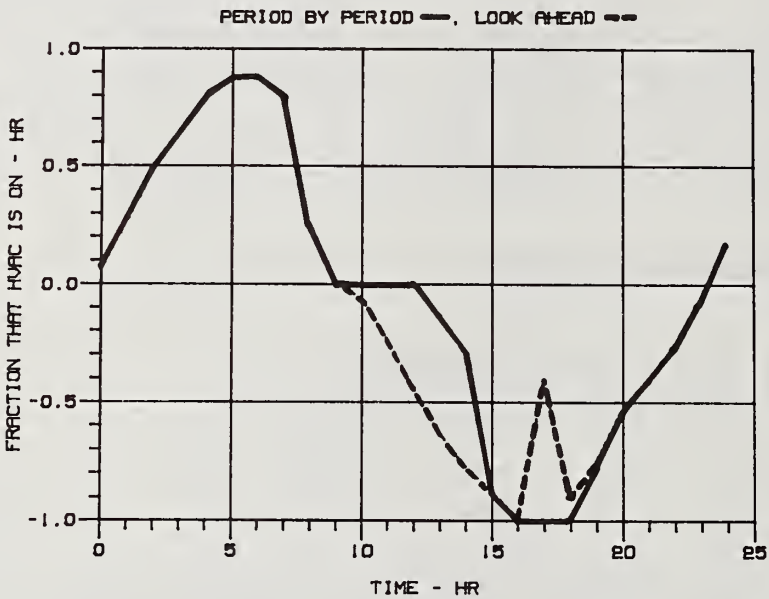
For the rapid changes, there were no significant differences between any of the calculations. In fact, this type of weather and schedule changes is nearly stochastic and the response of the building tends to reflect the average conditions since a knowledge of the future tends to be overpowered by the severity of the hourly changes. That is a knowledge that 3 hours hence the number of occupants will change or that they will retire is of little importance when compared to a substantial hourly change in the outside air temperature.

Figure 6: Room Temperature - Output



The scenario with the gentle changes gave markedly different results. Here, as shown on figures 6 to 10, a knowledge of the future can lead to significant changes in the operating schedule of the HVAC system, of the lights and shades, and in the constancy of the room air temperature. The figure compares the 0- and 3-hour results only since the 24-hour results did not differ from the 3-hour case results because the natural damping of the structure reduced the effects to zero after an elapsed time of several hours. Obviously, the effect of the look-ahead depends very strongly upon the promptness of the structure's thermal response when compared to the frequency of the changes in the external and internal effects. A convenient way of looking at the problem is by analogy with waves in dissipative media. High frequency waves have very short penetration depths while the low frequency waves have long penetration depths, but the definition of high and low frequency must be made in relation to the natural frequency of the media.

Figure 7: HVAC System Operating Time - Output



From hours 0 to 9, the two models (period by period (PP) and look-ahead (LA)) give exactly the same strategy and costs (figures 6,7,8,9,10). The heater is turned on until 8 o'clock and then it is off at 9 o'clock when the outside temperature has reached 82°F (figure 3). The shade 1 is going to be opened (partially) in hours 8 and 9 (figure 9) when there are lighting requirements and also heating load. The room temperature stays at the set point of 70°F (figure 6) until 9 o'clock. At 10 o'clock the outside temperature reaches 90°F with an expected rise up to 100°F for the next 2 hours (figure 3). The PP model finds it more costly to cool the space rather than paying the penalty cost for the temperature deviation, and a room temperature of 70.44°F and a cost of $0.01881 results. At this point, the LA model, which anticipates the increase in the outset temperature attempts to minimize the operating costs by closing the shades to reduce the solar gain, satisfying the lighting requirement by using artificial lighting, and cooling the room to 70°F with a resulting cost of $0.01894 (figures 6,7,8,10). In the next period, the PP model keeps the HVAC off (figure 7) with a room temperature of 71.77°F (figure 6) and a cost of $0.04533. The LA model again keeps the space cool at 70°F with a cost of $0.04537. In the next period the PP model room temperature reaches 73.39°F with a cost of $0.07572.

Comparing the total cost of these three periods, we see that there is a total of \$0.14186 for the PP and \$0.14003 for the LA. For the next two periods the PP model keeps the room temperature at the highest allowable temperature of 74°F, whereas the LA model keeps it at 70°F by performing more cooling.

Figure 8: <u>Lighting Power Requirements - Output</u>

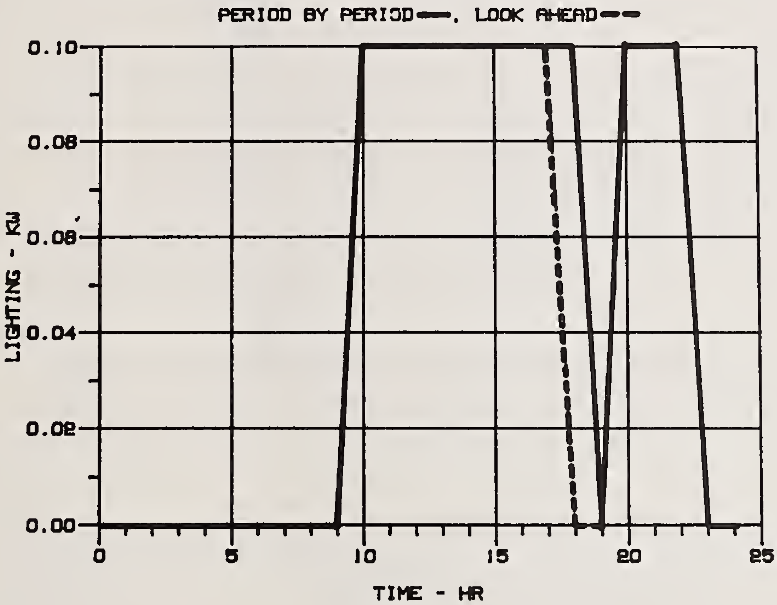


Figure 10 shows the hourly costs, computed from the optimal 3-hour costs for the look-ahead model. The total costs for 24 hours which is the integral under the curves have shown a 7.3 percent reduction in looking ahead rather than period by period optimization.

In the hours 16, 17, 18 there is a sharp decrease in the outside temperature, the LA model decides not to cool the space at a very high rate in hour 17, in order to use to the advantage of low outside temperature later on, but the PP model does not recognize this and keeps cooling at maximum level. However, because of the building mass it cannot cool the space to 70°F. The shades 2, 3, 4 are closed at all times except shade 2 which will be fully opened in period 20 for both models. This is because of a decrease in insolation at that time.

It is interesting to note that because the system response is determined through an optimization process which minimizes the total cost of the process, including the costs assigned by the occupant to deviations of arbitrary variables from arbitrarily defined set points, the use of a process which includes anticipation does not always guarantee improved performance, even though it may yield reduced costs. In figure 6, the room air temperature shows that although the air is maintained at the thermostat setting for most of the day, the deviation of 4°F at the

Figure 9: Shade Position - Output

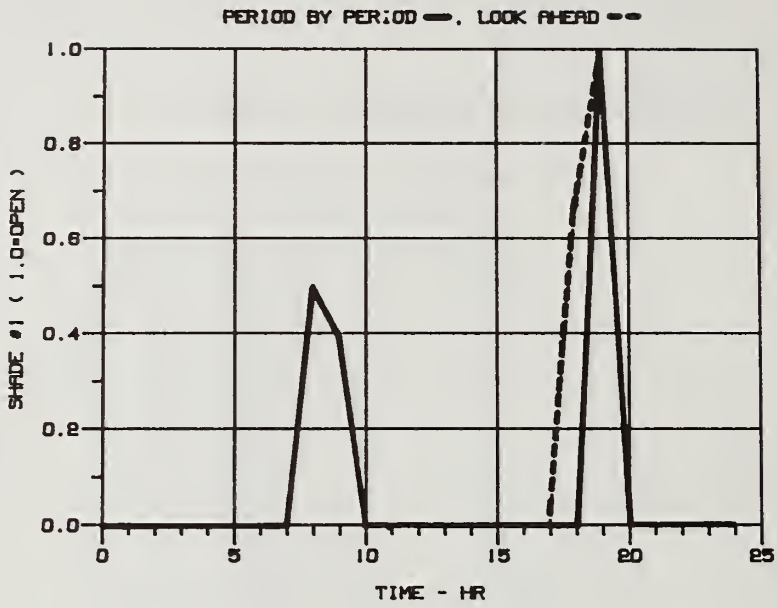
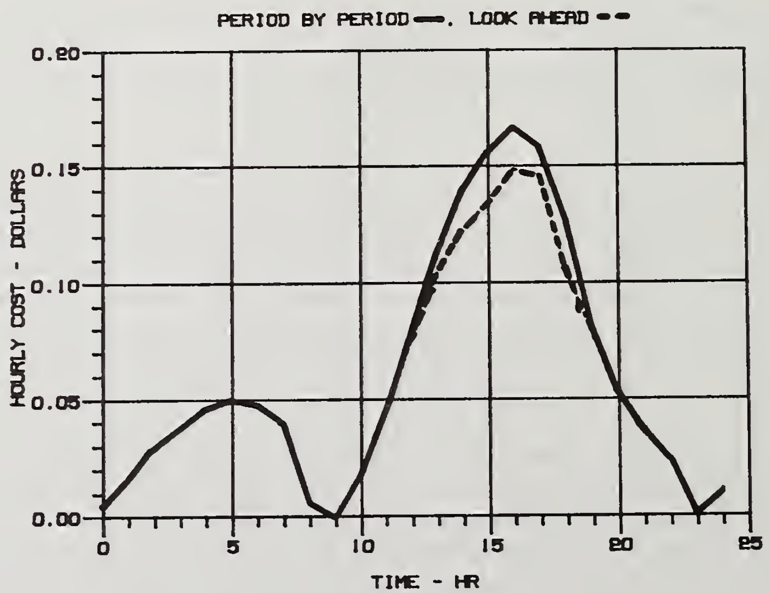


Figure 10: Hourly Total Cost - Output



17th hour is as much as the maximum deviation calculated for the 0-hour look-ahead. Figure 7, the duty schedule of the HVAC system, shows a strong cooling at times when the 0-hour calculation would turn the system off.

CONCLUSIONS

The limited results reported herein show that substantial savings in total operating costs can be achieved when the operation of an HVAC system is based upon an optimization process which includes the effect of anticipated changes in weather or other load producing schedules. How long one must anticipate these future changes depends strongly upon the frequency of the changes, the natural time constant of the structure, and the costs assigned by the occupants for deviation from the set points. For a typical building, a look-ahead period of about 3 hours appears to suffice. However, a more definitive value will require a series of parametric calculations involving different building masses, HVAC system capabilities, and cost values.

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ENERGY CONSCIOUS ELECTRICAL DESIGN

by

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Concern over the adequacy of future energy resources has led the Federal Government to require States to adopt energy conservation techniques for all new construction. Different approaches have been tried, such as Resource Utilization Factors, which consider how efficiently one source of energy can be converted into another (i.e., 3.04 Btu's of heat energy are required to produce and transmit 1 Btu of electrical energy to the point of use); and Resource Impact Factors, which consider the relative availability and renewability of a fuel.

The Department of Energy's current approach centers around the formulation of Building Energy Performance Standards, which prescribe energy consumption goals for various types of structures in different climates while allowing designers to achieve these goals in their own ways.

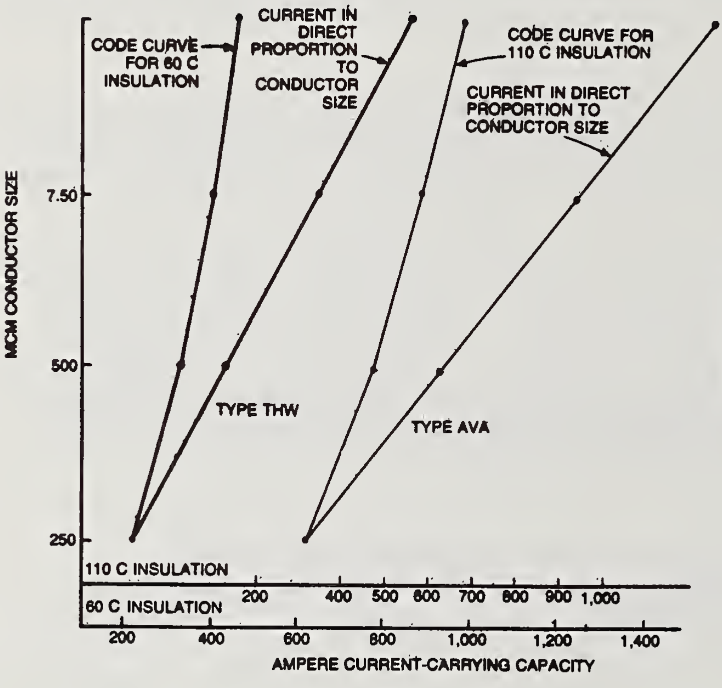
Thus, this paper will consider a number of electrical design techniques that contribute to minimizing energy consumption and maximizing the efficiency of electrical installations. Some of the techniques discussed also involve the source concept, as opposed to the boundary concept, of energy conservation: reducing the total energy expenditure required to construct buildings by minimizing the quantities of raw materials and finished products required.

Key words: Electrical design; energy distribution; National Electrical Code; power factor correction; source energy; transformers.

Distribution Utilization Voltage

As much as possible, a service voltage of 277/480 volts, three phase, four wire, should be utilized for all balanced three phase loads such as motors and electric resistive heating and for all overhead lighting systems, instead of using what is sometimes considered the more conventional 120/208 volt, three phase, four wire system. This will achieve a reduction of 57 percent in current. Due to its higher load carrying capacity, 277/480 volt wiring can carry 231 percent as much energy as 120/208 volt conductors. Also, because of the non-linearity of the current carrying capacity of copper conductors, larger conductors do not carry proportionally higher current capacities. (See figure 1.) Therefore, the size and number of current carrying conductors and raceways are increased.

Figure 1: Ratio of Conductor Size and Ampacity



CONDUCTOR MCM	CURRENT CAPACITY	
	TYPE 60 C	TYPE 110 C
250	215 A	315 A
500	320	470
750	400	580
1,000	455	680

By using a higher voltage, the (I^2R) heat losses will be lower. Voltage drop is also less of a problem in a higher voltage system.

These advantages of a 277/480 volt distribution can, of course, be negated by serving lighting or other major loads at 120/208 volts via local step-down transformers. When a large portion of the building load is served at this lower voltage, the local step-down transformers become larger as do their core and coil losses, introducing further energy wastage. To serve a given load, the transformer loss is now incurred twice, once at about 1.85 percent at the main primary to 277/480 volt transformer, and again at almost 5 percent in the 480 to 120/208 volt step-down transformers.

It is also possible to minimize the extent and cost of electrical services by deviating from the current trend of using lower voltage distribution design. In an office building or school facility, 120/208 volt, three phase, four wire service for receptacles and miscellaneous power should normally account for no more than 5 to 8 percent of the total load. If the proportion of the 120/208 volt load can be held down to this percentage (many designers routinely serve 40 to 50 percent of the load at 120/208 volts), then it is possible to eliminate the provision for one of two unit substations commonly used to produce two different voltages (by elimination of the 120/208 volt unit substation entirely and installing only a 277/408 volt substation). The small receptacle and miscellaneous power load can then be fed from small local step-down transformers located at the centers of load throughout the building.

Primary Transformers

Primary transformers should be a liquid type as opposed to a dry type due to their longer life expectancy: 60 to 80 years rather than the 12 to 15 years common with dry type primary transformers. This represents an additional mining and refining energy savings above and beyond building energy savings by extending the useful life of existing and finished goods. Although the pentachlorobiphenyl or PCB compounds formerly used to cool indoor liquid type medium voltage (601 to 15,000 volts) primary transformers are now obsolete and increasingly unavailable, they are being replaced with new biodegradable compounds.

Inert compounds that meet Toxic Substances Control Act minimum requirements and are approved by the Occupational Safety and Health Administration (OSHA) must be biodegradable, flame resistant, and have the following chemical characteristics:

1. A highly saturated paraffinic oil whose base fluids are refined by solvent extraction with hydrogenation and processed from high molecular weight paraffinic crudes, and

2. Silicone (POLYDIMENTHYLSILOXANES), long chained, high molecular weight polymers consisting of stable SI-O-SI MERS.

Hence, liquid type transformers are still a viable choice for primary to secondary step-down voltage applications. As a rule, liquid filled primary medium voltage step-down transformers have a full load core and coil loss of less than 3 percent of their kilovoltampere (kVA) rating at 0.9 power factor (P.F.).

In addition, incoming primary service transformers should not be wired wye-wye because their third harmonic currents (generated by fluorescent and high intensity discharge--HID--ballasts) can cause balanced three phase circuit neutrals to carry as much as 90 to 95 percent of the phase currents. If the primary is wired in wye, then this reflected neutral load loss will flow in the primary feeder neutral. Electrical load losses through the primary neutral are an unnecessary waste of energy, leading to higher energy costs and greater maintenance costs.

Secondary Transformers

Secondary dry type transformers rated 480 volts delta primary, 208 wye/120 V, 3ϕ - four wire secondary (such as those often installed in electrical closets) commonly come furnished with Class H insulation rated at 150°C. However, if operated continuously at peak load, these transformers could theoretically fail in as little as 2.3 years. Class H 150°C insulated 3ϕ transformers have full load losses of nearly 5 percent at 30 kVA, 3.5 percent at 45 kVA and 2.27 percent for a 300 kVA unit.

Instead, dry type transformers should be supplied with Class H insulation rated for only an 80°C temperature rise. This change could extend expected life to as much as 25 years at an additional cost of only 10 percent per transformer, which, in addition to reducing life-cycle operating costs, is true "source concept" material and energy resource conservation. Moreover, Class H 80°C transformers are more efficient than the 150°C type due to the larger conductors used to maintain low operating temperatures; the energy cost savings over 25 years will more than repay the small additional first cost. Class H 80°C insulated transformers can reduce load losses by as much as 22.5 percent; thus, a 30 kVA transformer would lose only 3.69 percent (of its total kVA rating) and a 45 kVA transformer only 2.74 percent.

Power Factor Correcting

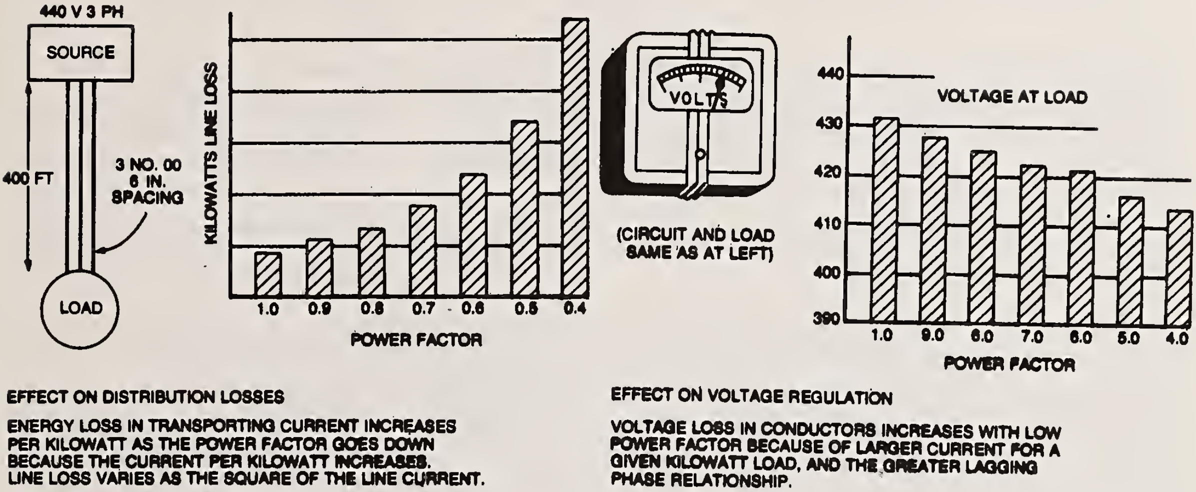
All electrical equipment and devices used should be specified with the highest power (P.F.) available. In particular, all fluorescent and HID lighting fixture ballasts should have a rated P.F. greater than 90 percent.

Where individual pieces of equipment consuming 1500 watts (W) of energy or more have a rated P.F. below 90 percent, capacitors should be installed to correct the P.F. to 95 percent or better. All motors of 2 horsepower (hp) (approximately 2715 VA) and above should come supplied with P.F. corrective devices.

Power factor correction should be employed to conserve energy and reduce life-cycle costs. It increases building distribution capacity (more kW from the same transformers), improves voltage regulation and reduces power losses (see figure 2).

Motors and other inductive equipment require two types of electrical energy. One type is working on power producing current, measured in kilowatts (kW). The second type is magnetizing current, measured in kilovoltampere reactive (kvar), which produces no useful work but is nonetheless necessary to the functioning of the equipment. Capacitors can be installed at motors and other inductive equipment to supply the necessary kilovars (kvar) of magnetizing current directly at the loads rather than throughout the distribution system. Thus, P.F. correction can be easily retrofitted to existing buildings.

Figure 2: Effect of Lagging Power Factor on AC Equipment

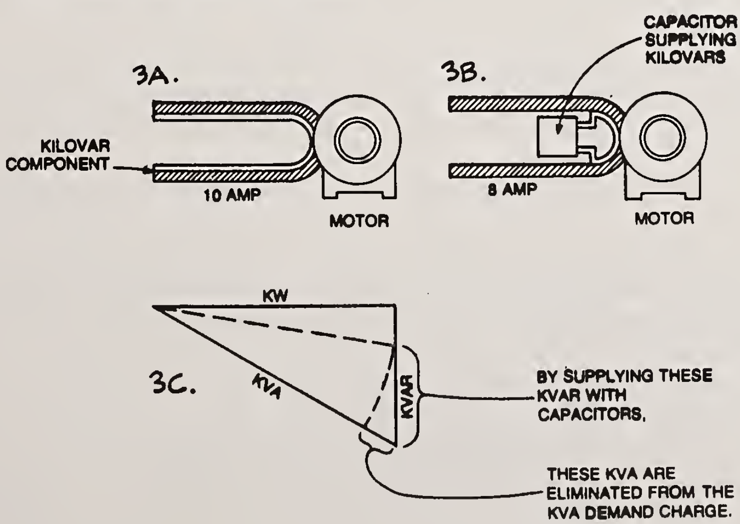


Low power factor equipment consumes more kvar than that rated at high power factors (0.8 or greater). Low power factor is also detrimental to the building electrical system in the following ways:

1. It cuts down system loadability; that is, it reduces the capacity of the power system to carry kilowatts (kW = kVA x P.F.). The capacity of all apparatus is determined by the kVA it can carry; hence, larger transformers, feeders, and switches must be provided for each kilowatt of load when the power factor is low.

2. Low power factor means more current per kilowatt, so each kilowatt of power carries a higher burden of line losses in the form of heat.

Figure 3: Capacitors and Motors



3. Low power factor may depress the voltage, with a detrimental reduction in the output of practically all electrical apparatus and more energy waste.

Although capacitors can be used at the service entrance to correct P.F., this has no effect on poor system power factor. Thus, capacitors are most effective when installed directly at points of load, as previously described. A simple illustration of the effect of capacitors is a motor drawing 10 amps of current. At 80 percent power factor, only 8 amperes produce working horsepower, while 2 amperes serve as magnetizing current only (see figure 3A).

In figure 3B, a capacitor has been added to the feeder to supply the kilovar directly at the motor. Now the feeder must deliver only 8 amperes for exactly the same horsepower output. In this way, capacitors reduce the line current and make possible the addition of more electrical equipment to fully-loaded feeders. If this same circuit fed four motors at 80 percent power factor, then the use of capacitors would permit another motor to be added to the line with no increase in the total current demand.

Capacitors release system capacity so that more motors, lighting, and other loads may be added to the system without overloading transformers and other distribution equipment. This system release continues as capacitors are added up to the point at which 100 percent power factor is reached. However, more kvar of capacitors are required per kW of released capacity as the power factor increases. Capacitors should, therefore, be added until the cost of capacitors to release a kW of capacity equals the cost per kW of new transformers and distribution equipment. Raising the power factor to at least 95 to 98 percent is usually economical. Capacitors to correct P.F. cost approximately $10 per kvar for a 277/480 volt system and $20 per kvar at 120/208 volts. This is another sound reason for the use of higher voltage distribution systems.

By improving the power factor of a squirrel cage induction motor from 0.8 to 0.95, substantial energy savings can be realized, as the following analysis indicates:

Voltage equals current times resistance (E = IR) and by algebraic manipulation, $I = \frac{E}{R}$ and $R = \frac{E}{I}$. Real Power (P) is the time rate of energy consumption and equals voltage times current when both quantities are in phase or have unity power factor (P.F. = 1). Thus, Power (P) in watts equals volts times amps times cos θ:

$$P = E(I)(P.F. = 1)$$

$$\text{power} = EI = (IR)I = I^2R$$

$$\text{current } (I) = \frac{\text{volt-amps}}{\text{voltage}}, \text{ or, } I = \frac{V.A.}{E}$$

$$\text{volt amps (V.A.)} = \frac{\text{watts}}{\text{P.F.}}, \text{ or V.A.} = \frac{W}{\text{P.F.}}$$

and,

$$I = \frac{\text{V.A.}}{E} = \frac{\frac{w}{\text{P.F.}}}{E} = \frac{\text{watts}}{E(\text{P.F.})}$$

Thus, $I(.8\ \text{P.F.}) = \frac{W}{E(.8)} = \frac{1.25w}{E}$, or, $I(.8\ \text{P.F.}) = 1.25I$ @ unity power factor.

The current at .8 P.F. has been increased by 1.25 times the current at unity power factor (P.F. = 1).

Thus, the power (@ .8 P.F.) $= \left(\frac{I}{.8}\right)^2 R = (1.25I)^2 R = 1.5625I^2 R$

and, power @ .95 P.F. $= \left(\frac{I}{.95}\right)^2 R = (1.0526I)^2 R = 1.108I^2 R$

The difference in power consumed at .95 P.F. versus .8 P.F. equals

$$\frac{(1.5625 - 1.108)}{1.5625} \times 100 = 29.088\%, \text{ or } 29.1\%$$

or, mathematically stated, the algebraic letters "I" and "R" are constant in value. Thus, the difference in percentage is

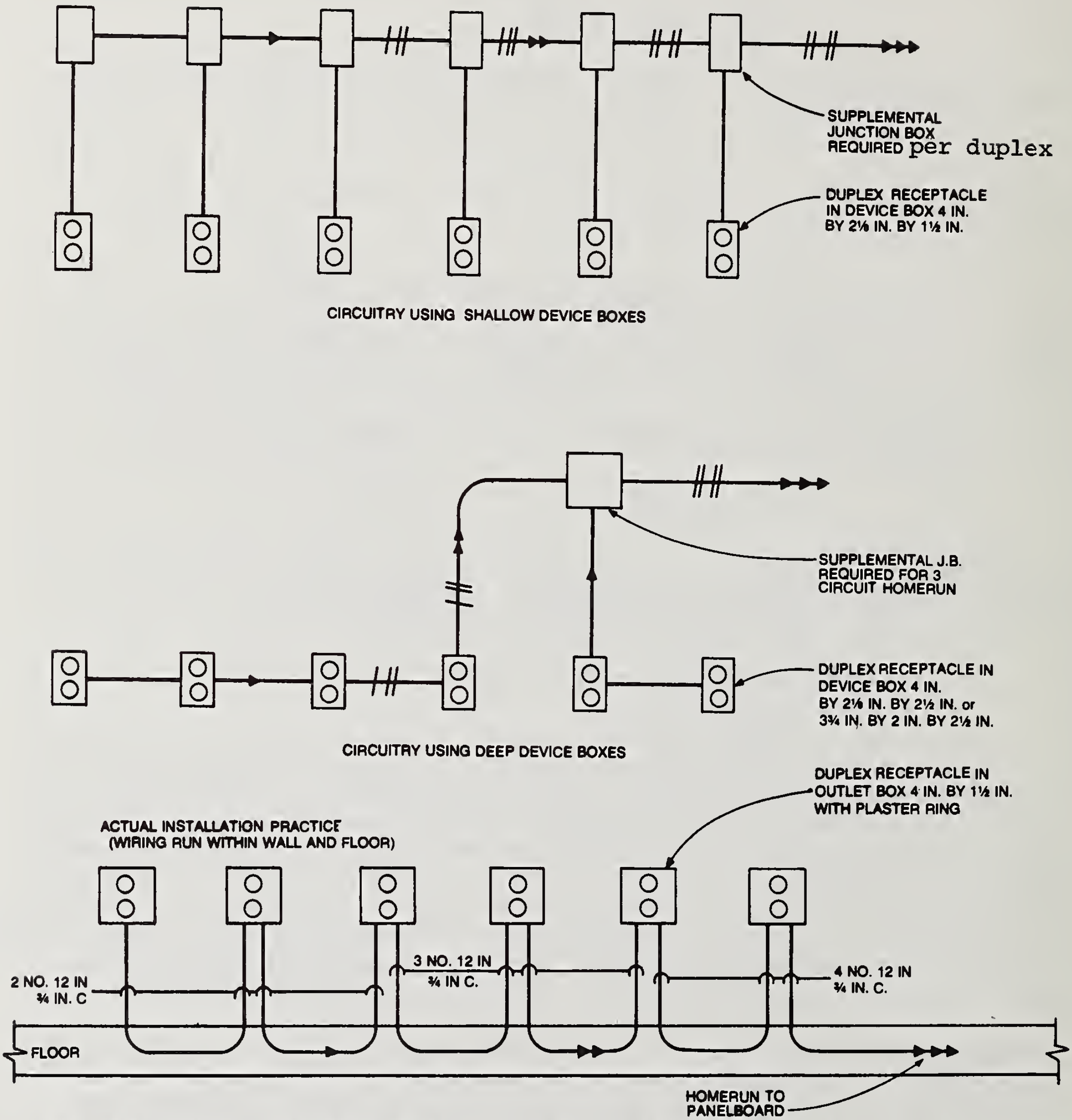
$$\left[\frac{\left(\frac{1}{.8}\right)^2 - \left(\frac{1}{.95}\right)^2}{\left(\frac{1}{.8}\right)^2}\right] \times 100 = 29.1\%.$$

By reducing the current utilized by electric motors (inductive devices) by improving their power factor, that current that is in phase with the voltage ($P = EI \cos \theta$) represents the real power (time rate of energy consumed) that can be reduced and conserved. Capacitors reduce system losses by reducing total current and power flowing through that system. For example, a 20 percent reduction of the total current will cut the power (energy) losses 36 percent. Savings from power loss recovery alone can give you an annual return on a capacitor investment of as much as 20 percent or more. In some facilities it can be paid back in a matter of months.

Receptacle Circuitry

In many conventional design applications such as office buildings and schools, little attention is paid to the receptacle device box (outlet box) either on the project drawings or in the electrical specifications. Frequently, in fact, they contradict one another: the project drawings will indicate groups of receptacles wired in unbroken circuits (often grouping three phases together with a common neutral), while the specifications call for receptacles to be installed in 4" x 2-1/8" x 1-1/2" device boxes. If the contractor attempts to follow both drawings and specifications - as frequently happens - the resulting installation will violate the National Electrical Code (NEC).

Figure 4: Circuitry Using Outlet Boxes with Plaster Rings



The reason for this is the small capacity of these device boxes. According to "Table 370-6(a) Boxes" from the 1978 NEC, the maximum number of #12 conductors permitted in a 4" x 2-1/8" x 1-1/2" box is four. However, the NEC requires that this maximum be reduced by two conductors to permit installation of a receptacle and the branch circuit grounding conductor, reducing to two the number of phase and neutral conductors permitted in the box. Therefore, a 4" x 2-1/8" x 1-1/2" box can be used only as a termination, and not for feed-through to a downstream receptacle.

To permit feed-through and sharing of one neutral by two phase wires, a box rated for the equivalent of six #12 conductors (receptacle, ground conductor, phase conductor connection, neutral and two phases) must be used. Suitable boxes would be 4" x 2-1/2" x 2-1/8", or 3-3/4" x 2" x 2-1/2". Their use allows through-wiring of the device boxes for up to two circuits, but still requires a supplemental junction box to connect the third circuit prior to homerunning to the panelboard (see figure 4).

In lieu of either of these approaches, specifying a standard 4" x 4" x 1-1/2" box with a plaster ring for all devices is the most practical solution for commercial and institutional work. The large capacity of the 4" x 4" x 1-1/2" box accommodates large numbers of wires and splices, while the plaster ring permits device mounting. Thus, three phase wires (3 circuits) sharing a neutral can be fed through the box while still accommodating a receptacle. Specification of the standard box for all wiring purposes also reduces the electrical contractor's inventory. This also reduces the total energy expenditure for finished goods processed from raw materials. It also reduces the amount of tool and equipment energy needed to make the initial installation as well as reduces life cycle energy use due to the reduction of materials and equipment used and less I^2R energy lost on branch circuit conductors.

1.	Comparison:	(Single CKTS) 3-2 Wire Circuits	= 6 wires
		(3 CKT Grouping) 1-4 Wire Circuit	= 4 wires
		Wire Saved	= 2 wires
	Homerun Wiring Savings		= 33-1/3 percent
2.	Comparison:	(Single CKTS) 3-3/4" Conduits	= 3-3/4"C
		(3 CKT Grouping) 1-3/4" Conduits	= 1-3/4"C
	Homerun Conduit Savings		= 66.7 percent

Electrically, grouping homeruns into threes through the use of 4" x 4" x 1-1/2" outlet boxes reduces I^2R energy losses by minimizing imbalanced neutral current.

Panelboard Branch Feeds

Some electrical contractors routinely run all branch circuit conductors from a panelboard through one or two large common raceways to a wiring trough above a hung ceiling, where the individual branch circuit conduits then diverge (see figure 5). This practice is usually justified on aesthetic or practical grounds, as making a neater or more compact installation.

The 1978 National Electric Code, Article 384-15 limits the number of overcurrent devices in one panel to 42 poles excluding the main overcurrent device. Assuming 42 single phase branch circuits, and grouping circuits in threes with a common neutral, there may be as many as 56 branch circuit conductors - 42 phase conductors plus 14 neutrals. If for some reason 42 separate branch feeds are made, then there could be 84 branch conductors - 42 phase wires and 42 neutrals.

If a fault occurs to a phase wire in a single group of three phase wires and a neutral (4 #12, 3/4"C), then only 3/42 (7.1%) of the panel circuits are affected at one time. However, if a fault occurs in the sub-feed of a panel having two conduit sub-feeds, half of the panel circuits are affected. With a single sub-feed conduit, a fault in a single phase wire could cause the burnout of the remaining 41 branch circuits. The second problem, non-compliance with the NEC, arises because most engineers and electrical contractors do not follow derating requirements. Note 8 to Tables 310-16 through 310-19: "more than three conductors in a raceway or cable" specifies the following:

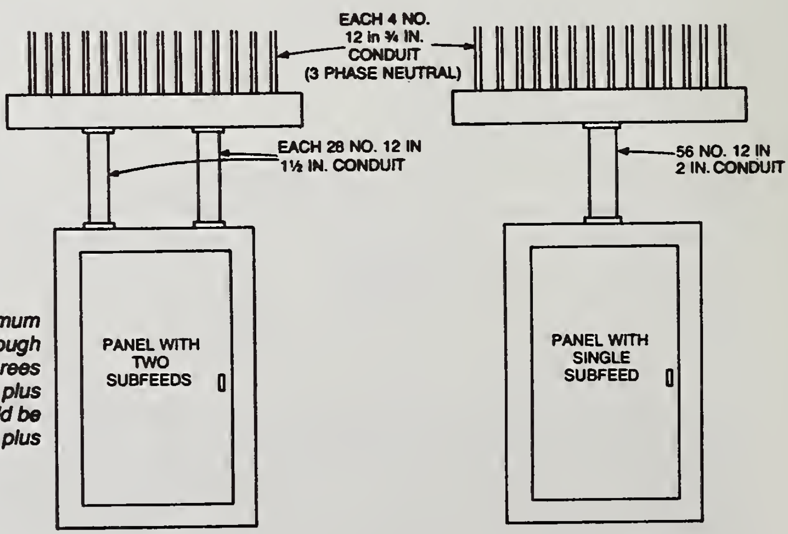
No. of Conductors	Percent of Values in Either 310-16 & 310-18
4 - 6	80
7 - 24	70
25 - 42	60
43 - and above	50

The neutral of a three phase, four wire circuit supplying electric discharge lighting is also considered a current carrying conductor, by note 10 (c). The neutral of a 3ϕ, four wire circuit supplying receptacles or other non-inductive or non-capacitive miscellaneous power is not considered a current carrying conductor.

As a result, an overhead fluorescent lighting system supplied by four #12 conductors in 3/4" conduit should be derated to 80 percent. The twin sub-feed panel's conductors should be derated to 60 percent, and the single sub-feed panel's conductors to 50 percent. The alternative is to oversize the conductors, which is also a poor utilization of resources and energy.

Figure 5: Branch Circuits

Assuming a 42 pole panel, the minimum number of conductors to the wire trough would be 56 (for circuits grouped in threes with a common neutral: 42 phase wires plus 14 neutrals). The maximum number would be 84 (42 separate circuits: 42 phase wires plus 42 neutrals).



Interior Lighting Circuitry

As an alternate to hard wiring (conductors in conduit), a flexible, coordinated and integrated plug-in electrical wiring system should be considered that meets all fixture wiring and switching requirements. Although the material cost of the flexible wiring systems may be higher, the cost of labor for installation is lower, resulting in a substantially lower installed first cost. The system is more flexible than hard wiring and allows changes to be readily made without the services of an electrician, while allowing for complete reuse of all system components. This last fact alone reduces the life cycle cost due to tenant changes, space reallocation and relocation, and represents "source" energy and resource conservation, since existing wiring and conduit need not be scrapped and replaced.

Heat of Light Concept

The energy conservative heat of light concept should be used with all fluorescent and HID fixtures. This technique incorporates return air through the lighting fixtures, in lieu of using static non-air handling fixtures. By so doing, the efficacy of the fluorescent lamps will be increased by about 25 percent, delivering more lumens per watt; and although HID lamp efficacy is not affected at all, both types of fixtures will realize increases in lamp and ballast life, and the heat load injected into the working space will be reduced to the minimum possible. This reduction of heat will in turn reduce the building air conditioning load, since, in general 1 watt of air conditioning load is required to remove every 2 watts of heat load:

$$\frac{1000 \text{ watts heat load}}{.2931 \text{ watts/Btu}} \div 12{,}000 \text{ Btu/ton} \times 1 \text{ hp/ton} \times 1 \text{ kW}$$

$$= .284 \text{ kW chiller input}$$

$$.284 \times 1.7 = .483 \text{ kW total air conditioning load required to remove 1 kW heat load}$$

This calculation is based upon the approximate equivalence of hp to kW for large equipment by taking into account motor efficiency.

The value of 1.7 is an empirical constant developed and found reliable in over 17 year's experience with large building designs, which takes into account peripheral mechanical equipment, such as pumps, fans, and air handler unit motors.

This brief, but intense, energy analysis of lighting design as part of a total building and mechanical system attempts to address the problem of design fragmentation, showing the important interdisciplinary relationships that should not be ignored for optimum functioning and greatest energy conservation possible.

Where fluorescent fixtures are specified, pattern control dampers should be used to control the air return through the side slots, which are used to supplement the air return through the heat removal slots in the same fixture. This will avoid excessive return air movement through the side slots, which would reduce the beneficial effects listed above. The heat removal return air slots that channel air through the lamp compartment will thus not be shunted or bypassed.

The lighting contractor should be directed to do the following:

- Work in conjunction with the heating, ventilating, air-conditioning (HVAC) balancing and controls specialist in adjusting the fluorescent fixtures' side slot dampers for the exact ft^3/min required.
- Utilize, as much as possible, all air return through the lighting fixtures' lamp compartment.
- Return any additional air as required through the side slot return that vents directly to the dropped ceiling cavity space.
- In no case should return air be allowed to shunt or bypass the lamp compartment when that air return capacity has not been exceeded.
- The HVAC contractor and HVAC balancing and controls specialist should adjust the air return grill dampers so that a minimum to maximum range of 25 to 45 ft^3/min of air will return through the lighting fixture compartment.

Internal Lamp Pressure

Fluorescent lamps operate most efficiently at a certain internal mercury vapor pressure. If this pressure either increases due to lamp overheating (as in static, non-air handling enclosed fixtures) or decreases due to cooling (as in outdoor fixtures or dynamic fixtures that supply air through the lamp compartment), light output as measured in lumens/watt decreases. Supplying cooled conditioned air through the lamp compartment of a louvered fixture causes a decreased temperature on the center portion of the lamp; and that portion of the lamp has a marked decrease in light output as compared to the non-cooled ends. The mercury vapor (MV) pressure throughout the lamp is decreased; thus, the light output from the entire lamp is less; but it is markedly less in the center, where chilling occurs. However, returning air through properly designed dynamic air handling fixtures maintains optimum lamp MV pressure and maximizes light output (and, as previously noted, also serves to extend lamp and ballast life). The optimal ambient air temperature for rated lumen output and fluorescent lamp operation is 77°F with the coolest spot on the bulb at about 100°F. Internal lamp MV pressure varies in direct proportion to internal lamp temperature, according to the formula:

$$P_2 = \frac{P_1 V_1 T_2}{V_2 T_1}$$

P_1, V_1, T_1 = initial pressure, volume, temperature

P_2, V_2, T_2 = new pressure, volume, temperature

High Pressure Sodium (HPS) and Super Metal Halide (SMH) Lamps

High pressure sodium (HPS) lamps offer the highest efficacy of any source used for general lighting up to 140 lumens/watt. (Low pressure sodium has considerably higher efficacies (183), but due to its objectionable monochromatic yellow color is seldom used in interior applications.) The HPS has, in the past, generally been relegated to street lighting applications due to the golden color of its light, which rendered colors and complexions poorly. In some commercial applications, though, conventional HPS has been successfully used for interior lighting. By illuminating to 100 footcandles (fc) or more and carefully coordinating furnishings to use colors that are enhanced by HPS lighting, the psychological impression of white light can be closely approximated.

Also, over the last 3 years, HPS lamps with increased vapor pressures have been developed that produce a nearly white light comparable with warm white fluorescent and phosphor coated metal halide lamps at an efficacy of 100 lumens per watt, far greater than that of fluorescent lamps. These improved, or "High CRI" (for high color rendering index) HPS lamps are now available from all major lamp manufacturers, so that, for the first time, HPS is a viable selection for interior lighting; in fact, HPS and super metal halide (SMH) promise to be the pre-eminent lighting sources of the next 50 years. Interior lighting with 150 or 250 watt HPS fixtures permits an ideal mounting height-to-fixture spacing ratio of 1:1.4. A variety of lenses can be used with HPS fixtures if a glass optical interface is used to disperse the heat that could otherwise damage standard acrylic lenses.

An alternate approach is to light general areas with 400 watt SMH fixtures equipped with HID acrylic refractors that offer a mounting height-to-fixture spacing ratio of 1:1.9, far exceeding spacing ratios normal with fluorescent fixtures. The SMH lamps provide excellent color rendition at an efficacy of 100 lumens/watt, and the latest model HID acrylic refractor produces a flattened or "softened" batwing distribution of light, permitting a wide, even pattern of illumination without the problem of fixture brightness often noted with conventional linear or spherical batwing lenses used on fluorescent fixtures. The refractor also obviates the problem of hotspotting that would otherwise be caused by using high-wattage lamps. Fewer fixtures are required using 400 watt SMH in place of 150 or 250 watt HPS, but light distribution and illumination in most low mounting height applications would be marginally less even, especially if bank-style open office architecture space planning partitions are used. These will tend to cause unacceptable shadowing with widely-spaced fixtures.

Fluorescent Lamps

Of course, in many applications, such as the situation just noted, fluorescent lighting is still the obvious choice. Yet, even when using this conventional and familiar lighting source, lamps should be selected and fixtures specified in ways that will tend to reduce life cycle costs due to maintenance and energy use. Consider first the 40-watt Rapid Start (R.S.) lamp:

- Straight 40-watt Rapid Start (R.S.) fluorescent lamps in the cool white series have 3150 lumens (78.75 lumens per watt efficacy). These lamps are normally rated for about 20,000 hours of life at 3 hours per start; 28,860 hours of life at 12 hours per start, and 37,700 hours of life on continuous burning at a cost of $2.37 each (fluorescent lamp prices are identical for the three major manufacturers). They are the least expensive and longest-lived lamps in general use, and are the most common interior lighting lamps. A four-lamp 2x4 fixture using 40-watt lamps consumes 184 watts, including ballast losses.

- The ballast and fluorescent tube, together, consume 54 watts in a single tube installation. A two-tube, 40-watt fluorescent ballast consumes 92 watts of power, or a 17.4 percent energy savings over two single 40-watt R.S. fluorescent ballast fixtures. Therefore, whenever possible, two-tube fixtures should be used.

The newer low-wattage (34- or 35-watt depending upon manufacturer) energy saving 4 foot long rapid start lamps (see figure 6) have efficacies between 81.4 and 89.7 lumens/watt (again varying according to manufacturer), and related lives similar to the 40-watt lamp. The higher efficiency lamps reduce energy use while maintaining nearly the same illumination level and cost $1.03 more than a standard 40-watt rapid start lamp. Over a 30,000 hour life, each low-wattage lamp represents savings of $6.00 to $7.20 based upon an energy cost of $.04/kWh. At a normal 60 hours use per week, energy saving lamps justify their increased cost within 14 to 17 months, which is dependent upon manufacturers. Where

Figure 6: Lamps Comparison

Manufacturer	Lamp	Watts	Rated Initial Lumens	Rated Lumens at 40 Percent of Average Life	Price	Cost Increase Compared to Cool White Rapid Start
Sylvania	Cool White Rapid Start	40	3150	—	$2.37	—
	Super Saver	34	2850	—	2.95	$0.58
	Super Saver II	34	3050	—	3.40	1.03
	Thriftmate 33	—	—	—	5.35	2.98
	U-Shaped	40	2950	—	8.00	5.63
Westinghouse	Cool White Rapid Start	40	3150	—	$2.37	—
	Econ-O-Watt	34	2850	—	2.95	$0.58
	Econ-O-White	34	3050	—	3.40	1.03
	U-Shaped	40	2950	—	8.00	5.63
General Electric	Cool White Rapid Start	40	3150	2770	$2.37	—
	Watt Miser	35	2850	2510	2.95	$0.58
	Watt Miser II	35	3050	2685	3.40	1.03
	U-Shaped	40	2900	2525	8.00	5.63

reduction in illumination levels of 9.69 percent can be tolerated, another high efficacy energy saving lamp can be used that costs only $0.58 more than a standard 40-watt lamp. Its energy savings are identical to the more expensive lamp, but because of its lower first cost, this lamp justifies its extra cost within 7 to 9 months at 60 hours per week use.

The low cost, lower efficacy energy saving lamp is particularly appropriate for retrofitting existing lighting installations. Since many lighting systems of the past 5 to 10 years were designed to deliver 70 to 150 fc, relamping with inexpensive low-wattage lamps offers a simple, effective way to cut operating costs while still meeting or exceeding today's lower illumination standards (currently, for example, NASA, the Navy and GSA require only 50 fc for office lighting). (See figure 6 for comparative lamp data.) Substantial annual energy savings can be realized by the use of these lamps as well as the spin-off air conditioning energy savings.

Fluorescent Ballasts

Conventional fluorescent ballasts should be specified as the Very Low Heat Rise type. The Very Low Heat ballast represents an additional initial dollar cost over a more conventional ballast (or $2.00 per four-lamp, two-ballast fixture). However, ballast manufacturers' figures indicate that even slight reductions in the continuous ambient operating temperature of a ballast will result in extension of ballast life by a substantial factor, thus, increasing the maintenance-free life of the lighting installation and substantially reducing the overall cost of ownership of the system by reducing energy consumption.

Low-wattage ballasts might also be considered for conventional fluorescent lighting. Depending upon the manufacturer, each low-wattage ballast can save 3 to 5 watts, which is a substantial saving for a large installation and they are compatible with 34-, 35-, and 40-watt fluorescent lamps. However, low-wattage ballasts cost up to $3.00 a piece more than conventional ballasts (or $6.00 more for a four-lamp, two-ballast 2x4 fixture), and the additional investment is not amortized for at least 6 years based on 60 hours use per week and 52 weeks per year (the payback period does not take into account the interest that must be paid on the additional principal used to buy the more expensive ballasts). One major manufacturer claims for its low-wattage ballasts a life expectancy 2 to 2-1/2 times that for normal fluorescent ballasts.

Alternate Ballast Switching

As an alternate approach to conventional switching, a two-level Hi-Lo switching system should be considered. One switch can control the ballast of the inboard tubes of 2x4 foot fluorescent fixtures, while the second switch controls the ballast of the outboard tubes. This provides the option of having all of the lamps on to give a high, even illumination of up to 70 fc. Alternate ballast switching is a poor man's dimming system, but it is very effective, as it permits local control of lighting levels at minimal costs. Since each switch controls two lamps in each group of fixtures, lighting and power consumption can be cut 50 percent in any given area while still leaving adequate illumination for most tasks. A minor, but no-cost refinement to this technique is to specify that the switch closest to the door lock jamb (that is, the switch nearest at hand) control the ballast of the inboard lamps, while the further switch controls the outboard lamps. Since lighting from the inner lamps is distributed with slightly higher efficiency than that from the outer lamps, the actual percentage of total fixture illumination available by operating only the most convenient switch is approximately 53 percent. Since power consumption for each pair of lamps (i.e., each ballast) is identical, there is no reason not to take advantage of this incremental increase in illumination available by the simplest of means, when only half the lamps are required for a given task.

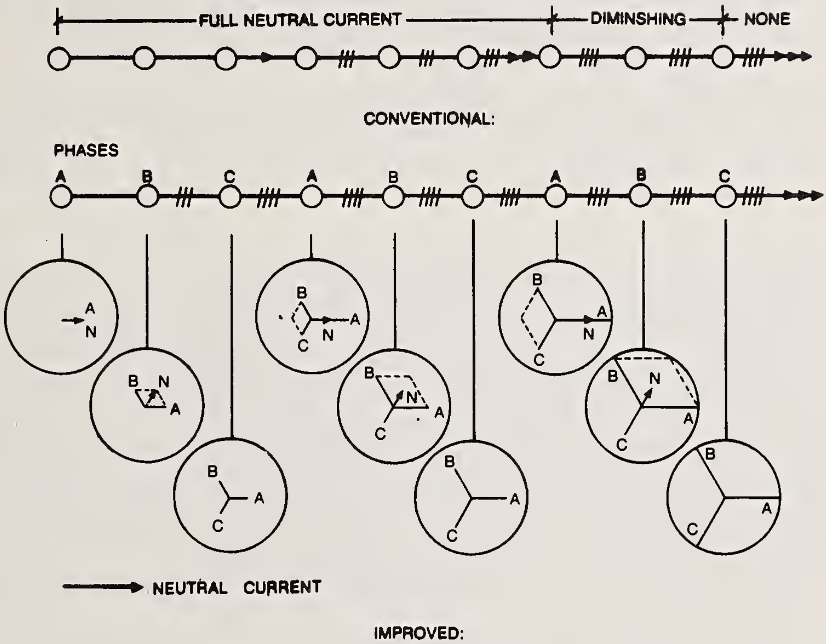
And, as previously noted, reducing lighting loads also reduces air-conditioning loads, which further increases energy savings.

Site Lighting Circuitry

Two factors are usually taken for granted in wiring outdoor lighting fixtures, without being considered in proper depth: one, the utilization voltage and two, the methodology of wiring as it affects voltage drop. Site lighting is frequently served at 120 volts and wired in discrete circuits (three phase wires sharing a neutral with up to 1920 watts of lighting load per 120 volt circuit). However, this requires that the feeder be sized for the voltage drop incurred by a two-way run--the phase conductor out and the neutral conductor back. And, due to the long wiring runs common in outdoor lighting, this method results in voltage drop problems of greater magnitude than usually seen in interior lighting.

Consideration should be given instead to using three phase, 277 volt circuits to serve outdoor lighting (by using HID lamp fixtures, all can be placed on the 277/480 volt service). Figure 7 shows the advantages: there are two wires to the last lighting fixture in the group (phase and neutral), three wires to the next fixtures (two phase wires and a neutral), and four wires to the remaining lighting fixtures (three phase wires and a neutral). This permits the first fixture on the three phase circuit to be on phase A, the second on phase B, the third on phase C, the fourth fixture on phase A, etc. Thus, the only imbalanced neutral current is that contributed by one fixture when there is either one extra fixture on a given phase or one extra fixture on each of two phases. Any condition of even numbers of lighting fixtures on all phases provides zero vector neutral current aside from any third harmonic distortion.

Figure 7: Outdoor Lighting Wiring Systems



This permits the use of fewer and smaller branch circuit conductors and thus fewer and smaller conduits as well, representing a significant "source" energy and resource saving. Further, serving fixtures on alternate phases of a three phase circuit reduces I^2R losses and voltage drop.

Even in large site lighting and street lighting installations such as industrial parks, and medical and college campuses, lighting should be served at 277 volts, if the overall system can be fed in sectors from different buildings. However, in the case of a large centrally-fed lighting system, voltage drop at 277 volts may be a serious problem, requiring excessive over-sizing of direct burial conductors and oversized raceways for those conductors where they pass under road beds or paved areas.

At this point it becomes practical to consider use of a higher distribution voltage for site lighting. Invariably, a large campus or industrial facility will employ the use of central chillers, fed by a 4160 wye/2400 volts, 3 ϕ, four wire distribution system. Thus, site lighting can be wired for series-multiple 2400 volt distribution.

If incandescent or quartz luminaires are used (which have low efficacies and short lives, thus high first and life-cycle costs and larger energy expenditures) each lighting fixture should be provided with a fused disconnecting pothead in the pole base. Otherwise, since a 2400 volt lighting system is normally wired in series-multiple, an entire circuit of lights would go out when a single luminaire failed (much like old-fashioned Christmas tree lights). However, with a fused disconnecting pothead, a transient surge voltage is created when a lamp burns out that melts the fused link, bypassing the burned-out lamp and preserving the circuit so that the remaining lamps continue to operate.

If, instead, HID luminaires are used, the 2400 volt primary--277 volt secondary ballasts can be used that act like transformers. Thus, if a single HID lamp is burned out it does not open-circuit the remaining fixtures.

Nowadays, the most commonly used intermediate range distribution voltages are either 13.2 kV or 34.5 kV. The preferred distribution voltage for industrial parks and colleges is 13.2 kV (or, for some utilities, 13.8 kV) in order to reduce first cost of distribution equipment, such as electrical feeders and primary switch gear and primary transformers. Thus, if a 2400/4160 volt chiller and a series-multiple street lighting system is used, a step-down transformer would be required, increasing first and life-cycle costs while causing additional energy waste in the form of transformer core and coil loss. If, for any reason, the step-down transformers serving the chillers are shut down at any time during the season, then the 2400 volts is unavailable for outdoor lighting.

Furthermore, if during the period the lighting is on and the chillers come on the line, a large surge of current through the transformer could create a large voltage drop in the transformer windings, causing a temporary lamp lumen depreciation or light flicker from the street lights. If this voltage dip is over 35 percent during windless warm weather or over 25 percent when the outside ambient temperature is 20°F, or the outside temperature is 35°F and there is a stiff wind blowing, (which can cause a lower chill factor equivalent temperature) the HID luminaire lamp arc plasma may extinguish. This condition would leave an installation in the dark for at least 10 minutes until at least some of the lamp arcs restrike; however, they will not reach full intensity for another 3 to 5 minutes. If, however, a lamp strikes and then extinguishes, another 5 to 10 minutes cooling period is required before the arc plasmas are cool enough to attempt a restrike.

Central Chiller Utilization Voltage

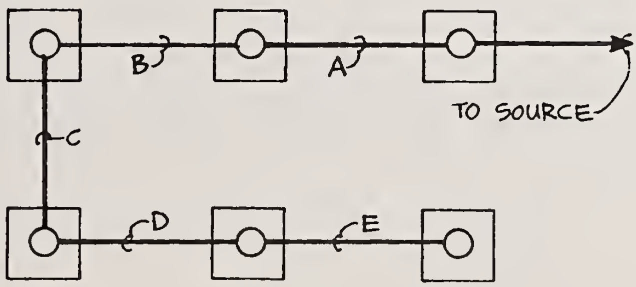
At this technological state-of-the-art in equipment and design, the use of 4160 volts for the service utilization voltage for large chillers is somewhat questionable. Present day techniques would indicate that 13.8 kV should be used, thus requiring no motor starter, although a switchgear is required in lieu thereof. Further, no 13.8 kV delta primary 4160 volt secondary transformer would have to be furnished and sized as follows for, say, a 200 ton chiller: six times full load kVA (for start-up kVA) times 200 tons times 1 kW/ton equals 1.2 megavoltampere (MVA) whereby an industry standard transformer unit of 1500 kVA size would be required. By using reduced voltage closed transition star-delta starting you could get by with a 750 kVA transformer per each 200 ton chiller. One disadvantage to using medium voltage (601 to 15,000 volts) starting is that for smaller motor sizes the initial dollar investment is larger. The smallest horsepower (hp) motor frame in this voltage range is 3500 hp. An additional consideration is that when using 4160 volts, there will be continuous transformer hysteresis core and coil losses even when the chillers are off the line or idling on the line.

Minimizing Voltage Drop

Branch circuit wiring should always be designed to minimize the length of wire and conduit runs. This not only saves material and labor but reduces voltage drop by reducing the total impedance (resistance) to current flow. Further, current-consuming equipment such as lighting fixtures should not be wired in a series loop where this will increase the distance that current must flow to each fixture. Rather, branch or tap-off connections should be made at the point of power supply to each group of fixtures. Reducing the physical distance that current must flow to each individual fixture in turn reduces the accumulated ampere-feet. The greater the ampere-feet, the greater the voltage drop and (I^2R) heat losses due to increased energy consumption.

This increased heat loss will increase energy consumption, shorten the life of electrical equipment and marginally increase the air conditioning load. These factors will tend to increase life-cycle operating costs for the electrical installation (see figures 8A and 8B).

Figure 8A: Series Loop Wiring



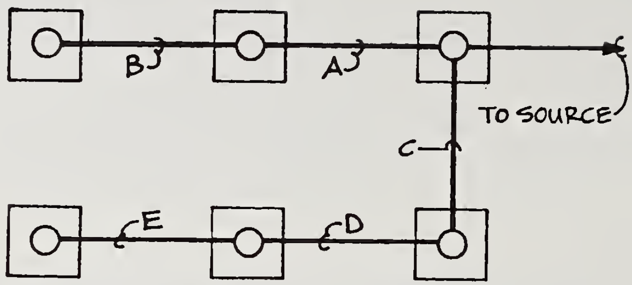
FLUORESCENT FIXTURES ON 6' - 0" CENTERS.

92 WATTS/FIXTURE ÷ 277 VOLTS = 0.33 AMP/FIXT.

AMP/FIXTURE X LENGTH OF RUN = AMPERE - FEET

A	.33	X	6	=	1.98
B	.33	X	12	=	3.96
C	.33	X	18	=	5.94
D	.33	X	24	=	7.29
E	.33	X	36	=	11.88
TOTAL					31.05 AMPERE-FEET

Figure 8B: Recommended Wiring



FLUORESCENT FIXTURES ON 6' - 0" CENTERS.

A	.33 X 6	=	1.98
B	.33 X 12	=	3.96
C	.33 X 6	=	1.98
D	.33 X 12	=	3.96
E	.33 X 18	=	5.94
TOTAL			17.82 AMPERE-FEET

Conclusion

The incorporation of these techniques into a carefully engineered overall design will result in efficient, energy conservative buildings and distribution systems. The quantities of finished electrical hardware used in a given project will be reduced (hence, also the total energy expended to provide the building's electrical components) without any sacrifice in performance and reliability.

During the life-cycle use of a building, less energy will be used since less material will have to be replaced and maintained. Most importantly, less energy will be required in the support of building systems since they will be less wasteful and more energy efficient. Each subsystem will be more energy efficient and will impart energy efficiency to other disciplines by reducing impact loads on these other systems, such as air conditioning.

POTENTIAL ENERGY SAVINGS IN BUILDINGS RESULTING FROM THE NCSBCS CODE COMPARED WITH BEPS

by

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In the State of Iowa, under the present State Energy Conservation Building Code (National Conference of States on Building Codes and Standards [NCSBCS] Code), all buildings that are larger than 100,000 cubic feet must be submitted for State approval, with a statement from a registered architect or engineer verifying that the plans and specifications meet the code requirements. During the past 2 years, more than 100 design professionals and about as many building inspectors have completed a training course organized by the Architecture Extension of the Iowa State University (ISU), and more than 400 building plans have been submitted to the Iowa Building Code Commission for approval. The required "Statement of Review" includes design conditions and overall U-values for exterior walls, roof/ceilings, floors, and the gross wall cooling thermal transfer value (OTTV).

During the 2 years since the code was introduced, some 412 buildings have been analyzed by the ISU Architecture Extension as to what degree the results compare with the corresponding code requirements. It was found that the results are encouraging. By an average, the U_o wall figures are about <u>40 percent better</u> than the allowable American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90-75 standards (or the revised ASHRAE 90.1-75R), the roof/ceiling values about 15 percent, and the OTTV values more than 50 percent better.

For the purpose of comparison with the Building Energy Performance Standards (BEPS), the results have been classified in 17 categories in anticipation of BEPS categories (splitting office buildings into large and small categories). The results illustrate characteristically how buildings of various types may approach or even exceed BEPS values. Of course, the U_o-values by themselves cannot be compared directly with BEPS performance standards and energy budgets, but a close implication can be seen from values produced by approximation.

As a second phase of the research, the Architecture Extension has been checking sample building plans in various parts of the State, in order to verify the accuracy of statements submitted. So far, the statements have been proven accurate, with only minor computation errors. Later on, another check is planned by inspecting those buildings for actual installations. Finally, energy audits are planned for verification of performance criteria. The ISU Building Energy Utilization Laboratory is also involved in studies of Iowa buildings.

Key words: Building code; building envelope; comparison; compliance; energy budget; energy conservation; performance standards; Statement of Review; verification.

In the State of Iowa, the energy crisis has been taken seriously. The State government has taken a number of steps to improve the energy situation and to reduce waste. One of the most attention getting programs has been the production of gasohol from our plentiful supply of corn; one of the least noticed has been our enforcement of the State Energy Conservation Building Code. However, from the point of view of energy conservation, the latter deserves a considerable amount of credit for its results.

Already in the summer of 1977, the Iowa Legislature called for an energy conservation building code. This was at the time when the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90-75 standards were still in the process of codification. As soon as the National Conference of States on Building Codes and Standards (NCSBCS) code became available, it was adopted by Iowa - with just a few modifications. Since some 80 percent of Iowa's more than 900 localities do not have a building inspector (although the other localities account for some 85 percent of building activity), it was decided that for any building that has more than 100,000 cubic feet of heated or cooled space a Statement of Review (see Appendix 1) had to be signed (and sealed) by a registered architect or engineer that the plans and specifications complied with the code, regardless of the location. These statements are to be sent to the Iowa Building Code Commission for approval. A fee of $10 is charged for the processing.

While this enactment took place, the Architecture Extension of Iowa State University (ISU) organized training courses for architects, engineers, designers, contractors, building inspectors and municipal officials. The first series of four simultaneous workshops was conducted in November 1977, with a team of national experts as pilot instructors. These workshops consisted of a four-day course for systems designers, two separate three-day courses for professionals and building inspectors, respectively, and a one-day introductory course for municipal officials. A series of 15 additional workshops around the State followed in 1978-79, and ten more workshops were held in 1980, to up-date the code requirements and to introduce the revised ASHRAE 90.1-75R, ASHRAE 100-series, and the Building Energy Performance Standards (BEPS). To date, some 150 professionals in Iowa have been trained by these courses and a similar number of building inspectors have taken the course.

As we attempt to evaluate the effects of the energy conservation building code in the State of Iowa, it is necessary to consider several different approaches. We have in hand the evidence produced by the statements of review. We can quantify the results of this portion of our program to a certain degree by comparing the presented U-values of building components with those allowable by the code, and we can make certain assumptions in order to convert these values into actual energy budgets. We do not have enough information to make a simulated energy analysis as is made in BEPS, but we can get close. At the same time, we need to know how accurate the statements are, whether the buildings actually are constructed in accordance with the documents, and we would like to know if the buildings are actually performing in the intended manner. And, as both ASHRAE 90 and BEPS are based on square foot values, we still do not know how efficient the buildings are per number of occupants. Also, we cannot legislate the quality of operations and maintenance.

Our first step towards evaluation was to compute the results of the first year and a half of Statements of Review received by the Iowa Building Code Commission and to compare the actual values with those allowable. (See figure 1.)

To our satisfaction, we found that the professionals had done more than the code dictated. The overall U-values for walls were generally more than 40 percent tighter than ASHRAE 90-75 standards, the roof values by more than 15 percent, and the OTTV-values by 50 to 60 percent. Only in a few cases, the values for building components failed to comply, while the buildings themselves did comply.

These results are important from several different points of view. When the NCSBCS code was adopted, the Iowa Energy Policy Council recommended that the component U-values be made about 20 percent tighter than the ASHRAE 90-75 values involved. In opposition, building contractors and materials and equipment manufacturers requested lower than the proposed set of values. As a compromise, the national code was adopted. But now we can see that the designers have been able to produce even more energy-efficient buildings than the Iowa Energy Policy Council recommended.

The proposed U.S. Department of Energy Building Energy Performance Standards--BEPS--are supposedly 20 to 25 percent stricter than ASHRAE 90.1-75R, the revised consensus standards. As the revised standards are primarily the same as the earlier ones, with the exception of residential buildings, we have available an approximate "yard stick" with which to compare our results in Iowa with BEPS, and by the first glance such comparison is favorable.

In order to compare the results with BEPS, the Architecture Extension that is providing this service to the Iowa Energy Policy Council classified the buildings in approximately the same categories as are anticipated by BEPS, with a few exceptions. As the annual design energy budgets are computed, certain assumptions have been made. While the heat losses and gains through the building envelope can be determined fairly accurately under normal design conditions, we do not have enough information about infiltration and ventilation. Consequently, we have assumed that from one to three air changes per hour are taking place, depending on the type of building, within modifications allowed by ASHRAE 90-75 standards.

By observing the results presented to us by Statements of Review, we did interpret the better U-values and OTTV-values to mean that the buildings generally had less windows and consequently less "crack" at perimeters

Figure 1: Potential Energy Savings in Buildings Larger than 100,000 Cubic Feet in Iowa as a Result of Implementing the State Energy Conservation Building Code

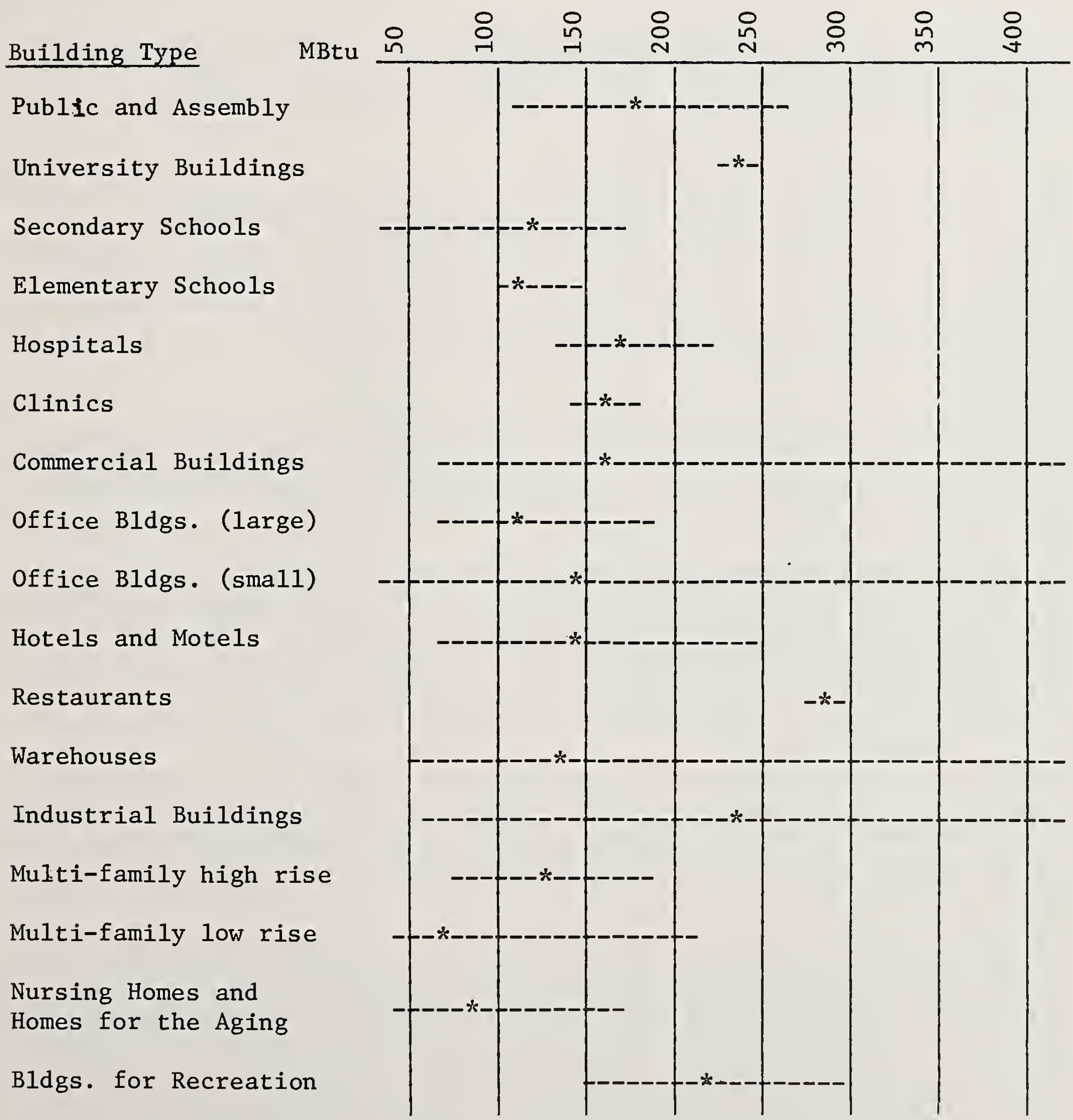
The following percentages represent reductions in U-values of building components, as being stricter than ASHRAE 90-75 standards. This group of Statements of Review were submitted between January 1, 1978, and July 1, 1979. Computations are by the Architecture Extension, Iowa State University.

Building Type	U_o Wall	U_o Roof	OTTV	Bldgs. Cooled	Total
Public and Assembly	43 %	11 %	60 %	13	14
University Buildings	12	32	54	2	2
Secondary Schools	48	6	53	12	16
Elementary Schools	41	(0)*	69	3	9
Hospitals	39	8	61	5	5
Clinics	34	37	66	2	3
Commercial Buildings	37	(7)	62	47	52
Office Buildings (large)	31	15	51	7	8
Office Buildings (small)	45	15	58	36	41
Hotels and Motels	31	26	48	6	8
Restaurants	46	(46)	85	2	2
Warehouses	54	(1)	57	14	37
Industrial Buildings	42	(9)	65	13	29
Multi-family high rise	39	28	44	5	5
Multi-family low rise	41	49	48	11	28
Nursing Homes and Homes for the Aging	48	47	49	4	8
Buildings for Recreation	48	5	77	7	10
Inadequate data					15
				189	292

*) Equal or negative ()

Figure 2: Approximate Actual Annual Design Energy Budgets for Buildings Larger than 100,000 Cubic Feet in Iowa, for Buildings Submitted Before July 1, 1979.

These are not computer simulations, but are based on energy losses through the building envelope, infiltration and ventilation, in Btu/sq.ft./year. Computations are by the Architecture Extension, Iowa State University.



* indicates average

Dotted line indicates the range of figures as computed for all buildings.

of openings. This factor was considered by taking 25 percent of the OTTV "improvement percentage" and reducing infiltration by that ratio (for instance, if the actual OTTV was 40 percent better, the resulting reduction in infiltration was 10 percent, while the ventilation factor remained the same). For the cooling cycle, an average of 2400 hours of infiltration, with a 10°F temperature difference was used. No attempt was made to estimate the effects of a fuel mix, and no resource impact factors (RIFs) and resource utilization factors (RUFs) or fuel equilization factors were considered.

In charting out the results of computations (see figure 2), we show the range of design energy budgets (MBtu=1000 Btu) in each category. The average values are shown by an asterisk, but we did not attempt to establish 20 percent or 80 percent ranges.

By numerical comparison (see figure 3), we find that in almost all cases the lowest annual design energy budgets obtained are well within BEPS requirements. Regarding the average values, about one-half of them meet BEPS, several are close, and in only a few categories is there a failure to comply. At the same time we need to note that in Iowa the sample is really random and reflects the "current practice" without any attempt to select certain buildings for further improvements.

As we continue to study Statements of Review submitted between July 1, 1979, and July 1, 1980, we find that the results are similar. We have not yet converted these values to annual design energy budgets, but will not expect significant differences. (See figure 4.)

We should emphasize that these results are not scientifically accurate, and cannot withstand serious criticism. However, they serve as an indicator that Iowa professionals have met the test and are conscientiously producing energy-efficient designs for buildings. And, the comparisons with ASHRAE 90-75 (and ASHRAE 90.1-75R) are relatively realistic, while those with BEPS give hope that such performance standards can be met.

We shall make no comment on the desirability of BEPS, nor on methods of computation and accuracies of BEPS standards. Personally, I am in favor of performance standards, as long as they do not set an unnecessary burden on professionals and on the building industry, and can be reasonably enforced by average building inspectors.

The next step in Iowa is to review a number of sample building plans and specifications to establish the accuracy of documents. Some of this work has been done, and we find the results satisfactory, with only a few computation errors and misinterpretations of the code. Some of these sample buildings will be inspected on-site. Later on, should we have adequate funds available, actual energy audits will be performed, to establish actual performances. As even in BEPS, the design energy budgets cannot be maintained without meaningful operation and maintenance standards; differences are bound to occur.

Figure 3: Approximate Actual Annual Design Energy Budget for Buildings Larger than 100,000 Cubic Feet in Iowa, Figures Compared with BEPS (see figure 2)

These figures show the lowest annual energy budgets, and averages, compared with BEPS, as computed by the Architecture Extension, Iowa State University. Figures are based on U-values of the building envelope, infiltration, and ventilation. BEPS values range: Omaha to Minneapolis. *)

Building Type	Lowest Design Budget	Average	BEPS range
Public and Assembly	(MBTU) 110	182	145-157
University Buildings	240	245	
Secondary Schools	38	140	126-138
Elementary Schools	98	105	105-122
Hospitals	130	170	338-335
Clinics	148	155	130-142
Commercial Buildings (Stores and Shopping Centers)	70	152	(145-155) (186-198)
Office Buildings (large)	70	120	115-123
Office Buildings (small)	30	145	107-117
Hotels and Motels	118	150	170-180
Restaurants	280	285	
Warehouses	52	135	76-93
Industrial Buildings	68	235	
Multi-family high rise	78	130	126-140
Multi-family low rise	40	72	106-110
Nursing Homes and Homes for the Aging	45	82	164-175
Buildings for Recreation	152	222	

*) BEPS does not show a Metropolitan Data Base for Iowa.

Figure 4: Potential Energy Saving in Buildings Larger than 100,000 Cubic Feet in Iowa as a Result of Implementing the State Energy Conservation Building Code

The following percentages represent reductions in U-values of building components, as being stricter than ASHRAE 90-75 standards. This group of Statements of Review were submitted between July 1, 1979, and July 1, 1980. Computations are by the Architecture Extension, Iowa State University.

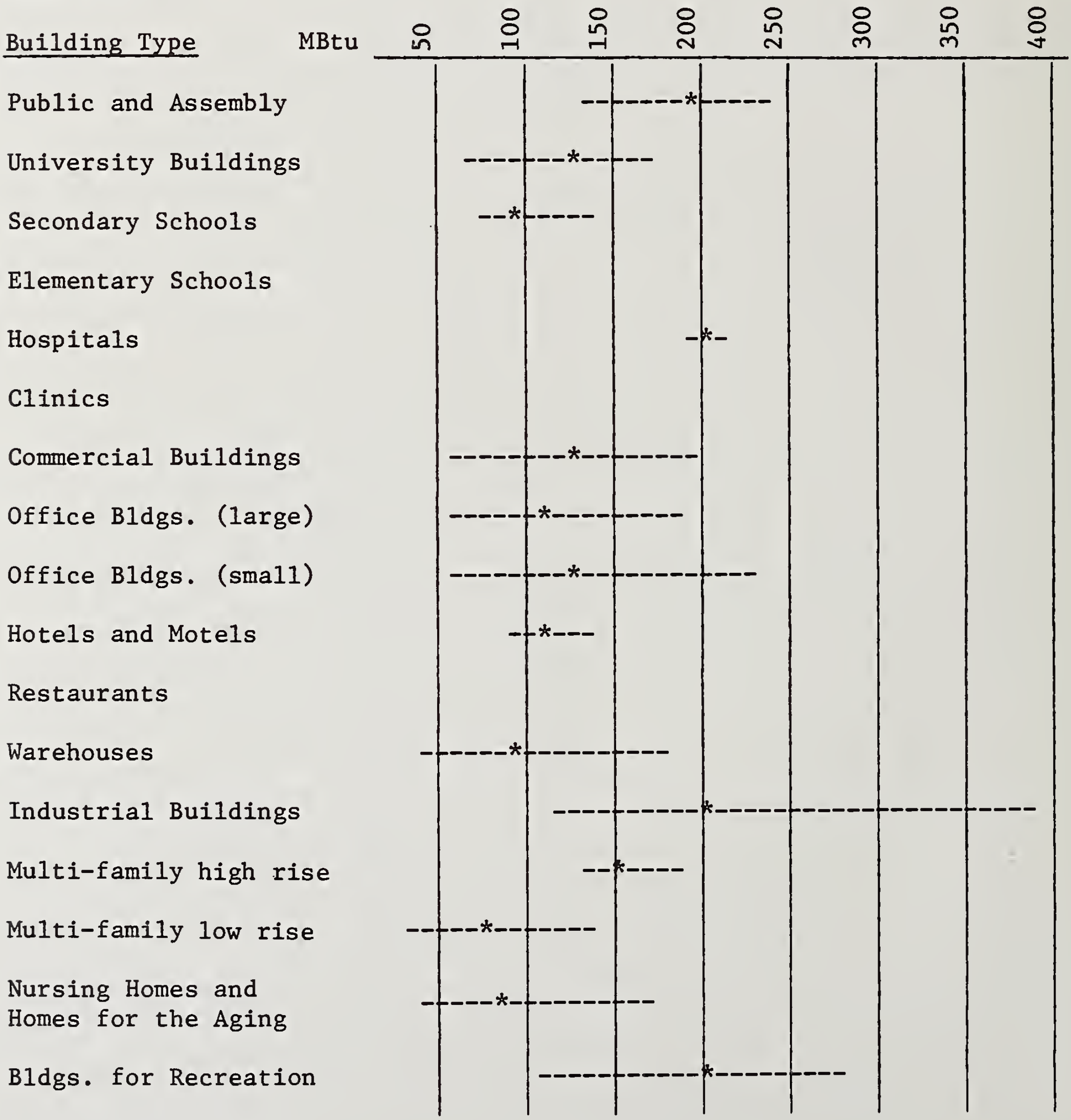
Building Type	U_o Wall	U_o Roof	OTTV	Bldgs. Cooled	Total
Public and Assembly	53 %	30 %	59 %	2	21
University Buildings	33	16	47	6	6
Secondary Schools	48	(10) *)	64	4	5
Elementary Schools					
Hospitals	17	8	45	1	1
Clinics					
Commercial Buildings	42	4	58	15	20
Office Buildings (large)	39	1	46	9	9
Office Buildings (small)	33	23	46	14	19
Hotels and Motels	(2)	23	29		2
Restaurants					
Warehouses	50	1	63	5	23
Industrial Buildings	37	2	65	12	23
Multi-family high rise	28	30	31	4	4
Multi-family low rise	42	59	26	9	13
Nursing Homes and Homes for the Aging	44	42	23	1	3
Buildings for Recreation	58	7	70	4	5
Inadequate data					4
				86	139

*) Equal or negative ()

To conclude, the State of Iowa has done and is doing what can be done with a relatively low enforcement budget, with good results. When BEPS is implemented, we will be prepared to educate our professionals, builders, and building officials in the manner required. Energy conservation is one way by which we can reduce waste significantly, and the building code has proven to be an effective way of implementation.

Figure 5: Approximate Actual Annual Design Energy Budgets for Buildings Larger than 100,000 Cubic Feet in Iowa, for Buildings Submitted Since July 1, 1979

These are not computer simulations, but are based on energy losses through the building envelope, infiltration and ventilation, in Btu/sq.ft./year. Computations are by the Architecture Extension, Iowa State University.



* indicates average

Dotted line indicates the range of figures as computed for all buildings.

STATEMENT OF REVIEW
FOR
COMPLIANCE WITH THE
IOWA STATE BUILDING CODE
ENERGY EFFICIENCY STANDARDS

BUILDING CODE COMMISSIONER
BUILDING NUMBER

BUILDING NAME ____________________
LOCATION ____________________
____
OWNER ____________________
ADDRESS ____________________
____
____

BRIEF DESCRIPTION ____________________
____
____
____

BUILDING TYPE:
RESIDENTIAL A1☐ A2☐
OTHER (TYPE B):
UNDER 3 STORIES ☐
OVER 3 STORIES ☐

OCCUPANCY TYPE(s) ____________________
(AS DEFINED BY THE UNIFORM BUILDING ADOPTED BY THE STATE BUILDING CODE)

THIS BUILDING IS INTENDED TO COMPLY WITH THE REQUIREMENTS OF SECTION ____________ (4, 5, or 6) OF REFERENCED CODE ADOPTED BY RULE 5.800(3) OF DIVISION 8 OF THE IOWA STATE BUILDING CODE.

DESIGN PARAMETERS

OUTDOOR DESIGN TEMPERATURE		
WINTER	DESIGN DRY-BULB	F
SUMMER	DESIGN DRY-BULB	F
	DESIGN WET-BULB	F
DEGREE DAYS HEATING		
COOLING HOURS		
DEGREES NORTH LATITUDE		

GROSS FLOOR AREA ____________ SQ. FT.
(HEATED OR COOLED SPACE)

GROSS VOLUME ____________ CU. FT.
(HEATED OR COOLED SPACE)

COMBINED GROSS EXPOSED WALL AREA ____________ SQ. FT.

% OPENINGS (WINDOWS, DOORS, ETC.) ____________

COMBINED GROSS EXPOSED WALL TRANSMITTANCE (Uo WALL) ____________ Btu./SQ. FT./HR./F

COMBINED GROSS ROOF/CEILING AREA ____________ SQ. FT.

% OPENINGS ____________

COMBINED GROSS ROOF/CELING TRANSMITTANCE
(Uo ROOF/CEILING) ____________ Btu./SQ. FT./HR./F

AREA OF FLOOR OVER UNHEATED SPACES
(HEATING or COOLING) ____________ SQ. FT.

MAXIMUM GROSS WALL COOLING THERMAL TRANSFER VALUE (OTTV) ____________ Btu./SQ. FT./HR./F
(TYPE B BUILDINGS ONLY)

MAXIMUM GROSS DESIGN HEAT LOSS (Btu/hr) ____________
MAXIMUM GROSS DESIGN COOLING LOAD (Btu/hr) ____________
MAXIMUM GROSS LIGHTING POWER BUDGET (KWH or W/sq. ft.) ____________

A REVIEW HAS BEEN COMPLETED FOR THE ABOVE BUILDING AND THE PROPOSED DESIGN IS IN COMPLIANCE WITH THE ENERGY AND LIGHTING EFFICIENCY STANDARD OF THE IOWA STATE BUILDING CODE.

SIGNED ____________________

DATE ____________________

ADDRESS ____________________
____
____

REVIEWER'S COPY

Appendix 1

SOLAR AND GEOTHERMAL HOUSING INNOVATIONS
via
INVERTED CAVE CONSTRUCTION SYSTEM

by

Thomas E. Loxley
Consultant Engineer/Builder
Shepherdstown, West Virginia

The cave offers many energy saving advantages, but the problems of underground construction severely limit its application. The author shows that modern materials can be used to build a house on grade as though it were a cave turned inside out. The result is a house of generally conventional appearance that functions like a cave.

The system consists of a highly insulated exterior wall and roof surrounding a central core of high thermal mass. Insulation extending to the base of the foundation isolates the house from outside temperature fluctuations. A concrete floor and central masonry wall then thermally couple the home interior to the underlying subsoil.

Reduced heating and cooling loads and the nature of the design introduce climate control options not possible with conventional construction. A piping loop placed directly beneath the slab floor permits the storage and circulation of water for use with a highly efficient water source heat pump. A modestly sized solar array is used in a simple, attractive arrangement to heat the loop water. This provides a radiant floor heating effect and boosts system efficiency.

Readily compatible with today's quality builders, this versatile system concept costs little more than current energy wasting construction.

Key words: Buildings; construction; energy conservation; ground coupled; hybrid solar energy system; inverted cave; low grade geothermal; radiant floor heating; space heating and cooling; thermal mass; walls; water source heat pump.

A heating engineer normally sees insulation and air infiltration control as the primary means to cut home heat losses. Increase insulation levels, eliminate unnecessary framing members, restrict window areas and plug leaks, and heating requirements can be cut in half. Historically, he has considered the temperature differential used in the heat loss calculation as a fixed term, governed by local outside air temperatures.

This is where a cave differs from a conventional house. The base temperature inside a cave depends on the subsoil temperature. Across much of the Northern United States, this temperature is a stable 45 to 60°F year round (see figure 1). A typical family often expends much of its yearly heating budget just to raise the temperature inside a house to that of the subsoil underneath. This typically represents 38 percent of the annual heating bill in Buffalo, 50 percent in Seattle, and 54 percent in Washington, DC. Needless to say, the cost of summer air conditioning could be eliminated entirely if we all move underground.

This phenomenon has inspired many to tackle the problems of building earth covered or underground homes. Complicated and expensive, such construction does not lend itself to widespread use. For many, the very idea conjures up images of damp and musty cellars; hardly the impression architects seek.

Geothermal power means using the earth as an active energy source. Too often visualized strictly as hot geysers and erupting volcanoes, geologists also talk of low grade heat flowing constantly through the earth's surface at about 20 Btu per square foot per hour [1]*. Our planet acts much like an enormous nuclear reactor, with the heat from its molten core dissipating in the atmosphere as it reaches the surface.

This paper describes a simple, comprehensive construction system which creates a house of generally conventional appearance that captures the benefits offered by the earth (see figure 2). Literally a cave turned inside out, the inverted cave construction system erects a highly insulated shell around a central masonry wall and concrete floor which thermally couple the home interior to the subsoil. Certain minimum house size considerations exist and the floor plan should be rather squarish in order to restrict perimeter effects. The nature of the system and the major reductions in the resulting heating and cooling loads introduce attractive climate control options not possible with conventional housing. A serpentine loop of 3- or 4-inch pipe placed directly beneath the slab floor permits the storage and circulation of water for use with a water-to-air heat pump. This offers more than double the best overall performance available from local use of the standard air-to-air heat pump. In addition, a modestly sized solar array can be used in a simple arrangement to heat the loop water. This provides a radiant floor heating effect and further boosts heat pump efficiency. Since all water stays within the home foundation, the system eliminates concerns over deleterious effluent or external energy effects.

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*Numbers in brackets refer to references at end of text.

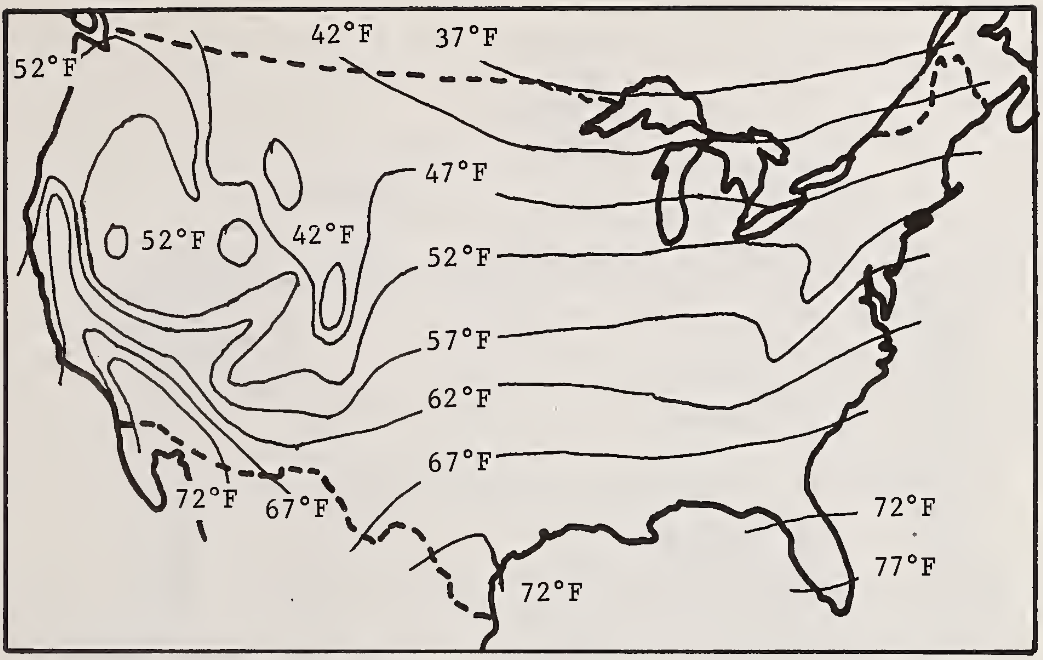

Figure 1 - Average Temperature of Shallow Ground Water (Source: U.S. Geological Survey,Water Atlas, Plate 30)

Figure 2 - Inverted Cave Construction System Split Foyer Demonstration Home

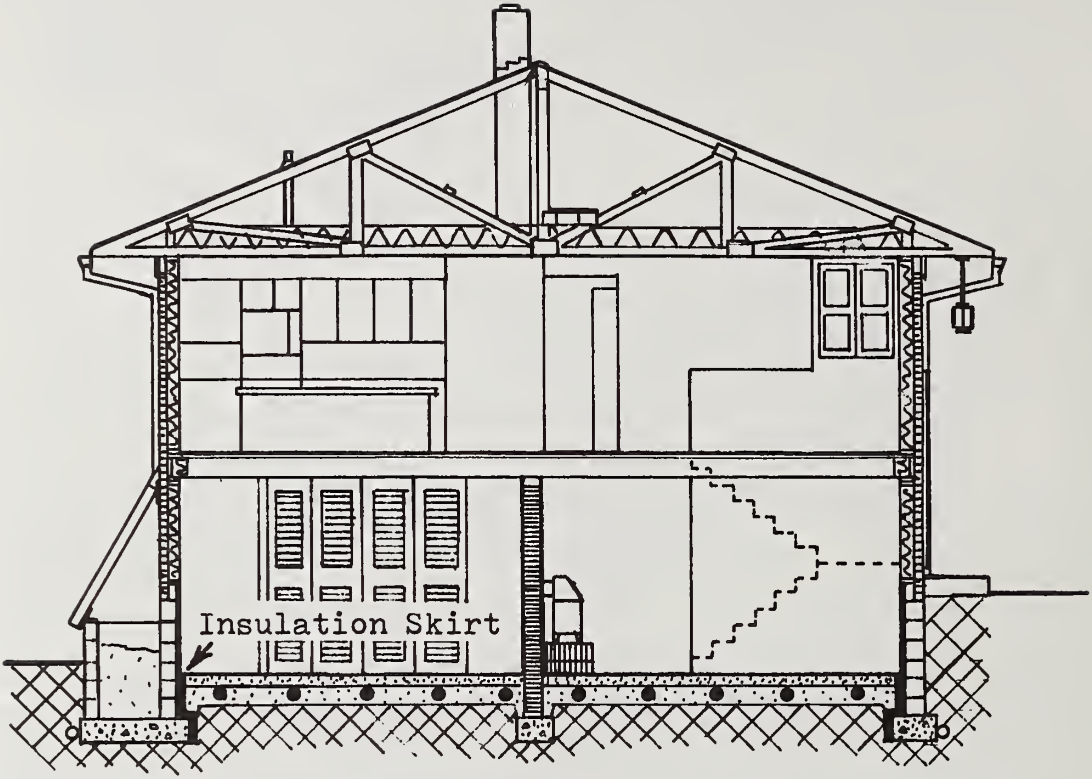

Figure 3 - Cross-Sectional Construction of Split Foyer Design

To prove the concept, a 2400 square foot split foyer version was constructed outside Shepherdstown in the eastern panhandle of West Virginia. This region's climate is characterized by a heating season of approximately 5500 heating degree-days (°F) and a cooling season of about 750 hours. The 99 percent assurance temperature limits are 6°F in winter and 93°F in summer.

The cross-sectional construction of this home is illustrated in figure 3. The conditioned space measures 30 feet wide by 40 feet long. Eight foot ceilings exist throughout, except for the upstairs hall where ductwork is contained in the dropped ceiling.

As shown, the insulation system starts at the very base of the foundation footing with the concrete actually being poured against the R-16 foam insulation. Lightweight 2-core block were then used to finish the foundation with the block cores being filled with perlite insulation. The R-16 foam insulation extends to the top of the slab floor to give an overall perimeter R-value of about 21. Above the floor, R-8 foam insulation is applied in a continuous fashion to the inside of the block knee wall. It is important that this wall be properly prepared and sealed before the foil faced foam slabs are glued in place.

The below grade insulation is integrated to form a continuous, tight skirt. All plumbing or electrical penetrations are restricted to locations either above grade or below the footing. Footing depth is governed by the local climate conditions. As usual, the base of the footer is kept below the frost line, the deeper the better. Extruded, closed cell polyurethane or polyisocyanurate slab insulation is preferred for low moisture absorption and high R-value per inch. Of course, the foundation must be properly waterproofed outside and effective drainage provided.

The framing system used has been popularized as the well proven, "Arkansas Story" approach [2]. Two-by-six studs spaced on 24-inch centers are combined with nailed and glued plywood headers and corners and steel drywall backup clips so as to form an exterior wall where 90 percent of the wall area contains fiberglass insulation. This compares to a 70 percent ratio for conventional 2x4 construction. Roof trusses and wall studs are stacked in-line to maximize structural integrity.

Fiberglass blanket and batt insulation of R-19 is used in the walls and R-38 in the roof. Considerable effort was made to ensure its proper installation and provide a sound foil or polyethelene vapor barrier. Standard black wall sheathing was preferred for its high permeability. Continuous ridge and eave vents were used to ventilate the roof area. Electrical wiring was constrained to avoid interference with the insulation. Likewise, all plumbing was restricted to interior walls and all ductwork contained within the insulated envelope.

Window design, size, and placement reflect an effort to maximize the distribution of natural light, fresh air ventilation, and emergency egress while minimizing the overall heat loss represented. Wood framed, horizontal sliding, double glazed units of 4-foot width were employed. Their size allowed ready incorporation into the framing with the minimal amount of carpentry. The windows selected also lend themselves to the possible incorporation of fixed storm glazing or sliding interior shutters. Total window area was restricted to 131 square feet.

All exterior doors are windowless, pressed steel construction with polyurethane cores and magnetic weather stripping. Storm doors are also used to boost entry insulation and air infiltration control.

Overall air infiltration control measures focus on provision of a tight vapor barrier and the massive use of butyl and polyurethane caulking. One side of all windows is caulked in place. Additionally, window and door units are caulked where they penetrate the frame wall and again where they penetrate the brick veneer. Sole plates are caulked and fiberglass sill sealer is applied on top of the block foundation wall. Band joists are wrapped with felt.

Every effort is made to seek out and seal any potential air leak. The remaining level of infiltration around the movable parts of doors and windows is considered to provide a beneficial and well distributed source of fresh air.

The physical heart of the system is the concrete and masonry which thermally couple the home interior to the underlying subsoil (see figure 4). Fine gravel or sand is used as fill under the concrete slab to provide drainage with good heat transfer. The central wall is a typical 8-inch brick garden wall which is 32 feet long and extends to the ceiling of the ground floor. This wall could be made of stone or concrete, the denser the better. A small chimney is provided for use of a combination wood or coal stove as an emergency heat source.

Figure 4 - Foundation and Central Wall in Split Foyer Home

Interestingly enough, this wall tends to cost less to construct than the standard fireplace installed in most homes this size. It also provides solid support for the upper floor, helps block noise transmission and is erected at the same time as the block foundation.

Some 400 feet of standard 4-inch polyvinylchloride (PVC) sewer pipe (ASTM D-3034, SDR 35) was used to form the serpentine water storage loop (see figure 5). This was terminated into upright 12-inch T-fittings to act as sump areas for the circulation pumps and a mixing chamber to temper the hot water leaving the solar array. This insures that the water temperature stays within the temperature restrictions of the PCV material. The loop assembly contains about 300 gallons of water. Special care was taken to fill the loop with the cleanest and softest water available. The P_h is adjusted to be slightly basic. Two small centrifugal pumps for use with the heat pump and solar array are mounted on the floor next to the loop outlet terminal and draw water using plastic foot valves submerged in the sump.

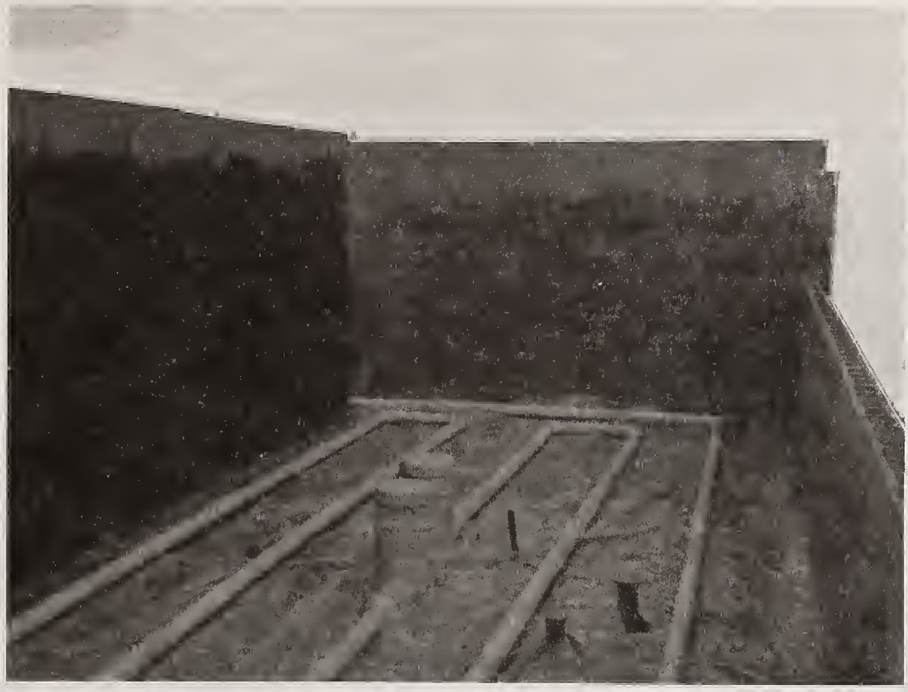

Figure 5 - Serpentine Storage and Distribution Loop Installation

The water-to-air heat pump used is a 2-ton unit made by the Carrier Corporation. Actual operation has been adjusted via the water and air circulation rate to tune the capacity to the 1.5 ton output required by the house. This also allows the cooling rate to be adjusted slightly for maximum humidity control.

Over the range of operating conditions anticipated, this unit offers a heating coefficient of performance (COP) of 3.4 and a cooling energy efficiency ratio (EER) of 15. Compare this to a COP of one for an electric furnace. Typical use of a good air-to-air heat pump in this local climate results in an average annual COP of 1.3 to 1.5 and a typical EER of 7. The water source unit is over twice as efficient.

The low overall performance of the standard air-to-air heat pump reflects its poor output at low temperatures and problems with frost formation. This requires special defrosting provisions and the use of supplementary electric resistance heaters which are activated in stages as the heat pump output drops off. Such complications are unnecessary with the water source unit which employs a simple single stage thermostat and offers a stable output over the range of operating conditions envisioned. In addition, the water source unit is fully self-contained and easy to install. There are no refrigerant lines to be installed on the job.

In order to operate properly, any heat pump requires provision for adequate return air circulation within the home. In this particular application, return air flow is provided via the central stairwell and the use of slit registers positioned under most of the upstairs windows and a large floor register positioned in the hall over the top of the wood stove. Wall registers are also positioned where necessary to feed air back to the heat pump blower inlet. Thus, all dead air spaces are eliminated and continuous air circulation assured throughout the house.

When the blower is off, the return air passages still allow cool dense air falling down the inside of the windows to power a natural air circulation pattern in winter which forces warm air up through the register in the hall (see figure 6). Thus, when the solar system is adequate, this natural air circulation quietly distributes the heat throughout the house without any need for the blower. Likewise, in the case of an electrical blackout, the combination wood or coal stove can be used to provide adequate, even heat to the entire home.

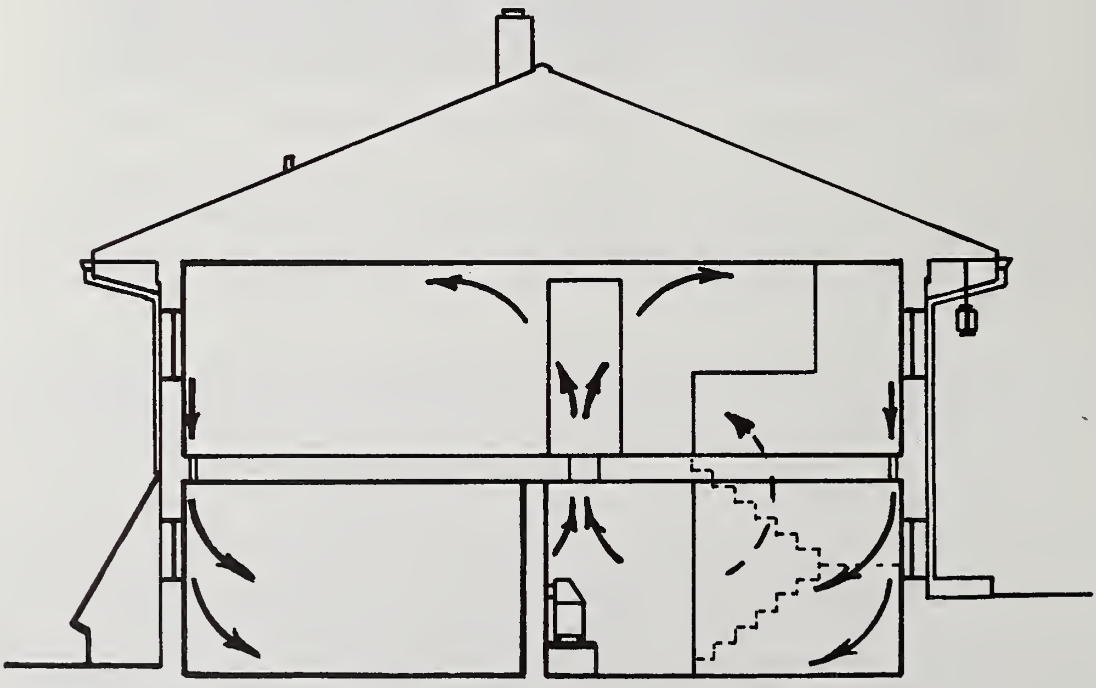

Figure 6 - Natural Air Circulation Pattern in Test Home Design

A liquid flat-plate solar array with a collection area of 200 square feet is positioned against the south face of the house, figure 7. The close proximity between the collector array and the storage loop is considered vital to system simplicity. The circulator pump is used to force water from storage up through the collector absorber plate. A small open drainback line on the collector side of the pump permits water in the collector to drain back to the storage loop when the pump shuts off. This constitutes a most reliable form of freeze protection with little expense and no moving parts. All effort is made to provide ample insulation (R-5) on all collector hookup lines.

Figure 7 - South Face of Split Foyer Home

A simple differential thermostat actuates the circulator pump when the collector absorber surface reaches a temperature 15°F above that of the pump inlet water. It then shuts off when this temperature difference drops to 5°F. The thermostat used has lightning surge protection and a variable high storage temperature limit. The latter shuts down the pump when the inlet temperature gets too warm, thus safeguarding the storage plumbing and avoiding overheating the house.

Water storage temperatures which range between 55°F and 80°F allow the collector to operate at maximum efficiency. The ground location also boosts collector performance significantly as sunshine reflects off any snow cover. Where durable winter snow cover cannot be relied on, using a reflective surface with the collector array will be more cost effective than any gross increases in collector area. The reflector could also flip back against the collector in summer to protect it from damage when the solar system is shut down.

The solar array is tilted for maximum performance in January. A 3-foot overhang and the body of the house act to shelter the collector array from wind and weather effects which would diminish efficiency or pose undue hazards. Likewise, the steep tilt angle and relationship to the house help shade the solar array from excess summer sun. This helps avoid unnecessary overheating and prolongs component life.

The close arrangement between the collector and the storage loop greatly simplifies system plumbing and allows all moving parts to be positioned inside the home. This greatly assists reliability and ease of maintenance. In place of an automatic vent valve, a simple air separator line connects the high point in the collector plumbing with the storage loop terminals. This allows easy filling of the collector, minimizes water losses, cuts flow noise and avoids vacuum resistance which might retard drainback.

The only moving parts in the entire solar system are the relay switch in the differential thermostat, the circulator pump and the foot valve in the pump inlet line. With its simplicity, this hybrid system clearly sidesteps many of the complications which have played havoc with some active solar installations.

The performance of the house has verified expectations, yielding a home which is naturally warm in winter and cool in summer. With outside temperatures hovering in the low teens and all heating equipment off, the base temperatures inside stood solidly at 52°F upstairs and 54°F downstairs. With summer temperatures of 82°F outside, the corresponding temperatures inside were 71°F upstairs and 67°F downstairs. During an unusual prolonged heat wave with temperatures climbing daily to 98°F, the base temperatures inside were 81°F upstairs and 76°F downstairs. In the latter case, the heat pump blower was used to force the cooler air upstairs during the day.

With the heat loss characteristics of the home construction known, the winter temperature differentials observed over long periods of time demonstrated a stable heat flux from the underlying earth of over 15,000 Btu per hour. This is well over the heat pump ground input of 12,000 Btu per hour needed to maintain a home temperature of 68°F under worst case conditions.

In spring and fall, the solar array provides much of the required supplemental heat. However, the local snow cover was limited last winter. A simple ground reflector design is being explored for use next winter, to bring the system up to peak potential. Heat pump use is seen as concentrated on sunless days and the months of December through February. Air conditioning assistance is almost unnecessary. Positive humidity control now appears best provided by a small central dehumidifier.

With the assistance of the Physics Department at Virginia Polytechnic Institute and State University, and the Virginia Center for Coal and Energy Research, the test house has recently been instrumented for comprehensive performance monitoring. Eight channels of temperature data will be recorded on 5-minute intervals. A separate meter has been installed to record power consumed by the heat pump.

Through various analyses, it will be possible to further evaluate and refine the system. These efforts should also aid design adjustments associated with implementing the concept in other geographical locations. Annual electric consumption for the 2400 square foot test house is expected to average less than 500 kilowatt-hours per month.

The enormous internal thermal mass is considered responsible for the even temperatures observed throughout the house. The system makes valuable use of the storage capacity of the fill and soil enclosed by the insulation skirt.

The slab floor in the split foyer test house averages less than 1 foot below grade. Standard one and two story inverted cave home designs have a floor level about 1 foot above grade and avoid the knee wall type foundation of the split foyer configuration. Various internal footing arrangements are being explored to maximize thermal coupling and simplify construction procedures.

Many people will wish to install foam backed carpeting over the slab floor. This is expected to have little effect on overall system performance, but will shift a greater responsibility to the heat pump.

The central masonry wall is probably unnecessary in a one-story building. However, so many people are attracted by such a brick or stone wall that it may prove ideal for curing people's love affair with energy-wasting fireplaces.

The inverted cave construction system lends itself to a variety of one and two story residential, commercial and industrial applications with a comfortable degree of architectural freedom. A natural for townhouses, it also lends itself to nursing homes, recreation facilities, and schools. Urban or rural locations make no difference. A minimal width of about 30 feet and a squarish floor plan are required.

With only slight modifications, the system appears suited to geographical sites ranging across the Northern U.S. and Southern Canada. Of course, increases in climate severity will require corresponding increases in insulation levels and minimal size considerations. Natural increases in foundation depth should have a compensating effect. In Buffalo, a minimal width of 32 feet may be required with triple glazed windows and an 8-inch wall construction like that in the University of Illinois "Lo-Cal" home design [3].

The Self-Inspecting Home of the Future

All Heating Equipment Left OFF
Outside Air Temperature : $15^{\circ}F$

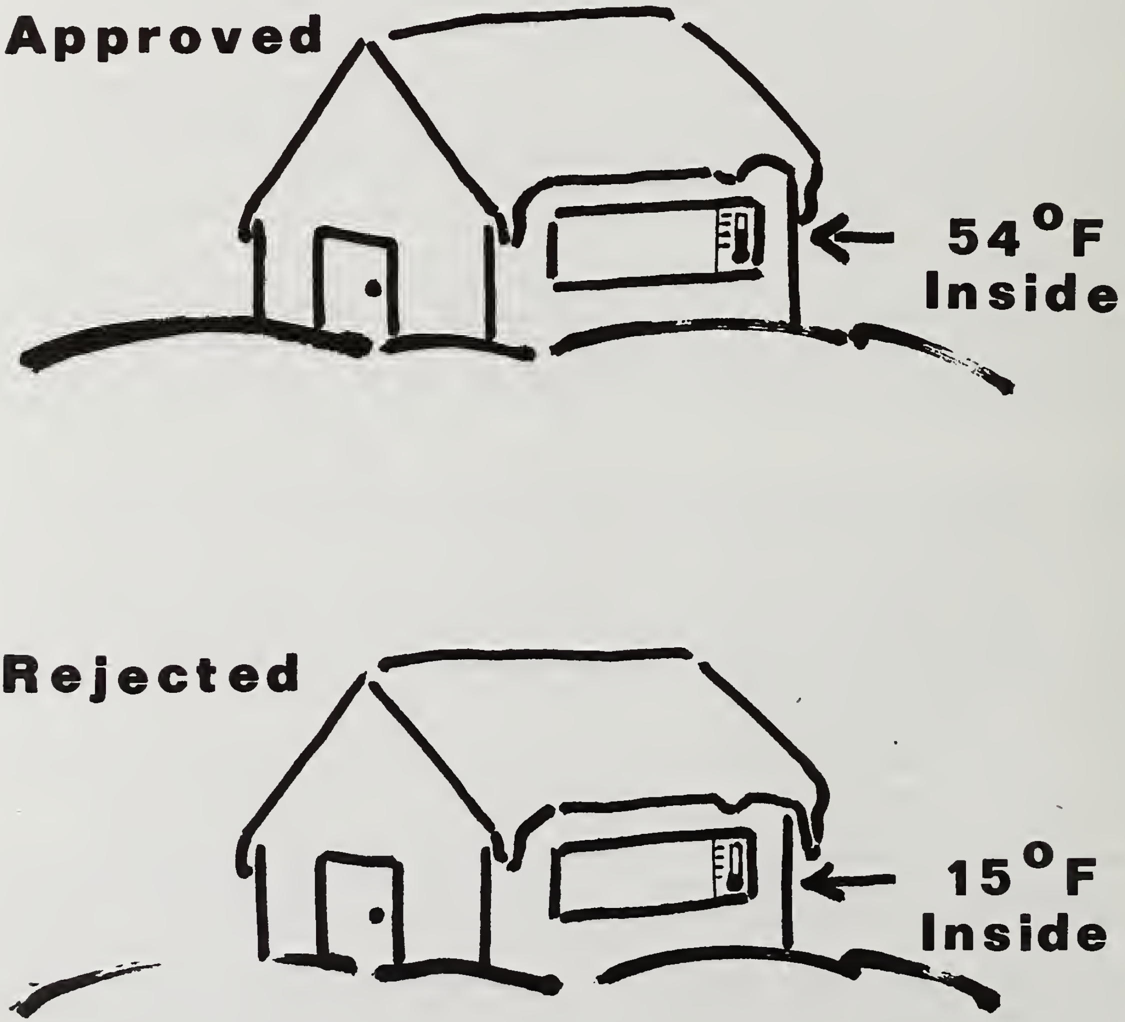

Figure 8

The inverted cave construction system is a logical extension of existing building codes and code approved materials. Experience shows it readily compatible with today's quality home builders with little additional cost compared to current energy wasting designs.

A further feature of the inverted cave construction system is that a building inspector can evaluate such energy conserving construction merely by checking the base temperatures inside on a cold day (see figure 8). Use of adequate insulation, poor workmanship or overlooked detail are reflected in this one simple measure. It may well represent the self-inspecting home of the future. Indeed, such an approach may have great merit when one explores the technical complexity and controversy associated with some of the energy conservation standards now under development.

In our national search for sophisticated answers to the energy crisis, we appear to have neglected the gold mine under our feet. The low grade energy emanating from our planet deserves respect for the power potential it represents. Anything that promises to provide half of a homes heating needs and most of the cooling is a clear source of climate control power. Call it earth power if you will. Dollar for dollar invested, the competition between earth power and solar power often suggests the legendary race between the tortoise and the hare. Day and night, rain and shine, winter and spring, the earth does its thing.

The development of this system began with the author's work at Virginia Tech to produce energy conservation programs for small builders. The experience with this conservative audience made it clear that the only way to lead builders was to be one. Thus, this project was undertaken entirely with limited personal funding in an effort to forge practical answers to any question a builder or subcontractor might ask. The author looks forward to pooling experience with other builders willing to try the inverted cave construction system.

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BASIC HUMAN VALUES AND ENERGY CONSERVING LIFESTYLES
OR
THE IMPLICATIONS OF CALIFORNIA'S INNOVATIVE NEW CLASS K CODE

by

Anon Forest
Member of the California State Building Standards Commission,
United Stand, and Former Member of the California State
Commission on Housing and Community Development

Presented by Rhett Wenzinger
Facilitated by David McElroy

With Special Thanks to
Stache Williams
Saul Krimsley
United Stand
Mendocino Grapevine
Ukiah, California

This report stresses the energy conserving implications of California's innovative new "Class K" code provision for primitive architecture and alternative technologies. The philosophy of United Stand, proponent of the "Class K" code, is here highlighted in the interest of energy conservation, and owner-builders across America who wish to maintain basic human values and energy conserving lifestyles.

We now propose a similarly conceived national code that will specifically mandate the right of owner-builders to employ alternative technologies in their own homes--a new code which will spell out functional performance rather than prescribe specific technology; a code written briefly, and simply, to provide a rule of thumb, rather than repression; a code which will legalize and facilitate low-cost, low-technology, energy-efficient housing, rather than discriminate against it. We ask for a code specifying the right of homeowner-builders to turn "OFF" a portion of our Nation's energy--their own.

Key words: Alternative; California; Class K Code; conservation; discrimination; energy; United Stand.

We are here to discuss energy issues, alternative technology, and the codes, in order to meet the needs of American people. Clearly, the need must be met. I am here to tell you that building codes now foster discrimination against those people who most want to conserve energy. I am talking about the kind of people who know that all energy-using devices have a conservation feature built-in. We have all seen it--it is called "OFF." The people I am speaking for are not afraid to turn "OFF" to conserve.

What we ask, responsibly, is that it be made the lawful right of owner-builders to choose that energy-conserving option called "OFF." I speak for owner-builders of the past, present, and future, that we may be specified the right to erect and reside within architecture befitting our needs as individuals. We need low-cost, low-technology, energy-efficient housing. Often, this happens to be "primitive" architecture.

How can this nebulous term be defined?

According to engineers Leckie, Masters, Whitehouse, and Young in their book, Other Homes and Garbage, "There are four general traits which characterize primitive architecture: unsupplemented use of natural locally available building materials and local construction skills; planning and massing as a result of specific functional requirements and site conditions, regardless of symmetry and general accepted taste; an absence of ornamentation which is not a part of the structure; and the identity of an enclosing form and enclosed space. This architecture is a simple and original response, the most economic shaping of space and form for the maximum benefit of body and soul."

Primitive or not, codes must allow owner-builders of existing and future homes and structures to choose alternate technologies. Alternative technologies must be integrated within, rather than discriminated by, codes for health and safety. They must allow individuals the right to turn "OFF" urban-oriented central systems which mass-produce energy-expensive utility services and goods, even though these services are standardized and uniform.

The State of California has responded to this need.

The California State Commission on Housing and Community Development adopted the "Class K" code in 1979 to provide owner-builders in rural areas with a code conducive to implementation of alternative technology and primitive architecture. This came about only after five years of work, numerous drafts, and public hearings. (See Appendix.)

The application of "Class K" is locally determined.

As approved by the California State Building Standards Commission, November 16, 1979, "Class K" is only mandatory upon a county if that county deems that there are rural areas within its jurisdiction appropriate for "Class K."

"Class K" has been accepted on the county level in concept.

The Sonoma County Board of Supervisors did accept "Class K" code as part of the housing element of the Sonoma County General Plan. However, the effect of this action was to adopt, at that time, "Class K" in concept only.

What does the "Class K" code say?

The "General Requirements" of the "Class K" code states that "Each structure shall be constructed and maintained in a sound structural condition to be safe, sanitary, and to shelter the occupants from the elements.

"It shall be the purpose and intent of this article to permit the use of ingenuity and preferences of the builder, and to allow and facilitate the use of alternatives to the specifications prescribed by the uniform technical codes to the extent that a reasonable degree of health and safety is provided by such alternatives, and that the materials, methods of construction, and the structural integrity of the structure shall perform in application for the purpose intended. To provide for the application of this article, it shall be necessary for the enforcement agency to exercise reasonable judgment in determining the compliance of appropriate structures with the general and specific requirements of this article."

"Class K" specifies that "a 'substandard building' is a structure or portion thereof in which there exists any condition to an extent that endangers the life, limb, health, or safety of the occupants."

But "Class K" considers that some "conditions which would not render a structure unsound are the minor deflections or elasticity of structural members, ceiling heights, size or arrangement of rooms, heating, plumbing, and electrification requirements; alternative materials; appliances or facilities, or methods of construction." Wood stoves are accepted and neither electrification nor plumbing is required.

Codes should be conducive to voluntary simplicity.

United Stand, behind the adoption of the "Class K" code, believes that "the voluntary simplicity movement is an extremely viable concept in a world that is just beginning to face the realities of finite resources. One just needs to look at the mushrooming popularity of such notions as organic farming, recycling wastes, alternative energy sources, and small simple housing, to understand this notion of consuming little and living simply, in harmony with our environment."

"Class K" facilitates energy conservation in broad concept.

"Class K" housing provisions promote such energy-saving concepts by allowing recycled and owner-produced building materials, alternative energy sources, and simplified solid and greywater systems, along with other cost-saving, ecologically sound ideas. It allows rural owner-builders to get away from energy-expensive mass-produced goods and services specified in uniform codes.[1]

But the discriminatory approach of some health departments is something like this: "Of course we'll let you put in a composting toilet, but you'll also have to install a full-size septic system to handle the greywater." And as soon as the homebuilder figures out what he will have to pay for the septic system in addition to his intended $1500 expense for the composting toilet, he forgets the composting toilet.

The time for "Class K" is forever.

With all the implications for energy conservation embodied in "Class K," we would urge your attention. The option to turn "OFF" centralized utility systems, the right to resort to low-technology alternatives, must be legalized if you are serious about conserving energy in America.

United Stand recognizes the meaningful police power of the State of California and the County of Mendocino, as well as other such agencies, to see that people's homes are safe, structurally sound, and have sanitary sewage and waste disposal systems. United Stand does not advocate the wanton building of homes that are unsafe or structurally unsound. However, United Stand believes the right to shape one's individual family life, in this case the construction of the home wherein that family life centers, is a fundamental one. We believe there is no compelling State interest to enforce the uniform building codes as the exclusive standards for rural home construction without regard to individual lifestyles which harm no one.

People are going to provide for themselves as best they can.

Regardless of any code, people have needs they are going to meet. Cabin-dwellers are willing to settle for less in the luxuries and amenities of their homes. Often, it is the only way they can ever hope to own a home.

There is a need for regulation, however.

Many cabin-builders are now building homes and dealing with their wastes. But they are often doing so without any type of governmental regulation whatsoever. Not even the most basic health and safety considerations are being safeguarded by any government agency. This is because many of our current laws which have been set up to provide this protection are quite inappropriately conceived or enforced when applied to cabin construction and/or the needs of owner-builders. But the Government has a rightful interest in regulating the building of homes and the disposal of wastes. The health and safety of our communities must be protected.

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[1]Editors Note: The use of the words uniform codes is taken to mean codes promulgated by the International Conference of Building Officials.

Owner-builders have been overlooked by the uniform codes.

The goal of reducing housing costs through the standardization of building materials and construction techniques in the best interests of homebuyers, was, and is, an admirable one. But not all homes are built by the construction industry for resale. The do-it-yourselfer has been grossly overlooked by code writers.

As a result, those persons who have taken it upon themselves to produce their own housing in accordance with their needs and within their economic limitations are forced to comply with industrial standards. The energy-saving owner-builders have been discouraged.

"Our experience," say members of United Stand, "has shown us that in many instances, even when scientific and technical evidence exists to substantiate claims, building officials demand that alternative designs be engineered or otherwise professionally 'accounted for' at great expense to the owner. This action effectively prohibits people from utilizing energy-conserving alternatives, and may even make it quite impossible for the disadvantaged to own their housing."

Our needs are not met within the uniform codes.

The application of existing model codes in rural areas does not guarantee rural people safe, healthful housing. Because of the urban orientation of the codes, their application may in fact deprive low-income rural people of housing opportunities they might otherwise have.

This is due to a lack of public input.

There is a lack of public participation in the code-writing and enforcement process; a tendency for Government to offer only regulation, and not education; enforcement rather than assistance; and the emphasis of existing law and social attitudes as to what may be ideal, rather than what may be realistically obtainable. United Stand concludes that our "diversity has no place in current uniform laws, although the public's economic, cultural, and environmental conditions are in no way uniform." And we note that the public is kept very poorly informed upon the deliberations of the code-writing bodies.

Something must be done.

In June of 1980, a suit was filed against the County of Mendocino, California, by a county group, the Committee For Sane And Equal Enforcement of Our Land Use Laws. This was reportedly a contractor-sponsored group recently formed.

This suit was directed at the county's estimated 3,000 to 5,000 "outlaw" homebuilders who have sought alternatives outside the uniform codes. These people have not been given the benefit of the "Class K" concept.

The suit resulted in a building code infraction ordinance, with heavy daily fines which could rapidly accrue unpaid, leading to county confiscation of "outlaw" properties.

This measure immediately stirred bitter opposition, and it even found owners of standardized, legal structures liable for even ridiculous "infractions." The infraction ordinance appeared blatantly as a tool for discrimination.

But there is hope.

In July, the directors of the Mendocino County Contractors' Association voted to favor "the general concept of a separate building code for limited density rural dwellings, providing the proper land usage is met according to the approved general plan, and that these structures can be built by anyone." This was a publicly-stated change of opinion.

This followed a Mendocino County Grand Jury statement which had been developing for some months. The Grand Jury suggests that the county adopt "Class K" to serve local needs. This was an unusual statement of recommendation, but the Board of Supervisors has failed to act upon it.

The public in Mendocino County is "hot."

Immediately following the announcement of the infraction ordinance, a petition was circulated. It quickly gathered the signatures of enough voters to place the issue on the November ballot, although some administrative forces are continuing to thwart this effort. And although the people who have signed this petition represent the broad spectrum of citizens, the Supervisors refuse to allow a vote.

Why can't government represent us?

United Stand would like to see the infraction ordinance repealed--flat out. "But if they put it on the ballot for all United Stand people to vote on, we still win, but at the expense of seeing our tax money wasted because our representative government cannot bear to represent us." And if they do nothing? United Stand says, "First we sue--then we win."

Local compromise is not good enough.

The County Supervisors have proposed a "Clean Slate" program to the "outlaw" builders, in light of the public furor. This is said to be a way to "get legal" with the county, a way to certify alternative homes hidden in the mountain forests. But United Stand fears that they are being handed a rope, because "it would legalize a few homes without legalizing the principles which built them."

United Stand asserts that "without the sanction of future freedoms to build, 'Clean Slate' will be a hollow victory at best. What we have had to be criminals to do, our children should be able to do with pride and legitimacy--build their homes."

An attitude of reason and cooperation is needed.

Self-reliant owner-builders are fearful in that "it simply does not make sense to avail oneself of the guidance and expertise of the health department, for example, if one must eventually 'destroy' one's home anyway because of 'insufficient floorspace,' 'failure to obtain permits,' or 'improper windows' and the like. Why submit your pride and joy, your own hand-built house, to an authority who will destroy it on the mere basis of non-uniformity?" Presently, there is only a chance of being properly, inexpensively, painlessly certified with authorities.

The right to utilize non-uniform alternatives must be legally specified in the interest of energy conservation.

This issue has been raging for years. It will continue to boil. It has been boiling in many communities across America.

Perhaps a national code based upon the concept of "Class K" and United Stand can be facilitated. A code which will assert the rights of owner-builders who wish to move closer to that "OFF" position on the nation's energy dial. A code that will permit individual lifestyles and common sense to dominate its language and intents. A code that gives the needed legitimacy and opportunity to those who wish to conserve the most, whether it be due to poverty or a quite conservative decision to live simply with less.

This seminar is concerned with energy conservation and the alternatives. United Stand has been fighting in this regard for years. It is concerned with energy conservation and the alternatives--our own.

We no longer will be "overlooked."

We call for a national building code which will facilitate the legal construction of low-cost, low-technology, energy-efficient housing, to be embodied with rules of thumb that are simply stated.

Of course, contractors, various governmental agencies, and special interest groups will attempt to limit owner-builders in attempting to preserve and foster powers of their own. Sometimes these interests seek code language which can be used to discriminate upon a class basis, or against individuals--sometimes against those who would conserve energy the most, those who would turn it "OFF."

You are going to hear about this subject again, and again. America needs low-cost, low-technology, energy-efficient housing--Now. Must archaic notions of "modern" codes of urban orientation forbid us to turn "OFF" energy to meet this need?

We demand that owner-builders be specifically mandated the right to turn "OFF" energy--their own. We require your attention.

APPENDIX

(NOTE: THIS IS A RETYPED VERSION OF THE ORIGINAL ORDER)

ORDER REPEALING AND ADOPTING REGULATIONS OF THE
COMMISSION OF HOUSING AND COMMUNITY DEVELOPMENT

After proceedings held in accordance with the provisions of the Administrative Procedures Act (Government Code, Title 2, Division 3, Part 1, Chapter 4.5) and pursuant to the authority vested by Sections 50559 and 19721 of the Health and Safety Code, and to implement, interpret or make specific Division 13, Part 1.5 (State Housing Law) Section 17910 through 17995 of the Health and Safety Code, the Commission of Housing and Community Development hereby repeals and adopts its regulations in Title 25, Chapter 1, Subchapter 1, California Administrative Code.

Repeal Article 10. Special guidelines for dwellings in rural areas, Sections 142 through 244.

Adopt Article 10. Regulations for limited density owner-built rural dwellings.

Sections 142 through 244 to read as follows:

REGULATIONS FOR LIMITED
DENSITY OWNER-BUILT RURAL DWELLINGS

142 Authority. This article is adopted in accordance with the provisions of the Administrative Procedures Act (Government Code, Title 2, Division 3, Part 1, Chapter 4.5) and with the authority vested specifically by Sections 50559 through 17923 and generally by Sections 17910 through 17995 of the Health and Safety Code.

PART ONE - ADMINISTRATION
Chapter 1 - Application

144 Purpose. The purpose of this article is to provide minimum requirements for the protection of life, limb, health, property, safety, and welfare of the general public and the owners and occupants of limited density owner-built rural dwellings and appurtenant structures.

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

146 Intent and Application. The provisions of this article shall apply to the construction, enlargement, conversion, alteration, repair, use, maintenance, and occupancy of limited density owner-built rural dwellings and appurtenant structures.

It is the intent of this article that the requirements contained herein shall apply to seasonally or permanently occupied dwellings, hunting shelters, guest cottages, vacation homes, recreational shelters and detached bedrooms located in rural areas.

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

148 *Existing Buildings. The provisions of this article regulating the erection and construction of dwellings and appurtenant structures shall not apply to existing structures as to which construction is commenced or approved prior to the effective date of this article. Requirements relating to use, maintenance, and occupancy shall apply to all dwellings and appurtenant structures approved for construction or constructed before or after the effective date of this article.* (T25-148)

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

Chapter 2 - Administration and Enforcement

150 *Local Standards. Pursuant to Sections 17958, 17958.5, and 17958.7 of the Health and Safety Code, the governing body of every jurisdiction in which there exist rural areas displaying conditions appropriate for the application of this article and designated as such by the appropriate local agency shall adopt regulations imposing the same requirements as are contained in this article.* (T25-150)

NOTE: Authority cited: Section 17922(b), Health and Safety Code.
Reference: Section 17922(b), Health and Safety Code.

152 Regulation of Use. (a) For the purposes of this article the sale, lease, renting or employee occupancy of owner-built structures within one year of the issuance of a Certificate of Occupancy shall be presumptive evidence that the structure was erected for the purpose of sale, lease or renting.

(b) The restrictions of this article on the sale, lease, renting, or employee occupancy of these dwellings may be reasonably amended to be more restrictive if the governing body determines that such an amendment is necessary to ensure compliance with the intent of this article.

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

154 *Abatement of Substandard Buildings. All structures or portions thereof which are determined by the enforcing agency to constitute a substandard building shall be declared to be a public nuisance*

and shall be abated by repair, rehabilitation, or removal in accordance with Health and Safety Code Sections 17980 through 17995. In cases of extreme hardship to owner-occupants of the dwellings, the appropriate local body should provide for deferral of the effective date of orders of abatement. (T25-154)

NOTE: Authority cited: Section 17980 through 17995, Health and Safety Code. Reference: Section 17980 through 17995, Health and Safety Code.

156 Interpretations. The Commission of Housing and Community Development may make specific determinations as to the meaning, intent, or application of the provisions of this article.

NOTE: Authority cited: Section 17930, Health and Safety Code. Reference: Section 17930, Health and Safety Code.

158 Intent of Interpretations. Interpretations by the Commission are not intended to preempt the exercising of building or housing appeals processes established by statute, but are intended to facilitate public understanding and the effective enforcement of this article.

NOTE: Authority cited: Section 17930, Health and Safety Code. Reference: Section 17930, Health and Safety Code.

160 Petitions for Interpretations. Any person or local agency may petition the Commission for an interpretation of any provision of this article. Petitions shall be submitted in writing, after which the Commission, or designated member(s), may consider such requests and the Commission may make a determination as to the meaning or intent of any provisions of this article with respect to the petition in question. The consideration of petitions for interpretation shall be discretionary with the Commission.

NOTE: Authority cited: Section 17930, Health and Safety Code. Reference: Section 17930, Health and Safety Code.

162 Notice of Findings. The Secretary of the Commission shall keep a record of all interpretations made by the Commission which shall be available for review by the public or any governmental agency and shall provide notice to the petitioner(s) of the Commission's findings.

NOTE: Authority cited: Section 17933, Health and Safety Code. Reference: Section 17933, Health and Safety Code.

164 Recording. No provision of this article is intended to prohibit or limit a local governing body from establishing and enforcing reasonable regulations for the recording of information regarding the materials, methods of construction, alternative facilities,

or other factors that may be of value in the full disclosure of the nature of the dwelling and appurtenant structures.

NOTE: Authority cited: Section 17958.5, Health and Safety Code.
Reference: Section 17958.5, Health and Safety Code.

166 Constitutional and Statutory Validity. It is the express purpose of this article to conform the regulations regarding the construction and use of limited density rural owner-built dwellings and appurtenant structures to the requirements of Article 1, Section 1, of the California State Constitution, and the statutes of the State of California which require the Commission to consider the uniform model codes and amendments thereto; and local conditions, among which are conditions of topography, geography and general development; and to provide for the health, safety, and general welfare of the public in adopting building standards. If any section, subsection, sentence, clause, or phrase of this article is, for any reason, held to be unconstitutional, or contrary to California statutes, such ruling shall not affect the validity of the remaining portions of this article.

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

168 Violations. The critical concern in the promulgation of this article is to provide for health and safety while maintaining respect for the law and voluntary compliance with the provisions of this article, and therefore, in the event that an order to correct a substandard condition is ignored, it is the intent of this section that civil abatement procedures should be the first remedy pursued by the enforcement agency.

NOTE: Authority cited: Section 17980, Health and Safety Code.
Reference: Section 17980, Health and Safety Code.

Chapter 3 - Permits, Inspections and Fees

170 Permits. Permits shall be required for the construction of rural dwellings and appurtenant structures.

NOTE: Authority cited: Section 17951, Health and Safety Code.
Reference: Section 17951, Health and Safety Code.

Exemptions. Permits shall not be required for small or unimportant work, or alterations or repairs that do not present a health or safety hazard, and which are in conformance with local zoning requirements or property standards. The determination, if any, of what work is properly classified as small or unimportant or with relation to health and safety hazards is to be made by the appropriate local agencies.

NOTE: Authority cited: Section 17951 (a) (b), Health and Safety Code. Reference: Section 17951 (a) (b), Health and Safety Code.

172 Issuance. The application, plans, and other data filed by an applicant for a permit shall be reviewed by the appropriate enforcement agency to verify compliance with the provisions of this article. Where the enforcement agency determines that the permit application and other data indicate that the structure(s) will comply with the provisions of this article, the agency shall issue a permit therefor to the applicant.

NOTE: Authority cited: Section 17951 (a) (b), Health and Safety Code. Reference: Section 17951 (a) (b), Health and Safety Code.

174 *Application. To obtain a permit, the applicant shall first file an application therefor with the designated enforcement agency. Permit applications shall contain the following information: (1) name and mailing address of the applicant; (2) address and location of the proposed structure(s); (3) a general description of the structure(s) which shall include mechanical installations with all clearances and venting procedures detailed, electrical installations, foundation, structural, and construction details; (4) a plot plan indicating the location of the dwelling in relation to property lines, other structures, sanitation and bathing facilities, water resources, and water ways; (5) approval for the installation of a private sewage disposal system or alternate waste disposal means from the local health enforcement agency; (6) a stipulation by the applicant that the building or structure is to be owner-built; (7) the signature of the owner or authorized agent; (8) the use or occupancy for which the work is intended; (9) and any other data or information as may be required by statute or regulation.* (T25-174)

NOTE: Authority cited: Section 17951 (a) (b), Health and Safety Code. Reference: Section 17951 (a) (b), Health and Safety Code.

176 *Plans. Plans shall consist of a general description of the structure(s), including all necessary information to facilitate a reasonable judgment of conformance by the enforcing agency. This may include a simplified diagram of the floor plan and site elevation in order to determine the appropriate dimensions of structural members. Architectural drawings and structural analyses shall not be required except for structures of complex design or unusual conditions for which the enforcement agency cannot make a reasonable judgment of conformance to this article based upon the general description and simplified plan(s).* (T25-176)

NOTE: Authority cited: Section 17951 (a) (b), Health and Safety Code. Reference: Section 17951 (a) (b), Health and Safety Code.

178 Waiver of Plans. The enforcement agency may waive the submission of any plans if the agency finds that the nature of the work applied for is such that the reviewing of plans is not necessary to obtain compliance with this article.

NOTE: Authority cited: Section 17951 (a) (b), Health and Safety Code. Reference: Section 17951 (a) (b), Health and Safety Code.

180 *Modifications. Modifications to the design, materials, and methods of construction are permitted, provided that the structural integrity of the building or structure is maintained, the building continues to conform to the provisions of this article, and the enforcement agency is notified in writing of the intended modification.* (T25-180)

NOTE: Authority cited: Section 17951 (a) (b), Health and Safety Code. Reference: Section 17951 (a) (b), Health and Safety Code.

182 Permit Validity. Permits shall be valid, without renewal, for a minimum period of three years.

NOTE: Authority cited: Section 17951, Health and Safety Code. Reference: Section 17951, Health and Safety Code.

184 Inspections. All construction or work for which a permit is required may be subject to inspection by the designated enforcement agency.

NOTE: Authority cited: Section 17951 (a) (b), and 17970, Health and Safety Code.
Reference: Section 17951 (a) (b) and 17970, Health and Safety Code.

186 *Issuance of Inspections. An inspection of the building or structure(s) shall be conducted after the structure(s) is completed and ready for occupancy, in order to determine compliance with the provisions of this article. Structures of conventional or simple construction shall be inspected at a single inspection.* (T25-186)

NOTE: Authority cited: Section 17970, Health and Safety Code. Reference: Section 17970, Health and Safety Code.

188 *Special Inspections.* Additional inspections may be conducted under the following circumstances: An inspection may be conducted where there is a reasonable expectation that the footing will be subjected to serious vertical or lateral movement due to unstable soil conditions; or the application indicates that interior wall coverings or construction elements will conceal underlaying construction, electrical or mechanical systems; or where an unconventional construction method is indicated which would preclude examination at a single inspection. (T25-188)

NOTE: Authority cited: Section 17970, Health and Safety Code.
Reference: Section 17970, Health and Safety Code.

190 *Inspection Waivers.* Inspections may be waived by the enforcement agency for structures which do not contain electrical or mechanical installations or for alterations, additions, modifications, or repairs that do not involve electrical or mechanical installations; or where the applicant stipulates in writing that the work has been conducted in compliance with the permit application and the provisions of this article. (T25-190)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

192 *Inspection Requests and Notice.* It shall be the duty of the applicant to notify the enforcement agency that the construction is ready for inspection and to provide access to the premises. Inspections shall be requested by the applicant at least (48) hours in advance of the intended inspection. It shall be the duty of the enforcement agency to notify or inform the applicant of the day during which the inspection is to be conducted. (T25-192)

NOTE: Authority cited: Section 17972, Health and Safety Code.
Reference: Section 17972, Health and Safety Code.

194 *Certificate of Occupancy.* After the structure(s) is completed for occupancy and any inspections which have been required by the enforcing agency have been conducted, and work approved, the enforcement agency shall issue a Certificate of Occupancy for such dwelling(s) and appurtenant structure(s) which comply with the provisions of this article. (T25-194)

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

196 *Temporary Occupancy.* The use and occupancy of a portion or portions of a dwelling or appurtenant structure prior to the completion of the entire structure shall be allowed, provided that approved sanitary facilities are available at the site and that the work completed does not create any condition to an extent that endangers life, health, or safety of the public or

occupants. The occupants of any such uncompleted structure shall assume sole responsibility for the occupancy of the structure or portion thereof. (T25-196)

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

198 *Fees. Fees may be required and collected by the enforcement agency to provide for the cost of administering the provisions of this article. It is the intent of this article that permit and inspection fee schedules be established to reflect the actual inspection and administrative costs resulting from the application of this article.* (T25-198)

NOTE: Authority cited: Section 17951, Health and Safety Code.
Reference: Section 17951, Health and Safety Code.

PART TWO - DEFINITIONS

200 Detached Bedroom. A "detached bedroom" is a separate accessory structure without kitchen or sanitation facilities, designed for and intended to be used as a sleeping or living facility for one family, to be employed in conjunction with a main structure(s) which include kitchen and sanitation facilities.

NOTE: Authority cited: Section 50559, Health and Safety Code.
Reference: Section 50559, Health and Safety Code.

202 Greywater. "Greywater" shall include all domestic waste water obtained from the drainage of showers, bathtubs, kitchen sinks, lavatories, and laundry facilities, exclusive of water utilized for the transport and disposal of body eliminations.

NOTE: Authority cited: Section 50559, Health and Safety Code.
Reference: Section 50559, Health and Safety Code.

204 Limited Density Rural Dwelling. A "limited density rural dwelling" is any structure consisting of one or more habitable rooms intended or designed to be occupied by one family with facilities for living and sleeping, with use restricted to rural areas that fulfills the requirements of this article.

NOTE: Autority cited: Section 50559, Health and Safety Code.
Reference: Section 50559, Health and Safety Code.

206 Owner-built. (a) "Owner-built" shall mean constructed by any person or family who acts as the general contractor for, or as the provider of, part or all of the labor necessary to build housing to be occupied as the principal residence of that person or family, and not intended for sale, lease, rent or employee occupancy.

(b) For the purposes of this article, the sale, lease, renting (see local authority Section 152(b)) or employee occupancy of owner-built structures within one year of the issuance of a Certificate of Occupancy shall be presumptive evidence that the structure was erected for the purpose of sale, lease or renting.

NOTE: Authority cited: Section 50559, Health and Safety Code. Reference: Section 50559, Health and Safety Code.

208 Rural. For the purposes of this article only, "rural" shall mean those unincorporated areas of counties designated and zoned by the appropriate local agency for the application of this article. In defining "rural," the agency shall consider local geographical or topographical conditions, conditions of general development as evidenced by population densities and the availability of utilities or services, and such other local conditions that the agency deems relevant to its determination.

Suitable areas may include those wherein the predominant land usage is forestry, timber production, agriculture, grazing, recreation, or conservation.

NOTE: Authority cited: Section 50559 & 17922, Health and Safety Code. Reference: Section 50559 & 17922, Health and Safety Code.

210 *Sound Structural Condition. A structure shall be considered to be in sound structural condition when it is constructed and maintained in substantial conformance with accepted construction principles, technical codes, or performance criteria which provide minimum standards for the stressing of structural members; footing sizes when related to major load-bearing points; proper support of load-bearing members; nailing schedules where essential to general structural integrity; and provisions for adequate egress, ventilation, sanitation, and fire safety. Conditions which would not render a structure unsound are the minor deflections or elasticity of structural members; ceiling heights; size or arrangement of rooms; heating, plumbing, and electrification requirements; alternative materials, appliances or facilities; or methods of construction.* (T25-210)

NOTE: Authority cited: Section 17921, Health and Safety Code. Reference: Section 17921, Health and Safety Code.

212 *Substandard Building. A substandard building is a structure or portion thereof in which there exists any condition to an extent that endangers the life, limb, health, or safety of the occupants. Except as amended by the provisions of this article, Chapter 10 of the Uniform Housing Code, 1976 Edition, as published by ICBO, shall be the determining criteria for compliance with the standards of this article and the defining of a substandard building.* (T25-212)

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

PART THREE - GENERAL REQUIREMENTS

214 *General Requirements. Each structure shall be constructed and maintained in a sound structural condition to be safe, sanitary, and to shelter the occupants from the elements.* (T25-214)

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

216 *Intent of General Requirements. It shall be the purpose and intent of this article to permit the use of ingenuity and preferences of the builder, and to allow and facilitate the use of alternatives to the specifications prescribed by the uniform technical codes to the extent that a reasonable degree of health and safety is provided by such alternatives, and that the materials, methods of construction, and structural integrity of the structure shall perform in application for the purpose intended. To provide for the application of this article, it shall be necessary for the enforcement agency to exercise reasonable judgment in determining the compliance of appropriate structures with the general and specific requirements of this article.* (T25-216)

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

218 *Technical Codes to be a Basis of Approval. Except as otherwise required by this article, dwellings and appurtenant structures constructed pursuant to this part need not conform with the construction requirements prescribed by the latest applicable editions of the Uniform Building, Plumbing, and Mechanical Codes, the National Electrical Code, or other applicable technical codes; however, it is not the intent of this section to disregard nationally accepted technical and scientific principles relating to design, materials, methods of construction, and structural requirements for the erection and construction of dwellings and appurtenant structures as are contained in the uniform technical codes. Such codes shall be a basis for approval.* (T25-218)

NOTE: Authority cited: Section 17921, Health and Safety Code.
Reference: Section 17921, Health and Safety Code.

PART FOUR - SPECIFIC REQUIREMENTS

Chapter 1 - Construction Requirements

220 *Structural Requirements. Buildings or structures constructed pursuant to this article may be of any type of construction which*

will provide for a sound structural condition. Structural hazards which result in an unsound condition and which may constitute a substandard building are delineated by Section 1001(c), Uniform Housing Code (1976 Edition). (T25-220)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code. Reference: Section 17951 (b), Health and Safety Code.

222 *Foundations. Pier foundations, stone masonry footings and foundations, pressure treated lumber, poles, or equivalent foundation materials or design may be used, provided that the bearing is sufficient for the purpose intended.* (T25-222)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code. Reference: Section 17951 (b), Health and Safety Code.

224 *Materials. Owner-produced or used materials and appliances may be utilized unless found not to be of sufficient strength or durability to perform the intended function; owner-produced or used lumber or shakes and shingles may be utilized unless found to contain dry rot, excessive splitting, or other defects obviously rendering the material unfit in strength or durability for the intended purpose.* (T25-224)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code. Reference: Section 17951 (b), Health and Safety Code.

226 *Mechanical Requirements. Fireplaces, heating and cooking appliances, and gas piping installed in buildings constructed pursuant to this article shall be installed and vented in accordance with the requirements of Chapter 37 of the Uniform Building Code (1976 Edition), Chapter 9 of the Uniform Mechanical Code (1976 Edition), and Chapter 12 of the Uniform Plumbing Code (1976 Edition). Alternate materials and methods of venting shall be permitted if substantially equivalent in safety and durability.* (T25-226)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code. Reference: Section 17951 (b), Health and Safety Code.

228 *Heating Capacity. A heating facility or appliance shall be installed in each dwelling subject to the provisions of this article; however, there shall be no specified requirement for heating capacity or temperature maintenance. The use of solid fuel or solar heating devices shall be deemed as complying with the requirements of this section. If non-renewable fuel is used in these dwellings, rooms so heated shall meet current insulation standards.* (T25-228)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code. Reference: Section 17951 (b), Health and Safety Code.

230 *Electrical Requirements.* *No dwelling or appurtenant structure constructed pursuant to this article shall be required to be connected to a source of electrical power, or wired, or otherwise fitted for electrification, except as set forth in Section 232.* (T25-230)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

232 *Installation Requirements.* *Where electrical wiring or appliances are installed, the installation shall be in accordance with the provisions of the National Electrical Code adopted by the Commission for single family dwellings.*

Exceptions to Installation Requirements. *In structures where electrical usage is confined to one or more rooms of a structure, the remainder of the structure shall not be required to be wired or otherwise fitted for electrification unless the enforcement agency determines that electrical demands are expected to exceed the confinement and capacity of that room(s). In such instances, the enforcement agency may require further electrification of the structure.*

It is the intent of this subsection to apply to buildings in which there exists a workshop, kitchen, or other single room which may require electrification, and where there is no expectation of further electrical demand. The enforcement agency shall, at the time of a permit application or other appropriate point, advise the applicant of the potential hazards of violating this section. (T25-232)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

234 (RESERVE)

236 *Room Requirements.* *There shall be no requirements for room dimensions provided that there is adequate light and ventilation and adequate means of egress. In single family dwellings not exceeding two stories in height where, due to the location or to the surrounding terrain, emergency rescue from the exterior is not feasible, egress windows from sleeping spaces may be omitted when an additional doorway or an approved exit escape hatch is provided for egress from such rooms. The doorways provided shall open directly to the exterior of the building or shall open onto corridors or passageways which lead to individual exterior exits. The corridors or passageways provided shall not cross nor shall they follow the same route in whole or in part to the building exterior. Approved exit escape hatches shall be installed in accordance with the terms of their approval.*

Exception: Openable windows or exterior doors for emergency egress or rescue from sleeping rooms of single family dwellings may be omitted when such rooms are located on a mezzanine floor or loft area which is at least 50 percent open to the floor below. Such mezzanine or loft area shall have at least two means of evacuation acceptable to the enforcing authority and may include stairways, ladders, escape hatches, or any other design or arrangement which will allow egress in the event of an emergency. (T25-236)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

Chapter 2 - Sanitation Requirements

238 *Sanitation Requirements. Sanitation facilities, including the type, design, and number of facilities, as required and approved by the local health official, shall be provided to the dwelling sites. It shall not be required that such facilities be located within the dwelling.*

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

240 *Plumbing Specifications. Where conventional plumbing, in all or in part, is installed within the structure, it shall be installed in accordance with the Uniform Plumbing Code (1976 Edition). Alternative materials and methods shall be permitted provided that the design complies with the intent of the Code, and that such alternatives shall perform to protect health and safety for the intended purpose.* (T25-240)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

242 *Sanitation Facilities. A water closet shall not be required when an alternate system is provided and has been approved by the local health official. Where an alternative to the water closet is installed, a system for the disposal or treatment of greywater shall be provided to the dwelling. Greywater systems shall be designed according to water availability, use and discharge. The design, use, and maintenance standards of such systems shall be the prerogative of the local health official.*

A bathtub or shower and a lavatory, or alternate bathing and washing facility approved by the local health official, shall be provided at the dwelling site. (T25-242)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

244 *Water Supply.* *Potable water shall be available to the dwelling site, although such water need not be pressurized. Where water is not piped from a well, spring, cistern, or other source, there shall be a minimum reserve of 50 gallons of potable water available. Where water delivery is pressurized, piping shall be installed in accordance with the provisions of this article.* (T25-244)

NOTE: Authority cited: Section 17951 (b), Health and Safety Code.
Reference: Section 17951 (b), Health and Safety Code.

SETTING STANDARDS FOR BUILDING ENERGY PERFORMANCE IN HAWAII

by

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The State of Hawaii is unique in its energy supply and energy consumption patterns. Precariously dependent on imported petroleum, Hawaii has the potential for meeting much of its energy needs through the development of its solar, wind, geothermal, and ocean resources. These issues will play important roles in the formulation of policy in the statewide approach to energy conservation in buildings. The proposed Building Energy Performance Standards (BEPS) and the existing American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90-75 standard have raised questions among design professionals and at the State planning level about appropriate climatic criteria, design energy budgets and weighting factors for fuels. The climate of Hawaii was not represented in the Baseline Energy Study by the American Institute of Architects (AIA) Research Corporation and does not appear in the list of Standard Metropolitan Statistical Areas (SMSA) in the Notice of Proposed Rulemaking for BEPS. Weighting factors developed by the U.S. Department of Energy (DoE) for the various fuels used for lighting, cooling, and water heating seem to be inappropriate for Hawaii.

A modified BEPS approach is proposed which would probably offer advantages over the present ASHRAE 90-75 based building code. This would encourage the use of renewable energy and passive techniques in meeting design energy budgets and in reducing the State's dependence on imported fossil fuels.

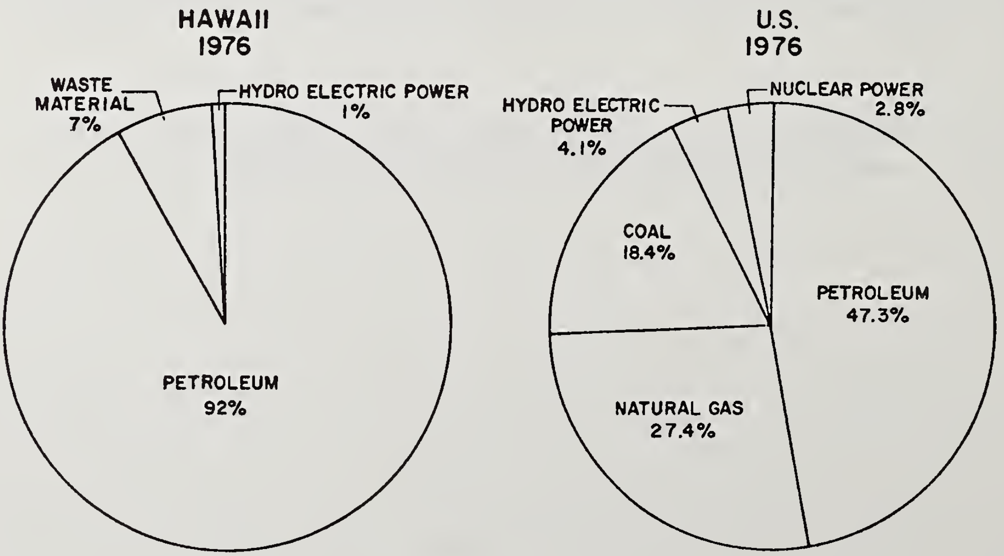
Key words: Building energy performance; codes; energy conservation; energy policy; Hawaii; performance standards.

In addition to its unique location and reputation as an island paradise, Hawaii is blessed with one of the simplest governmental structures in the Nation. For regulatory purposes, it is a State with only four counties and no municipalities or townships. This has streamlined democratic processes in the consideration and adoption of new building codes and regulations. In 1978, Honolulu adopted by ordinance an ASHRAE Standard 90-75 based energy conservation addition to the Uniform Building Code (UBC). This ordinance, chapter 53 of the UBC, has now been adopted by all jurisdictions in Hawaii. In chapter 53, the simpler Massachusetts Lighting Code Standard is used in place of section 9 of ASHRAE 90-75.

It is important to consider the circumstances in Hawaii which have led to the enactment of energy conservation regulations and which distinguish this State from all others represented at the National Conference of States on Building Codes and Standards (NCSBCS) Conference.

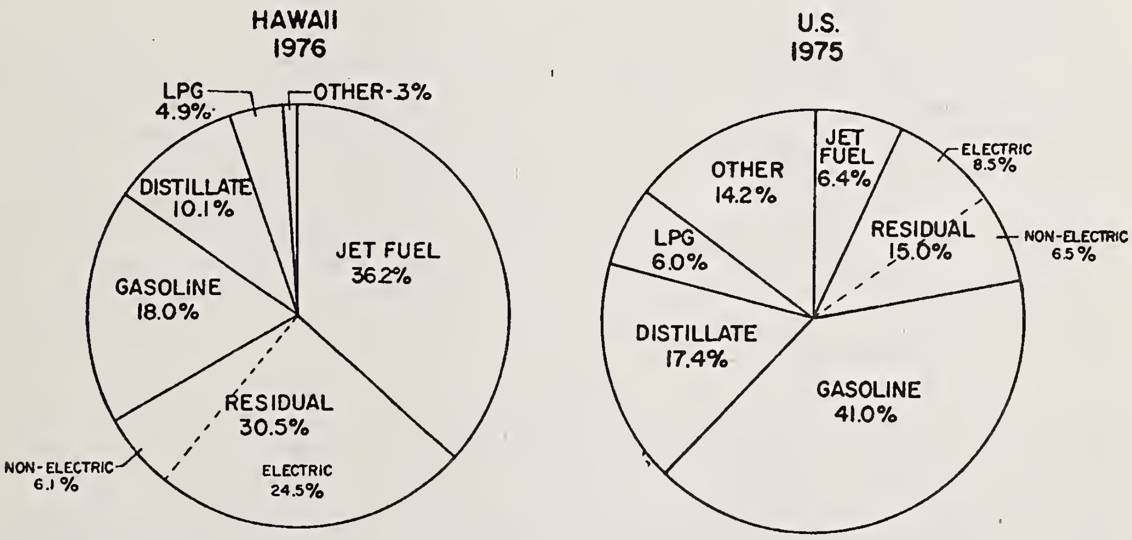
Hawaii, which is entirely volcanic in origin and geologically young, has no fossil fuel resources of its own. Dependent entirely on imported petroleum, 90 percent of which is of foreign origin, it is the most vulnerable of the States to dislocations and disruptions in energy supply. The estimated Strategic Petroleum Reserve for the operation of electric utilities is not more than 15 days. The lack of any power lines or pipelines between the islands within the State further complicates and increases costs and vulnerability of energy delivery systems. Figure 1 shows the sources of energy for Hawaii, which derives 92 percent of its energy from petroleum, compared to the United States as a whole, which depends on petroleum for only 47 percent of the total.

Figure 1: Sources of Energy for Hawaii Compared with the United States as a Whole. From Energy Use in Hawaii, Department of Planning and Economic Development, State of Hawaii, 1977, p. 4.



The end-use consumption of fuel, shown in figure 2, is also quite different from that of the United States as a whole. Most significant from the point of view of building energy use is the fact that in Hawaii, generation of electricity is three times more dependent on petroleum than in the United States as a whole.

Figure 2: End-use of Petroleum by Fuel Type. From Energy Use in Hawaii, op. cit., p.5.

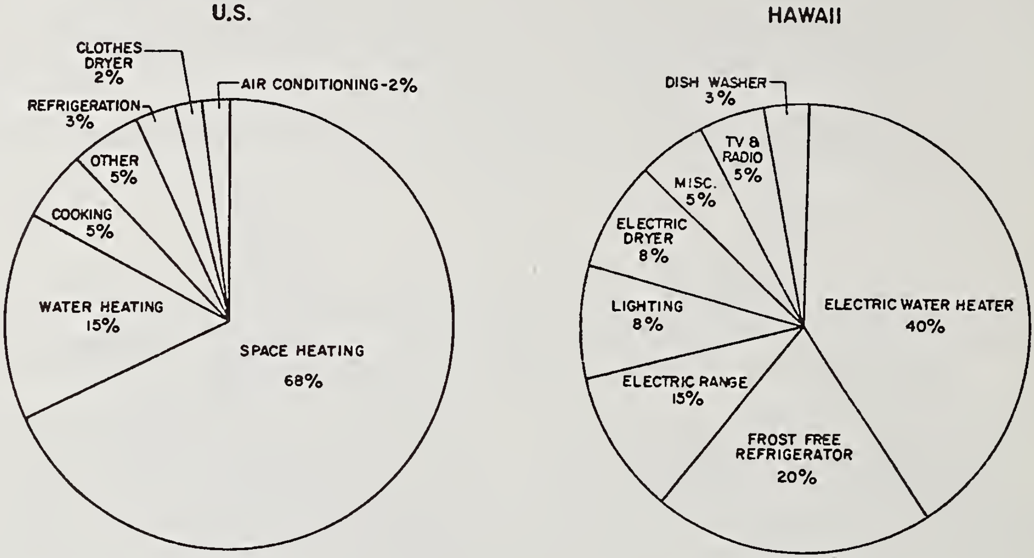


With a permanent population hovering around one million, plus the 3.5 million tourists who visit each year, petroleum consumption in Hawaii is about 40 million barrels per year, which is equivalent to the Nation's consumption in 1 day. Of this oil, about 10 million barrels, or one fourth, is used for the generation of electricity. Each resident consumes a total of about 220 million Btu's per year, compared with the national per capita annual consumption of 340 million Btu's. The annual per capita consumption of electricity is 6000 kWh compared to a national average of 8000 kWh. Lower per capita energy consumption in Hawaii can be accounted for by the fact that there is virtually no need for space heating, there is relatively little manufacturing industry, and gasoline consumption per motorist is the lowest in the Nation.

Figure 3 shows the end use of residential electricity in Hawaii. Water heating is the single largest residential end use of electricity, and this is a major energy conservation opportunity.

Hawaii has the potential of producing a great deal of its own energy needs, perhaps more than any other State, and interest in energy production is developing in the following areas: direct use of solar energy for water heating and the generation of electricity from wind,

Figure 3: End-use of Residential Electricity. From Energy Use in Hawaii, op. cit., p.8.



geothermal, ocean thermal and solar thermal, and biomass sources. In July 1980, a 200 kW experimental wind turbine was dedicated on the Island of Oahu, the fourth in the current series of medium scale wind energy test facilities. In the same month, a 1 MW Ocean Thermal Energy Conversion (OTEC) test facility was deployed off the coast of Oahu after earlier, very encouraging results from a mini-OTEC generating station. A site at Kaunakakai on the Island of Molokai has been selected by DoE for the demonstration of solar thermal electric power for small communities. Geothermal steam in commercial quantities on the big island of Hawaii is being developed for power generation. Bagasse, or sugar cane waste, has been burned for many years to generate electricity for sugar refining and processing needs and presently accounts for 9 percent of all electric power generation in Hawaii. Residential solar water heating is widespread and is a fast-growing industry in the State.

If conservation can be considered the cheapest new source of energy, then great potential for designers exists in the residential, commercial, and industrial sectors. However, State policy in energy conservation lags behind the promotion of new sources of supply. Various reasons are given for this, such as the belief that conservation means a reduction in the standard of living, or "giving something up." In reality, the economic penalty we have paid for increased reliance on imported oil has already resulted in reduced disposable income and an erosion of the standard of living. Stories about the promise of new technologies which will allow the continuation of high levels of energy consumption make for better press than stories about conservation and the reduction of energy needs.

Nevertheless, in Hawaii the economics of energy supply and operating costs, which can no longer be easily absorbed or passed on, are resulting in the widespread use of engineering and architectural conservation techniques. Some of the mechanical and electrical methods being used now for conserving energy are the following: electrical load management programs and control systems which reduce consumption and peak demand for electricity; condenser heat recovery systems for heating domestic and service hot water and swimming pools; air-to-water heat pumps for water heating; and, high efficiency lighting systems.

Architectural techniques for conserving energy have recently reappeared after 20 years of hibernation during the free-swinging era of high technology and cheap energy. During this time, there was a proliferation of climatically non-specific styles of architecture in Hawaii which were usually poorly suited to the climate of the islands. One now sees the rediscovery of techniques which, before 1960, were necessary for comfort and livability in the tropics. There is a growing energy consciousness among designers and a search for a regionally and climatically appropriate architecture. Architects now consider site planning, location, orientation and form of buildings in order to achieve enhanced thermal and visual comfort and reduced energy use. Strategies which avoid the problems of overheating and which permit daylighting and natural ventilation are being accepted by designers and are in fact usually demanded by sophisticated clients in their building programs.

Regulatory standards for building energy performance are looked upon as more than just the minimum possible performance by some designers who are able to exceed these standards by clever design in almost every aspect of building energy use. Recent apartment dwellings in Hawaii have single-loaded corridors which allow through-ventilation; solar shading and control devices such as awnings, blinds and louvers are appearing on new buildings. This is not to say that climate-conscious design is universal; one still sees in new buildings large, unshaded, inoperable windows and skylights with rooms which are impossible to naturally ventilate. This, in spite of the "natural air conditioning" which is available 10 to 11 months out of the year. Looking down on the roofs of Honolulu, one is also struck by the large number of dark, heat-absorbing surfaces which should be an anathema in a tropical climate.

The proposed Building Energy Performance Standards (BEPS) have raised questions among design professionals, and at the State planning level about appropriate climatic criteria, design energy budgets and weighting factors for fuels. It appears that Hawaii's special circumstances in climate, energy supply, and energy consumption patterns were not considered in the data base mentioned in the Notice of Proposed Rulemaking (NOPR).

The climate or Hawaii was not represented in the Baseline Energy Study performed by the American Institute of Architects (AIA) Research Corporation and does not appear in the list of Standard Metropolitan Statistical Areas (SMSA) in the NOPR. Hawaii's climate is significantly different from those SMSA's shown and, furthermore, in Hawaii microclimatic differences within a few miles radically affect the use of energy in otherwise similar buildings.

Another issue is the application of the weighting factors for various fuels, which as proposed, will encourage the consumption of natural gas and petroleum over the use of electricity. The weighting factors are calculated from relative national average gas, oil, and electricity prices projected for 1985. The application of weighting factors appears to discourage the use of hydro, geothermal, OTEC, wind, biomass and solar thermal generated electricity. The use of the weighting factors seems to be inappropriate as they are stated for use in Hawaii because there is no natural gas in Hawaii and there are no weighting factors listed for the most commonly used petroleum distillate fuels used in buildings in Hawaii (i.e., propane, no. 2 diesel oil and synthetic natural gas). It is for these reasons that the weighting factors are seen as delaying the development of domestic, non-fossil energy supplies.

Electric utilities in Hawaii favor basing energy budgets on building energy use in specific ambient climatic conditions, regardless of the source of energy. Therefore, the comparatively less efficient designs permitted in buildings designed to maximize the use of natural gas and petroleum under the proposed standards and weighting factors would not be allowed.

The baseline energy performance of various prototypical building types has been shown in an unpublished study by Frederick H. Kohloss and Associates. It is interesting to compare these figures for a prototypical office building in Hawaii to the results of a study done by Flack and Kurtz (see reference 5), for a similar office building in Denver. The two studies compare pre-ASHRAE 90-75 building energy use versus 1979 energy use.

Annual Energy Consumption, 1000 Btu/ft^2

Location	Lighting and Power	Cooling	Heating
Honolulu			
pre-ASHRAE	58	18	0
post ASHRAE	38	10	0
Denver			
pre-ASHRAE	31	17	44
post ASHRAE	25	10	15

This comparison indicates that Hawaii has some distance to go in matching the conservation of lighting and power which is possible in other locations. It would be expected that a strict BEPS design energy budget would effectively decrease lighting levels on a priority basis in hot climates, because of the additional energy consumption penalty associated with electric lighting. The heat of lights must usually be carried away by the air conditioning system, so a reduction in lighting would result in an automatic reduction in cooling load. Electric lighting is an inherently inefficient use of electricity, whereas air conditioning systems have a coefficient of performance greater than 1.0 and offer the opportunity for heat recovery for service water heating. A design energy budget without weighting factors would have the effect of beneficially discriminating against certain specific end uses of electricity, where there are functional and operational linkages such as in the above example. To carry the example further, efficient heat recovery from the air conditioning system would allow the end use of more hot water and more air conditioning without exceeding the design energy budget. The present ASHRAE 90-75 based standards do not address or encourage such techniques of overall design integration.

In order for techniques such as in the example above to help qualify a design for compliance either under BEPS or under existing codes as a parallel equivalent, the standard evaluation technique should countenance innovative methods for saving building energy. This will require periodic review, updating, and evaluation as new technologies and methods of saving energy through design integration emerge.

The implementation of the proposed BEPS will require considerable education of building code officials and design professionals. It is felt at State planning levels and at the municipal building department level that Federal assistance as a part of the BEPS implementation plan would be both desirable and necessary to ensure a smooth transition to new codes and standards. Parallel to this desire is a feeling that instead of sanctions (or in addition to sanctions) for non-compliance or non-implementation, there should be a program of financial and technical assistance incentives to stimulate successful implementation of BEPS or parallel standards. This could be augmented by a local program of bonuses, awards, or other public recognition for exceptionally energy-conserving building designs which would positively promote the goals of the program rather than having the emphasis on penalties for non-compliance. Credit for energy conserving designs could take the form of consideration in requests for a variance, for instance.

The State of Hawaii is eager to lessen its dependence on imported petroleum and to equitably stimulate and encourage energy conservation in buildings. It appears that several circumstances unique to Hawaii have been neglected in the DoE proposed Building Energy Performance Standards. These oversights could be addressed by further research to establish baseline performance standards and to gather information about how BEPS designed buildings would compare to those designed under current standards in Hawaii. Evaluation techniques adapted for use in overheated zones must allow for full and free innovation in reducing total energy consumption in buildings. Climatic sensitivity of design energy budgets in various building types must be evaluated so that the standards can be equitably applied.

This may require the maintenance of ASHRAE 90-75 as a prescriptive base for regulation with a BEPS equivalent as a parallel alternate until these difficulties can be resolved.

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7. Francis Lau, Building Department, City of Honolulu, Hawaii.

A SIMPLIFIED LOW COST TECHNIQUE FOR EVALUATING BUILDING ENERGY PERFORMANCE STANDARDS SUBMITTALS

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The Building Energy Performance Standards propose a "Standard Evaluation Technique" based almost entirely on the modeling of energy performance by computer techniques. This modeling requires elaborate data, manipulation of complex data bases, large amounts of memory, and is feasible only with the latest in computer technology. Currently, where such technology is available, its use is prohibitively expensive.

A study was made on the University of Illinois CYBER 175 computer using an energy analysis program similar to the one required by BEPS. This study found, for the test case, that lines of input could be reduced by up to 77 percent, that the number of surfaces needed to describe the building could be reduced by 80 percent, and that the computer cost of running this analysis could be lowered by 75 percent. It was found that all of these reductions could be made and still maintain a high degree of accuracy (within six percent) as compared to the thorough base run.

The results indicate a large potential for the reduction of building code officials' time in preparing the computer input and for the reduction in cost for running such energy evaluation programs on large computers.

Key words: BLAST; Building Energy Performance Standards; computer modeling; maintain accuracy; reduce cost; reduce input; "standard evaluation technique."

INTRODUCTION

The initial architectural design decisions establish the energy performance of buildings. Heat gain, cooling load, heat loss, lighting requirements--the total energy picture--is decided by the earliest spatial organization and orientation as well as by construction, materials, fenestration, shading and many other variables. It is imperative that one realize that mechanical systems, which are often cited as the primary factor in energy use, can only respond to these initial decisions. Therefore, a quick and inexpensive method for evaluating the performance of several alternatives at schematic levels is desirable. Such a method, with a known tolerance, would also be a valuable tool for energy code officials.

In addition, the coming of the Building Energy Performance Standards (BEPS) has brought the field of architectural energy analysis to the attention of the building industry. The BEPS propose a "standard evaluation technique" based almost entirely on the modeling of energy performance by computer techniques.[1] This quantitative modeling is based upon the mathematical representation of building construction and operation, weather, climate, mechanical systems, and consumed energy as it undergoes complex thermodynamic and luminous behaviors. Accurate modeling requires elaborate input, manipulation of complex data bases, large amounts of memory, and is feasible only with the latest in computer technology. Currently, where such technology is available, its use is prohibitively expensive. Although BEPS presumably promises simpler "alternative approval techniques," they limit the range of design alternatives. The architectural profession at best will value computer modeling, or at worst, will be forced to choose it over limited creativity in design. We have undertaken a preliminary study of what might be done in computer energy analysis to reduce the cost and demand for detailed data to a point where it becomes a feasible tool for design professionals and code enforcement officials.

This study was made on the University of Illinois CYBER 175 using the BLAST 2 program. This Control Data CYBER 175 operates with 256K words of central memory and an additional 512K words of Extended Core Storage under control of Control Data's Network Operating System. This timeshare system is currently capable of handling up to 190 active text and graphic terminals simultaneously as well as card batch jobs. The CYBER series computers are considered to be approximately seven times faster than the IBM 360/75 in execution of FORTRAN programs. During our study, all program and data files were maintained on high speed disc storage for rapid access during execution.

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[1]Basic research for establishing the proposed energy budgets was based upon the computer modeling of the energy conservative redesign of typical buildings.

The Building Loads And Systems Thermodynamics (BLAST) program was developed by the U.S. Army Construction Engineering Research Laboratory (CERL) and originally released in December of 1977. Under sponsorship of the General Services Administration, the program was extended and improved resulting in the release of BLAST Version 2.0 in June of 1979. The BLAST program is a comprehensive set of subprograms designed for predicting energy consumption, energy systems performance, and energy cost in buildings. This set contains three major subprograms:

1. The Space Load Predicting Subprogram computes hourly space heating and cooling loads from user input and weather data.

2. The Air Distribution System Simulation Subprogram calculates hot water, steam, gas, chilled water, and electrical demands based upon the hourly loads found above, weather data, and the user's description of the building air handling system.

3. The Central Plant Simulation Subprogram uses the results of the above two subprograms, weather data, and a description of the central plant. This subprogram simulates the performance of boilers, chillers, onsite power generation, and solar systems and calculates monthly and annual fuel and electrical power consumption. In addition, this subprogram may estimate life-cycle costs for mechanical systems.

OBJECTIVES

In our investigation of the use of energy analysis computer programs we set certain objectives to make them economically attractive options for initial architectural design and code enforcement. These objectives may be outlined as follows:

1. Maintain a tolerance of 10 percent in energy analysis results as compared to the results obtained using very precise and complete input data.

2. Reduce the quantity of input data for description of the building.

3. Simplify the input data that is required.

4. Reduce the time, storage, and cost required for each computer run.

By successfully reaching these objectives, we felt that the time spent in preparation of the data and the cost of running the analysis could be justified as a design or code enforcement tool.

PROCEDURE

The example used for testing our hypotheses was a thorough BLAST input prepared for a two story small office building for the Rockford Park District in Rockford, Illinois. The building has an exposed concrete frame and is based on 30 foot square bays. The facility was designed by C. Edward Ware Associates Inc., Architects.

BLAST uses a three dimensional coordinate system which allows the user to input a detailed description of building geometry. Additional input commands allow the user to describe the construction, air handling systems, and central plant. The user normally describes the building in zones which correspond to the mechanical system zones. BLAST then performs all calculations for each zone.

To reduce the quantity of input data, we prepared two additional input files in which the number of zones was reduced. In the first of these, the building description was reduced from the original five zones to two zones--each representing one complete floor. The second input further reduced the number of zones to one--which represented the entire building. We felt that reducing the number of zones would greatly reduce the computation time with little effect on the total heating or cooling loads generated.

At the same time, we grossly simplified the building geometry by calculating total wall, floor, and roof areas and describing them as simple rectangular shapes. We grouped window areas and similar wall sections without changing their orientations--all south facing wall and window areas remained south facing. This reduces the number of surfaces described and subsequent computations and computer time. Interior partitions were also removed from the descriptions.

In addition, we attempted to limit the number of subroutines called by omitting the fan systems and central plant. Again, we were interested only in predicting the loads generated and not the performance of the HVAC equipment.

After preparing these three input files, we ran and benchmarked the BLAST program for modeling of two design days, Rockford summer and Rockford winter. Finding these results favorable, we subsequently ran and benchmarked the analysis on the three files for calculation of hourly loads over a full year.

RESULTS

The following tables indicate the results of the final six runs we made. The quantities which were measured include:

1. CPU time - the length of time for which the job used the Central Processor Unit.

2. Connect time - the length of real time which had elapsed during the run (in thousands of seconds).

3. MS activity - a measure of the use of mass storage devices by the job (in thousands of units).

4. PF activity - an indication of the number of accesses to permanent files by the job (in thousands of units).

5. SRU - the number of "System Resource Units" used for each computer run. This is the total measure of computer use and the basis for billing.

6. Cost - the cost in dollars to the user's account. (For a private user of this system, the actual dollar cost would be slightly less than twice this amount.)

RUN NO. RUN1-DD

DESCRIPTION: ORIGINAL 5 ZONE EXACT BUILDING DESCRIPTION
RUN FOR ANALYSIS OF TWO DESIGN DAYS

	START	END	AMT. USED
	*****	***	****
CPU TIME (SECS.)	10.037	18.238	8.201
CONNECT TIME (KSEC.)	0.117	0.901	0.784
MS ACTIVITY (KUNS.)	0.286	13.117	12.831
PF ACTIVITY (KUNS.)	0.052	0.079	0.027
SRU (UNTS.)	10.732	817.001	806.269
CURRENT COSTS ($)	0.07	5.56	5.49

HEATING LOAD = 6.725 E + 06 BTU
COOLING LOAD = 1.688 E + 06 BTU

RUN NO. RUN2-DD

DESCRIPTION: 2 ZONE SIMPLIFIED DESCRIPTION
ANALYSIS FOR TWO DESIGN DAYS

	START	END	AMT. USED
	*****	***	****
CPU TIME (SECS.)	9.461	12.908	3.447
CONNECT TIME (KSEC.)	1.421	1.900	0.479
MS ACTIVITY (KUNS.)	14.859	23.648	8.789
PF ACTIVITY (KUNS.)	0.195	0.222	0.027
SRU (UNTS.)	909.536	1341.802	432.266
CURRENT COSTS ($)	6.18	9.12	2.94

HEATING LOAD = 7.059 E + 06 TOLERANCE = 5%
COOLING LOAD = 1.535 E + 06 TOLERANCE = 9%

The first three runs analyzed the two design days and represent the original five zone input, the two zone input, and the one zone input, respectively. The next three runs calculated hourly heating and cooling loads for an entire year, again for the original five zone input, for two zones, and for the one zone description. The results were as follows:

RUN NO. RUN3-DD

DESCRIPTION: ONE ZONE SIMPLIFIED DESCRIPTION
ANALYSIS FOR TWO DESIGN DAYS

	START *****	END ***	AMT. USED ****
CPU TIME (SECS.)	1.783	4.442	2.660
CONNECT TIME (KSEC.)	1.174	1.637	0.466
MS ACTIVITY (KUNS.)	6.739	13.935	7.196
PF ACTIVITY (KUNS.)	0.104	0.131	0.027
SRU (UNTS.)	302.877	645.580	342.703
CURRENT COSTS ($)	2.06	4.39	2.33

HEATING LOAD = 6.655 E + 06 TOLERANCE = 4%
COOLING LOAD = 1.626 E + 06 TOLERANCE = 1%

RUN NO. RUN1-YR

DESCRIPTION: ORIGINAL FIVE ZONE EXACT DESCRIPTION
ANALYSIS OF A FULL YEAR

	START *****	END ***	AMT. USED ****
CPU TIME (SECS.)	0.821	102.022	101.201
CONNECT TIME (KSEC.)	0.405	3.377	2.972
MS ACTIVITY (KUNS.)	11.216	66.706	55.490
PF ACTIVITY (KUNS.)	0.114	0.141	0.027
SRU (UNTS.)	252.301	6786.435	6534.134
CURRENT COSTS ($)	1.72	46.15	44.43

HEATING LOAD = 4.632 E + 08 BTU
COOLING LOAD = 4.960 E + 07 BTU

RUN NO. RUN2-YR

DESCRIPTION: NEW TWO ZONE SIMPLIFIED DESCRIPTION
ANALYSIS OF A FULL YEAR

	START *****	END ***	AMT. USED ****
CPU TIME (SECS.)	0.212	32.721	32.509
CONNECT TIME (KSEC.)	0.671	2.999	2.328
MS ACTIVITY (KUNS.)	4.387	31.363	26.976
PF ACTIVITY (KUNS.)	0.066	0.093	0.027
SRU (UNTS.)	108.135	2620.183	2512.048
CURRENT COSTS ($)	0.073	17.82	17.09

HEATING LOAD = 4.924 E + 08 TOLERANCE = 6%
COOLING LOAD = 4.597 E + 07 TOLERANCE = 7%

RUN NO. RUN3-YR

DESCRIPTION: NEW ONE ZONE SIMPLIFIED INPUT
ANALYSIS FOR A FULL YEAR

	START *****	END ***	AMT. USED ****
CPU TIME (SECS.)	0.107	22.157	22.050
CONNECT TIME (KSEC.)	0.171	1.672	1.501
MS ACTIVITY (KUNS.)	3.963	21.138	17.175
PF ACTIVITY (KUNS.)	0.062	0.089	0.027
SRU (UNTS.)	73.946	1724.436	1650.490
CURRENT COSTS ($)	0.50	11.73	11.23

HEATING LOAD = 4.506 E + 08 TOLERANCE = 2%
COOLING LOAD = 4.498 E + 07 TOLERANCE = 6%

The results of the six computer runs produced results greater than anticipated by the research team. The analysis of these results can be compared with the original objectives of the project as follows:

1. Maintenance of a 10 percent tolerance in energy analysis results as compared to more exact data: The most important question to ask is whether by simplifying the input data we have reduced the accuracy of the computed heating and cooling loads. We felt that since computer modeling in general is only a good estimate, we could accept a tolerance of up to 10 percent in heating and cooling loads from the original data and still have figures which would accurately estimate the building's actual loads. The results of our experiment indicated that we could stay within 10 percent of the results obtained from much more exact data. The simplification of the input data had little effect on the total heating and cooling loads. In fact, according to our data, the much simplified single zone input generated results very similar to the original exact five zone input. We feel that demonstration of a 75 percent reduction in costs with a precision of better than 10 percent in the results has significant implications for the computer modeling of building energy performance in the future. The results are as follows:

INPUT	HEATING LOAD (MBTU) TWO DESIGN DAYS	%DEVIATION
5 zones	6.725	-
2 zones	7.059	5%
1 zone	6.655	4%

INPUT	COOLING LOAD (MBTU) TWO DESIGN DAYS	%DEVIATION
5 zones	1.688	-
2 zones	1.535	9%
1 zone	1.626	1%

INPUT	HEATING LOAD (MBTU) FULL YEAR	%DEVIATION
5 zones	463.2	-
2 zones	492.4	6%
1 zone	450.6	2%

INPUT	COOLING LOAD (MBTU) FULL YEAR	%DEVIATION
5 zones	49.60	-
2 zones	45.97	7%
1 zone	44.98	6%

2. Reduction in quantity of input data: Input data was substantially reduced by limiting the number of zones to be analyzed and by combining building envelope components. The actual figures are below.

INPUT	LINES OF INPUT	%REDUCTION
original 5 zone	1,026	-
2 zones	530	49%
1 zone	232	77%

Not only does limiting the input data reduce the computer storage and computation time required, it also allows the architect or code official to spend less time in preparation of the input.

3. Simplicity of required input data: The building description was simplified a great deal by limiting the number of wall, roof, floor, and window surfaces to the absolute minimum. Actual results are shown below.

INPUT	NUMBER OF SURFACES	%REDUCTION
original 5 zone	94	-
2 zones	27	71%
1 zone	17	82%

It was anticipated that by reducing the number of surfaces described, the amount of computer time and storage would be significantly reduced.

4. Reduction of computer time, storage, and cost needed by each run: Computer time, storage, and most importantly cost would indicate the success or failure of our hypotheses. The figures, which support our hypotheses, are:

INPUT	CPU TIME (SECS) TWO DESIGN DAYS	%REDUCTION
5 zones	8.201	-
2 zones	3.447	58%
1 zone	2.660	68%

INPUT	CPU TIME (SECS) FULL YEAR	%REDUCTION
5 zones	101.201	-
2 zones	35.209	68%
1 zone	22.050	78%

INPUT	MASS STORAGE (KUNS) TWO DESIGN DAYS	%REDUCTION
5 zones	12.831	-
2 zones	8.789	31%
1 zone	7.196	44%

INPUT	MASS STORAGE (KUNS) FULL YEAR	%REDUCTION
5 zones	55.490	-
2 zones	26.976	51%
1 zone	17.175	69%

INPUT	COST ($) TWO DESIGN DAYS	%REDUCTION
5 zones	5.49	-
2 zones	2.94	46%
1 zone	2.33	58%

INPUT	COST ($) FULL YEAR	%REDUCTION
5 zones	44.43	-
2 zones	17.09	62%
1 zone	11.23	75%

In the final analysis, the reduction of computer time and storage produced a significant reduction in the cost of performing energy analysis using the BLAST computer program.

Although a single example is not enough to prove our hypotheses, we feel that with such success in the reduction of the computer time, storage, and costs with this example, further investigation of a wider variety of building types and conditions could substantiate our findings. If our hypothesis is proven correct, complex computer energy analysis using such programs as BLAST 2 or DOE-2 could be used in preliminary architectural design and code enforcement with a nominal amount of time, effort, and money.

ENERGY AUDITS OF PUBLIC BUILDINGS IN ILLINOIS

by

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and

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The Illinois Capital Development Board is a State governmental board which manages the construction of $200 - 400 million of public buildings and related facilities per year.

This paper will discuss the technical experience gained in the energy audit program wherein approximately 277 public buildings have been audited and recommendations made to change operating and maintenance procedures and make construction changes. When implemented, the changes, estimated to cost $5 million will save approximately $75 million over a 15 year period.

Types of buildings audited to date include dormitories, schools, dietary facilities, hospitals, offices, steam generation plants, and general and mechanical stores. Approximately 10.3 million gross square feet (GSF) have been audited. The largest building audited was 444,000 GSF, the smallest 1500 GSF.

The cost of performing the audits is, on the average, repaid in 2 years by the savings realized from implementation of recommended operating and maintenance changes alone. This program was praised by Region V U.S. Department of Energy (DoE) Headquarters, Chicago, Illinois.

Also discussed will be the Technical Research Unit, its energy functions and goals.

Key words: Cost; construction; energy audit; energy conservation; Illinois; maintenance; public buildings; state government.

HISTORY OF UNIT

The State of Illinois owns and manages the operation of approximately 3000 public buildings, plus some 5000 elementary and secondary school buildings. A survey conducted in early 1977 by the Illinois Capital Development Board (CDB) revealed energy usage in some buildings as high as 470,000 Btu per square foot per year. The potential for better energy utilization was thus determined to be substantial. In addition, the general deterioration of many structures, some approaching 100 years of age, was well known.

The Capital Development Board's Energy Management Unit was organized in 1977 for the purpose of fulfilling CDB's obligations under Plan 16, "Energy Management for State Buildings and Facilities," of the Illinois Energy Conservation Plan funded by the Federal Department of Energy (Public Law 94-163) via the Illinois Institute of Natural Resources. This federally funded unit was authorized to audit State-owned buildings larger than 50,000 gross square feet (GSF) with a staff of seven persons. Plan 16 requires that this seven person federally funded staff conduct energy audits of 164 code agency buildings comprising 11.8 million GSF by the end of calendar year 1980. To date, the Federal unit has audited and prepared reports on 157 buildings.

The early audits done under the Federal audit program confirmed CDB's suspicions of a large energy savings potential, not only in the buildings covered by Plan 16, but also in code agency buildings of less than 50,000 GSF and in central heating plants and utility systems. Since the federally funded unit was not authorized to investigate conservation opportunities in these other locations, CDB added a State funded audit staff of nine persons. Attachment "A" shows the number and size distribution of all significant State buildings. This unit will also be examining central heating and cooling plants and utility distribution systems and reporting its findings. To date, the State unit has audited and prepared reports on 120 buildings. The annual budget for the federally funded and State funded audit teams is approximately $175,000 each.

Both the Federal and State teams of the Energy Management Unit follow up the energy audit report recommendations by revisiting the audited buildings and meeting with maintenance and administrative staff to explain and assist in implementation of operations and maintenance recommendations listed in the audit report. The unit also presented a review of the most commonly recommended operations and maintenance changes reports at the 1979 Annual Chief Engineers Short Course. Copies of CDB's "Operating and Maintenance Practices for Energy Conservation in Buildings" were distributed to the approximately 120 State building chief engineers present at the conference.

The Energy Management Unit staff is comprised of twelve engineers, two data technicians, and a secretary. The supervisor of the unit is a registered professional mechanical engineer, as are two of the staff. The remainder of the engineers are mechanical engineers by degree and/or experience with the exception of one degreed electrical engineer. All engineers in the unit have extensive experience with buildings, their construction, systems, operation, and control.

AUDIT PROCEDURES

The Federal and State teams use the same methodology in conducting energy audits and report preparation. Initially, contact is made with the building manager or chief engineer to arrange for a mutually agreeable time for the site visit and also to request that as-built drawings of the building and historical energy consumption data for the building be made available to the audit team. The drawings are reviewed by the team members so as to familiarize themselves with the building design and construction including the mechanical and electrical systems and their operation and control. If possible, control drawings are obtained from the manufacturer of the building temperature control system. The historical energy consumption data is analyzed to determine the Energy Utilization Index (EUI) which is the British thermal units (Btu's) per gross square foot of building area per year. A comparison of this index with recommended levels categorized by building type is a valuable indicator of the energy efficiency of the building.

After the preliminary analysis is completed, a site visit is performed to determine the extent of building variances from the construction drawings; the condition and probable efficiency of energy consuming systems; maintenance, occupancy and operational schedules; and the present programmatic uses of the building and their effects on the energy consumption of the building. The chief engineer or building manager is asked to accompany the audit team on the site visit so that questions on the facility may be answered by a person with an intimate knowledge of the building's systems and their operation. Building personnel are also asked to contribute any ideas of their own for energy conservation and also to respond to audit team suggestions for possible operational changes, such as a night temperature setback. Any additional energy consumption records not already obtained by the audit team are also requested. These might include hot water and steam consumption at a building located in a facility with a central boiler plant. Site visits also include the taking of pictures to document and illustrate points of inefficient energy use, and the taking of quantitative measurements such as light levels, air flow, fluid flow and heat transmission through the building envelope.

After the site visit is completed, a mathematical model of the building is constructed with the aid of a minicomputer which simulates the following: heating, cooling, ventilating and lighting systems and their operation and control; the building envelope, its insulating values including glass areas, and all fenestrations and their contribution to infiltration; operational and occupancy schedules. Once the energy analysis model has been constructed actual historical energy consumption data is used to verify and refine it so that it agrees with the actual energy performance of the building. With a reliable energy analysis model of the building, the analysis of possible energy conservation opportunities (ECO) requires only that the input data of the model pertinent to the proposed modification be altered and the model run through the minicomputer again. The difference between the original building energy consumption and the reduced consumption of the altered model is the energy saving potential of the proposed modification. Typical ECO's for a building include increased roof insulation, reduced lighting levels, reduced domestic hot water temperatures, conversion of multizone heating, ventilating and air conditioning systems to variable air volume systems, or the installation of a solar heating system. In the case of operational or maintenance changes which can be implemented by the building staff for little or no cost, a recommendation for immediate implementation is made to the building staff and these changes are also reiterated later in the published report. In the case of retrofit recommendations requiring capital expenditures, a complete economic analysis is performed on promising energy saving ideas. The economic analysis performed is as follows: Given the CDB bond interest rate, plant and operation and maintenance savings, fuel savings for the first full year of operation, the investment cost of the retrofit project, and a 10 percent discount rate as recommended by the Federal Department of Energy, a computer program computes the payback period. Annual cash flows for each year throughout a 25 year period are determined by the computer program. The annual cash flow is equal to the algebraic sum of the annual bond retirement payment (which is equal to the investment divided by 25 year bond life plus annual bond interest) plus fuel savings (gas, coal, electricity, oil, propane, etc.). The program compares the present value of the cumulative savings for each year with the present value of the cumulative outstanding debt. When the present value of the cumulative savings equals the present value of all of the remaining outstanding debt service payments, payment is said to have occurred.

The program takes into account the estimated escalations of the various fuels. The source for these escalation factors is the "Federal Methodology and Procedures for Life Cycle Cost Analysis," as published in the January 23, 1980, Federal Register. At the present time, the Federal guidelines recommend a discount rate of ten percent and that rate is being used. The CDB bond interest rate is currently 6.67 percent and that rate is automatically programmed into the computer. In many cases, there are negative fuel savings which also must be allowed for and these are entered into the program simply as negative numbers. The program also computes the 25 year present value life cycle cost to permit comparison of alternative schemes. The CDB is currently not recommending funding projects of more than 7 year payback period. Projects of 7 to 10 years payback are, however, listed in audit reports for possible future funding. The fuel escalation factors now in use are as follows:

	Annual Percentage Increase		
Fuel	1980-'85	1986-'90	After 1990
Natural Gas	10.19%	9.52%	10.17%
Distillates	9.78%	11.54%	10.29%
Coal	8.56%	9.74%	9.9%
Electricity	8.6%	8.45%	8.53%

These numbers are all based upon an overall inflation rate of eight percent per year throughout the balance of this century.

With a favorable economic analysis indicating an investment payback of less than 7 years, a retrofit recommendation is included in the energy audit report. This report contains a description of the existing facility including its configuration, envelope construction, and condition, and the type and use of all existing energy consuming systems in the building. It also contains a complete energy use analysis after which all operations and maintenance and retrofit recommendations are delineated. The retrofit recommendations section includes the economic data used to evaluate its viability. These include the estimated project cost, the projected first year and 15 year cumulative savings, and the calculated payback period for each recommendation.

The following are examples of recommended retrofit projects which resulted from energy audits:

Project	Estimated Cost	Estimated First Year Savings	Estimated Fifteen Year Savings	Estimated Payback Period
Kankakee Community College (Kankakee, Illinois)				
VAV* fan system conversion	$440,000	$76,000	$1.6 million	4.15 years
Energy Management System Installation	$ 86,000	$19,000	$383,000	3.32 years
*Variable Air Volume				
Lewis and Clark Community College (Godfrey, Illinois)				
Energy Management System Installation	$ 48,000	$ 3,000	$ 60,000	8.71 years
HVAC System Modifications	$ 35,000	$15,000	$397,000	1.73 years
Adlai Stevenson Hospital (Dixon, Illinois)				
Recirculating Air System Installation	$ 58,000	$41,000	$969,000	1.2 years
Electric Chiller Installation to Replace a Steam Absorber	$167,000	$13,000	$353,000	7.4 years

Lakeland Community College (Decatur, Illinois)				
Energy Management System Installation	$91,000	$25,000	$463,000	2.66 yrs.
Solar Assisted Heating and Cooling System Installation	$306,000	$9,000	$240,000	13.78 yrs.
Mt. Vernon Regional Office Building (Mt. Vernon, Illinois)				
Ventilation Air Reduction	$27,000	$12,000	$967,766	1.85 yrs.

HISTORICAL STATISTICS

In its 3 year history, the Energy Management Unit, comprised of federally funded and State funded audit teams, has audited 277 buildings, making up approximately 10.3 million square feet of space. The audits have resulted in 182 measurable recommendations, such as lowering night-time heating temperatures, that can be implemented by the maintenance staff at almost no cost. The unit also has recommended 401 energy saving remodeling construction projects for older buildings.

PRESENT ACTIVITIES

Currently, design or construction of retrofit projects is underway at 29 facilities. These projects will cost the State $3.4 million, but result in 15-year cumulative energy savings of $47.4 million. The unit also has identified $1.5 million in energy-conserving remodeling projects included in the Governor's Fiscal Year 1981 budget.

FUTURE ACTIVITIES

For the future, approximately 2,000 State buildings remain to be audited. Data from audits already completed show an average estimated energy savings of 55 percent of present consumption for all audited buildings, an average 15 year estimated cumulative savings of $19 per square foot versus an estimated retrofit cost of $1.65 per square foot of retrofitted buildings.

TECHNICAL RESEARCH UNIT

Energy savings projects are being identified by the Energy Management Unit while another CDB Unit is researching alternate sources of energy to power State facilities. This unit, the Technical Research Unit, serves as the research arm of the Capital Development Board, keeping the board staff current in building design and construction technology by conducting research and intra-agency technology transfer sessions with other board staff, primarily, but not exclusively, in the three primary areas of energy (coal combustion, coal conversion, pollution control regulation and technology; energy efficient building mechanical and electrical systems; and alternate and renewable energy sources); technical research (design criteria, life cycle costing, higher education co-op projects, and product material research); and building energy codes (CDB and American National Standards Institute [ANSI] Accessibility Standards, code organization activities, and the proposed State Building Code).

The Technical Research Unit staff is comprised of a registered professional mechanical engineer as supervisor, one licensed architect, two registered professional electrical engineers, one economics technician and one secretary.

Specifically, unit staff perform the following duties:

A. <u>Energy</u>

1. Study informational documents, attend workshops, seminars, etc., and invite industry experts to CDB for lectures, prepare technical reports, and work with other CDB staff and user agencies to include desirable new technology in future projects.

2. Develop funding proposals for desirable alternate energy and energy conservation projects for presentation to the State Legislature for funding.

3. Boiler plant upgrading by conducting studies of existing central heating and cooling plants for determining feasibility and cost of new coal stoker techniques and coal and ash handling techniques, all of which will enable the State to get longer and more efficient life from existing plants.

4. Conduct feasibility studies for conversion of existing central heating and cooling plants from gas/oil firing to coal firing.

5. Research new and emerging air and water pollution technology to permit the increased use of Illinois coal as an energy source and to identify new methods and products for improvement of the Illinois environment.

6. Identify and categorize those building mechanical and electrical system types and energy management system types which are most energy efficient, and keep board staff informed of same to facilitate their incorporation into CDB projects.

7. Prepare a passive solar energy design manual for issuance to architectural/engineering (A/E) firms for their use on CDB designed projects to promote energy conservation in State-owned buildings.

8. Select, for funding, three cost effective active solar projects, three wind power or biomass projects, and three total energy or co-generation projects for FY 82 funding. This will require consultation with recognized authorities on the national level, at universities, the Illinois Institute of Natural Resources, and attendance at regional conferences and seminars.

9. Select and evaluate heat recovery equipment capable of use on CDB projects and keep board staff informed of the desirability of its use on future projects.

B. <u>Technical Research</u>

1. Update and maintain CDB's design criteria contractual documents and establish design standards for user agencies, by building occupancy type.

2. Evaluate material and product quality, performance, user acceptance, and energy efficiency and develop a feedback mechanism to improve the design process.

3. Conduct research to develop appropriate fuel cost escalation information for use by the Energy Management Unit and Technical Services Section in their life-cycle costing activities.

4. Coordinate agency and the University of Illinois programs in architecture.

C. <u>Building and Energy Codes</u>

1. Involve unit staff in recognized building code agency activities (Building Officials and Code Administrators International, Inc., Uniform Building Code, National Building Code, ANSI, National Institute of Building Sciences, National Electrical Code, National Fire Protection Association, American Society of Heating, Refrigerating and Air-Conditioning Engineers, etc.) for purposes of monitoring their energy related activities and extracting information useful to the CDB.

2. Identify the need and justification for a State Building Code and propose the enactment of one into law for the purpose of promoting more efficient and less costly construction in Illinois.

3. Monitor the process of revision of ASHRAE 90-75 and 100-P Series of energy conservation standards and recommend to the board those standards and/or revisions found to be desirable and beneficial to CDB activities.

4. Study the ramifications of the implementation of the Federal Building Energy Performance Standards (BEPS) upon CDB so as to minimize any adverse impact in the event of BEPS being mandated into law.

D. Miscellaneous Activities

The unit will provide technical research and engineering support to other CDB staff in the completion of miscellaneous assignments.

Through these and many other diverse projects, the Illinois Capital Development Board has assumed a leadership role in the State's ongoing efforts to conserve diminishing energy resources.

Attachment "A"

User Agencies	NUMBER OF BUILDINGS					
	0-10,000 GSF	10,000-20,000 GSF	20,000-30,000 GSF	30,000-40,000 GSF	40,000-50,000 GSF	TOTAL
Code Agencies						
Conservation	5	0	0	0	0	
Mental Health/DD	486	169	123	56	22	
Corrections	443	94	42	12	8	
Transportation	338	33	14	5	5	
State Fair	80	10	1	1	0	
Child. & Fam. Svcs.	52	15	9	5	1	
Law Enforcement	51	1	1	0	0	
Military & Naval	45	20	18	8	7	
Administrative Svcs.	10	11	0	2	4	
Historical Library	9	1	0	0	0	
Secretary of State	0	3	3	2	1	
Public Health	1	0	0	0	0	
Agriculture	3	1	0	0	0	
Courts of Illinois	0	2	0	1	0	
Registration & Educ.	8	1	0	0	0	
Veterans Affairs	27	6	4	5	0	
Subtotal	1,558	367	215	97	48	2,285
Higher Education						
Univ. of Illinois	123	37	20	11	17	
So. Illinois Univ.	231	21	6	6	4	
Board of Governors	31	9	6	8	3	
Board of Regents	99	5	6	7	3	
Subtotal	484	72	38	32	27	653
TOTAL	2,042	439	253	129	75	2,938

A PROFESSIONAL APPROACH TO CLASS A AND SCHOOL AND HOSPITAL ENERGY AUDITS, WITH CASE STUDIES

by

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The State of Iowa has probably one of the toughest but most appropriate programs of Class A Energy Auditor Certification. As a first requirement the applicant must be either a registered architect or engineer. Secondly, he or she must take a 3-day training course organized by an advisory committee composed of representatives from the professions and industry and from the Iowa State University (ISU), and finally pass an all-day test which includes a partial energy audit with instrumentation. The training courses have been given seven times since late 1978, and additional courses are scheduled in the future. Nearly 200 Class A Energy Auditors have so far "graduated." Special courses are also given on school and hospital energy auditing. The first part of this paper will deal with the training aspects and requirements.

The second part of the paper will concentrate on results of these audits which are both quantitative and qualitative. Several hundred energy audits on government buildings, schools, and hospitals have taken place, partly financed by Federal programs. Information on Iowa buildings is being computerized and analyzed.

At a recent case study workshop, specific aspects were highlighted, including a number of building environmental topics, decision making criteria, computer applications, audit procedures, cost of audits and energy conservation measures, and codes and standards. The impacts on finances, building energy consumption, personnel, and the profession were discussed. Means to improve results of future energy audits by sharing experiences was the main objective. The results are encouraging.

Key words: Certification; Class A Energy Audit; economic analysis; energy analysis; energy conservation; Federal programs; government buildings; rate of return; schools; hospitals; technical assistance.

Nearly one third of the United States' energy consumption is for heating and cooling buildings. The amount of fuel needed could be considerably reduced by energy conservation measures based on detailed energy audits. Consequently, professional architects and engineers need to know not only how to design energy-efficient buildings which are safe and healthful for the occupants, but also--if they wish to be involved in such a detailed energy auditing process--how to measure with instruments the various energy consuming functions in a building, analyze the results (often with a computer), perform an economic analysis and make recommendations for the owner. There are several Federal programs that support energy audit activity for existing buildings.

The State of Iowa has taken the energy conservation challenge seriously. The Iowa Energy Policy Council (IEPC) was established to administer all Federal and State programs dealing with all kinds of energy problems. The Class A Energy Auditor Certification Program is a part of a national program of energy audits and the most thorough in scope. In Iowa, only those registered architects and engineers who take a 3-day training course and pass an examination based on the course contents can be certified by an advisory board and authorized by the IEPC to perform Class A Energy Audits. In addition, these authorized energy auditors can perform a number of other types of energy audits, such as for schools and hospitals, and provide technical services to the owners of large buildings. The 4-day course and examination schedule is very intensive and requires attendance from early morning to late evening on 3 days, and a full-day examination on the fourth day. The program includes lectures and demonstrations, practice sessions with instruments, and dealing with sample problems. It is highly technical and requires a good background of understanding and experience in building design. During the final examination, the participants perform an actual energy audit and thermal and economic analyses.

Professionals who are not yet registered as architects or engineers, but who wish to enroll in the course may do so. If they complete it satisfactorily and pass the examination, they will be recognized as "Associate Class A Energy Auditors" until such time that they become registered and (if they do so within 1 year) are authorized as Class A Energy Auditors. These associate auditors often work at offices of authorized professionals and perform various duties connected with the audits.

The workshop is organized by the Class A Energy Auditor Advisory Board which is composed of representatives of the faculty of the Iowa State University (ISU), the professions, and industry. It is sponsored by the ISU Engineering Research Institute under contract with the IEPC, together with Architecture and Engineering Extensions in cooperation with the Iowa Engineering Society and the Iowa Chapters of the American Institute of Architects, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, and the Illuminating Engineering Society. The fee for the workshop has varied from $60 (when subsidized heavily by the IEPC) to $200 which includes the course workbook and other materials, four lunches, two dinners, daily refreshments, and bus transportation to the energy audit building.

Several minimum requirements have been set for the course content. It is considered necessary that participants receive adequate information about various energy audit programs involved; technical instruction on thermal, ventilation and air handling, combustion, refrigeration, service water heating, electrical systems and lighting criteria. Several hours of practical training is given in the use of instruments for measuring energy transfers and systems performance. Considerable time is devoted to methods of energy analysis and application of the Building Energy Management Index (BEMI), which is an excellent tool in charting energy performance and following the effects of energy conservation measures. Heavy emphasis is on economic analysis, showing the advantages and differences of the rate of return on investment over simple payback, and ranking the various applicable, mutually inclusive energy conservation opportunities on the basis of life cycle costing for decision making.

The participants are instructed in practical procedures in making a complete Class A energy audit, including the use of various forms for data collection, computations, and reporting. Evening sessions are spent in learning and getting practice in energy calculations, sample problems, and in reviewing course work. For the final examination, field audits by various instruments are performed at Carver Hall, a building that is continuously monitored for its energy performance by a computerized system. An energy analysis follows the field experience, and an economic analysis occupies most of the second half of the test.

The more than 200 professionals who have so far taken the course include both architects and engineers in approximately a one to four ratio. The passing rate, which requires a minimum of 70 percent grade, is also similar to that ratio. The overall passing rate has varied between 75 and 85 percent of course participants. An unsuccessful candidate is allowed to retake the examination without having to retake the entire course, but several have chosen to repeat the whole experience.

For an out-of-state applicant to be certified as an Iowa Class A Energy Auditor without taking the Iowa training course it is necessary for the applicant to qualify for professional licensing in Iowa, as well as for the applicant's State to have an equivalent training and certification program, meeting Iowa's requirements for authorization. Until now, out-of-state applicants have preferred to take the Iowa course, and no applicants have been qualified by other means.

It is true that for schools and hospitals and for government buildings simpler energy audits are performed under other Federal programs. These include a data gathering phase, a "walk-through" audit and other phases. However, for technical assistance, the Federal rules require professional engineers or architect/engineer teams with technical qualifications. In Iowa this means Class A Energy Auditors as authorized by the IEPC. The IEPC furnishes a list of authorized auditors to interested owners and agencies when requested, and addresses requests for bids for energy audits for State-owned buildings to this group.

The State of Iowa received a rather modest amount of Federal monies for its programs. For instance, while Iowa is one of the forerunners in gasohol research and production, only one small grant was received from a recent appropriation. Similarly, the Iowa Energy Policy Council is expected to receive only about $10 million per year from the proposed new Federal program of $2 billion in the next 3 years. For energy audit programs, about $2,120,000 has been awarded for schools, hospitals, and government buildings. These included some 120 technical assistance grants and 77 energy conservation measure requests. New applications have been received for 70 technical assistance cases and 120 energy conservation measures. In addition, separately funded energy audits have been performed for scores of other buildings, and the Building Energy Utilization Laboratory (BEUL) of the ISU has done a large number of data collecting audits on State-owned buildings. The BEUL maintains a computerized data storage system that already has information on more than 2000 Iowa buildings.

At the recent case study workshop at the ISU, some 50 energy auditors gathered to exchange information and experiences. The director of IEPC grants program, B. Karachiwala, gave an overview of State programs, and we heard from Howard Ross of the U.S. Department of Energy (DoE). It appears that energy auditing does not have much appeal. One of the problems is the extremely low fee structure that is supposed to cover the federally funded audits. The range of audit costs experienced by participants to the workshop varied from 2.5¢ to 12¢/sq. ft. for technical assistance, but pilot Class A Energy Audits showed much higher figures, up to 40¢/sq. ft. or even more. While such costs are often justified in comparison to energy conservation savings, they are unattractive when first quoted to the clients. For schools and hospitals, the lower range seems to prevail. Some of the most active professional firms reported to have completed 25-70 energy audits for schools and hospitals.

The participants in the case study workshop included professionals from four neighboring States. We had an opportunity to compare the Iowa program with that of Minnesota. The Minnesota program is larger, but does not include the kind of training provided by Iowa, nor as strict qualifications for auditors. It appears that most States have based their programs more on the basis of the schools and hospitals energy audit requirements than on Class A energy audit standards. The workbook published by the American Institute of Architects seems to follow the same less strict line, although the information on systems' calculations is very extensive.

Another problem that the participants reported on was the "red tape" and inconsistent interpretation of audit requirements in dealing with government officials. For instance, regarding the economic analysis, Iowa's system of computing life cycle costing and rate of return on investment is shunned by the DoE which likes the simple payback method. Reviews of applications are often based more on the image than on substance, i.e., filing of forms and not on cost/benefit results in terms of energy saved. The 12-month completion cycle from the date of the award for technical assistance for schools may sometimes conflict with fiscal years.

Professional performance of case study speakers and discussion participants was as anticipated after completion of training for certification as Class A Energy Auditors. The quality of their services also exceeded what might have been expected on the basis of low fees. Several had computer systems at their disposal, and many had developed their own outlines and forms for conducting energy audits. Some seemed to be very well organized and displayed excellent management systems for energy auditing.

The Federal energy audit programs are supposed to encourage the use of solar energy in retrofitting buildings. On the basis of simple payback, however, one of the participants who has a great deal of experience in both passive and active solar design reported that an energy conservation measure for active solar would take 90 years amortization by simple payback, while its life-cycle costing figure would be 22 years, considering 16 percent fuel cost escalation per year. Other long term investments are a replacement of windows or of a roof. These measures could be cost-effective only if required as part of overall maintenance.

The cost of some energy conservation measures was found "prohibitive" in some cases. It is also hard to prove that the actual results could be substantial enough, by simple analyses. Because of the combination of variables, the client may not be able to interpret the results. Some buildings are "building envelope intensive" while others depend more on mechanical and electrical systems. Because of the short time during which we have had experience with energy audits, it is not yet possible to measure the results of some actual energy conservation measures. Future audits and monitoring of systems will be necessary to establish actual results. Observation and improvement of operations is a key part of energy audits, checking compliance with codes is also necessary, and building aesthetics should be maintained.

In reporting on their experiences, several participants told of improvements they had incorporated in their energy auditing procedures. They also had conducted studies to establish reasonable crew sizes and time schedules for audits of various sizes. For Class A energy audits, a four-person team may spend 2 days in the field collecting data and taking measurements; then work for 3 weeks at the office analyzing energy conservation opportunities and economics involved; and then take 3 more days in writing a report and recommendations to the client.

For economic analysis, several speakers reported that the client insisted on a simple payback method even when life cycle costing figures were available. Some clients with in-house economists did their own analyses. It appears that life cycle costing and rate of return figures are often confusing to a client with limited education, or an interest in only 1 to 2 years simple payback. Uncertainty of projections on energy cost increases is one of the discouraging factors. Lack of good computer programs is another factor, although one advanced program for hand-held calculators is available from the ISU, prepared by Dr. Geraldine Montag, an economics professor. Nationally, the American Society for Testing and Materials (ASTM) is currently developing a new standard for life-cycle costing. In Iowa, life-cycle costing is required for all State building projects, although not rigidly enforced. Regarding State buildings that are energy audited, the Office of Planning and Budgeting may request life-cycle costing for the resulting energy conservation measures, but seldom does so.

An interesting study was reported on the University of Iowa energy conservation program. Operated with district heating, many buildings have in the past had poor controls, but a turning point has resulted from energy auditing. One important point was made: savings resulting from energy audits should be allocated for additional energy conservation measures. One particular incident shows that some measures can result in an almost immediate savings. A $80,000 system installation resulted in a timely discovery of a problem that would have cost $75,000 in damages if allowed to continue. Four-year payback results were found in cycling controls and condensate return line insulation installations.

Because of poor recording of energy consumption information on the part of many building owners, they are sometimes unaware that they may be paying wrong rates. One such discovery by an energy auditor resulted in a refund of $13,000 to the owner, a school system. If it had been in reverse order, the auditor confessed that he would have followed an old rule, "silence is sometimes golden." Reasons for client interest in energy audits often vary, from public relations programs to personnel awareness and actual energy savings to the owner and taxpayers. Sometimes the successful passage of a bond issue election serves as a motive.

The Building Energy Management Index (BEMI) is one of the results of a complete Class A energy audit. This index permits annual budgets of energy consumption to be computed (sometimes with computer simulation) and a comparison with the proposed DoE Building Energy Performance Standards (BEPS) may be made. In response to public hearings on BEPS, the ISU's Building Energy Utilization Laboratory recommended that instead of certifying computer programs, qualified professionals such as Iowa's Class A Energy Auditors should be certified. In sponsoring this program, the State of Iowa may be leading the nation in the area of energy audits. The dedicated application of techniques of energy and economic analyses by those trained in Iowa as Class A Energy Auditors should make a major contribution to energy conservation in the nation.

A SIMPLIFIED PROCEDURE FOR THE USE OF SOLAR ENERGY IN COMPLYING WITH THE COLORADO ENERGY CONSERVATION STANDARDS FOR RESIDENTIAL BUILDINGS

by

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This study reviews the history of the residential energy conservation building standards in Colorado. Attendant educational efforts are described. Results from performance testing of trainees are presented. Numerous sources have requested simplified code compliance methodologies. Presented is a simplified strategy for code compliance through the use of solar energy. Code conflicts with solar are identified. The effects of the Building Energy Performance Standards (BEPS) on solar use are briefly discussed.

Key words: BEPS; code compliance; code conflicts; energy conservation standards; solar energy; trainee performance testing.

HISTORY

Even the legislative intent of Colorado's most recent residential energy conservation standard (Senate Bill 292) [1]* is simplification. In particular, the following quote (from SB 292) displays this concern. "To provide in graphic illustrations and charts the information needed, by a person who applies for or obtains a homeowners permit to build his own home to correlate the R-values to the U-values of the more energy conserving performance standards."

In October 1977, Senate Bill 159 [2] went into effect. It consisted of two basic components. The first is prescriptive and read as follows:

"6-7-105 Insulation standards and energy conservation alternatives:

1) Minimum insulation standards for residential buildings on which construction or renovation commences on or after July 1, 1977, shall be as follows:

    a) Insulation having a minimum R-value of 11 shall be used in all exterior walls contiguous to unheated areas above grade.

    b) Insulation having a minimum R-value of 19 shall be used in all exterior ceilings of unheated areas above grade.

    c) All windows above grade shall be double-glazed.

    d) All exterior doors or doors leading to unheated areas above grade shall be weather-stripped and sliding glass doors shall be doubled-glazed."

The above verbiage was easily understood and builders readily complied with the code according to unofficial reports from code officials.

The second portion of SB 159 is a performance based option. It read as follows:

2) "Computations submitted by a licensed architect or engineer that the total energy required in a residential building, through design or otherwise, equals or is less than the total energy used if the dwelling is built or renovated according to the standards contained in subsection (1) of this section and shall be considered an acceptable alternative for conformance with the prescriptive standards set forth in subsection (1) of this section. The total energy required shall be computed as the annual estimated Btu's necessary to heat, cool, and light the proposed building. For purposes of this calculation, the exterior walls shall consist of no more than the equivalent of 20 percent doors and windows."

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*Numbers in brackets refer to references at the end of text.

Since this section is of utmost importance to any building which deviates ever so slightly from the prescriptive standards (in subsection 1), and since the performance option is ill defined, the first round of Department of Energy (DoE) funded training sessions conducted by Colorado State Government employees addressed this performance option. One prime example of a home that would not meet the prescriptive standards is the log cabin. This is because the walls of a log home seldom have an R-11 insulating value.

An entire half day training session in 1978 was devised by the author around the log home example. The approach was to personally train builders and building code officials in the art of heat loss calculations. A heat loss calculation is a method of analyzing each individual component of the building's envelope (walls, roofs, floors) to arrive at a total heat loss for the entire building. The author modified the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Steady State [3] method to reflect one overall U-Value (U_o) for an individual building. Once this concept is applied to a building built in accordance with the prescriptive standards, the method can then be reapplied to the home in question (e.g., a log home). Both values are then compared and compliance with the code is easily determined.

Though this method of teaching was never thoroughly evaluated, response was favorable. A total of 322 people attended six statewide training sessions. The participants consisted of building code officials (30 percent), design professionals (26 percent), contractors and business people (19 percent), administrators and planners (14 percent), and others (11 percent).

A nonresidential energy code was enacted simultaneously with SB 159. It is based on the ASHRAE 90-75 [4] approach and has three distinct compliance options. This code was also made available as an alternate to SB 159 for residential buildings. In this study when the nonresidential code is to be used for residential buildings it will be referred to as the Model Code [5].

The second round of energy code training sessions in early 1979 addressed the Model Code as it related to residential buildings. The author devised a 5-hour session which reviewed heat loss calculations. These calculations were then applied to furnace sizing as a logical progression. Some in the audience were building code officials who had attended the first round of training sessions. The author attempted to gauge the relative audience understanding of heat loss calculations through increased audience participation. This not only helped gauge the effectiveness of teaching methods, but allowed the author to provide additional help to those needing it. Once again a qualitative evaluation showed favorable response. A total of 455 people attended these training sessions. Building code officials made up 21 percent of the audience. The remainder consisted of contractors and design professionals. Fewer administrators attended this round of training sessions.

Though the example home used during this second round of training was a passive solar design (Thrombe Wall) the author did not delve into solar calculations. Instead, it was shown that in this case, the solar home complied with code requirements on merits of energy conservation features alone (i.e., insulation, furnace efficiency).

In 1979, the Colorado Legislature passed Senate Bill 292 [1], eventually replacing SB 159, but not eliminating the Model Code as an option for residential buildings.

SB 292 contains three compliance options. The first is prescriptive in nature. The second allows "tradeoffs." A tradeoff is used when, for instance, a wall with a low insulating value is compensated for by a ceiling with a high insulating value. The third option allows for the consideration of energy derived from nonfossil fuel sources. It reads as follows:

> "Computations submitted indicating that the total fossil fuel energy required in a residential building, through design or otherwise, equals or is less than the total fossil fuel energy used if the dwelling is built or renovated according to the standards contained in subsections (1) and (2) of this section shall be considered an acceptable alternative. The total fossil fuel energy required shall be computed as the annual estimated Btu's necessary for the proposed residential building."

This study will concentrate on SB 292. Emphasis will be placed on the utilization of solar energy by residential buildings as it might be used to comply with the aforementioned code.

Eight training sessions which solely addressed SB 292 were conducted in the fall of 1979 and winter of 1980. A quantitative evaluation of some participants was conducted.

EDUCATIONAL BACKGROUND

The educational range of the participants is quite broad. The mechanical engineer might be a solar specialist while the homebuilder may be a carpenter specialist by trade. On the other hand, the code official must be knowledgeable about mechanical systems as well as construction techniques. Because the code official is a code specialist, he/she will extend into the full range of the construction industry. For this reason, the code official can be considered as a typical representative for the construction industry.

Building code officials, excluding administrators and senior supervisors, tend to fall in one of two job categories. The first category is the plan checker, who reviews and approves plans for code conformance prior to issuance of the building permit. The second category are field inspectors who inspect the actual construction for compliance with the approved plans and code. K. C. McKenzie of the New Mexico Energy Institute has compiled the following information in Regional Training Energy Conservation Code Workshops for Building Officials [6].

"Of the roughly 120 building officials in New Mexico, approximately 15 percent are Plan Checkers. Plan Checkers typically have completed 16 years of education and have a Bachelor's degree in Architecture, Engineering, or some similar field. Field Inspectors constitute the remaining 85 percent of building officials. Field Inspectors typically have completed 12 years of education and have a high school diploma."

From the 1970 Census, it is learned that of the 19,754 employed Colorado male construction craftsmen (excluding carpenters), 4065 have 8 years or less of completed schooling, 4789 have 1 to 3 years of high school, 8541 have 4 years of high school, 2046 have 1 to 3 years of college, and 313 have 4 years or more of college. Employed Colorado carpenters show a similar trend. A total of 9856 carpenters were employed in 1970. Those having 8 or less years of schooling totaled 2048, 2428 have 1 to 3 years of high school, 4034 have 4 years of high school, 1136 have 1 to 3 years of college, while 210 have 4 or more years of college.

A total of 15,782 employed male engineers displayed the greatest number of years of schooling. Only 156 had 8 or less years of schooling, 411 have 1 to 3 years of high school, 2282 have 4 years of high school, 3054 have 1 to 3 years of college, while the largest number, 9879, have 4 or more years of college.

Using a base level of 12 years of education and a high school diploma, it appears that it was not unreasonable to attempt to fit the person to the job of calculating the annual fossil fuel difference as used in the codes performance option.

The author has undertaken and completed a study evaluating the performance of trainees who attended energy code seminars. The results of the study are presented here.

Three residential code workshops were held in the winter of 1980 in Greeley, Colorado Springs, and Grand Junction, where U-value calculations were taught. To ascertain the performance of trainees in calculating U-values after they had received a 3-hour intensive workshop, a sample problem was devised. The sample problem required an assimulation of the information presented in the 3-hour workshop. It was not an exact repetition of previous work completed by the trainees.

The evaluation considered six separate approaches to better understand where problems occur. The approaches are:

1. Total points [6]
2. R-values
3. Conversion R total to a U-value
4. Mathematics
5. Proper set-up of the problem
6. Number that attained 100 percent

The results will be presented for six categories of trainees. The categories are:

1. Total number of trainees
2. Builders/contractors
3. Materials suppliers
4. Building code officials
5. Architects/engineers
6. Others (planners, citizens, etc.)

The average score of the trainees was 77 percent on a whole. Nearly half (47 percent) of the trainees answered all the questions correctly. The important procedural process of set-up of the equation was accomplished with proficiency of 85 percent. The greatest sources of errors were missing or incorrect R- and U-values. Though 31 of 64 erred on the final U-value, this may be somewhat misleading. The 21 that erred on R-values, obviously erred on the subsequent U-value. Thus, ten persons erred on the U-value with correct R-values in place. Most of these ten simply omitted the final U-value. (See table 1.)

Table 1: Evaluation Details

	Number Tested	Total Pts. Scored / Total Pts. Possible	Number Scoring 100%	ERRORS			
				# Erring on R-Values	# Erring on U-Values	# That Set Up Equation Incorrectly	# Erring on Basic Math
All Trainees	64	294/384=77%	30	21	31	9	11
Material Suppliers	6	30/36=83%	3	2	3	1	0
Building Code Officials	18	87/107=81%	10	4	7	3	2
Builders/ Contractors	26	116/180=64%	10	10	13	5	7
Architects, Engineers	3	16/18=89%	2	0	1	0	1
Others	11	51/66=77%	5	5	7	0	1

A set of six true or false questions was also asked. The average score was 84 percent correct answers.

Considering that the average score on true or false questions was 84 percent and the average score on the U-value calculation was 77 percent (with 86 percent able to properly set up the equation), it could be concluded that the major concepts of the code are being communicated. More effort needs to be exerted on the importance of choosing the correct R-values.

SOLAR AND CODE

The use of solar energy to comply with energy conservation codes has been attacked recently. The author has heard the following comments: "Oh, put a solar collector on a sieve." "Let them build the house poorly, then use solar instead of insulation." "We should encourage solar, but not at the price of insulation."

These are recent comments. Five years ago the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) began developing an energy conservation standard. The final standard was a true industry-wide consensus standard and contained substantial encouragement for solar utilization through a performance option. When ASHRAE Standard 90-75 [4] was codified and adopted by counties and municipalities it took on the force of law. Colorado's nonresidential code is derived from ASHRAE Standard 90-75. Section 403.0 is entitled <u>Buildings Utilizing Nondepletable Energy Sources</u> [5] and states:

> "Any proposed building utilizing solar, geothermal, wind, or other nondepletable energy sources for all or part of its energy source shall meet the requirements of Section 401 of this code, except such nondepletable energy may be excluded from the total energy consumption allowed for the building by that section."

The code gives further privileges to buildings of less than 20,000 gross square feet that derive 30 percent of their total annual energy requirements from nondepletable energy sources.

Senate Bill 292 [1], the latest Colorado residential code, defines performance options in terms of the use of fossil fuel energy. Clearly, lawmakers favor encouragement of solar through this code since it allows a "credit" for the use of nondepletable energy.

Certain special cases benefit from the pure, unadulterated use of this performance option. A case in point is the passively heated underground house with a great amount of south facing glazing. If properly designed, this home can be far more energy efficient than a "typical" code complying home. But when calculated according to ASHRAE steady state methods [3] for use with the code, the walls may not comply. The solar performance option could then be needed.

If a building uses a solar domestic water heater to comply with the code, a number of factors should be considered. First, the home can use no more fossil fuel than allowed by the code. Secondly, occupant habits such as setting thermostats back, though an energy conserving technique in of itself, tends to decrease the energy savings directly attributable to thermal envelope approaches such as increased insulation levels. On the other hand, solar systems, which typically provide less than 100 percent of the load, are virtually unaffected by occupant habits such as night set-back. The solar system consistently replaces a set quantity of fossil fuels on the average. A third advantage to the encouragement of solar energy usage through the code is an increased visibility for the industry. The visibility reaches far beyond the new construction market into the retrofit, renovation market. This is an intangible benefit not to be overlooked as is the final benefit from increased solar usage. The use of solar energy is apt to raise more issues than the application of internal energy conservation measures. Some of these issues are solar access, land use planning, building orientation, tax incentives, financing opportunities, and the subsequent breakdown of other institutional barriers. Thus, the question of encouraging "solar at the expense of insulation" is somewhat immaterial.

The present residential standards are considered by many to be far too lenient. Thus, at this time, the use of solar in code compliance could result in a home with very little in the way of energy conservation. If one looks ahead to the time when the standards will be significantly upgraded by pressure from the Federal Government (Building Energy Performance Standards--BEPS), the use of solar for code compliance will most likely have to be coupled with increased prices for fuel and increased energy conservation requirements, the economics of solar will become more attractive.

The Federal Government's (and Colorado's) policy of encouraging the use of solar has another beneficial aspect. That is an increased research and data base associated with investigations of both solar and energy conservation strategies. In striving for a more efficient building we have found that window orientation alone can be more important than the R-value. Similar findings by George Tsongas of Portland State University, et. al [7], have shown that a reduced insulation (R7) is the best performing configuration for a south facing frame wall in Oregon. Thus, we must all be constantly reevaluating our thinking concerning energy efficient buildings.

Since the traditional approach to residential energy conservation codes in Colorado (and to code compliance) has been a prescriptive one dealing primarily with insulation, very little has been done to encourage the use of solar through the performance options. In fact, no guidelines have been published for the use of Section 4 of the nonresidential/residential Model Code. Easy to use and understand guidelines for the performance option of SB 292 have met with positive reactions, also. One participant at a training session remarked that finally the code has put conservation and solar on an equal basis. But this is not always true.

Regarding the Model Code, detached greenhouses are exempted by virture of being classified a type M (agricultural) building. This exemption is found in Section 103.0 (Scope).

An attached greenhouse could be (and has been) considered part of the residence. If the greenhouse is heated by depletable energy sources, its exterior envelope must be included in the U-value calculation in such a case. This may or may not pose a code compliance problem. If the remainder of the building envelope is well insulated, the resultant U-values could conceivably comply.

Certain designs allow the greenhouse to "freeze out" in the winter. Daytime heat in the winter is collected and distributed into the home with no storage for nighttime use. Of course, no plants are grown during this period. If the greenhouse is not heated to over 50°F it is then exempt from the code by virtue of Model Code Section 103.1 (Exempt Buildings).

If none of the above criteria apply, an analysis of the residence and attached greenhouse would be required as described in Section 4 of the Model Code.

Regarding the legislated energy conservation standards (SB 159 and SB 292), an interesting conflict arose. Senate Bill 159 prescribed double pane glazing among other concerns. Code officials applied this to residential greenhouses as well. Certain manufacturers provided only single glazed greenhouses. This same problem has plagued the makers of single pane window units with removable insulation. Hopefully, the move to SB 292 (a performance code) will alleviate this narrow interpretation.

In addition, many passive solar and earth sheltered designs utilize removable night insulation schemes for use with glazings. The effects of such insulation can be calculated with the proper data and some effort.

It is imperative that the benefits of night insulation be brought forth at this time. The first energy code in Colorado was of a prescriptive nature. It stated that all windows were to be double glazed. With the use of single pane windows virtually banned, passive solar schemes with single glazing were given a black eye even if night insulation was used. It can be an advantage to use only one pane of glass, since more solar radiation will be transmitted into the home.

A number of investigators contend that window orientation is directly related to heat loss (and heat gain) [8,9]. It is well known that certain orientations <u>can be</u> net heat gainers at various times of the year [3]. Unfortunately, extenuating circumstances make the calculating of an actual annual heat loss or heat gain factor complex, rather than simple.

If SB 292 were to encourage window orientation simply on the merits of a heat loss/heat gain ratio, the following partial list of factors could go unrecognized:

1. localized overheating of the interior space
2. subsequent venting or dumping of excess heat (thereby destroying the heat loss/heat gain ratio)
3. summer overheating potentially causing a greater cooling load
4. landscaping and shading by other buildings
5. air infiltration increases
6. variable occupant behavior regarding the use of drapes, etc.

Yet, the question continues to be raised. "Isn't a southfacing window better than a northfacing window?" The BEPS will be allowing credit for orientation [10]. The performance option of SB 292 could consider the effects of orientation.

Swimming pools that are heated and are an integral component of the building (on the rooftop or structurally tied to the building) are included in Section 508.3 or Section 608.3 of the Model Code [5]. The actual code language states:

> "a) Heated swimming pools shall be equipped with controls to limit heating water temperatures to no more than 80°F. Exception: Pools used for therapeutic purposes are exempt from this requirement when approved by the Building Official.
>
> b) Uncovered (unenclosed) heated pools shall be controlled so that the electric or fossil-fueled pool water heating systems are inoperative whenever the outdoor air temperature is below 60°F."

The above language applies to all nonresidential buildings as well. There are probably more heated pools (that are integral components of the building) being built in the commercial sector than in the residential sector. The author has received many telephone requests for technical assistance concerning heated pools. Between mid-July and November 1, 1979, 12 telephone requests were received.

A large amount of resort development occurs in Colorado. Many of these vacation retreats provide outdoor heated pools. This is an opportunity for both pool covers and solar pool heating to be considered if an extended season and/or a water temperature beyond 80°F is desired.

An example of an enclosed pool should be presented in future training. The difference in energy consumption between maintaining the water temperature at 80°F and 85°F should be illustrated as well as the effects of a pool cover.

The approach could identify three primary concerns. The first is simply that solar is a viable option for those wishing to vary from these code requirements. The second identifies the enormous energy consumption of heated swimming pools. This alerts the building officials to the importance of these provisions. Finally, pool covers should be discussed.

The author has heard a number of participants ask "How much energy can you get from a solar collector? And, is there an easy way to figure this out?"

If there were an "easy way," many people could benefit. Persons dealing with the energy code could quickly determine the area of solar collectors needed to comply. Code officials, in a like manner, could quickly determine compliance. If. . .

The author decided to determine the availability of simplified measures for the previously stated purpose and then adopt the most appropriate method to the code.

A morass of methods for calculating the performance of active solar systems is available. The range is from very simple graphic methods to full computer analysis.

A multitude of simplified methods are available for collector sizing. No one method studied provides accurate information for all collectors and systems available. Therefore, it was decided that this phase of code compliance should be individually calculated by a capable solar system designer.

The building official is predominantly interested in health and safety considerations. If a solar system is installed, he/she checks the plans for compliance with numerous codes. The energy conservation code is only one of these. The only (residential) situation in which the actual energy output of a heating system is required is in the sizing of a heating system "capable of maintaining 75°F at a point 3 feet above the floor" [11]. This is a Uniform Building Code (UBC) requirement. Since a backup system capable of providing full heating will be required with all solar systems, the building code official has little incentive to scrutinize the energy performance of solar systems. The emphasis by the code official at this time will probably continue to be on health and safety aspects, not solar system efficiency.

If solar energy is used to provide compliance with the energy conservation codes, the building official is faced with accepting calculations stating that the solar system will provide a certain amount of energy. A helpful service would be to provide a compilation of selected calculation methods.

SIMPLIFIED CALCULATION STRATEGY

As in all cases, a comparison must be made between the proposed design and a dimensionally identical standard design which complies with the code. This is not difficult to calculate under SB 292, but must be done. The calculation result is the quantity of energy (Btu's) that the proposed design would use in excess of that allowed by the code. It is this quantity that must be supplied by renewable energy for code compliance. The strategy is then a simplified method for determining this quantity.

In the case of solar domestic hot water (DHW), this quantity could then be divided by the estimated annual energy consumption for heating water. The result would then be a solar fraction of DHW required for compliance with the energy conservation code.

The next step is to provide the code official with calculation results that show a given solar system will provide the aforementioned solar fraction. These calculations would be provided by the solar designer as solar calculations are site specific and dependent on numerous variables, often very complex.

Since the code has been in effect for a relatively short period of time, there is no history of a deficiency in execution. A clear definition is the existence of a gap in guidelines relating specifically to the performance option. Thus, the training need is to be a tool to fill this gap.

The tool will need to provide the information required to effectively design the annual energy comparison equation and solve it. In addition, further guidelines to aid in calculating the actual solar energy input would result in a tool as complete as possible for the general construction industry.

Though personalized training sessions have been staged in the past, they are not without drawbacks. Though limited data is available concerning energy code training sessions, most participants or potential participants are concerned about taking time from work to attend [6,12, 13,14]. This concern is leavened with a knowledge that the training is an aid to doing the job. Thus, a desire for more training has been documented in Colorado [12,14]. Along with this is a desire for more time spent on the training range far and wide. Solar topics are in demand [14]. The author's experience with these training sessions is that the participants, when questioned, will usually state a desire for solar information amongst other topics.

To date, no charge other than lunch fees and $1.00 for the 85-page codebook have been charged participants of residential energy code training programs. Numerous training books have been distributed free of charge. Essentially, all training has been free of charge. The cost of any program is of concern to the participants [14]. With the recent programmatic budget cuts, the Office of Energy Conservation will begin charging a cost recovery fee for all training materials.

Requests from the Colorado construction industry are quoted below [12].

> "All but one building official responding had attended a State-sponsored (training) program. They suggested that training be more basic, more extensive, and for longer periods of time. They requested more easy-to-follow graphs, charts, and manuals. Many indicated they have problems getting time off for training.
>
> "Seventy percent of the architects, engineers, and contractors responding had attended a State-sponsored training program and felt it was adequate. They requested smaller training groups and better notification of sessions.

"A majority of the material and equipment suppliers responding had not attended State training."

The final recommendation concerning the training program as stated was:

"The State program of training and technical assistance should be continued and improved, particularly for local enforcement officials" [12].

Faced with the dilemma of increased requests for training and decreased budget, the author proposed to further convey the strategy through a written training tool.

The Michigan Energy Extension Service presents evidence indicating that written materials are most favored by small business. The following quotes are from its Energy Conservation Needs Assessment for a Business with Under 250 Employees [15].

"In the course of planning and initiating Michigan small business energy conservation two needs assessments were completed on three different business populations.

These were:

1) General Small Business - whereby a representative sample of 1400 small businesses were asked to complete a written questionnaire.

2) Small Business Energy Related Contractors - whereby a written survey was sent to all small businesses which install or design for use of energy conservation materials or equipment.

3) Small Industry - whereby a random sample of 500 industries with 250 employees or less were sent a questionnaire."

The most favored format for disseminating energy technology was via written material distribution.

Of the various techniques presented including seminars, workshops, expositions, on-site consultation, efforts to organize the small business community and all other techniques, distribution of written materials was favored over all other dissemination techniques.

Consistent with the above results, the overwhelming majority of small businesses indicated that they now obtain most of their energy information from newspapers and magazines and journals.

To design a training tool, one must evaluate the tasks at hand. A topic analysis for the use of the performance option is shown below.

TOPIC: Use of performance option

DUTY: Understanding the code

A. Task: Concept of Code Requirements

Elements:
1. The code is a law
2. Due to climate variations, the code requirements may vary throughout the State
3. Site specific requirements may be obtained from the local building code official
4. The basic requirements are separate U-values for the wall, roof, and floor (over an unheated space).

B. Task: Concept of the performance option

Elements:
1. The intent of the code is to conserve fossil fuels
2. The code is flexible in that there are 3 compliance options
3. One of the compliance options allows the comparison of the annual fossil fuel consumption of the design against that of a dimensionally identical home (standard design) that complies with the minimum requirements of the code
4. If the design uses more fossil fuel, the difference between it and the standard is the energy needed from nonfossil fuel sources.

DUTY: Understanding the Calculation Procedure

A. Task: Concept of the Calculation Comparisons for use with the performance option

Elements:
1. Calculate individual U-values for the wall, roof, and floor (over an unheated space) for the proposed design. It is assumed that this calculation can be executed by the trainee
2. If the U-values are in compliance, go no further for code purposes.
3. If not in compliance, two sets of calculations of annual code controlled fossil fuel use will be required
4. The equation to use is: Btu=(UrAr + Ufaf + UwAw) (Degree Day) (24 hours)
5. First calculate the proposed design
6. Next calculate a dimensionally identical structure which complies with the minimum code requirements (standard design)
7. Subtract the standard design from the proposed design to determine the number of Btu's to be supplied by nonfossil fuel sources such as solar.

B. Task: Understanding the general areas (and percentage) of energy use in the home

Elements: 1. A graphic illustration of general areas of energy use in the home, shown in percentages
2. The additional annual energy requirements for a heated swimming pool.

C. Task: Proving Compliance

Elements: 1. An unlimited number of combinations of solar devices can be used to obtain the required energy. Full design freedom is allowed
2. Calculation methods to show actual energy output of solar devices are not specified by the code
3. Numerous calculation methods are available for this purpose
4. Calculate the annual energy output of the solar device(s)
5. When the energy output of the solar device is calculated, present this calculation with all previous comparison calculations to the local building official to prove compliance.

This strategy is an envelope approach only. The comparison of envelope components was chosen for the following reasons.

1. The Colorado code required U-values and is predominantly an envelope centered approach [1].

2. Research in both Colorado and Massachusetts indicated the code's envelope requirements are the most understood and complied with portion of the code [16].

3. Energy code training sessions have been aimed predominantly at envelope requirements.

4. Trainees have exhibited a satisfactory level of understanding of the envelope calculations and requirements.

5. The March/April 1980 edition of Alternative Sources of Energy Magazine indicates that builders are not sold on solar yet [17].

> "U.S. builders are not sold on solar energy. That is the general conclusion of a survey of the building industry by SRI International conducted in 1978. The sample was based on a stratified random sampling of 1,420 builders throughout the United States. The main determinant is the feeling that solar systems are largely inadequate and expensive. Interestingly enough, approximately 65 percent of solar installations are taking place among small home-builders (less than 75 units per year). Marketing of solar systems is concentrated mainly where solar equipment manufacturing is the highest: the Southeast, Southwest and the North Central regions."

6. The target audience has been assessed at a 12th grade education.

7. A simplified envelope comparison calculation can be developed.

8. The components of the calculation are readily available and currently used in practice.

9. The simplified calculation is akin to the results of an ASHRAE steady state heat loss analysis [3] (when converted to yearly totals using no infiltration value) with accuracy lost only when envelope components are adjacent to unheated spaces which are typically above ambient temperatures (e.g., crawl spaces, garages).

10. In a climate such as Colorado's, cooling considerations can be eliminated from the comparison calculation.

All year-round homes are required to have some heating capabilities. This is a basic building code requirement. There is no specific cooling capability requirement, though the code requires a minimum amount of operable window area for safety and ventilation. Of 311,200 owner occupied housing units in the Denver Standard Metropolitan Statistical Area, 72,100 had air conditioning (cooling) capabilities [18]. This is less than one-fourth of the housing units surveyed. Room units totaled 38,900 while 33,200 had central systems. Central systems are probably predominantly electric powered with some evaporative cooling. Evaporative cooling is less energy intensive when compared to electric compression units.

In general, as elevation increases cooling degree days decrease. For example, Denver (at 5,280 feet above sea level) has 625 cooling degree days. Silverton, Colorado (at 9,322 feet above sea level) has no cooling degree days. Most of Colorado's growth is projected to occur along the Front Range and the Western Slope. Cooling degree days are roughly outnumbered nine to one by heating degree days in Denver. Cooling degree days in Grand Junction are outnumbered five to one by heating degree days. Thus, cooling needs are substantially less than heating.

Other States may have significant cooling considerations as well as other circumstances that would make this strategy inappropriate. Other States which have adopted the Model Code might be able to utilize this strategy in lieu of a Section 4 analysis when a building is in full compliance except for the thermal envelope criteria.

To illustrate the effect of the Building Energy Performance Standards (BEPS) on the residential home in Denver, Karpay Associates of Rockville, MD, used the DoE-2 computer program [19]. Of 21 computer runs, only six examples would comply with the current BEPS without the use of solar domestic water heating.

The "typical" home assumes that the gross floor area is 1,550 ft.^{2}, the window area is 150 ft.^{2} (with a majority located on the south wall), that there is no heat loss to the basement, and the air infiltration is equivalent to 0.6 air changes per hour. The domestic hot water use is set at 29,500,000 Btu/yr/unit for natural gas and 54,600,000 Btu/yr/unit if an electric water heater is used.

The first variation is roughly equal to the first Colorado energy code. As can be seen, if the house were built with R-11 walls, R-19 ceiling, and double pane windows, one would need to use solar in all cases. With natural gas as the heating fuel, the solar system would need to provide 19 percent of the domestic hot water.

It is anticipated that the Colorado code will eventually be upgraded to meet the BEPS. Certainly the use of solar energy to meet the code will be a reality, thus justifying the intent of this study at this time. Further justification for the use of simplified methods is submitted when one considers the fact that Mr. Karpay (of Karpay Associates) reports that 8 hours are needed to prepare the input for one run of the DoE-2 program for residential buildings [19]. This time element has only been attained after approximately 100 runs of DoE-2. Computations that the builders could do by themselves will help contain the costs of solar installations and residential housing.

The National Association of Home Builders (NAHB) estimates that a single computer analysis of a conventional home per BEPS would cost $500. An additional $500 would be needed for an analysis of a solar system [20]. The NAHB feels this is a roadblock to solar and supports the development of simple, straightforward techniques to encourage the use of solar [20].

Table 2: Design Energy Budgets

Location: Denver, Colorado

Design Energy Budgets: Gas 33.7 MBtu/ft.^{2} - Yr
Electric 38.4 MBtu/ft.^{2} - Yr

Variation (R-value ceiling, R-value wall, and number of glazings)	Solar DHW Fraction Required to Meet BEPS		
	Fuel Type		
	Natural Gas*	Electric Resistance	Heat Pumps**
19/11/2	.19	1+	.35
30/11/2	.07	.91	.22
38/11/2	.03	.83	.17
30/16/2	.01	.77	.13
38/11/3	0	.48	0
38/19/2	0	.46	0
38/19/3	0	.21	0

* 70% seasonal efficiency
** Seasonal COP of 1.52

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SOLAR SYSTEMS FACILITATED BY THE PROPER APPLICATION OF EXISTING BUILDING CODES

by

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The California Energy Commission (CEC) and the California Building Officials, Inc. (CALBO) have jointly developed a manual designed to assist local building officials in identifying, understanding, and completing a code analysis of solar systems presented to building departments for permit approval. Published by the International Conference of Building Officials (ICBO), the Solar Systems Code Review Manual provides both building departments and builders a set of clear guidelines to be followed by specifying the code sections which will be applied in the plan check and inspection processes. The manual is based on the rationale that the plumbing, structural, electrical, and mechanical components of both solar and conventional space conditioning and water heating systems are largely similar and can, therefore, be regulated by existing codes and standards. Several code items have been identified which, if rigidly enforced, could serve to inhibit the implementation of solar systems, and a process has been developed for resolving such problems without sacrificing important health and safety standards.

Key words: Building codes; building officials; codes and standards; convective loops; greenhouses; heat exchangers; light and ventilation; solar systems; space heating and cooling; training programs.

INTRODUCTION

Space heating and cooling and domestic water heating are low temperature applications ideally suited for the implementation of current solar energy technology. The old expression that "there is nothing new under the sun" is especially true when we consider how long we have known how to derive energy from the sun. In the fifth century B.C., entire Greek cities were laid out on an east-west axis so that the long side of each building faced south. By the first century A.D., the Romans had built their famous baths with large south-facing windows to warm the rooms with the sun. In 1200 A.D., the Indians of Mesa Verde, Colorado, built their homes into the south-facing cliffs to obtain protection from the hot summer sun and to allow the low winter sun to penetrate and warm the thick adobe walls out of which their dwellings were constructed [1].*

The first solar water heater was patented in 1891 and by 1897 30 percent of the homes in Pasadena, California had solar water heaters [2]. Many of these systems, while primitive when compared to those manufactured today, are still operative, suggesting that our concerns with durability may be exaggerated. With the advent of cheap fossil fuels in the 1930's and 1940's, the need to design homes as independent "power plants" capable of providing their own energy for space conditioning and water heating came to an end. Following World War II, the era of mass produced, drafty, and underinsulated buildings using mechanical systems for heating and cooling commenced.

For the past half century, our storehouse of fossil fuels has been recklessly depleted, forcing us to reconsider our oldest and most dependable source of energy, the sun. The successful application of solar energy systems in the construction of new buildings, or the retrofit of existing structures, is dependent upon their acceptance by local government jurisdictions and the readiness with which these jurisdictions facilitate and promote their use. If we are to reduce our dependency on fossil fuels by incorporating solar systems in our buildings, then we must eliminate some of the barriers which currently exist. Local governments exercise numerous powers affecting energy, including the authority to set land use densities, determine the size and shape of the building envelope, adopt building codes, require easements, attach conditions to planned developments, and require conformity to architectural guidelines. These powers can be used to facilitate solar, or they can be exercised in ways that create barriers.

The application of building codes and standards to protect health and safety is, perhaps, the most frequently mentioned barrier to the successful implementation of solar systems. Several factors account for this perspective of the building codes: frequent conflicts between solar installing companies and building departments, inconsistency in the application of codes from jurisdiction to jurisdiction, lack of effective code enforcement resulting in shoddy installations, the fact

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*Number in brackets refer to references at end of text.

that the codes are largely prescriptive in nature thereby tending to stifle innovation, health standards for which no sound health basis exists, the rigid application of codes in situations in which flexibility would not endanger health or safety, and lack of building department personnel familiar with solar systems. This last factor, lack of knowledge about solar systems, is probably the most important, as well as the most easily remedied. The elimination of this significant barrier has been the cornerstone of the California Energy Commission's (CEC) program with California's building officials.

In 1977, the CEC had proposed to develop a model solar code under a Federal grant. Recognizing that the organization of building officials in California (California Building Officials--CALBO) would be the most logical group to prepare such a document, the CEC entered into discussions with CALBO. There was general resistance to the concept of a special set of codes and standards for solar systems on the grounds that it would lead to conflicts between the special solar code and the existing codes, that it is unnecessary since the existing codes are adequate to cover solar systems, that a special solar code would tend to perpetuate the myth that solar systems are synonymous with active solar systems, and, finally, there existed in California a deep concern that a model solar code might lead to increased burdens on building departments in the post-Proposition 13 era of shrinking tax dollars.

The concerns of the building officials, the obvious need for training building personnel in the application of codes to solar systems, and the recognition that when applied to building structures solar systems are simply alternative methods for providing energy for space conditioning and water heating, led to the conclusion that a new model code for solar systems was not really necessary. It was generally agreed that the significant difference between solar and conventional systems is that electric resistance elements, gas, or fuel oil burners are replaced by solar collectors; in every other respect, the structural, plumbing, electrical, and mechanical systems are virtually the same and readily regulated by the existing codes and standards.

In February 1978, the CEC awarded a contract to CALBO to prepare a manual for California's building officials which would describe the generic solar systems, identify the codes applicable to such systems, provide some guidelines for plan checkers, identify potential code-related problems with citations of the appropriate code references, and provide a simple field inspection check list. As originally conceived, this manual was to be used as the basis for a series of training seminars for building department personnel which were to be incorporated into the CEC's Solar Applications Workshops for Local Government Officials planned for the fall of 1978.

A number of delays were encountered in the development of the manual and in the planning process for the Solar Applications Workshop Program with the final draft of the manual completed in January 1979, about 6 months behind schedule, and the final workshop plans completed in February 1979, also 6 months behind schedule. The manual was submitted to the International Conference of Building Officials (ICBO) for comments and suggestions for modifications. Following this review and modification of some of the code citations, ICBO expressed an interest in publishing the manual for its own distribution. In the belief that the manual would receive wider acceptance if published as an ICBO document rather than a CEC publication, an agreement was reached whereby the CEC obtained a sufficient supply of the manual for free distribution to building departments in California, with ICBO free to sell it to all others.

In early 1978, the Department of Energy (DoE) commenced a series of public meetings to consider the development of a Model Solar Code. The first of these meetings was held in Washington, D.C. in May 1978 and the CEC was represented by the co-author of this paper, Patrick McLafferty, who described the Solar Systems Code Review Manual project and indicated California's preference for this approach to facilitating solar systems. The DoE contracted with the Council of American Building Officials (CABO) for development of the Model Code Document, and drafts of it were presented at public meetings in California in May 1979 and December 1979; both CEC and CALBO presented comments at these meetings expressing concern about the absence of any consideration of passive solar systems, the Federal regulatory nature of the document, the predominantly prescriptive approach, and reiterating California's preference to apply the existing codes.

In the spring and fall of 1979, the CEC and the League of California Cities presented a series of Solar Applications Workshops for Local Government Officials. The format and content consisted of a plenary session in the morning for all participants and covered solar systems and solar economics, a luncheon session featuring a speaker with experience in solar at the local government level, and three separate afternoon seminars tailored to the specific needs of the three major target groups: decision makers, planners, and building officials. Out of a total workshop attendance of 1044, the majority were planners and building officials. This came as no surprise since the work of these two groups of officials would be significantly affected by the introduction of solar systems in residential and commercial development [3].

Of particular interest to the CEC was the impact of these seminars for building officials on the number of "complaint" phone calls received by the CEC concerning building code problems and solar installations. Prior to the seminars and distribution of the Solar Systems Code Review Manual, it was normal to have from two to five complaint calls per week. Following completion of the training project, the number of complaint calls had dropped to two or three per month.

METHODOLOGY

The Solar Systems Code Review Manual is formulated in a manner which emphasizes a practical approach to the health and safety regulations affecting solar systems. Based on the applicable California law, the following model codes and regulations were utilized in the manual preparation:

Uniform Building Code, 1979 Edition (ICBO)
Uniform Mechanical Code, 1979 (ICBO and the International Association of Plumbing and Mechanical Officials [IAPMO])
Uniform Plumbing Code, 1979 (IAPMO)
Title 20, Chapter 2, Subchapter 8, Solar Energy, California Administrative Code

Additionally, because many of California's building departments utilize other codes, the following have also been included:

Uniform Solar Energy Code, 1979 (IAPMO)
ICBO Plumbing Code, 1970 (ICBO)
Uniform Fire Code, 1979 (ICBO and the Western Fire Chief's Association [WFCA])

The manual format first describes the "generic" types of space conditioning and water heating systems. These systems are described in terms of their basic functions of collection, storage, and distribution. The descriptions are specifically designed to allow building department personnel to identify and understand the function of "generic" systems. The manual then describes the component parts of each system, which are illustrated. Code references are cited, relating to each component identified. Plan Check/Design comments follow the code analysis of each system. While no specific code interpretations are provided, approaches to code problems are discussed.

TECHNICAL ISSUES

As a part of the CEC contract, CALBO identified code items which might potentially inhibit the use of solar systems. The items so identified included:

1. Light and Ventilation in Habitable Rooms - Many passive solar designs call for minimizing exterior glazing on the east, west, and north sides of buildings; such designs may conflict with sections of the Uniform Building Code (UBC) which require minimum glazing standards for light and minimum wall openings for ventilation. For the same reasons, these UBC sections may inhibit the use of solar greenhouses in both new construction and retrofit situations [4].

2. <u>Heating</u> - The UBC requires that every dwelling unit and guest room shall be provided with heating facilities capable of maintaining a room temperature of 70°F at a point 3 feet above the floor in all habitable rooms [5]. This generally results in the need for expensive and sometimes unnecessary backup systems.

3. <u>Heat Exchangers</u> - Sections of the Uniform Plumbing Code (UPC) address the issue of cross-connections in potable water systems; however, the issue of contamination which might result from the use of toxic heat transfer fluids in the collector loops of solar systems is not addressed. At issue are double vs. single wall heat exchangers and the differences in both efficiency and cost. The International Association of Plumbing and Mechanical Officials (IAPMO) had, at one time, issued approvals of single wall heat exchangers. Those approvals have since expired and will not be renewed. The County of Los Angeles Health Department has issued a widely known report which is the basis of its approval of only double-walled units.

   While specific guidance on this issue is not available in any of California's State-adopted codes, it is clear that such guidance is essential, as there is a significant lack of uniformity in this regard.

Of particular interest to the authors have been the issues posed by the retrofitting of solar greenhouses and the construction of convective loop houses. In the case of the greenhouses, several jurisdictions in California have refused to permit their construction unless additional, and often quite expensive, alterations are made to the structure to which the greenhouse is attached, invoking the provisions of Section 1205 of the UBC. In the instances in which this problem has been brought to the attention of the CEC, the local building official was insisting on either skylights being added to the roof of the existing structure, or at least half of the common wall being removed. Adding skylights to a California style tile roof becomes prohibitively expensive and requires appropriate insulating shutters to prevent winter heat loss and summer heat gain. Removing half the common wall between the greenhouse and existing structure affects the functioning of the greenhouse, is costly, and may be undesirable to the use of the existing structure.

When the <u>Solar Systems Code Review Manual</u> was prepared and published, it was felt that this problem was resolved by Section 3.3 of the manual which states that light and ventilation "must be taken through the greenhouse and adequate windows and/or vents need to be installed in the greenhouse walls or roof." In most cases, this interpretation has been accepted and a permit has been issued; however, there have been a few cases in which the building department has rigidly interpreted UBC Section 1205. Working with the CALBO Advisory Committee to the CEC, it is hoped that a solution can be developed and Section 3.3 of the manual revised in the next ICBO edition.

The convective loop style of architecture is of special interest for a number of reasons. First, convective loop houses are not necessarily built as solar houses; energy savings are obtained theoretically through the design of a double shell north wall which allows for a convective loop of warm air to circulate upward on the south side of the structure, with the north wall serving as a plenum chamber for the return portion of the loop, with cooler air returning through this wall and back under the house, where it is again heated by Btu's from the earth (if not, solar glazing is present).

Regardless of the merits of this design in terms of energy efficiency, it is being built in a significant number of locations in California and has caused a considerable stir among building department personnel. While the CEC takes no position on the merits of the architecture, designers and individual home builders have turned to the CEC Solar Office for assistance in facilitating their building permits. In addition to the questions of light and ventilation posed by this design, the major issue is fire protection. The design results in a plenum chamber within a concealed space in the north wall without any fire stopping. A number of solutions have been proposed, ranging from lining the concealed space with 1-hour fire resistant sheet rock to providing smoke detectors and sprinkler systems in appropriate locations.

The current status of this problem in California is that the CALBO Advisory Committee to the CEC has asked convective loop home designers to submit their proposed solutions to the Committee. These solutions will be reviewed; if one or more is found to be acceptable, a memorandum describing the proposed solution will be sent by the committee to all building departments in the State suggesting that building officials consider the proposed solutions. Obviously, the committee's recommendations cannot be binding.

SUMMARY

A successful program of applying the existing building codes to solar systems has been implemented in California. This program has been based on the publication of the Solar Systems Code Review Manual by ICBO, which was prepared by CALBO under contract to the CEC, implementation of a training program for building department personnel as a part of a series of 17 Solar Application Workshops for Local Government Officials, and procedures utilizing the CEC-CALBO Advisory Committee to resolve some of the issues which remain.

Two remaining tasks are being undertaken. A supplement to the Solar Systems Code Review Manual covering swimming pools and spas is being prepared by CALBO under contract to CEC, and a Request for Proposals to develop a Course of Study on the Application of the Existing Building Codes to Solar Systems is being processed by the CEC. The proposed Course of Study will consist of an Instructor's Guide, a series of

lesson plans, and a student workbook of home study exercises. The Course of Study would become a part of the California Community College Program for building inspectors which culminates in a Certificate of Achievement.

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DEVELOPMENT OF RECOMMENDED REQUIREMENTS TO CODE OFFICIALS FOR SOLAR HEATING, COOLING AND HOT WATER SYSTEMS

by

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Under a Department of Energy contract, the Council of American Building Officials has developed "Recommended Requirements for Code Officials on Solar Heating, Cooling and Hot Water Systems." The recommended requirements treat all the major code categories - building, electrical and mechanical/plumbing.

These requirements will serve as a guide for building code officials to judge the health and safety aspects of solar systems and their proper installations. Where requirements exist in a major model code they are referenced with commentaries provided for technical backup or where further explanation is needed.

The development of the recommended requirements through the consensus process is described.

Key words: Building codes; building officials; consensus; construction; document; installation; recommended requirements; solar energy; solar systems.

Numerous requests from local and State building code agencies to the Department of Energy (DoE) for assistance in developing individual solar energy regulations for their jurisdictions set in motion the events leading to the development of "Recommended Requirements to Code Officials on Solar Heating, Cooling and Hot Water Systems." In public meetings conducted by DoE during the Domestic Policy Review of Solar Energy, there were expressions of concern that different, conflicting code requirements would be adopted and that they would inhibit early utilization of solar energy on a widespread basis.

There was general agreement among the local and State agencies seeking DoE assistance that this could be avoided through development of a guideline document for their use. This belief was confirmed in a DoE funded study conducted by the National Bureau of Standards with the participation of major national organizations active in the subject area.

Subsequently, DoE executed a contract with the Council of American Building Officials (CABO) for the project. The primary objectives were:

1. Utilize existing institutional mechanisms at various levels of government and in the private sector to develop recommended requirements in accordance with consensus procedures and due process.

2. Promote greater understanding to facilitate acceptance of solar technologies among code enforcement personnel.

The primary role of DoE has been to provide funding assistance to facilitate and accelerate the voluntary efforts of experts--technical and non-technical--who contributed their time and expertise in order to develop the requirements expeditiously in response to the immediate needs of local and State Governments.

Developing the document within the time frame of the contract required CABO to undertake two concurrent tasks. One task consisted of assembling appropriate committees and technical support staff to prepare a working draft. The second task was concerned with developing procedures acceptable through the American National Standards Institute (ANSI) process.

The three methods recognized by ANSI for developing evidence of a consensus are:

1. Accredited Organization
2. American National Standards Committee
3. Canvass

CABO selected the Accredited Organization method which requires compliance with the following criteria:

1. There is evidence the organization has a substantial history of developing similar requirements that have been extensively used for the purposes for which they were developed. (Where an organization meets the criteria for accreditation with the exception of evidence of a substantial history, ANSI may accredit the organization for a limited period in order to provide the organization the opportunity to demonstrate implementation of its procedures.)

2. The organization's operating procedures shall provide:

   a. The opportunity for participation by all national interests substantially concerned

   b. Balanced membership on each committee among those interests having potential concern with the specific project

   c. Consideration of all objections with the aim of resolution and response to each commentator indicating that consideration has been given to the comments and reporting the action taken or reasons why the comments could not be resolved

   d. A supervisory body to attest that the procedures have been followed and that the approval requirements set forth in the procedures have been met

   e. An appeal mechanism to hear appeals of any action or inaction within the organization.

3. The organization has submitted the title and scope of each committee that is operating under ANSI approved procedures.

4. The organization agrees to periodically furnish ANSI the current program of work of its committees and prompt announcement of the initiation of new work.

5. The organization agrees to provide continuity for producing and updating its work, and has knowledgeable staff.

6. The organization agrees to assist in obtaining evidence of consensus.

7. The organization agrees to maintain adequate records to permit ANSI consideration of its work, and agrees to make such records available upon request.

CABO developed the needed criteria for approval as an Accredited Organization. CABO has subsequently been audited by ANSI verifying adherence to the criteria.

A consensus committee was formed to develop the guideline document within the approved CABO Consensus Procedures. Composed of some 50 organizations and groups representing the diverse interests in solar energy development and application, it includes representation from consumer and public interest groups, standards organizations, design professionals, labor, industry, and local, State and Federal Governments. The committee is responsible for:

1. Development and approval of the document

2. Assignment of development tasks to appropriate technical committees

3. Identification and recommendation of technical committee members

4. Assuring that the consensus procedures have been met

5. Identification of specific needs and tasks and their implementation

6. Holding open meetings to provide the opportunity for participation by all interested individuals and organizations.

The consensus committee elected, from among its membership, a ten-member coordinating committee which administered and coordinated the work of the consensus committee and its technical committees. The coordinating committee membership has the same balance of interests as required for the consensus committee membership. Responsibilities of the coordinating committee include:

1. Advising technical committees in the preparation of documents

2. Reviewing analyses, recommendations and decisions of the technical committees

3. Resolving conflicts and/or duplication among the work of the technical committees

4. Holding open meetings

5. Considering and attempting to resolve all challenges submitted

6. Maintaining a continuous overview of the work of the technical committees to assure an expeditiously, orderly and effective progress which will avoid duplication of effort and conflicting requirements.

Technical committees were appointed to cover the major subjects of building, electrical, mechanical and plumbing which are found in the codes. The membership of each technical committee has the same balance of interests as required for the consensus committee membership. The technical committees, in open meetings, reviewed drafts prepared by the technical support staff and assisted in the resolution of any challenges submitted.

In the development process, two sets of hearings, open to the public, were conducted. There were three, 1-day meetings held throughout the country in each set of public hearings; one set was held in Atlanta, Kansas City and San Francisco and the other set was held in Washington, D.C., Denver and San Diego. Announcements were made 60 days in advance of the public meetings and of the availability of document drafts to allow ample opportunity for individuals and organizations to review the drafts and to plan to attend. More than 500 persons attended the public hearings and in excess of 1500 comments and proposed changes were processed. The dedication, cooperation, and level of effort contributed by all who participated is attested to by the volume of comments that were processed and completion of the technical work in 18 months even though widely diverse interests were involved. Printing of revised drafts is always a critical element in the process and DoE was particularly helpful in processing the drafts expeditiously.

Throughout the development phase, particular attention was given to the ever-present challenge confronting code officials considering new technology. This entails protecting the public health without impeding the introduction of technological innovations. Passive solar energy designs present such a challenge. It was found that this subject was largely covered in the model codes; thus no additional recommended requirements were necessary. Suggested design alternatives are included as a commentary to assist code enforcement personnel.

Provisions contained in the document are intended to be used in conjunction with existing model codes. Where a solar relevant provision is adequately covered in a model code, the section is referred to in an appendix. Commentaries are included in the text explaining the coverage and intent of present model code requirements and suggested alternatives that may, at the discretion of the building official, be considered as providing reasonable protection to the public health and safety.

The primary purpose of the document is to provide for reasonable protection of the public health and safety and at the same time, encourage consumers, builders, designers, manufacturers, installers and others to utilize solar energy technologies while permitting experimentation and innovation.

Provisions are included for electrical, building, mechanical and plumbing installations for solar energy systems used for space or process heating and cooling, and domestic water heating. Durability, life expectancy and related requirements of these systems are not addressed.

The provisions in the document are multi-purpose in nature and will be of interest to all segments of the building community:

- The code enforcement official will use them as a reliable reference guide for reviewing and approving solar energy system installations.

- The design professional, builder, manufacturer, supplier and installer will have a means for determining the parameters under which components and systems will be judged.

- The standard and code writing organizations will have a means for identifying problems, setting priorities and updating documents to provide for solar energy systems.

- The consumer, environmental organization, and consumer protection agency will use them to foster better understanding of the ways in which public health and safety can be protected when utilizing solar energy systems.

A METHOD FOR RETAINING AN EXPERIMENTAL ATTITUDE IN SOLAR CODES

by

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The viability of the incipient solar age will in large part be determined by humankind's ability to learn new technologies. The basis of learning is being able to experience the failure or success of one's ideas. For innovative structures, the most direct and readily available means of experiencing their workability is to live in them. Proposed solar building codes are based on our existing solar methodology, thereby leaving little room for a person wanting to experiment with a new idea on his/her own home.

In order to solve the problem of the code becoming a barrier to further development of solar technology, the author proposes recording on the property deed a notation stating that the property has a building whose solar system is not according to code.

A 2-year field trial of the Recommended Requirements to Code Officials on Solar Heating, Cooling, and Hot Water Systems, developed by the Council of American Building Officials, is suggested to enable the public and building inspectors time to acquaint themselves with it and work out any bugs.

Key words: Deed; developers; energy wars; experimental code; field test; guideline; low income; non-code; policymaking; protestors; solar code; victim role.

I see the solar building code as a two-edged sword. It is good for those who either want or need a set of specific directions to follow in order to move us toward living in unison with nature. It is discouraging for those that do not work well under dogmatic regulations. I think parts of the Recommended Requirements are less than a fair representation of our highest level of conduct.

One aspect in which I think the Recommended Requirements may be going astray is poorly written sections which will mislead builders, contractors, and developers, causing them to disrespect or oppose them. For example, section B-111.2a disallows the use of drapes and curtains to count toward insulating windows, while demanding the insulation be installed as part of the aperture. Yet, in the next paragraph they allow both drapes and permanent devices to count for shading. The logic of this rule evades me. Why cannot drapes be used to conserve energy as they have been doing for ages? Why is this subject treated at all in these Recommended Requirements, which claim to be concerned only with health and safety factors?

The various sections covering controls, pressure and temperature relief, and freeze protection would appear to either disallow the installation of some of the least expensive homemade units or make them so costly that one may as well buy a commercial unit. It is not at all clear that a manual drain down is permissable for freeze protection. To build a bread box water heater you will have to hire an engineer to prove it will not freeze or get hotter than the "maximum design operating temperature" of water? At the best, these sections are confusing. If an individual wants to take the risk of it springing a leak from freezing or boiling, that should be their business. The Government has a legitimate involvement to protect a consumer from getting a poorly designed commercial unit, but it has no right making it a crime to build your own system when would harm no one but the builder if not properly maintained.

Are the labeling and testing requirements really meant to prohibit people from using their own homemade absorber plate?

In envelope-type passive houses, smoke activated fire dampers are the only type allowed. I wonder if manufacturers have not assured themselves a market for their products. A wider choice would include sprinkler systems and heat activated fire dampers. If the Recommended Requirements are into mentioning specific types of manufactured items with respect to safety, I suggest they discourage use of smoke detectors using radioactive Americium which can be released to the environment by fire or improper disposal.

With natural lighting allowed in section B-111.6 being dependent on existing code requirements and electric lighting consuming some 20 percent of all electricity sold in this country, it is suggested those requirements be reexamined. The minimum standards for lighting have tripled in the last 25 years and appear to be beyond what is needed, especially in the commercial sector.

All of which brings me to question whether the "Recommended Requirements to Code Officials on Solar Heating, Cooling, and Hot Water Systems" is ready to be made law without some field testing which could serve to expose them for input from the public who are going to have to live with them. As most building inspectors are not trained in solar, it might be nice for them to have a year or so to familiarize themselves with the Recommended Requirements before having to enforce them.

I suggest calling it a "Proposed Solar Building Guideline," and asking all jurisdictional recipients to try it out for a year or two on a pilot program basis, letting you know of any problems or suggested changes.

As a more guideline format, I suggest removal of the Section and Item numbers, retaining the paragraphs and headings but type the document on line-enumerated legal brief type paper so that any portion can be readily referred to. In the preface specify this guideline is not intended to be complete and should not be considered ready for incorporation into existing codes. Comments on the workability of that incorporation should be sought as that is the eventual intention of the guideline. It should be suggested that local code officials not use the guideline as a final answer in dealing with the public, but rather encourage the public to try alternative ways and report back with the results to the code writers.

If at the present the code writers feel they have a workable set of regulations, as indicated by the prefacing statement "These new provisions should be considered for incorporation into existing codes," there should be no hesitancy to let the public try it out before declaring it ready for mandating by local governments. Some innovative policymaking changes could result from switching to a grass roots mode of operation midway through the code promulgation process.

By way of solving some of the aforementioned problems within the Recommended Requirements, I can imagine some changes regarding the creative spirit and wasted human energy.

The do-it-yourselfer has been left out with the Recommended Requirements. The backyard builders who read Popular Science Magazine, Mother Earth News, Popular Mechanics and Organic Gardening; people making ovens, parabolic reflectors, bread box and thermosyphon water heaters in the 1960's and early 1970's before the Energy Research and Development Administration (ERDA) was even conceived of; these people and like-minded ones in the future, are being told by these Recommended Requirements they cannot build for themselves and their friends, simple, inexpensive, sometimes recycled, homemade solar units.

The fact that these Recommended Requirements can be interpreted as being in favor of the rich getting richer at the expense of, and while suppressing, the lower income earners, serves to reinforce the theory that our energy shortage exists only in the minds of our profit oriented corporations and power-hungry Government, that it is not less than a corporate/Government conspiracy.

While I believe this paranoiac conclusion is unfounded, I do believe that enforceing these Recommended Requirements in their present form will remove an important sector of our population from participating fully in the solution to our energy shortage. Such non-participation will serve to fuel local energy wars which are creating ever widening credibility gaps between factions of our society who we should be striving to bring together into a united front to solve our energy problems.

Professor Luther Gerlach, at the University of Minnesota, who has studied the social and cultural factors in energy conflicts, describes the motivations and self-images of the two warring factions, the developers and the protestors. The developers are characterized as seeing themselves defending the country's energy independence, its commitment to economic progress, their technological investments, and law and order. He characterizes the protestors as seeing themselves protecting local autonomy and the rights of the individual pitted against a dictatorial government and its exploiting corporations.

Both sides in Gerlach's view are shown to consider themselves as victims. They both believe somebody is encroaching on their turf and they have to defend it. But by playing the victim, each side creates a niche for a victimizer, which then polarizes them even further. One way to stop this catch 22 cycle and bring the two factions together is for us to learn to stop playing the victim role and accept the fact that we are doing it to ourselves. We have the ability to change the rules of the game so as to lessen the opportunity for creating real victims, thereby also lowering the occurrence of imagined victims with their wider effect on the schism.

It is time to redirect some of our creative technological genius toward creating new types of laws and methods of governing that will allow a larger percentage of our population to have more direct control over their own lives.

For instance, a solar building code which sticks its nose into areas where it does not really have to, will cause some real victims. Perhaps only a few, but these few cases can spread like wildfire via the victim/victimizer game thereby creating polarization problems which will be a barrier to having solar happen in the building sector. What I propose is to change the rules of the solar code so as to lessen the chance of victimized feelings occuring.

I suggest the following addition to the Recommended Requirements be considered by cities, counties, and States when contemplating adopting them. Preferably this addition would be incorporated into them at the Federal level, or alternatively, included in the appendix in order to offer the adopting entities a wider variety of choices. It is an experimental solar system clause based on deed of property or land abstract listing not unlike a cloud to clear title.

EXPERIMENTAL SOLAR SYSTEM CLAUSE

> "Solar energy systems shall be permitted that do not conform to these guidelines provided their use and maintenance is not a hazard to public health and safety. Systems permitted under this section shall have recorded on the publicly recorded deed to the subject property, a notation stating that the property has a building whose solar system is not built in accordance with the solar code."

The spirit of this clause is akin to the situation of offering each of a group of people, a large piece of drawing paper with a medium-sized border already drawn on it and requesting they draw a picture. Most people will place their picture inside the border. But, occasionally, one will be drawn beyond the border and still work aesthetically. It is that spark of creativity which we must be careful to not suppress, for it is easily perverted into anti-social reactions. During this time of designing the foundation of the solar age it will reward us to enlist the aid of all interested parties.

A person with an idea for a solar system not covered in the code would need to get it engineered. That means they are going to have to be rather wealthy in order to try out their idea because of the need to hire an engineer to meet the paperwork proof needed before you can get a building permit. With the deed listing clause a poor inventor could accept the responsibility of his own system's faults, and try it out by living in it, which is the only real way of knowing how it works anyway.

This method allows the code officials to become an expert notary service who are requested by the builder to come verify that the structure has been built in a particular fashion. When that expert witness's verification is recorded on the deed or property abstract, it thereby notifies any future buyer of its status. The buyer is then able to determine the value of the structure accordingly.

The vertification on the deed could be as simple as stating which structure is built according to an existing code or not in conformance to any code, or as complex as entering a description of each part of the structure. Both code and non-code building methods could be incorporated into a single solar system by listing in the deed which portion is experimental. The concepts of legal and illegal need not exclude one another. We can benefit from the guiding experience of the code writers and we can have the open-ended freedom to try out new ideas. In short, we can have our cake and eat it too.

This deed listing method could also be applied to any kind of building code, not just solar. The governing body could offer, say half a dozen different codes for building any one part of a structure. The builder would choose which code he wanted to use for which portion of the structure, build it accordingly, have the notary verify it, and list it on the property deed. This would relieve the bureaucracy of a lot of its responsibility and neutralize conflict.

With the deed listing method of code regulation the governing body does not have to choose what it thinks is best for all the people and then try to make everybody conform to it by expenditures of enforcement time, money, and possible loss of credibility. Regulators have a chance to learn to trust the public with freedom, rather than trying to retain control over every aspect of our lives. And, the people's awareness will be raised as they learn of new aspects of their lives to care for.

Physicist Arthur Kantrovitz of nuclear fusion and artificial heart valve fame laments the loss today of what he calls the "atmosphere of technological adventure" we had 15 years ago. What I lament and ask, is when have we ever had an atmosphere of adventure in the realm of governmental regulation and policymaking? Thank you for the privilege of addressing this gathering with its recognition that there is no time more in need of policymaking adventurers than this time.

The challenge is offered of having similar regions adopt differing solar codes then watching to see which attains energy self-sufficiency most easily. A game we all win at, there are no losers.

STATE GOVERNMENT ROLES IN NATIONAL SOLAR COLLECTOR LABELING, CERTIFICATION, AND RATING

by

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Dr. Ron Doctor of the California Energy Commission and Dr. David Block of the Florida Solar Energy Center initiated a program in late 1979 to encourage reciprocity between States in their regulations concerning solar collector certification and labeling. Florida and California had both instituted testing and certification programs at that time which were required for their tax credits for solar devices and used for other regulatory purposes. Also, the Solar Energy Industries Association (SEIA) and the Air-Conditioning and Refrigeration Institute (ARI) had come up with two additional labeling and certification programs. Potential confusion and duplication of effort seemed to be developing so a meeting was called of 25 States active in solar energy matters.

Several meetings have now been convened and remarkable progress has been made toward the goal of a single national program for rating, labeling and certifying solar collectors, and eventually, for complete solar systems. The four programs now in existence (both State and industry) were represented, as well as about 30 State solar offices which have been considering implementing such programs.

At an April 1980 meeting there was a preliminary agreement that there should be a single national system, run by a non-profit corporation with a Board of Directors composed of individuals nominated by SEIA and ARI and representatives of the State Government consensus effort initiated by Dr. Block and Dr. Doctor.

This paper details progress to date and projects completion dates for a national testing program, labeling program, and rating program for solar collectors. An applications manual is also planned, as well as additional work on systems and eventually certification.

Key words: Certification; consumer protection; Interstate Solar Coordination Council; labeling procedures; national testing program; regulation; solar collector; standards; voluntary program.

In April 1979, a voluntary meeting was held between State and other public agency representatives in Washington, D.C. to review issues relating to solar collector testing and certification. At that time there were four collector certification programs in place: State of California; State of Florida (mandatory by legislation); Solar Energy Industries Association (SEIA) voluntary industry certification; and the Air-conditioning and Refrigeration Institute (ARI) preliminary collector certification procedures. All used the ASHRAE standards for experimental determination of collector efficiency and required testing by an independent laboratory.

Since two States had already instituted certification procedures primarily to provide for consumer protection mechanisms, and several other States were in the process of developing solar regulations for similar reasons, it was clear that State Government involvement in solar certification was necessary. Dr. Dave Block, Director of the Florida Solar Energy Center, and Dr. Ronald Doctor, Commissioner of the California Energy Commission, initiated the Interstate Solar Coordination Council (ISCC) following the April 1979 meeting. Initial funding was provided by the U.S. Department of Energy to bring together State energy officials, recognizing that it would be inappropriate for all States to develop and operate solar collector testing programs.

Recognizing the need for coordination of a single national program, and the need to minimize duplication of effort among industry and State officials, the Interstate Solar Coordination Council held a meeting in April of 1980 with State officials from 21 States and representatives from SEIA, ARI, and other industry groups. Draft documents of the ISCC were presented to industry representatives, programs were compared, and great progress was made toward the goal of a single national program for labeling and certification of solar collectors. A new non-profit corporation will be formed to certify and label solar collectors (and eventually systems) nationwide. ARI and SEIA will set up the corporation with members from the ISCC serving on the Board of Directors. The ISCC role is largely to fill the gap between the consuming public and the professionals who administer and develop solar standards, and to ensure that consumer protection concerns (such as reliability and durability of collectors) are addressed by the national program.

Drawing on the experience of California, Florida, and the Tennessee Valley Authority, as well as solar industry groups, ISCC subcommittees have drafted preliminary procedures for the national consensus program. SEIA and ARI are working with these subcommittees to negotiate details. The new program should minimize certification costs by creating a single national program.

On-going projects of the ISCC for 1980 include:

1. Development of a solar collector consumer rating procedure with a common means for rating collectors in different climatic areas operating at different temperatures in a way that is meaningful to laypeople and consumers;

2. Development (with industry groups) of a solar applications manual for installers and designers covering technical applications data and recommended procedures;

3. Continuation of work to develop procedures for solar systems evaluation, testing, and certification;

4. Determination of procedures for laboratory accreditation for the new national program;

5. Representation of state and local government concerns by membership on the SEIA/ARI (non-profit) Certification Board, on the American National Standards Institute (ANSI) Steering Committee, and on the Model Solar Code Implementation Group appointed by the Department of Energy.

Additional funding for 1980-81 has been sought from the Department of Energy (DoE), and the group is exploring means of sustaining the ISCC effort afterwards without DoE funding. A meeting is planned for September 1980 to review the work of many very active subcommittees, and solicit the participation of all the 50 States in the national program.

The institutional challenges created by programs to utilize a decentralized energy resource like solar energy are great. The ISCC is an early example of the kind of coordination efforts likely to become much more common in the 1980's as State, local and national agencies seek their proper roles in promoting and regulating the use of solar and renewable energy.

RESIDENTIAL CONSERVATION SERVICE PROGRAM

SOLAR MODEL AUDIT

by

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The Residential Conservation Service (RCS) has been developed by the Department of Energy (DoE) as a requirement of the National Energy Conservation Policy Act (NECPA). The goal of the program is to reduce non-renewable energy use in the Nation's homes through increased application of conservation methods and the use of solar and wind energy systems to displace conventional energy sources.

The DoE program includes development of a model audit to assist the States in preparation of the State plans for implementation of RCS. Oak Ridge National Laboratory managed the model audit development effort with the Solar Energy Research Institute (SERI) assigned responsibility for development of the solar and wind energy systems portions of the audit.

This paper discusses the solar model audit development and the potential impact for homeowners, utilities, and solar suppliers/contractors. An overview of the solar model audit reviews the regulation requirements pertinent to solar with emphasis on standards, warranties, and installation considerations. A discussion is presented on the program impact on utilities, especially with regard to identifying sufficient numbers of qualified auditors and the training of these auditors. The active and passive solar and wind energy portions of the audit are described including data bases used, assumptions for respective solar or wind system measures, and examples of the audit use on a field trial home.

Key words: Auditor training; energy conservation; program measure; Residential Conservation Service; Solar Model Audit.

INTRODUCTION

The U.S. Department of Energy (DoE) is implementing the Residential Conservation Service (RCS) Program as part of the National Energy Conservation Policy Act (NECPA), Public Law 95-619. The RCS program's purpose is to encourage residential customers of larger gas and electric utilities as well as home heating suppliers to install energy conservation measures in existing homes. This paper is to describe the RCS program in general and presents in detail the solar model audit developed by the Solar Energy Research Institute (SERI) in support of the program.

The law requires that each State submit a plan for compliance with the RCS provision of NECPA. The State plans require covered utilities and participating home heating suppliers to offer to eligible customers a comprehensive energy audit. Utilities covered are those public utilities that have sales of natural gas for purposes other than resale exceeding 10 billion $ft.^3$ or sales of electric energy for purposes other than resale exceeding 750 million kWh. The RCS is a 5-year program, and it is estimated that 65 million program announcements will be mailed to eligible customers within a 6-month period beginning September 1980.

The energy audit to be completed by utility personnel will provide estimates of costs and savings associated with the installation of program or State measures. The cost and savings estimates are to be based on an energy usage analysis of the residence. The analysis will preferably determine the residence energy usage based on past billing history, but if this history is not available the residence energy usage may be estimated from building heat load analysis methodology.

The following energy conservation measures and renewable resource measures shown in table 1 are covered in the RCS regulation:

TABLE 1, RCS Regulation Measures

Energy Conservation Measures	Renewable Resource Measure
Caulking	Solar Domestic Hot Water
Weatherstripping	Active Solar Space Heating
Furnace Efficiency Modifications	Combined Active Solar Space Heating and Domestic Hot Water
Replacement Furnace and Boiler	
Furnace Replacement Burner	Direct Gain Systems
Flue Opening Modification	Indirect Gain Systems

Electrical or Mechanical Ignition System

Replacement Central Air Conditioner

Ceiling Insulation

Wall Insulation

Floor Insulation

Duct Insulation

Pipe Insulation

Water Heater Insulation

Storm or Thermal Window

Storm or Thermal Door

Heat Reflective and Heat Absorbing Window or Door Material

Electric Load Management Devices

Clock Thermostats

- Water Walls
- Trombe Walls
- Thermosyphon Air Panels

Sunspace Systems

Window Heat Gain Retardants

Wind Energy Devices

Replacement Solar Swimming Pool Heaters

PROGRAM PARTICIPANTS

The RCS Program is structured so that activity at three levels results in an energy audit for the residential energy consumer. At the Federal level, DoE is responsible for regulation promulgation, development of the Federal model audit, and review and approval of the State plans.

The States are required to prepare a plan for implementing the RCS Program. The tates must require each covered utility and each participating home heating supplier to comply. The States are to prescribe warranty provisions and installation requirements including mandatory inspections of certain installed measures.

The States are to maintain a master list of suppliers, installers, and lenders to be provided to audit recipients by the utilities. Each State's list will contain only those individuals or companies wishing to be included. Those listed sell, install, or finance program measures and must meet the program's criteria for installation quality, warranties, or financing procedures.

The program's utility and home heating supplier activities are characterized by direct contact with energy consumers, the solar industry, and system installers. Utilities and home heating suppliers are required to provide a Program Announcement to each eligible customer no later than 6 months after approval of the respective State plan. The Program Announcements must include:

- a list of the program measures;
- an estimate of the energy savings (in dollars) likely to result from installation of the program measures; and
- a list of energy conserving practices and the energy savings likely to result from adoption of the practices.

The announcement should contain an unconditional offer of a program audit within 2 years. The information provided to the homeowner is to include the cost of the audit and a brief explanation of the benefits of the Federal and applicable State energy tax credits.

The content of the RCS Program Audit used by any State will be far more comprehensive than the energy audits presently being offered by a number of progressive utilities. As an example, the Residential Energy Audit Program offered by Public Service Company of Colorado is one of the most thorough and efficient of the existing audit packages. This program has been in effect in Colorado since 1978 and covers the following conservation areas: insulation, caulking, weatherstripping, infiltration, combustion air, space and water heating, appliances, and lighting. In contrast, the RCS program covers all the conservation measures listed in an earlier paragraph as well as the renewable resource measures.

The requirement to provide a more comprehensive RCS Program Audit will have a significant impact on utilities and participating home heating suppliers. The greatest impact will be in the areas of numbers of auditors, the increased training required for the auditors, and the utility's cost to implement the RCS Program. The RCS will create an estimated need of 15,000 to 20,000 trained energy auditors during the first year of the program. The existing training programs for auditors will necessarily have to be upgraded to address the increased sophistication of the conservation measures and the new material encompassed in the renewable resource measures.

As part of its technical assistance program to the States for RCS, DoE has prepared a package of instructional materials for use in training energy auditors. This set of materials is available to the States to use as their needs dictate. The Federal audit training package addresses the measures required in the regulation by developing technical background for each measure, outlining how the measure is applied, and presenting example audits to include system performance and cost saving estimates.

The DoE estimates a typical RCS audit requires 2 to 2.5 hours including renewable resource measures. The additional employee cost required to support the RCS program, the labor cost required to complete the millions of audits expected during the Program tenure, and the supporting infrastructure overhead all add to additional costs that must be financed in some manner by the utilities. The latest DoE requirement on program costs allows the utility to charge a customer a maximum of $15 for the audit. The remaining cost to the utility is financed by treating program costs as a current operating expense of providing utility service. This method will charge RCS Program costs to the utility's ratepayers in the same manner as other current operating expenses.

A further area of utility involvement in the RCS Program is in the area of utility supply, installation, and financing of energy conservation and renewable resource measures. The RCS regulation essentially prohibits a utility from supplying or installing program measures unless the utility was engaged in such activity on November 8, 1978. Waivers to this requirement are possible if the request is supported by the State's governor and if the utility's activity does not have a substantial adverse effect upon competition. Utilities may offer financing for program measures under the current regulation.

SOLAR AUDIT - ACTIVE, PASSIVE AND WIND MEASURES

The DoE developed the RCS Model Audit as an integral part of its technical assistance to States, utilities, and participating home heating suppliers. The Model Audit is designed to satisfy the audit requirements of Section 456.307 of the RCS Final Rule and may be used as part of an RCS State plan or nonregulated utility plan. The Model Audit has been prepared solely to assist States and nonregulated utilities in preparing an effective RCS audit. The use of this model can eliminate much of the work which would be required in developing many State-specific audit procedures. The Model Audit is not meant to restrict the use of alternative auditing procedures for homes, does not represent a DoE standard for auditing, nor has it been subjected to the comment and debate which such a standard would require. Rather, the Model Audit is one of many acceptable procedures for inspecting homes as part of the RCS program.

The Model Audit contains detailed step-by-step auditing procedures for each program measure within each climate zone. Minor changes by a State to the Model Audit, such as format or the order in which the residence components are inspected, would not detract from the procedure.

In developing the Model Audit, factors such as audit cost, accuracy, nominal audit time per residence, and auditor capability and training requirements were carefully balanced. In order to optimize the efficiency of the auditor's time on-site, the audit is fully integrated; i.e., many of the observations and measurements made by the auditor will be used to compute the costs and savings of several program measures (weatherization, furnace, solar, and wind). The audit is designed for completion in 2.5 hours on-site for most houses. This includes time for computation and presentation of the results to the customer, but not travel. The computational procedures, designed to be simple and relatively quick, do not require the use of a computer. Whenever feasible, the accepted engineering practices for auditing and energy modeling were used.

An earlier draft of the Model Audit was subjected to limited field testing in the States of Tennessee, Colorado, Massachusetts, Wyoming, Oregon, Washington, California, and New Mexico. Some weaknesses in the flow and timing of the procedure were discovered and corrections were incorporated in the present procedures. However, detailed testing and validation of the current procedures have not been completed.

In order to facilitate the planning process for States and nonregulated utilities, the Model Audit was issued as a near-final draft while testing and validation are continuing. This draft was used in the preparation of some RCS State plans.

The Model Audit includes both conservation and renewable resource measures. The six renewable resource measures, comprising the solar portion of the audit include:

- Solar domestic hot water systems;
- Active solar space heating systems;
- Combined active solar space heating and solar domestic hot water systems;
- Passive solar space heating and cooling systems (direct gain systems, indirect gain systems, solaria/sunspaces, window heat gain retardants);
- Replacement solar swimming pool heaters; and
- Wind energy devices.

The DoE is committed to full consideration of State-added measures, providing the measures demonstrate compliance with final RCS regulations.

Positive life-cycle cost analyses have been performed for all solar and wind measures in each of several regions within the country. Analyses were based on purchase price of typical solar and wind energy systems, meteorological data reflecting the amount of available solar and wind energy in each of the regions, current and DoE-projected costs of conventional energy in each region, operation and maintenance cost estimates of each renewable energy system, and type of house to be retrofitted. The table of program measures contained in the regulations indicates which renewable resource measures are cost-effective for the regions of each State, based on the analyses. As an example, the program measures applicable to Colorado and New York are shown in table 2.

TABLE 2 - PROGRAM MEASURES

STATE	HUD/MPS REGION	CATEGORY OF RESIDENTIAL BUILDING	CONSERVATION MEASURES: Ceiling Insulation (R-Value)*	Wall Insulation	Floor Insulation (R-Value)*	Storm or Thermal Windows	Storm or Thermal Doors	RENEWABLE RESOURCE MEASURES: Solar Domestic Hot Water Systems	Active Solar Space Heating Systems	Combined Active Solar Space Heating & Solar Domestic Hot Water Systems	Wind Energy Devices
Colorado	6	Electricity	30	X	19	X	X	X	1	1	X
		Gas	30	X	11	X					X
		Oil	30	X	11	X		X	1	1	X
		Electric Heat Pump	30	X	19	X	X				X
	7	Electricity	38	X	19	X	X	X	1	1,2	X
		Gas	30	X	11	X					X
		Oil	30	X	11	X		X	1	1,2	X
		Electric Heat Pump	38	X	19	X	X				X
New York	6	Electricity	30	X	19	X	X	X			X
		Gas	30	X	11	X					X
		Oil	30	X	11	X					X
		Electric Heat Pump	30	X	19	X	X				X
	7	Electricity	38	X	19	X	X	X			X
		Gas	30	X	11	X					
		Oil	30	X	11	X					
		Electric Heat Pump	38	X	19	X	X				X
	8	Electricity	38	X	19	X	X	X			X
		Gas	38	X	19	X	X				X
		Oil	38	X	19	X	X				X
		Electric Heat Pump	38	X	19	X	X				X

NOTE: 1 = Single-family 2 = Attached buildings 3 = Mobile Homes

*These R-Values are minimums. The State may propose, in a State Plan, either (1) to substitute a higher level, subject to the Assistant Secretary's approval, as the program measure, or (2) to offer other levels (higher or lower) as State measures in addition to the program measures.

Note that the above table does not present passive solar measures. In assessing the life cycle economic feasibility of passive systems throughout the Nation, DoE concluded that the cost-effectiveness of passive systems depends on the particular characteristics of individual buildings rather than on the characteristics of easily defined broad categories. The DoE determined that auditors would be capable of evaluating the applicability of passive systems on a particular residence. Therefore, passive solar measures are designated as program measures in all States and applicability criteria have been added to the audit criteria.

An energy audit will be conducted for conservation, solar, and wind program measures that meet applicability criteria outlined in the regulations. If it is determined, by meeting these criteria, that the measure will function satisfactorily at a particular site, an auditor will determine the approximate costs, energy savings, and associated maintenance costs of installing the measures.

The active solar systems portion of the model audit is based on prototypical systems and the National Oceanic and Atmospheric Administration (NOAA) climatic data base. This climatic data base represents the most complete and recent compilation of solar and other climatic data, organized in a consistent geographic structure.

The United States was divided into 97 areas, each of which contained a National Weather Service Station whose measured (or, in some cases derived) solar and wind data were representative of the area. The NOAA climatic regions follow county boundaries but not necessarily State boundaries.

The solar insolation value, reported at the measuring station in each NOAA climatic region, was considered to be representative of the entire region and, in the absence of more refined data, was applied uniformly throughout the region.

The NOAA wind speed data were generally recorded at airport sites which tend to be located in relatively calm locations. In addition, these data represented monthly averages which, if used in the analysis, would tend to underestimate the energy obtainable from a small wind system compared to the use of the actual wind resource encountered at a specific site. In the absence of on-site anemometer measurements, therefore, a procedure was developed to estimate the wind resource enhancement at a well exposed site as compared to the wind resource measured at the weather station site.

The general applicability criteria for active solar systems require an audit to be completed for the measure if:

- the measure is not already present in the residence;
- installation of the measure is not a violation of Federal, State, or local laws or regulations;

- a site exists on or near the residence that is free of major obstruction to solar radiation.

For active space heating systems, the residence must not have a steam heating, electric resistance heating, or electric resistance baseboard heating system.

Passive solar systems parallel the first two general applicability criteria of active systems. In addition, direct and indirect gain systems can be applied only if the residence's living space has either a south-facing ($\pm$ 45° of true south) roof or an integral south-facing ($\pm$ 45° of true south) wall free of major obstructions to solar radiation. The solar greenhouse measure can be applied if a south-facing ground-level wall is free of major obstruction to solar radiation.

A wind energy system audit is completed if there are no major wind obstructions and minimum 10 mph annual average wind speed exists. These criteria supplement the first two items required of active and passive solar systems.

To illustrate this portion of the model audit, a home in Lakewood, Colorado was selected. The home is shown in plan and elevation view (south wall) in figure 1 and specific characteristics are defined in table 3.

TABLE 3 - Lakewood, Colorado Home

General Description

- Home built in 1973, second owner
- 2x4 Frame construction with brick veneer
- Unfinished basement, enclosed garage
- 3-1/2" fiberglass batts in wall (R-14), 11" loose fill fiberglass in attic (R-31)

Lifestyle

- 2 adults, 3 children (under 8 years of age)
- Dishwasher, washing machine

Energy Usage

- Heating System - Gas heat, central, forced air furnace; room duct with operable dampers
- Heating Energy Use Rate - 756 Btu/Hr.°F
- Approximate Annual Heating Cost - $430($0.35/CCF)

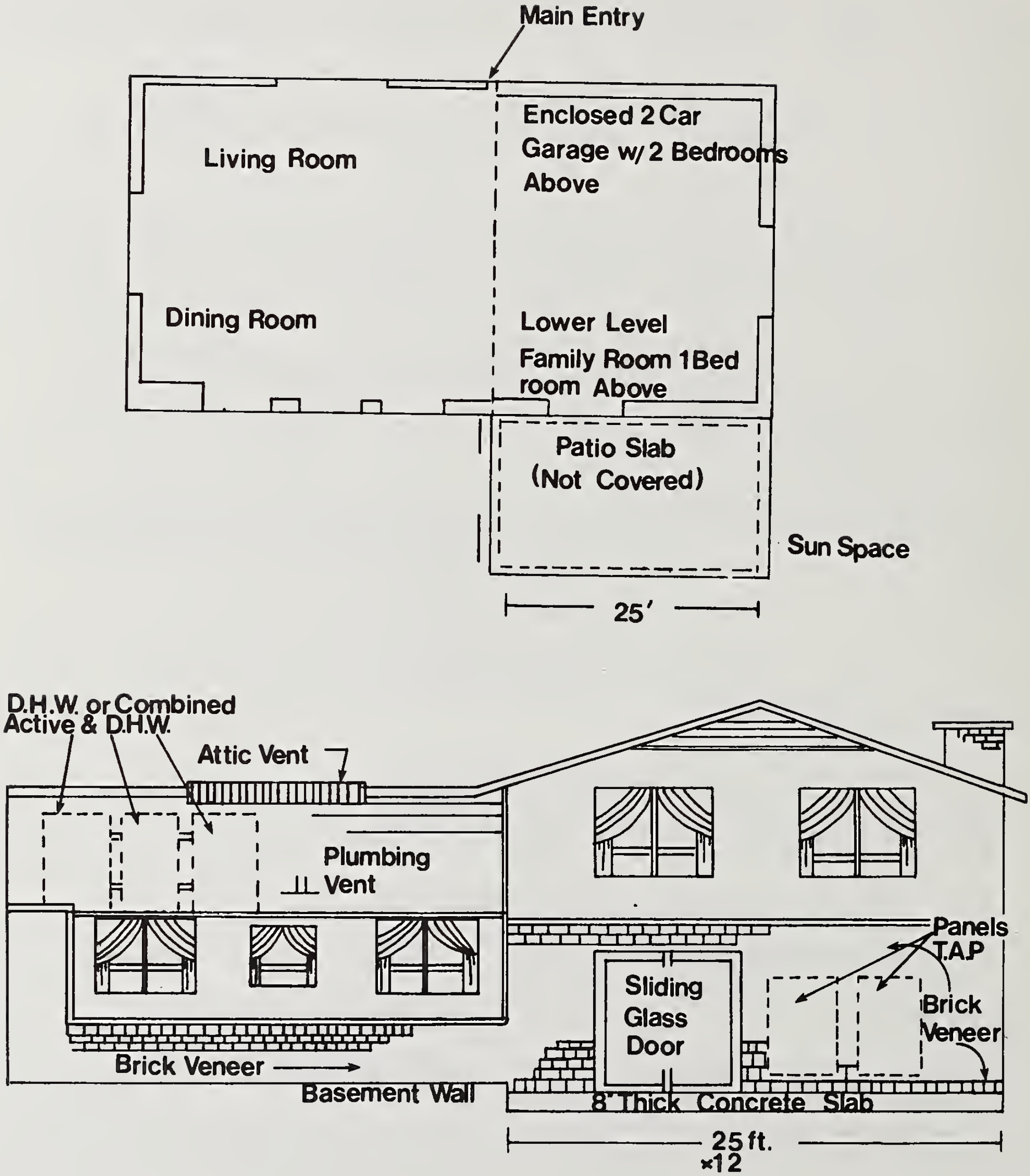

Figure1: Example Audit Home

This home was chosen since it illustrates very well the actual RCS Audit process where some renewable resource measures are applicable and others are not on a given home. The following table lists each renewable resource measure, shows whether the audit procedure was completed for the measure, and summarizes the pertinent audit information for completed procedures:

TABLE 4 - Example Audit Procedure

Solar Domestic Hot Water

Annual Energy Requirements (10^6 Btu)	26
Solar Savings Fraction	0.9
Collector Area (ft^2)	115
First Year Savings ($)	100
Resident Installed Cost ($)	2,490
Contractor Installed Cost ($)	2,920

Combined Solar Space Heating and Hot Water

Annual Space and Water Heating Costs ($)	530
Solar Savings Fraction	0.5
Collector Area (ft^2)	284
First Year Savings ($)	265
Contractor Installed Cost ($)	8,370

Solar Pool Heating

This measure is not applicable since the home does not have a pool.

Window Heat Gain Retardants

This measure is not applicable since the home does not have air conditioning.

Direct and Indirect Gain

The Direct Gain measure procedure was not completed since it was determined that installation of additional glazing on the south wall would not be feasible.

The Trombe Wall and Waterwall applications of the Indirect Gain measure were not considered since these measures require structural characteristics not present in this home.

Thermosyphon Air Panel

Panel Area (ft^2)	84
Annual Energy Saved (10^6 Btu)	3.36
First Year Savings ($)	23
Resident Installed Cost ($)	420
Contractor Installed Cost ($)	672

Sunspace/Greenhouse

Sunspace Length (ft)	25
Glazing Area (ft^2)	250
Solar Savings Fraction	0.3
First Year Savings ($)	117
Resident Installed Cost ($)	1,250
Contractor Installed Cost ($)	3,750

Wind Energy Devices

This measure is not applicable since the Denver area does not have a 10 mph average annual wind speed.

Note that in the calculation estimate for measure installation cost and first year savings, the 40 percent Federal tax credit was not included in the calculation. The State tax incentive was not included; for Colorado, this tax credit is 30 percent in 1980.

In conclusion, the RCS Model Audit is the first audit procedure to be offered on a nationwide basis that incorporates standard conservation measures as well as renewable resource measures including solar and wind. The RCS Program supported by the model audit and other State-developed audit procedures promises to have a significant impact on use of solar technologies for residential building retrofits.

BUILDING CODES VS.
THE DESIGN OF PASSIVE SOLAR HEAT STORAGE

by

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This paper explores the difficulties in complying with the major national building codes when designing thermal mass storage elements into a low-mass (wood frame), direct-gain passive solar building. Experience with one of the first pre-manufactured passive solar buildings in the United States (the Boise Cascade solar prototype house recently erected near Denver) is presented. Different strategies for the design of thermal mass elements and their acceptability to code administering authorities are discussed.

Key Words: Codes; concrete; masonry; prohibitions; re-examination; thermal storage; wood structure.

Of the several types of passive solar architecture, direct gain design has perhaps been the most popularly accepted. This method presents the most "normal" appearance, can most easily be accomplished with established residential construction techniques, and has the side benefits of abundant natural light and the preservation of views through the gain aperture. However, one of the most difficult aspects of producing a successful direct gain design is the proper placement of thermal storage elements so that they are properly irradiated during the day and are in a good position to give back their heat at night. They should ideally be part of the building (hopefully lending to its esthetic qualities) and be designed to discourage being shaded by various items of decor, furniture, plants, etc.

To accommodate the construction method used in an overwhelming majority of housing units in the United States (wood frame) several storage strategies have evolved:

1. Containers of water, a fairly good heat storage medium per weight, are placed usually in a vertical position just inside the solar aperture, or in front of a back wall where they are charged by a high window or clerestory.

2. Encapsulated phase change material, usually eutectic salts, is positioned similarly to water elements and can also be suspended from ceilings (made possible by a high storage capacity to weight ratio).

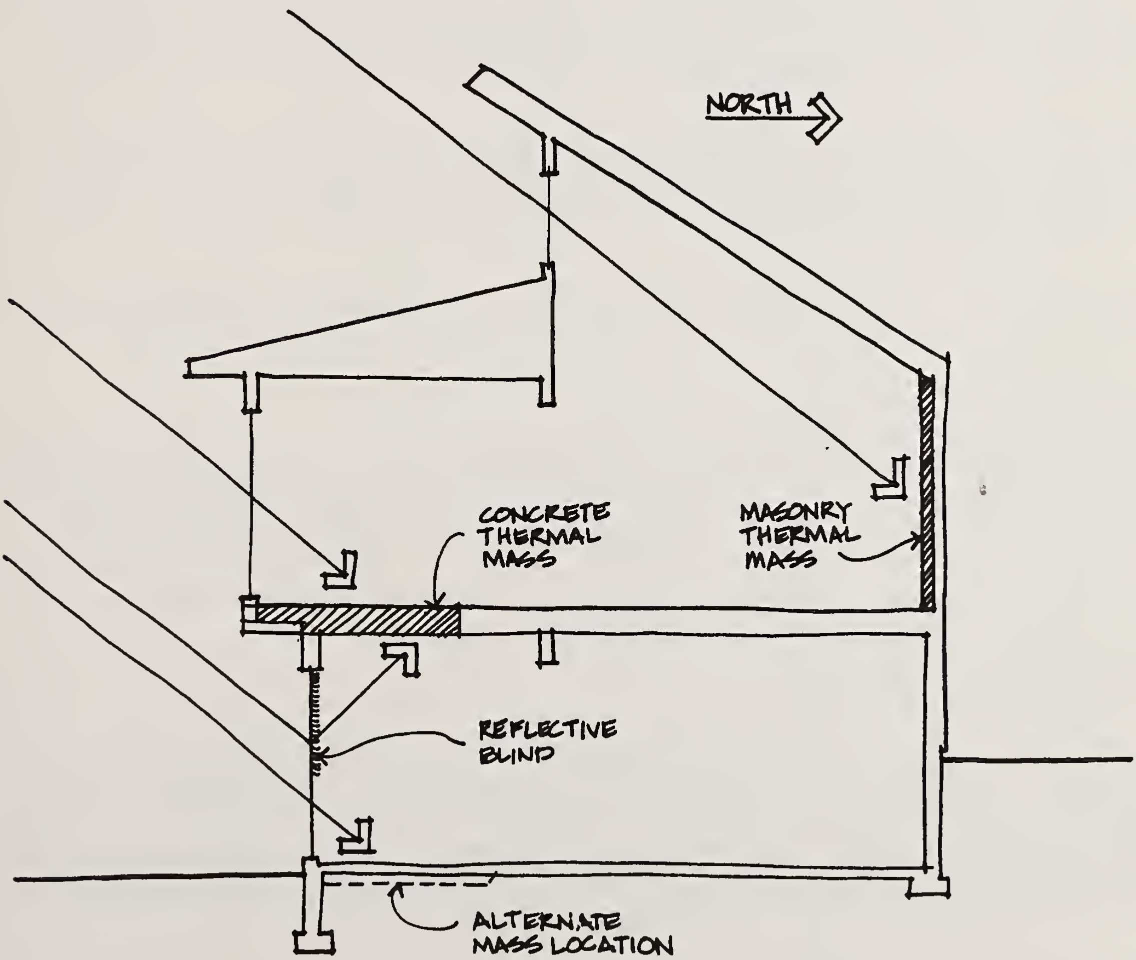
3. More traditional looking (but least desirable thermally) dense building materials such as masonry, tile, concrete, or plaster are placed in all storage positions but most prevalently on walls and floors.

At the present time strategy number 3 appears to be the most widely accepted, probably due to its more familiar appearance and the relative abundance of tradespeople experienced with the materials employed.

Placement of dense, solid materials in an otherwise lightweight building presents a few construction problems. These are magnified by the fact that most solids have a lower specific heat and thermal conductivity than water and a much lower heat storage capacity than phase change materials. The result is a larger weight of solid material for equal heat storage. Structurally supporting all this added weight has not presented insurmountable difficulties, but the bearing of loads of concrete and masonry on wood members has in some cases been made impossible by building codes.

This problem presented itself during the design and construction of the Boise Cascade Passive Solar Prototype erected near Denver in 1979. This single family residence was designed to be a pre-manufactured building, eventually to be marketed to builders as a package of panels and precut pieces. Because of shipping limitations, all of its thermal storage elements were added in the field. The lightweight wood design, including a wood foundation, presented a stereo-typical example of the problem of adding thermal mass to a low mass structure. Figure 1 shows the location of the thermal storage elements.

Figure 1: Location of Thermal Storage Units



The concrete floor is designed to be poured between the supporting joists with tile on top and a left-in-place metal form on the bottom. This storage location is near ideal since it is in proximity to both upper and lower levels and can be irradiated from below (with the use of a reflective blind) as well as from above. Occupants who prefer carpeted floors in the bedroom would especially appreciate this arrangement. Storage for the clerestory windows was placed on the back wall as a 4 inch brick veneer. Both of these strategies were counter to the adopted code in this locality. During construction, the floor was installed nearly as designed. The brick veneer was replaced with multiple layers of gypsum board and a finish of ceramic tile largely because of the interior designer's requirements rather than any pressure from building officials. This substitution, though legal, has been judged less than satisfactory due to the insulating effect of the paper layers and the relatively low density of the gypsum cores. The code problem with the original design has been one of the deterrents to the mass marketing of this solar home.

In a paper entitled, "Deadweight on Toothpicks..." [1]*, Douglas R. Coonley addresses the structural detailing problems of added thermal masses. Most of what he suggests, however, is likely to be in violation of the building codes.

The following is a review of the four major national building codes in regard to the supporting of concrete or masonry on wood structures.

Uniform Building Code [2]

The 1973 through 1976 editions, in paragraph 2516, specifically prohibit the support of masonry or concrete by wood structural members, except in the case of non-structural flooring material no greater than 4 inches thick. This was changed in the 1979 code to allow masonry veneers not exceeding 25 feet in height on walls. Support of greater amounts of concrete and masonry is still prohibited.

Standard Building Code [3]

All editions since 1973 have stated in paragraph 1409.4 that support of masonry on wood is prohibited. The only exception is prefabricated masonry partitions not exceeding 30 lbs/square foot. (One wythe of brick would probably weight slightly more than this.) Wood support of concrete decks for roofs or floors is allowed, but inferred is the disallowing of the support of concrete in a vertical position.

Basic Building Code [4]

The 1975 through 1981 editions have no specific reference to the support of masonry and concrete on wood and presumably do not prohibit the practice. There are two obscure references in paragraphs 861.1 and

*Numbers in brackets refer to references at end of text.

834.4 regarding the use of combustibles and/or wood in masonry construction, but they are minor points. Also, it could be inferred from paragraph 854.4.3 that wood cannot support 4 inch masonry veneers. The paragraph limits the height of such veneers to 25 feet "above its supports on foundation wall or on corbels of masonry or steel." Reference is made to ANSI standards A41.1 and A41.2. These could not be located at the time of this writing and would bear some checking if the Basic Building Code is being used.

National Building Code [5]

In the 1976 edition (current with 1977 amendments) paragraph 913.2d prohibits the support of masonry on any form of wood construction except for wood piles and miscellaneous small wood lintels, blocks and decorative wood inserts. Brick floors are exempt from this requirement. (No maximum thickness is stated.) This provision is restated in the same terms in paragraph 929.3c for masonry veneers. No requirements for the support of concrete walls and floors are apparent. This code indirectly contradicts itself by mentioning in paragraph 909.4a that wood foundations designed in accordance with NFPA Technical Report No. 7 [6] are permitted. This document clearly shows brick veneers being supported by wood construction. It is assumed this contradiction will appear elsewhere as other code drafting bodies and agencies embrace the wood foundation concept.

Older editions of codes are mentioned here because so many of them are still in use owing to the usually slow political process of adoption by local governments. Also to be considered is the fact that some larger governmental entities have written their own codes, basing them on past editions, and do not necessarily have the machinery to update their code when revised editions of the model code appear.

From conversations with other solar designers, it appears that for the most part these prohibitions are not being very rigorously enforced. This is probably due to the relative obscurity of the provisions and the generally less thorough inspection of housing as a building type than to any desire among building officials to encourage solar architecture. This fact should not be used to justify the use of these techniques in the face of contrary code provisions. There is always the chance of damaging the progress of work, causing losses in time, money, and project quality if the code is enforced, and also, increased legal liabilities for the designer may occur if a code is violated and some defect appears (even if the defect is caused by faulty materials or installation).

Investigation into the reasoning behind the code provisions not permitting concrete or masonry to bear on wood were inconclusive. Conversations with code administrators and personnel at the code drafting agencies produced only a few suggestions. The increased vulnerability of wood to decay, warping, fire, failure, etc., was most often mentioned. Its dimensional stability and quality control failings were also suggested. Opinions were as unharmonious as the different code provisions and most comments were of a subjective nature.

It is suggested that all of these code provisions be examined carefully in light of the need for effective solar designs and hopefully be eliminated. There are many arguments for this course:

1. Masonry bearing on wood is a time tested building technique. It began in a large scale in the 14th century with the advent of half timber construction. Many of these buildings have lasted hundreds of years without the benefit of modern techniques and preservatives.

2. Structural members in any design cannot "see" the load. Why is it less desirable for wood to be supporting concrete or masonry than supporting a bathtub full of water, a billiard table, or a grand piano? If wood is suitable for supporting a snow loaded roof over our heads, should not it be acceptable for supporting a brick veneer on an interior wall?

3. Wood is unlikely to fail spectacularly in any structural situation. In a fire, steel, for example, would be much more vulnerable than wood and thus more likely to fail spectacularly.

4. Most of the drawbacks to wood construction, dimensional instability, warping, and decay can be easily handled with the proper detailing, techniques, and preservatives.

For the present, the codes appear stacked against the one solar heat storage strategy which is most likely to be widely accepted by the majority of home builders at least for the near term. It is hoped that this situation can be remedied, leaving a storage option which is necessary to the rapid growth of passive solar design.

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2. Uniform Building Code; International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, California 90601.

3. Standard Building Code; (formerly Southern Standard Building Code); Southern Building Code Congress International, Inc., 900 Montclair Road, Birmingham, Alabama 35213.

4. Basic Building Code; Building Officials and Code Administrators International, Inc., 17926 South Halsted Street, Homewood, Illinois 60430.

5. National Building Code; American Insurance Association, 85 John Street, New York, New York 10038.

6. NFPA Technical Report No. 7; National Forest Products Association, 1619 Massachusetts Avenue, N.W., Washington, D.C. 20036. (This document provided the basis for the Design, Fabrication and Installation Manual for the All-Weather Wood Foundation System, also published by NFPA.)

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The Proceedings of the Fifth Annual NBS/NCSBCS Joint Conference on Research and Innovation in the Building Regulatory Process contain 17 technical papers. This year's joint conference addressed solar energy and energy conservation.

These proceedings include papers on:

- Energy programs in the State of Colorado
- Building energy performance standards concepts
- State energy audits
- Energy and building systems services
- Solar energy and building codes

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